Thesis No. 059/MSE/309

TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS
DEPARTMENT OF CIVIL ENGINEERING

ARSENIC, IRON AND COLIFORMS REMOVAL EFFICIENCY OF HOUSEHOLD LEVEL BIOSAND FILTERS

BY
PREM KRISHNA SHRESTHA

IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN ENVIRONMENTAL ENGINEERING

December, 2004
Lalitpur, Nepal

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By

Prem Krishna Shrestha

A thesis submitted in partial fulfillment of the requirements of the degree of
Master of Science in Environmental Engineering

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December, 2004
Lalitpur, Nepal

CERTIFICATE

This is to certify that this thesis work entitled "Arsenic, iron and coliforms removal efficiency of household level biosand filters" submitted by Mr. Prem Krishna Shrestha is a bonafide thesis work carried out under my supervision and guidance and fulfilling the nature and standard required for the partial fulfillment of the degree of Master of Science in Environmental Engineering. The work embodied in this thesis has not been submitted elsewhere for a degree.

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ABSTRACT

Experimental investigations were carried out to study the removal of Arsenic, Iron and Coliforms in drinking water by Bio-sand Filters using Iron nails. Three cycles of experiment were performed using two Household Filters. The experiments were carried out using different quality of waters such as arsenic spiked ground water, tap water and natural arsenic contained ground water. The filters under study consist of two parts combined in a single unit. The top part of the filter consists of iron nails for the adsorption of Arsenic, while the bottom part of the filters is basically a small size slow sand filter, which removes the suspended materials present in water. At the same time it also removes the micro organisms present in water by biological action.

Both the filters showed moderate results regarding the removal of As, Iron, and Coliforms during the first cycle of study. First cycle of study was carried out for 32 days using arsenic spiked ground water of Pulchowk Campus complex, containing very high concentration of phosphate (31 mg/l).

The performances of filters were found satisfactory in second cycle of study, in which arsenic spiked tap water was used. Average removal of Arsenic in Filters A and B was 85% and 76% respectively. Both filters produced water with acceptable concentration of Arsenic (50 ppb), when the As concentration of raw water was up to 400 ppb and 200ppb in Filters A and B respectively. When raw water concentration of Arsenic exceeded 400 ppb, the treated water exceeded the interim standard of Arsenic for Nepal.

The average removal of Arsenic is found about 91%, when tested at Sunawal VDC of Nawalparasi district.

The efficiency of filters to remove Iron and Turbidity is satisfactory. Iron removal is about 50% in both the filters. But, maximum concentration of 1.75 mg/l of Iron was reduced to 0.2 mg/l. Average turbidity of 12 NTU was reduced to value of less than 1NTU.

Efficiency of filters to remove coliforms is found moderate. Although the coliform removal percentage is about 94% in both the filters, the quality of water is still doubtful by public health point of view.

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ABBREVIATIONS

AAN	Asia Arsenic Network
AAS	Atomic Absorption Spectrophotometer
ABF	Arsenic Biosand Filter
As	Arsenic
CFU	Colonies Forming Unit
D_{10}	Tenth Percentile Particles (Effective size)
D_{60}	Sixtieth Percentile Particles
DWSS	Department of Water Supply and Sewerage
ENPHO	Environment and Public Health Organization
FAO	Food and Agriculture Organization
GV	Guideline Value
IDI	Information Dissemination Initiatives Pvt. Ltd
IOE	Institute of Engineering
L/hr	Liters per hour
LPCD	Liters pr capita per day
MCL	Maximum Contaminant Level
mg/l	Milligram per liter
MIT	Massachusetts Institute of Technology
NRC	Nepal Red Cross Society
NTU	Nephlometric Turbidity Unit
ppb	Parts per billion
ppm	Parts per million
SORAS	Solar Oxidation
µg/l	Micro gram per liter
UN	United Nations
UNICEF	United Nation's children Fund
USEPA	United State Environmental Protection Agency
UV	Ultra Violet
WHO	World Health Organization

CHAPTER I

1.0 INTRODUCTION

1.1 General

Availability of adequate amount of safe water is the basic need of human being. Access to safe drinking water is the basic human right. (Kofi Annan, United Nation, 2003). It is a right of people to get the safe water for their livelihood. But, unfortunately, the situation of Nepal regarding safe water supply is not satisfactory. Many people living in rural as well as urban area are compelled to drink contaminated water. Many people in the rural area of Nepal, lack access to safe and adequate amount of drinking water.

Statistically, only 71.6% of the total populations of Nepal have access to piped or built in water supply systems. Splitting the data, about 76% of the total population residing in the urban area and only 70.9% of the population residing in rural area have access to piped or built in water supply systems. Remaining portion of the people are using natural springs and surface water. (Tenth Plan, NPC)

If we talk about the treated water supply, the percentage of beneficiaries is very small. There are only countable numbers of treatment plants in Nepal. There is high possibilities of contaminating the treated water when they reach at point of use. It is mainly due to poor and aged distribution networks and bad handling practices.

Nepal is divided in three ecological regions, viz, Mountain, hills and Terai. Terai is the flat plain in the southern part of the country, and is a part of Gangetic watershed. About 48% of total population of Nepal inhabits in this region, and about 90% of them are using ground water as major source of drinking water. Most of the water in Terai is drawn from shallow aquifer, using hand pumps and dug wells. There is very little central treatment system in Terai region. Obviously, there is very little chance of treating the shallow tube well water.

In all above mentioned condition, there is a high chance of getting the water contaminated microbiologically at the point of use. High incidence of water borne diseases is the evidence of above statement.

Required level of treatment and supply of water at the point of use is the best solution to get ride of water borne diseases. But at present, this is nearly a day-dream for country like Nepal. The construction as well as the operation cost of the treatment plant is very high. The poor country like Nepal may not afford at this time. Only viable option at present is there fore treatment of water at point of use. In other words, the household level treatment system is the best option at present.

This kind of treatment is also suitable for the scattered water sources like shallow tube wells, in which the central treatment system is almost impossible. The household level treatment option is suitable for treating biologically, physically and chemically contaminated water at low cost.

1.2 Microbiologically Contaminated Water

Water borne diseases spread due to the microbiologically contaminated water is one of the major challenged being faced by Nepal. Annual death of 30000 Childs, only due to diarroheal incidence is enough to illustrate the situation.

Diarrohea, dysentery, worms, typhoid, jaundice, polio, etc are some of the major diseases transmitted through contaminated water in Nepal. There is no central data base about the loss of life and property due to these diseases. However, the deaths due to these diseases are considerable.

1.3 Arsenic Contamination

Arsenic (As) contamination in the ground water of Terai in Nepal is now becoming a new challenge for the nation's water supply sector. According to the arsenic data base prepared by the Department of Water Supply and Sewerage of July, 2004, 3.1% of the 306262 tube wells tested are found to contain arsenic level above national limit of 50 ppb. Similarly, 11.9% tube well are above WHO limit of 10 ppb. Maximum concentration of Arsenic detected so far is 2620 ppb in Rupendehi district. (DWSS, 2004).

Studies have also indicated that the arsenic distribution is not uniform throughout the country. Many of the villages in Nawal parasi, Kapilvastu and Rautahat districts and some of the villages in other Terai districts (Bara, Parsa, Siraha, Saptari, Kapilbastu, Rupendehi, Bardia and Kailai) are found to be highly affected by Arsenic. (R.R. Shrestha et. al., 2004).

1.4 Remedy for Arsenic Contamination

Use of Arsenic free water source is one of the best solutions to get ride of arsenic problems. But this is not always possible. Supply of centrally treated water is not possible (at least at present) in all parts of the country. In this context only option available is to treat the contaminated water at point of use.

Many technologies have been tested in arsenic effected area. For example, sharing of arsenic free tube wells, two pitcher filter, three pitcher filter etc. Due to higher operation cost, difficulty in handling and low flow rate, none of the above techniques have been accepted well by rural peoples of Nepal.

To overcome the prevailing problems, a local NGO, Environment and Public Health Organization (ENPHO), in collaboration with Massachusetts Institute of Technology (MIT) and Rural Water Supply and Sanitation Support Program (RWSSSP) developed a household water filter. This filter is basically a combination of two Point of use technologies, three gagri filter and Bio sand filter. This filter uses the principle of adsorption of arsenic in the ferric hydroxide, similar to three gagri system. It also uses the principle of Bio sand filter, Developed by Dr. David Manz, to remove the iron flocs and pathogens. Compare to other household arsenic removal technologies, this filter is easy in operation, cheap and sustainable. These filters are still under study. Until now more than 500 units of filters are distributed in arsenic prone area. At present, the cost of filter is quite high in relation to income of poor rural people.

Some of other Governmental and non governmental agencies are planning to promote the technology for arsenic removal. But, until now, no any agencies except MIT and ENPHO have done scientific experiment on the efficiency of these filters. Regarding the sensitivity of public health issues, it seems outmost necessary to have independent researches to evaluate the efficiency of filters. Such product of direct health concern, in massive scale, should be promoted with adequate and multi sector experiments only.

This study will make an independent study on the efficiency of Arsenic Bio Sand Filter, to remove Arsenic, Iron and Coliforms. The purpose of study will be to look the possibility of technical improvement in Bio Sand Filter to reduce the cost and increase the performances.

1.5 Objective of Study

Over all objective of the research is to find out the effectiveness of bio sand filters using iron nails to remove Arsenic, Iron and coliforms present in water.

The specific objectives are:

- To evaluate the Arsenic and Iron removal efficiency of filters.
- To evaluate the efficiency of filters in removal of coliforms.
- To find the possibilities of design modifications for reducing cost and enhancing performances.

1.6 Limitation of Study

The limitations of study are as follows:

- The time available is not sufficient for in depth study.
- The field test of the filters is done in only one village in Terai Nepal.
- Only two models of filters have been studied.

1.7 Organization of the Report

The report has been divided in five chapters.

Chapter I Introduction: This chapter mainly deals with the rational, objectives and limitation of study of study.

Chapter II Literature Review: This chapter is dedicated to illustrate the relevant literatures and the recent works related to the study.

Chapter III Materials and Methodology: The materials used and methodologies adopted for the study is described in this chapter. The study parameters and test methods are given briefly in this chapter.

Chapter IV Results and Discussion: The analysis of test results, tables and figures are presented in this chapter.

Chapter V Conclusion and Recommendations: The conclusion of study and recommendations are given in this chapter.

The detail result sheets, photographs etc are given in appendix A to C.

CHAPTER II

2.0 LITERATURE REVIEW

2.1 Introduction

The name Arsenic is derived from the Greek word *arsenikon*, which means yellow orpiment. Arsenic compound have been mined and used since ancient times. The extraction of the element from arsenic compound was first reported by Albertus Magnus in 1250 A.D. Arsenic ranks 20th in earth's crust, 14th in sea water and 12th in human body. Arsenic exhibit metallic as well as non-metallic characteristics and corresponding chemical properties. Hence, it is called metalloid.

Arsenic is one of the oldest human poisons known to mankind. It has six specific characteristics (Azcui & Nriagu, 1994):

- It is a virulent poison on acute ingestion.
- It is extremely toxic on long term exposure to very low concentrations.
- It is not visible in water and food.
- It has no taste.
- It has no smell.
- It is difficult to analysis, even when occurring in concentration twice as high as WHO guidelines.

2.2 Environmental Chemistry of Arsenic

Arsenic in its various chemical forms and oxidation states is released into the aquatic environment by various process and industrial discharges. On release to aquatic environment, the arsenic species enter into methylation / demethylation cycle, while some are bound to the sediments or taken up by biota where, they could undergo metabolic conversion to other organo-arsenicals. Arsenic generally exists in the inorganic form in water samples. Under different redox conditions arsenic is stable in the +5, +3, -3, and 0 oxidation states. The pentavalent (+5) arsenic or arsenate species include AsO_4^{3-}, and H_2AsO^{4-}. The trivalent (+3) arsenic or arsenite species include $As(OH)^{4-}$, $AsO_2(OH)^{2-}$, and AsO_3^{3-}. The pentavalent arsenic species are predominant and stable in the oxygen-rich aerobic environment, whereas the trivalent arsenic species are predominant in the moderately reducing anaerobic environment such as groundwater (Ghosh and Yuon, 1987). The stability and predominance of different arsenic species in the aquatic environment at different pH ranges is shown in Table 2.1 (Gupta and Chen, 1987). As^0 and As^{3-} are rare in aquatic environments. Methylated or organic arsenic occurs at concentration less than 1 ppb, and is not of major significance in drinking water treatment (Edwards, 1994)

Table 2.1 Inorganic arsenic speciation in water

pH	0-9	10-12	13	14
As (III)	H_3AsO_3	H_2AsO_3	$HAsO_3^{2-}$	AsO_3^{3-}
pH	0-2	3-6	7-11	12-14
As (V)	H_3AsO_4	$H_2AsO_4^-$	$HAsO_4^2$-	AsO_4^{3-}

2.3 Properties of Arsenic

Arsenic is a chemical element in the Nitrogen family, existing in both yellow and grey crystalline forms. Although some forms of the Arsenic are metal-like, it is best classified as metalloid and non metal. Some of the significant properties of Arsenic are listed in Table 2.2.

Table 2.2 Properties of arsenic

Parameter	**Value**
Atomic Number	33
Atomic Weight	74.92158
Melting point	814^0 C at 36 atm
Boiling point	$616\ ^0$ C
Density: Gray form Yellow form	5.73 g/cm^3 at $14\ ^0$ C 2.03 g/cm^3 at $18\ ^0$ C
Specific gravity (,♭,)	2.026,4.7,5.727
Latent heat of fusion	27,740 J/(mol-K)
Oxidation number	-3, 0, +3, +5
Electronic configuration	2-8-18-5
Covalent radius	121 pm
Ionic radius	69 pm
Metallic radius	139 pm
Hard ness (Moh's scale)	3.5

2.4 Arsenic in Water

Arsenic may be found in water which has flowed through Arsenic rich rocks. Arsenic concentration in natural water varies widely depending upon the source of water, source of Arsenic and local conditions. Arsenic concentration in river water is normally low. But some polluted river water may have high concentration of Arsenic. Sea water normally shows relatively constant arsenic content of 1.5 μg/l.

Arsenic content in atmospheric precipitation and snow is the lowest, typically less than 0.03 μg/l

The concentration and variation of Arsenic in ground water is the highest. It is because of its long and strong interaction with rocks and soils under physical and geochemical conditions favorable for the arsenic dissolution and accumulation. The concentration of As in ground water ranges from less than 0.5 to 5000 μg/l with a background concentration of less than 10 μg/l. Arsenic contamination of ground water all over the world is attributed geothermal sources, reductive desorption, oxidizing desorption at high pH and pyrite oxidation. Reductive desorption dissolution under anoxic condition are believed to be the main mechanism of Arsenic mobilization from soil to water phase in aquifers in Bangladesh, west Bengal, Romania, inner Mangolia, Taiwan, Veitnam, Hungery and Nepal. (Smedley and Kinniburgh, 2002)

2.5 Sources of Arsenic

There are mainly two sources of Arsenic, which are as follow:

a) Natural Sources

In nature, the Arsenic is distribute in variety of minerals, commonly as arsenide of iron, copper, lead, silver and gold or as sulfide minerals, for example arsenopyrite. The geochemical cycling of arsenic in the environment is through interaction of natural water with bedrock, sediments and soils, together with the local atmospheric deposition. The weathering of different geologic formation such as volcanic rock, as well as mining waste consequently results in high level of arsenic in surface and ground water.

b) Anthropogenic Sources

Anthropogenic processes such as industrial activities are great sources of arsenic emissions. Arsenic based compounds have been used in pesticides, herbicides, insecticides, fungicides, rhodenticides, algaecides, dye-stuff, dipping agent for sheep, and vine killer. However, most developed countries have replaced such inorganic compounds by organic arsenicals in agriculture. Arsenic-based chemicals such as CCA (copper-chrome-arsenate) have been used in wood preservation industries and there by caused widespread contamination of soil and water. Other anthropogenic activities resulting high arsenic level in the environment are mining, smelting and ore benefaction.

2.6 Human Exposures to Arsenic

Arsenic is ubiquitous micro pollutant. It is naturally found in atmospheric air in concentration levels about 0.4 to 30 ng/m^3, in food at concentration level about 0.4 to 120 μg/kg and in water at concentration levels from undetectable to few mg/l.

Approximate environmental concentration levels and human exposure through air, food and water to Arsenic is given in Table 2.3. The figures in the table are based on the estimation of WHO 1996.

Table 2.3 Approximate environment concentration level of arsenic

Medium	**Concentration**	**Daily Intake**	**Daily Exposure**	**Remarks**
Air	0.4-30 ng/m^3	20 m^3	0.01-0.6 μg	may be higher in industrial area
Food	0.4 - 120 μg/kg	1 kg	0.4-120 μg	75% inorganic and 25% organic
Water	1-2 μg/l	2 L	2-4 μg	Mainly inorganic

Water	up to 12000µg/l	2 L	24000 µg	Causing endemic diseases

Inorganic Arsenic, especially As III, is more toxic for human than organic arsenic. For the reason, the arsenic exposure of water is more serious than that of the food. As mentioned in table the arsenic ingested through food contains considerable portion of organic arsenic. The exposure of human to arsenic through water is now believed to be most hazardous to public health.

2.7 Effects of Arsenic on Health

Arsenic called the king of all poison. The fatal dose, the dose which is sufficient for the death of person, is 125 mg. The arsenic is 4 times stronger than mercury. Arsenic enters the human body either from respiration or from mouth. The effects of arsenic after it enters by breathing or meals and drinks depend on the amount and physico-chemical states.

Arsenic has been identified as cause of cancer by the International Agency for Research on Cancer (IARC). Many people died due to the cancer caused by arsenic.

According to the consumption of arsenic in human body, its toxicity can be divided in three categories.

1. Acute toxicity
2. Sub acute toxicity
3. Chronic toxicity

Chronic arsenic poisoning, which occurs after long-term exposure through drinking- water is very different to acute poisoning. Immediate symptoms on an acute poisoning typically include vomiting, esophageal and abdominal pain, and bloody "rice water" diarrhoea. Chelation therapy may be effective in acute poisoning but should not be used against long-term poisoning.

The symptoms and signs that arsenic causes appear to differ between individuals, population groups and geographic areas. There is no universal definition of the disease caused by arsenic. This complicates the assessment of the burden on health of arsenic. Similarly, there is no method to identify those cases of internal cancer that were caused by arsenic from cancers induced by other factors.

Long-term exposure to arsenic via drinking water may causes cancer of the skin, lungs, urinary bladder, and kidney, as well as other skin changes such as pigmentation changes and thickening (hyperkeratosis). Increased risks of lung and bladder cancer and of arsenic associated skin lesions have been observed at drinking water arsenic concentrations of more than 0.05 mg/l.

Absorption of arsenic through the skin is minimal and thus hand-washing, bathing, laundry, etc. with water containing arsenic do not pose human health risk.

Following long-term exposure, the first changes are usually observed in the skin: pigmentation changes, and then hyperkeratosis. Cancer is a late phenomenon, and usually takes more than 10 years to develop. The relationship between arsenic exposure and other health effects is not clear-cut. For example, some studies have reported hypertensive and cardiovascular disease, diabetes and reproductive effects.

2.8 Measurement of Arsenic Concentration

Accurate measurement of arsenic in drinking water at levels relevant to health requires laboratory analysis, using sophisticated and expensive techniques and facilities as well as trained staff not easily available or affordable in many parts of the world.

Analytical quality control and external validation remain problematic. Field test kits can detect high levels of arsenic but are typically unreliable at lower concentrations of concern for human health. Reliability of field methods is yet to be fully evaluated.

2.9 WHO's Activities on Arsenic

WHO’s norms for drinking water quality go back to 1958. The International Standards for drinking water established 0.20 mg/l as an allowable concentration for arsenic in that year. In 1963 the standard was re-evaluated and reduced to 0.05 mg/l. In 1984, this was maintained as WHO’s "Guideline Value"; and many countries have kept this as the national standard or as an interim target. According to the WHO Guidelines for Drinking water Quality (1993):

- Inorganic arsenic is a documented human carcinogen.
- 0.01 mg/l was established as a provisional guideline value for arsenic.

Based on health criteria, the guideline value for arsenic in drinking water would be less than 0.01 mg/l. But, due to large amount of budget required to meet that standard, some developing countries, including Nepal, Bangladesh, and India have fixed 0.05 mg/l as an interim standard for Arsenic.

Because the guideline value is restricted by measurement limitations, and 0.01 mg/l is the realistic limit to measurement, this is termed a provisional guideline value. The WHO Guidelines for Drinking water Quality is intended for use as a basis for the development of national standards in the context of local or national environmental, social, economic, and cultural conditions.

2.10 Global Situation of Arsenic Contamination

The delayed health effects of exposure to arsenic, the lack of common definitions and of local awareness as well as poor reporting in affected areas are major problems in determining the extent of the arsenic in drinking water problem. Reliable data on exposure and health effects are rarely available, but there are many countries in the world where arsenic in drinking water has been detected at concentration greater than the WHO Guideline Value of 0.01 mg/l or the prevailing national standard. These include Argentina, Australia, Bangladesh, Chile, China, Hungary, Nepal, India, Mexico, Peru, Thailand, and the United States of America. Countries where adverse health effects have been documented include Bangladesh, China, India (West Bengal), and the United States of America.

Scenarios of some of the countries facing the arsenic problem are described below.

- The first case of Arsenicosis was reported in Chile in 1962. It is estimated that about 7% of the deaths from 1989-1993 are caused by previous exposures to arsenic in this country.
- The arsenic problem was reported in 1968 in Taiwan. More than 19% of tube well among 83000 tested tube well were reported to be contaminated

with arsenic concentration above 50 µg/l. But the problem of arsenic is reported to be solved to great extent in Taiwan.

- In USA, about 347,000 people had received public supplied water containing Arsenic more than 50 µg/l. Probably it is only the country which has carried out a nation wide survey of arsenic occurrence in drinking water.
- In India, arsenic contamination was first discovered in 1982. About 6.97 million people are estimated to be exposed to high arsenic content in drinking water. Some 300000 people are likely to be suffering from various stages of arsenicosis.
- An estimated 5.63 and 14.66 million people in 29 out of 32 provinces of China are drinking water containing arsenic exceeding 50 and 10 µg/l respectively. More than 30000 cases of arsenicosis have been diagnosed in China.
- According to a British Geological Survey study in 1998 on shallow tube-wells in 61 of the 64 districts in Bangladesh, Arsenic concentration in 46% of the samples were above 0.010 mg/l and 27% were above 0.050 mg/l. When combined with the estimated 1999 population, it was estimated that the number of people exposed to arsenic concentrations above 0.05 mg/l is 28-35 million and the number of those exposed to more than 0.01 mg/l is 46-57 million (BGS, 2000).
- In Vietnam, Arsenic in ground water was first detected in Hanoi in 1997, where arsenic concentration of 29% tube well were above 0.05mg/l.

There are many other countries in the world having arsenic problem in drinking water. Pakistan, Laos, Mexico, Mangolia, Hungery, Combodia etc are some of the examples. Nepal is also facing same problem in southern Terai.

2.11 Nepal's Situation Regarding Arsenic Problems

Arsenic contamination in ground water drawn from shallow tube wells is one of the emerging challenges to Nepal. Among 306,262 tested shallow tube wells of 24 districts, about 3.1% of tube well are found to be contaminated with arsenic in concentration above 50 ppb. Similarly, about 11.9% of the tube wells are found to have concentration of arsenic between 10 and 50 ppb. About half million people residing in Terai belt of Nepal are supposed to be exposed with arsenic concentration level more than 10 ppb. (DWSS, 2004)

First study on Arsenic: His Majesty' Government of Nepal/DWSS conducted a study to find out the arsenic contamination in three districts of Eastern Development Region. In total 268 samples from shallow tube well were tested in the study. Among them 22 sample were found to have arsenic concentration between 10 and 50 ppb. Similarly, 2 samples were found to be contaminated with 50 ppb and more. (Sharma, R.M, 1999)

After this study, many other National and International agencies started to investigate the concentration of arsenic in drinking water. Nepal Red Cross Society, RWSSSP, Nepal Water Supply Corporation, Nepal Water for Health (NEWAH), Plan, Birgunja Municipality, Fund Board etc are some of the agencies which conducted study on arsenic in different districts. Currently, under the financial assistance of United Nation's Children Fund (UNICEF), Department of Water Supply and Sewerage is conducting complete tube well test (Blanket test) in 8 Terai districts.

2.12 Drinking Water Criteria for Arsenic

Arsenic in drinking water affects human health and is considered one of the most significant environmental causes of cancer in the world. Keeping in view, the toxic effects of inorganic arsenic on human and other living organism. It is necessary to understand the level of arsenic in drinking water, and its chemical speculation, to establish regulatory standards. The Food and Agriculture Organization(FAO) health limit for As in groundwater was 50μg/l, but in view of recent incidences of arsenic poisoning in Bangladesh and India, a decrease in groundwater as concentration to 5-10 μg/l is being considered by a number of regulatory bodies throughout the world. The provisional WHO guideline value adopted for arsenic in drinking water is 10 µg/l, which is based on a $6x10^{-4}$ excess skin cancer risk. WHO states that the health based drinking water guideline for arsenic should be 0.17µg/l. However, the detection limit for most laboratories is 10 µg/l, which is why the less protective guideline was adopted.

The United State Environmental Protection Agency (USEPA) drinking water standard for arsenic (50 µg/l) was set in 1975. On the basis of the investigations initiated by national Academy of Science, It was concluded that the previous standard did not eliminate the risk of long term exposure from low arsenic concentrations in drinking water causing skin, bladder, lungs and prostate cancer. To achieve the Environmental Protection Agency's goal of protecting public health, recommendations were made to lower the safe drinking water limit to 5 µg/l. Recently the USEPA has established a health based non forceable maximum contaminant level goal of zero arsenic and an enforceable maximum contaminant level (MCL) of 10 µg/l in all drinking water systems as against the previous MCL of 50 µg/l set by the USEPA in 1975. However, the current drinking water guideline for arsenic of 10 µg/l, adopted by WHO and USEPA, is higher than the Canadian and Australian MCL of 5 and 7 µg/l respectively. The national limit in India and Bangladesh is 50 µg/l (WHO, 1999). Nepal has also set 50 µg/l, as interim National standard for Arsenic.

In Nepal, guideline value for national drinking water quality standard has not been finalized. Many organizations are working in this direction. The water quality standard for Nepal, as suggested by Department of Water Supply and Sewerage is tabulated in Table 2.4.

Table 2.4 Drinking water quality standard of Nepal (proposed)

Category	Parameters	Units	Desirable	Maximum. Permissible
General	pH	-	6.5-8.5	9.2
	Calcium	mg/l	<75	200
	TDS	mg/l	<1000	1500
Aesthetic	Turbidity	NTU	5	20
	Color	TCU	<5	15
	Ammonia, NH_3	mg/l	<1.5	5
	Chloride	mg/l		250
	Sulphate,SO_4	mg/l	<250	
	Total Hardness	mg/l	150	300
	Manganese, Mn	mg/l	0.1	0.5
	Iron, Fe	mg/l	0.3	1.5
	Copper, Cu	mg/l	<1	2.0
	Chloride, Cl	mg/l		250
Chemical (Inorganic)	Cyanide, CN	mg/l	<0.07	0.2
	Cadmium, Cd	mg/l	<0.003	0.01
	Fluoride, F	mg/l	0.5	1.5
	Nitrate, NO_3	mg/l	<50	
	Arsenic, As	mg/l	<0.01	0.05
	Lead, Pb	mg/l	<0.05	0.1
	Chromium	mg/l	0.05	0.05

Source: (IDI/DWSS, 2004)

2.13 Prevention and Control of Arsenic Contamination

The most important remedial action is prevention of further exposure by providing safe drinking water. The cost and difficulty of reducing arsenic in drinking water increases as the targeted concentration lowers. It varies with the arsenic concentration in the source water, the chemical matrix of the water including interfering solutes, availability of alternative sources of low arsenic water, mitigation technologies, amount of water to be treated, etc.

Control of arsenic is more complex where drinking water is obtained from many individual sources (such as hand pumps and wells), which is common in rural areas. Low arsenic water is only needed for drinking and cooking. Arsenic rich water can be used safely for laundry and bathing. Discrimination between high-arsenic and low-arsenic sources by painting the hand pumps (e.g. red and green) can be an effective and low cost measure to reduce exposure to arsenic when accompanied by effective health education.

Alternative low arsenic sources such as rain water and treated surface water may be available and appropriate in some circumstances. Where low arsenic water is not available, it is necessary to remove arsenic from drinking water. The technology for arsenic removal for piped water supply is moderately costly and requires technical expertise. It is inapplicable in some urban areas of developing countries like Nepal, and in most rural areas world wide.

New types of treatment technologies, including co-precipitation, ion exchange and activated alumina filtration are being field-tested. Until now, there are no proven technologies for the removal of arsenic at water collection points such as wells, hand pumps and springs. Simple technologies for household removal of arsenic from water are few and have to be adapted to, and proven sustainable in each different setting.

2.14 Arsenic Remediation Technologies

Thousands of Scientists and researchers around the globe are working hard to find the effective, easy and cheap technology for removal of Arsenic in water. Arsenic can be removed by various processes like, oxidation, coagulation/ co-precipitation, sedimentation, filtration, adsorption, ion exchange and membrane filtration etc. Each of the technology has its own merits and de merits. Some of the technologies adopted for the removal of Arsenic from drinking waster are listed in the appendix C. Among them, Simple aeration, Bucket treatment unit, Safi filter, 3 pitcher filters etc are more popular in this south Asian region.

In Nepal, since identification of Arsenic problems some efforts are being made to reduce the adverse effect. Nawalparasi, Rupendehi, Kapilvastu and Rautahat are defined as high risk districts. In those high risk districts, highly contaminated tube well are marked with cross, to warn the people. Some new tube well have been installed to supply safe water.

Three pitcher and two pitcher house hold filters were introduced in those districts to remove the arsenic from tube well water. Those filters were found efficient to remove the arsenic contamination. With preliminary positive response of users, some government and non government agencies distributed more than 500 such filters in above mentioned high risk districts.

But the strong draws back of those filters are low flow rate. The flow rates of the filters are only 2 L/hr. Many families of the Terai districts are not happy with the flow rate of filters. As a result, the people started to use tube well water without filter.

At later stage, the group of people from MIT, ENPHO and RWSSSP invented a new filter called Arsenic Bio sand Filter (ABF). It is basically combination of Bio sand Filter and Three pitcher filter. The arsenic removal efficiency as well as the flow rates of those filters was found very satisfactory. More than 1000 ABF made of concrete are in use in those three districts. High installation cost, heavy weight, construction difficulties are some of the problems in this filters. To overcome the problems, a filter made of plastic has been developed. Many studies on the efficiency of filters in the laboratory as well as field level are going on.

CHAPTER III

3.0 MATERIALS AND METHODOLOGY

The proposed study work is mainly focused to find out the removal of Arsenic from the water by sand filter using iron nails. The main hypothesis of the proposed system is adsorption of arsenic molecules present in water in the surface of ferric hydroxide. Production of ferric hydroxide is enhanced by the use of rusted iron nails. The arsenic laden ferric hydroxide particles are removed by passing the water through sand bed. In short, the proposed filter uses adsorption mechanism to separate out the arsenic from water, and it applies the principle of slow sand filter to remove the bigger particles. Since the filter uses the principle of slow sand filter, it will remove the micro organisms present in the water to some extent.

The proposed filter is one of the easy, cheap and user friendly household technologies for arsenic removal. The proposed technology is still in research stage. Its removal efficiency and effectiveness in different situation is yet to be determined.

Two plastic filters have been used in this study. The design of both the filters is almost same, except some minor modifications. The details about the filter and its ingredients have been described in subsequent pages.

3.1 Study Area

The study is proposed to be conducted in two phases;

- ❖ Laboratory study and
- ❖ Field study

The first two phases of the study have been conducted to study the performances of filter in the IOE environment laboratory in a controlled environment. Efficiency of filters in term of Arsenic, Iron and coliforms removal have been conducted in laboratory using synthetic arsenic contaminated water. The third phase of study is conducted in Sunwal VDC of Nawal Parasi district.

In first phase of study, the ground water of IOE compound, with the addition of Artificial Arsenic, was used. Like wise for the second phase of study the tap water of IOE laboratory itself was used. In this case also the Arsenic was added artificially.

3.2 Experimental Model

For the experiment, two types of filters are prepared. The principle of both filters is almost same, only some minor changes have been made in the design of two filters.

3.2.1 Filter A

Filter A is the filter made with single plastic bucket. This filter consists of a plastic bucket of 50 liters capacity with lid. A plastic pan, which exactly fit on the bucket, is also used in this filter. The schematic diagram of the filter is given in Figure 3.1. The major ingredients of the filters are fine sand, coarse sand, gravels and iron nails. An out let pipe of PVC is also arranged in the filter. The outlet level of the pipe is kept at the level of 5 cm above the top layer of fine sand.

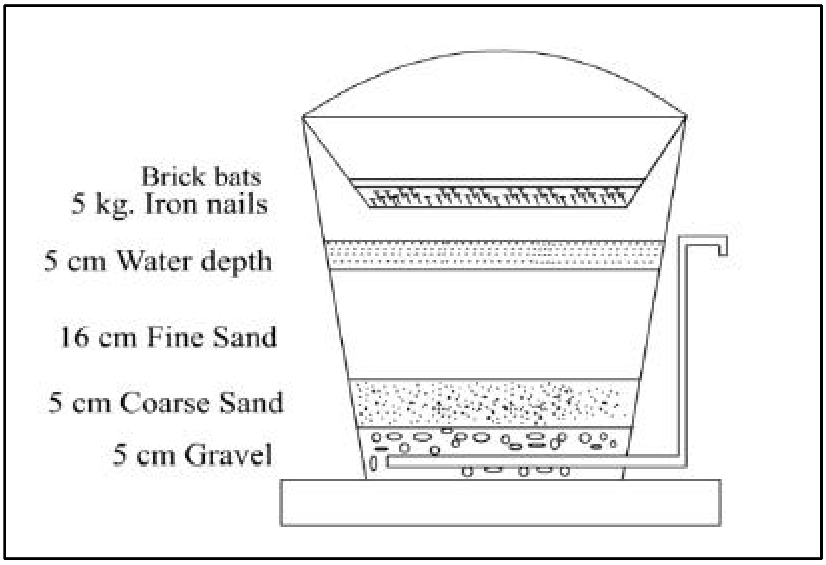

Figure 3.1: Schematic diagram of filter A

3.2.2 Filter B

This filter is prepared using two plastic buckets of size 25 liters and 16 liters. The lower bucket is of 25 liters capacity with lid, and the upper bucket is of 16 liters capacity. The out let arrangement similar to filter A, is made in the lower bucket. A plastic pan with holes at bottom is kept inside the upper bucket. The iron nails are kept on this pan. The major ingredients of filter B are also fine sand, coarse sand, gravels and nails, as used in filter A. The schematic diagram of filter B is given in Figure 3.2.

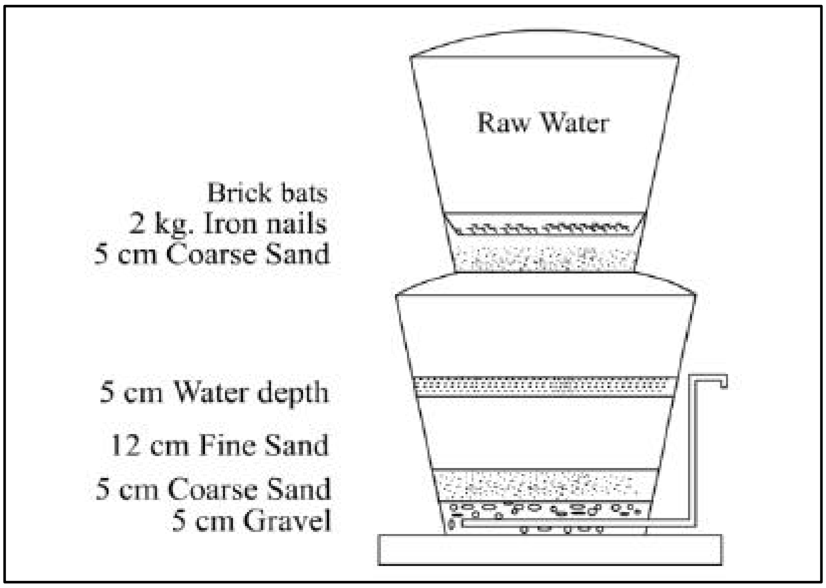

Figure 3.2: Schematic diagram of filter B

3.3 Materials Used for the Preparation of Filters.

3.3.1 Plastic Bucket

In both the filters, plastic buckets are used as main body. Single 50 liter capacity plastic bucket is used in Filter A and two buckets of size 25 liter and 16 liter are used for Filter B. Two holes of 6 mm dia were made at the bottom of upper filter to let the raw water to percolate down. An outlet arrangement was made at the bottom of the bucket in both the filters.

3.3.2 Plastic Pan

A plastic pan, with holes at the bottom, are used in both the filters. But the size of the pan is different. In Filter A, the plastic pan just fit at the top of the bucket. But in filter B, the pan is kept inside the upper bucket. The purpose of both pans is to hold the iron nails. Numbers of holes are made in both the pan, which helps to percolate the raw water to the sand layer.

There are 20 holes of about 3 mm dia in pan for Filter A and 8 holes in pan for Filter B.

3.3.3 Outlet Arrangement

An outlet arrangement using 12 mm PVC pipes and fittings is made in both the filters. Using two plastic bends and PVC pipe, the outlet point of the pipe is kept higher than the top layer of fine sand by 5 cm. It helps to create a permanent bio film layer (schumtz deck) above the sand layer. No any flow control devices are used in the filters.

3.3.4 Gravel

The gravels used in both the filters are of small size. The size of the gravel ranges from 1/4" to 1/2". The gravel was cleaned and dried before use.

3.3.5 Coarse Sand

Coarse sand of 1 mm to 6 mm size is used in the filter. The sand was also washed carefully before use.

3.3.6 Fine Sand

Fine sand media was prepared from the sand collected from the Rapti river of Parsa district. The sand was first thoroughly washed to remove the dust and other unnecessary particles. The sand was then dried adequately. The sand was then sieved to find out its characteristics. Sieve analysis data of the sand used are presented in the Table 3.1. Similarly, Figure 3.3 shows the sieve analysis results of the fine sand. The sand retained in the sieve of 1 mm size has been removed.

Table 3.1 Sieve analysis of fine sand

Sieve Size, (µm)	**Wt Retained (gms)**	**Cumulative Wt Retained**	**% Retained**	**% Passing**
1000	0	0	0.00	100.00
850	25.29	25.29	2.02	97.98
600	96.25	121.54	9.71	90.29
425	166.58	288.12	23.02	76.98
300	282.63	570.75	45.61	54.39
250	182.56	753.31	60.20	39.80
212	202.4	955.71	76.37	23.63
150	180.2	1135.91	90.77	9.23
Pan	115.5	1251.41	100.00	0.00

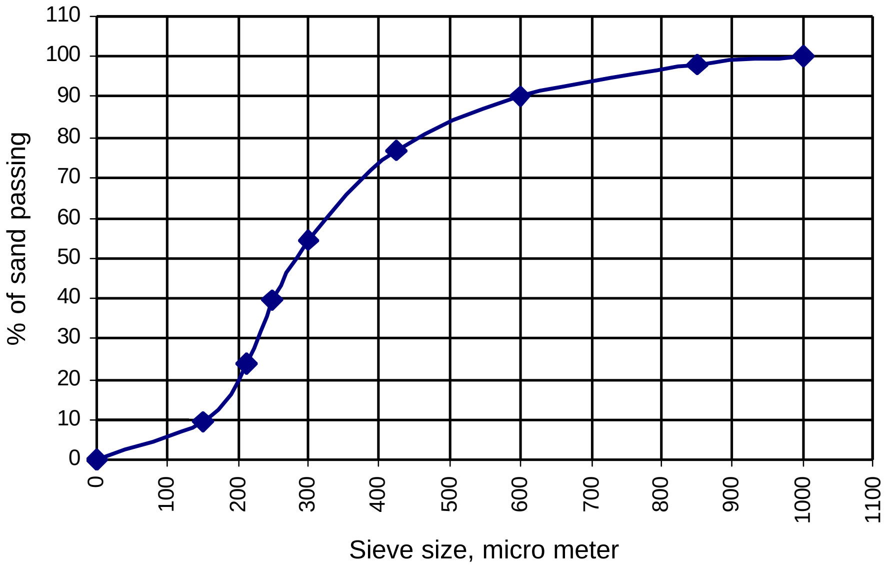

Figure 3.3: Sieve analysis of fine sand

The sand is then tested for the acid test. A known mass of washed and dried sand was soaked in conc. HCL for twenty four hours. The sand is then washed with distilled water several times and dried in oven. The weight lost in the process is calculated. For the suitability of filter media in slow sand filter, the loss should not be more than 5%. The weight lost in the sand was only 0.68%. The characteristics of fine sand are presented in the Table 3.2.

Table 3.2 Characteristics of fine sand

S.N.	Parameters	Units	Values
1	Effective size (D_{10})	mm	0.175
2	60% finer size (D_{60})	mm	0.32
3	Uniformity coefficient		1.83
4	Porosity	%	44.58
5	Density (Bulk)	Kg/ m^3.	1359
6	Specific gravity		2.65
7	Weight loss in acid test	%	0.68

3.3.7 Iron Nails

Iron nails of 12 mm size, called ***Lwang killa***, were used. The nails were cleaned with water and kept open for 24 hours in moist condition to allow the rusting.

3.4 Filter Installation

Following procedures were used to install the filters.

3.4.1 Filter A

The small size gravels are spread at the bottom of the bucket. The depth of the gravel was about 5 cm. It covers the outlet pipe of the filter. The coarse sand is then spread over the gravel bed. The depth of coarse sand was also 5 cm. The fine sand was then slowly added in the filter. The sand was kept layer by layer and water was added after each layer of sand to have evenly distributed sand layer. The sand is added until the top layer of sand is 5 cm below the outlet pipe. The total depth of the fine sand is 16 cm. Extra water added to flow through outlet pipe. The top layer of sand was then smoothen out by hand. The depth of water above the sand layer was measured. The stagnate water depth above fine sand layer is made exactly 5 cm.

The plastic pan with holes at bottom is then placed. The iron nails were then spread over the pan. Shaking the pan, the nails were distributed evenly.

Since raw water is used to fill up the sand and other media, it is outmost necessary to disinfect the filter before its commencement. Hence, 15 ml of chlorine solution is applied in filter and whole set was left for 24 hrs.

3.4.2 Filter B

Similar to filter A, gravel of size 6 to 12 mm size were kept at the bottom of lower bucket. The depth of the gravel was kept about 5 cm. A layer of coarse sand was then spread over the gravel layer. The depth of the sand layer was also 5 cm. Above it, sand was added layer by layer. To distribute the sand evenly and to avoid the pocket formation, water was added after each layer. 12 cm of sand was kept in the filter. The gap between top layer of fine sand and outlet pipe is kept 5 cm. About 8 liters of water was then added slowly in the filter to flow out. A polyester cloth is kept at the bottom of the upper bucket. On top of that, a layer of coarse sand is kept. The plastic pan with holes at bottom is then placed inside the bucket. The bucket was then filled with 2 kg of iron nails. Similar to the filter A, disinfection of filter is done using chlorine solution, and kept for 24 hours. The photographs of Filter A and B are given in Appendix B.

3.5 Water for Test

3.5.1 Natural Ground Water

For the laboratory test of the filters, the ground water of IOE compound and tap water were used. The water thus used contains iron and other constituents similar to Terai water except Arsenic. To imitate ground water quality of Terai, arsenic was spiked in different concentrations.

There is no any treatment implied in the IOE ground water. The water is directly supplied to the tap point from pumping station. The Water Quality of raw water used has been analyzed. Some of the parameters were tested in IOE laboratory and some of the parameters were tested in CEMAT Water lab, Kathmandu. The water quality of raw waters used is presented in Table 3.3.

Similarly, the tap water of IOE compound was used in second phase of study. To imitate the ground water quality of Terai, Arsenic was added like in first phase.

The arsenic III and Arsenic V were added in approximately 80:20 ratios. The concentration of Arsenite and Arsenate in most of the ground water of Nepal is in ratio of 79: 21. (Tommy ngai,2002). The water was spiked with stock solution prepared in the laboratory. To prepare the stock solution of Arsenite and Arsenate, $NaAsO_2$ and $Na_2AsO_4.H_2O$ were used respectively.

3.5.2 Preparation of Stock Solution of Arsenite and Arsenate

To prepare stock solution of Arsenite, 0.1734 gm of $Na As O_2$ was weighted in micro balance. The powder is put in 100 ml of distilled water and mixed thoroughly by shaking. Distilled water is then added to make the total volume equals to 1000 ml. This stock solution of Arsenite becomes the solution of strength 100 ppm.

Similarly, to prepare stock solution of Arsenate, 0.4160 gm of $Na_2Al As O_4.H_2O$ was weighted in micro balance. The powder is mixed with 100 ml of distilled water thoroughly by shaking. Distilled water is then added to make the total volume equals to 1000 ml. This stock solution becomes the solution of strength 100 ppm.

Table 3.3 Water quality of raw waters (Used in three phases).

S. N.	Water Quality parameters	Observed Value (First phase)	Observed Value (Second phase)	Observed Value (Field)	Units
1	Turbidity	14*	1*	1	NTU
2	pH	7.9*	8.2*	7.5	
3	Color	49	1	_	Haz
4	Electric conductivity	1006	247	512	ds/cm
5	Total Alkalinity	524	127	306	mg/l as $CaCO_3$
6	Total Acidity	98	N/A	_	mg/l as $CaCO_3$
7	Carbonate	Nil	Nil	Nil	mg/l as ($CO_3^{-2)}$
8	Chloride	4.8	6.4	4.8	mg/l
9	Nitrate	3.45	0.47	_	mg/l as N
10	Ammonia	64.32	<0.01	0.03	mg/l as N
11	Total Hardness	208	138	305	mg/l as $CaCO_3$
12	Total Phosphate	31.57	0.41	0.05	mg/l as PO_4
13	Total Iron	1.17	0.04	1.20	mg/l
14	Manganese	0.19	<0.01	<0.01	mg/l
15	Sulphate	3.5	5.3	4.5	mg/l as SO_4

* Measured in each test.

3.6 Experimental Methods

3.6.1 Experiment Parameters

Removal of Arsenic is the main objective of the study. Nevertheless, some major water quality parameters were tested during study. Beside Arsenic, the water quality parameters studied are removal of iron and coliforms. Along with these parameters, pH, temperature, turbidity, flow rate etc were also measured. The parameters tested and the methodologies adopted for the test are as follow.

3.6.1.1 Arsenic

Removal of total arsenic by the use of filters was studied in detail. Each day, minimum of 30 and maximum of 100 liters of water were used in each of the filters. The concentrations of total arsenic in influent and effluent water were tested. The difference of the concentration was attributed to the efficiency of the filters. Since the arsenic is trace element, it was measured in unit of ppb or μg/l.

3.6.1.2 Total Iron

Total iron is another important parameter chosen for the study. Though, there is no any serious health implication of higher iron concentration in drinking water, it gives unpleasant aesthetic looks. Iron removal is desirable because effective iron removal is a key pre-requisite for effective arsenic removal. The surface of iron particles is usually loaded with arsenic, because of the chemical interaction between arsenic and ferric hydroxide. Therefore, if iron is found in the filtered water, then arsenic is very likely to be found as well. (Tommy Ngai and Sophie Walewjik, 2003).

3.6.1.3 Coliform Test

The filter, under study, removes certain number of micro-organisms present in the water. It is very difficult to test the pathogenic micro-organism in drinking water. To overcome the above stated problems, coliform tests are done. Coliforms are indicator organisms. Presence of which shows the probability of contamination in water. During the study of filter efficiency, both total coliforms and E-coli test were done. Presence of E-coli indicates the contamination of water with feces of warm blooded animals. Similarly, the presence of total coliforms indicates the contamination of water with other contaminants. Membrane filter tests were done to study the population of micro organisms in influent and effluent water. The methodology adopted for the test of coliforms is as per the Standard Method.

3.6.1.4 pH

pH is one of the very important parameter of water. A large number of chemical reactions are pH dependent. So it is outmost necessary to know the pH of water.

3.6.1.5 Temperature

Temperature is another important water quality parameters. During study, temperature of both influent and effluent water was measured.

3.6.1.6 Flow Rate

Flow rate of the filter is one of the very important factors for social acceptability of the filters. People prefer the filter with high filtration rate. People want to collect the required amount of treated water as quickly as possible. Collection of treated water from the filters having very low filter rate is tedious.

3.6.2 Laboratory Test Methods

All the laboratory tests and analysis of water samples were carried out in IOE Environment Lab and CEMAT Water lab. Brief description of test methods and analysis are given below.

3.6.2.1 Arsenic

Arsenic tests were done in two stages. In each day of experiment, the concentration of the arsenic was measured using arsenic test kits. The method adopted was one of the simple methods available in the country. The kits used were AAN kit (developed by Asia Arsenic Network) and Wage Tech Arsenator. As the name suggests, the method is not of very much accurate methods. It gives only a semi qualitative results and some indication of the concentration.

For more precise and accurate determination of concentration of Arsenic in both influent and effluent water of the filters, the water sample from both influent and effluent water were tested in CEMAT water lab using Hydride Generated Atomic Absorption Spectrophotometer (AAS). The test methods adopted and operation of AAS machine is as per the Standard method and manuals of equipments.

The test of water sample for arsenic contamination was done once in every week by AAS. The water sample from both the filter is collected in poly propylene water bottle. For the preservation of water 10 to 15 drops of concentrated Hydrochloric acid (HCl) was added in the sample. HCl was added in the sample to lower the pH of water. As per the standard method of sample preservation, the pH of the sample should be below 2. The sample bottles were kept in room temperature. The results of the test kit and AAS equipment are discussed in Chapter IV.

3.6.2.2 Total Iron

Total iron concentration of the sample water was done in the IOE laboratory using standard phenanthroline methods. Iron concentrations in both influent and effluent water were tested. The detail about the test procedure is as given in Standard Methods.

3.6.5.3 pH

pH of the water samples were measured using portable HANNA pH meter. The instrument was calibrated with standard pH -7 buffer. pH of both influent and effluent water has been measured.

3.6.2.4 Temperature

Temperature of water before and after the filtration was measure using HANNA digital thermometer.

3.6.2.5 Flow Rate

The filter is designed as intermittent flow filter. Raw water is poured in the filter and the filtered water flows out slowly. The flow of the filter is not constant; it depends upon the water level above the sand layer. Obviously, the flow of filter is higher when there is maximum water level above sand layer and the flow decreases as the level decreases.

For consistency in calculation, the flow rate of the filter was measured after about 5 minutes of pouring full raw water in the filter. The procedures adopted for the flow measurement is as follow.

- 15 liter of raw water was poured in the filter.
- Wait for 5 minutes to make the flow steady.
- Using stop watch, time required to fill the 2 liter measuring cylinder was noted.
- To calculate the average flow rate, time required to fill 10 liters bucket was also noted down.

3.6.2.6 Coliforms Test

Total coliforms test was done once in a week. For the purpose, samples were taken from the raw water and filtered water. The samples were immediately filtered through 0.45 micron size filter paper using vacuum pump. Using M-endo broth as culture medium, the filter papers were incubated for 20 hours at 37.5 degree centigrade. The red colonies with metallic sheen were counted.

Similar process was adopted for the E-coli test too, only difference being the incubation temperature. The incubation temperature maintained for the E-coli test was 44.5 degree centigrade. The greenish red colonies with metallic sheen were counted as E-coli colonies.

CHAPTER IV

4.0 RESULTS AND DISCUSSION

Three cycles of experiment were performed in both the filters prepared. Two cycles of experiments were performed in IOE Environmental Lab using synthetic arsenic. Third cycle of study was conducted in field using Arsenic contaminated natural groundwater. The analysis for the efficiency of the filters is done based on the results of three cycle of study.

The ground water of IOE compound was used in first cycle of study. Similarly, the tap water of IOE was used in second cycle of study. In both the cases, the arsenic was added artificially. The first cycle of study was conducted for 32 days, while the second cycle of study was conducted for 25 days. The field study was carried out for 15 days. Same filters were used in all study cycles.

The results of the experiments, for the removal of Arsenic, Iron, turbidity etc are presented and discussed in following pages

4.1 Water Quality Parameters

Arsenic concentration, Iron and Coliforms were the main parameters to judge the performances of the filters. Nevertheless, Turbidity, pH, Flow rates and Temperature were the other governing parameter in the study. The discussions in the following pages are concentrated on above mentioned parameters.

4.2 Arsenic

The water used for the experiment in laboratory does not contain arsenic. Arsenic was added artificially in water before starting the experiments. The stock solution of Arsenic (As III and As IV) was added to make the concentration of 50 ppb to 690 ppb. The Arsenic concentration of influent water was also measured in each test.

Sunawal VDC of Nawal parasi districts was selected for the field test of the filters. The measured Arsenic concentration of shallow tube well water of the Sunwal VDC ranges from 0 to 500 ppb. But only four tube wells having As concentration 70 to 220 ppb were used for study.

4.2.1 Efficiency of Filter A in Arsenic Removal

The Filter A was used in all three cycles of study. The filter was cleaned before commencing each cycle of study.

First cycle :

The Filter A was tested for 32 days in first cycle. All together 1200 liters of Arsenic spiked water was filtered in filter A during this cycle of study. The ground water of IOE complex was used for study. In its natural condition the water does not contain any Arsenic. Arsenic was added in water in varying concentration during study. The water used in this cycle of study contains very high concentration of phosphate. The water quality of the groundwater used for the study is given in Table 3.3. The concentration of Phosphate in the groundwater was as high as 31.5 mg/l. Similarly, the concentration of Ammonia was also considerably high (64.32 mg/l).

Arsenic concentration in the influent and effluent of both the filters were measured daily with help of Arsenic test kits (AAN test kit and Wage Tech Arsenator). Results obtained with kit were not consistent, and hence are not considered for analysis of this study. The water samples were then tested with Atomic Absorption Spectrophotometer (AAS).

Five kg of iron nails was placed in this single unit filter. The designed contact time, between raw water and iron nails, is approximately 15 minutes. The removal of the arsenic in this filter is found between 17.6% and 64.3% of initial concentration. Raw water having Arsenic concentration of 119 ppb was reduced to 62 ppb. The average Arsenic concentration of influent and effluent water of filter A was 102 and 60 ppb respectively. The average Arsenic removal was found to be 42 ppb and average percentage of Arsenic removal was 41.23%. The correlation between the effluent concentration, age of the filter and removal efficiency could not be established. Table 4.1 below shows the removal of Arsenic in Filter A.

Table 4.1 Removal of arsenic in filter A (First cycle)

Date	Arsenic concentration in Raw Water, ppb	Arsenic concentration in Filtered Water, ppb	Arsenic Removal, ppb	Arsenic Removal Percentage
4-Aug	94	50	44	46.81
6-Aug	70	25	45	64.29
13-Aug	110	60	50	45.45
18-Aug	125	62	63	50.40
20-Aug	114	70	44	38.60
23-Aug	102	61	41	40.20
27-Aug	119	60	59	49.58
8-Sep	104	73	31	29.81
10-Sep	108	54	54	50.00
13-Sep	86	70	16	18.60
17-Sep	91	75	16	17.58
Average	102	60	42	41.23

Second cycle

The filter was tested for 25 days in this cycle. The volume of water filtered is 1800 liters. Instead of ground water, the city supply water of IOE laboratory was used in this cycle. The water used for the test contains very small phosphate concentration, about 0.4 mg/l. Similarly, the residual chlorine at the point of use was zero. The detail about the water quality parameters are given in Table 3.3.

Arsenic was added artificially in the water to imitate the natural ground water of the Terai. The concentration varied from 50 ppb to 690 ppb.

The removal efficiency of filter in this cycle is very high compare to first cycle of study. In an average the removal of the Arsenic is about 85%. The maximum and minimum removal of Arsenic is 89% and 77% respectively. A maximum of 617 ppb of Arsenic was removed from the filter. However, the effluent concentration of As is found always above 10 ppb, which is WHO guideline value for Arsenic. But in most of the test the effluent concentration was below 50 ppb, interim standard for As in Nepal. The Arsenic concentration of Filter effluent exceeded 50 ppb, when the influent concentration was more than 400 ppb. The Table 4.2 gives detail of As removal by filter A in second cycle of study. Though, the effluent concentration of As vary between 11 ppb to 73 ppb, the percentage removal is very much consistent.

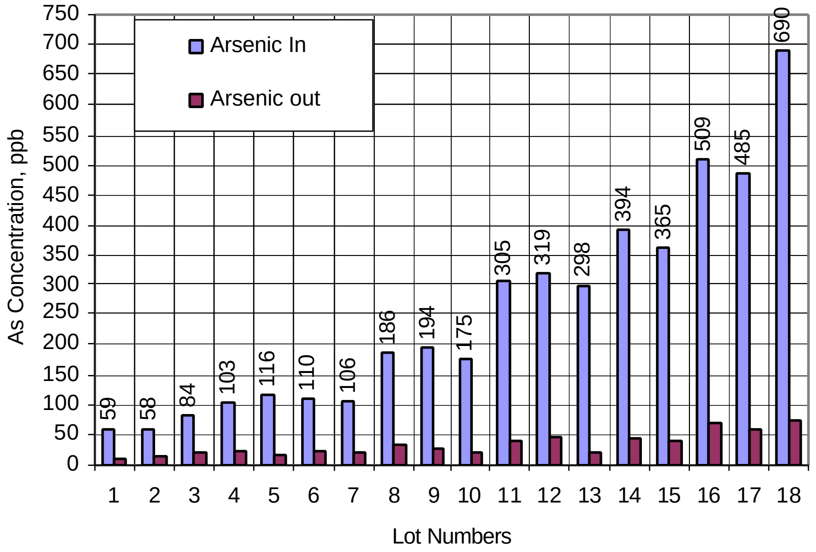

Figure 4.1 Arsenic removal in filter A (Second cycle)

Table 4.2 Removal of arsenic in filter A (Second cycle)

S.N.	Date	Lot No	Volume	Arsenic Concentration			
				In ppb	Out ppb	Removal ppb	Percentage
1	1/7/61	1	100	59	11	48	81
2	2/7/61	2	100	58	12	46	79
3	3/7/61	3	100	84	19	65	77
4	12/7/61	4	100	103	22	81	79
5	13-7-61	5	100	116	17	99	85
6	14-7-61	6	100	110	24	86	78
7	15-7-61	7	100	106	21	85	80
8	16-7-61	8	100	186	34	152	82
9	17-7-61	9	100	194	28	166	86
10	18-7-61	10	100	175	19	156	89
11	19-7-61	11	100	305	40	265	87
12	20-7-61	12	100	319	45	274	86
13	22-7-61	13	100	298	21	277	93
14	24-7-61	14	100	394	43	351	89
15	25-7-61	15	100	365	39	326	89
16	26-7-61	16	100	509	68	441	87
17	1/8/61	17	100	485	58	427	88
18	12/8/61	18	100	690	73	617	89
	Average			253	33	220	85

Field Test

The same filter was tested in four tube wells of Sunwal VDC, ward no 8, Naduwa of Nawalparasi district. About 300 liters of water from each tube wells were filtered. The water sample from influent and effluent of filter were tested for Arsenic concentration. The average arsenic removal efficiency of filter A was found 91%. The effluent concentration of Arsenic in all wells is below 50 ppb. The maximum effluent concentration of Arsenic is 46 ppb. The influent and effluent concentrations of Arsenic in Filter A is given in Table 4.3.

Table 4.3 Arsenic removal in filter A (Field test)

S.N.	Cumulative Volume	As inflow, ppb	As out flow, ppb	Removal ppb	Percentage removal	Remarks
1	100	73	7	66	90	Tube well 1
2	200	75	7	68	91	
3	300	85	6	79	93	
4	400	70	15	55	79	
5	500	118	1	117	99	Tube well 2
6	600	115	5	110	96	
7	700	110	5	105	95	
8	800	172	15	157	91	Tube well 3
9	900	172	10	162	94	
10	1000	189	33	156	83	
11	1100	203	6	197	97	Tube well 4
12	1200	220	15	205	93	
13	1300	203	46	157	77	
14	1400	198	18	180	91	

Comparative Analysis

The Arsenic removal efficiency of Filter A is very much similar in second cycle of laboratory experiment and field study. But the removal efficiency was very less in first cycle of study. The reason of less removal of Arsenic in first cycle may be due to the interference of phosphate. The concentration of phosphate in groundwater of IOE is very high compare to tap water. The ground water of Sunwal contains very small amount of phosphate. From the results analyzed, it can be concluded that the phosphate concentration hinders the removal of Arsenic.

The results showed that Filter A is efficient to filter the water having Arsenic concentration up to 400 ppb in influent water. The effluent Arsenic concentration of filtered water of 400 ppb is below the Interim Arsenic standard of Nepal. Once the Influent concentration exceeds 400 ppb, the effluent concentration exceeds 50 ppb.

4.2.2 Efficiency of Filter B in Arsenic Removal

Similar to Filter A, the Filter B was used for three cycle of study.

First cycle

The Filter B was tested for 32 days in first cycle. All together 800 liters of Arsenic spiked water was filtered during this cycle. The ground water of IOE complex with artificially added Arsenic was used for study.

Arsenic removal in Filter B is similar to the Filter A. In filter B, only 2 kg of nails was used. But the contact time between raw water and nails is increased by making only two small holes at the base of the bucket. The flow rate of raw water from upper bucket to lower bucket is kept about 47 liter per hour.

Table 4.4 shows Arsenic removal in Filter B. The average influent and effluent Arsenic concentrations were recorded as 102 ppb and 65 ppb respectively. The average Arsenic removal is 36 ppb while the average percentage of Arsenic removal is 34.6%. Maximum removal up to 57 ppb was recorded. The effluent concentration of arsenic was higher than 50 ppb, except in one case, which is interim standard for the drinking water in Nepal.

Table 4.4 Removal of arsenic in filter B (First cycle)

Date	Arsenic Concentration in Raw Water, ppb	Arsenic Concentration in Filtered Water, ppb	Arsenic Removal, ppb	Arsenic Removal Percentage
4-Aug	94	50	44	46.81
6-Aug	70	62	8	11.43
13-Aug	110	72	38	34.55
18-Aug	125	74	51	40.80
20-Aug	114	82	32	28.07
23-Aug	102	58	44	43.14
27-Aug	119	62	57	47.90
8-Sep	104	54	50	48.08
10-Sep	108	71	37	34.26

Date	Arsenic Concentration in Raw Water, ppb	Arsenic Concentration in Filtered Water, ppb	Arsenic Removal, ppb	Arsenic Removal Percentage
13-Sep	86	72	14	16.28
17-Sep	91	64	27	29.67
Average	102	66	36	34.65

Second cycle:

The Filter B was tested for 25 days in this cycle. The volume of water filtered is 1800 liters. Instead of groundwater, the city supply water of IOE laboratory was used in second cycle of study.

To imitate the natural ground water of the Terai, Arsenic was added artificially in the water. The concentration varied from 50 ppb to 690 ppb. The removal efficiency of Filter B in this cycle is found very high compare to first cycle of study. The average removal of the Arsenic is about 76%. The maximum and minimum removals of Arsenic are 83% and 71% respectively. A maximum of 405 ppb of Arsenic was removed from the filter. The detail of the Arsenic removal in Filter B is given in Table 4.5.

Table 4.5 shows that the effluent As concentration is below the Nepalese Interim Standard concentration of 50 ppb until the influent concentration is 200 ppb. But the effluent As concentration becomes more than 50 ppb when the influent concentration is above 200 ppb.

Table 4.5 Arsenic removal in filter B (Second cycle)

S.N.	Date	Lot No	Volume	Arsenic Concentration			
				In ppb	Out ppb	Removal ppb	Removal Percentage
1	1/7/61	1	100	59	12	47	80
2	2/7/61	2	100	58	10	48	83
3	3/7/61	3	100	84	24	60	71
4	12/7/61	4	100	103	18	85	83
5	13-7-61	5	100	116	31	85	73
6	14-7-61	6	100	110	28	82	75
7	15-7-61	7	100	106	27	79	75
8	16-7-61	8	100	186	38	148	80
9	17-7-61	9	100	194	48	146	75

S.N.	Date	Lot No	Volume	Arsenic Concentration			
				In ppb	Out ppb	Removal ppb	Removal Percentage
10	18-7-61	10	100	175	49	126	72
11	19-7-61	11	100	305	58	247	81
12	20-7-61	12	100	319	82	237	74
13	22-7-61	13	100	298	76	222	74
14	24-7-61	14	100	394	103	291	74
15	25-7-61	15	100	365	93	272	75
16	26-7-61	16	100	509	107	402	79
17	1/8/61	17	100	485	95	390	80
18	12/8/61	18	100	690	285	405	59

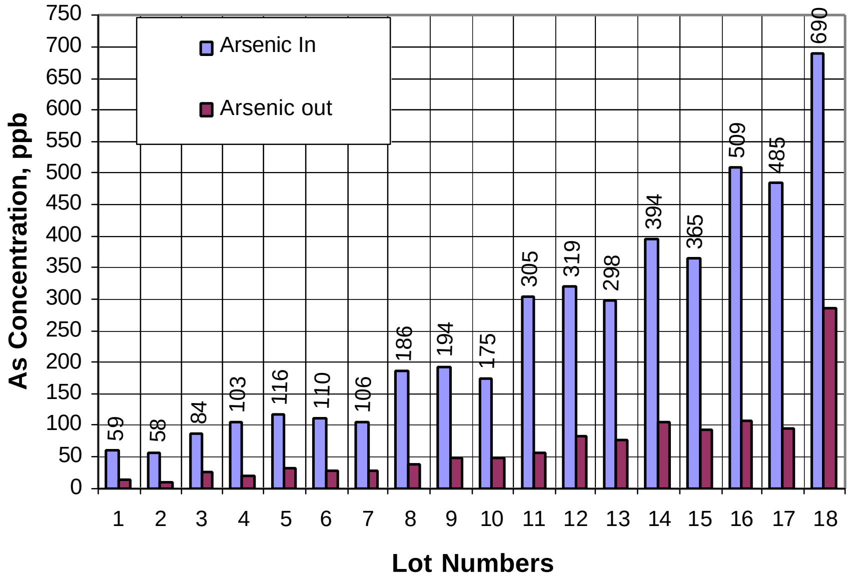

Figure 4.2 Arsenic removal in filter B (Second cycle)

Field Test

As in the case of the Filter A, the filter B was also tested in four tube wells of Sunwal VDC, ward no 8, Naduwa of Nawalparasi. About 300 liters of water from each tube wells were filtered through this filter. The water sample from influent and effluent of filter were tested for Arsenic concentration. The average arsenic removal efficiency of filter was found 87%. The effluent concentration of Arsenic in all wells is below 50 ppb. The detail about arsenic concentrations are given in Table 4.6. Due to some practical constraints, the filter could not be tested in tube wells having As concentration above 300 ppb.

Comparative Analysis

The arsenic removal efficiency of Filter B during first cycle was very low due to presence of high phosphate in raw water. But the arsenic removal efficiency of Filter B during second cycle of study was found very high. Filter B is found to be suitable for arsenic removal up to influent arsenic concentration of 200 ppb in water containing low or no phosphate.

Table 4.6 Influent and effluent concentration of arsenic in filter B (Field test)

S.N.	Cumulative Volume	As inflow, ppb	As out flow, ppb	Removal ppb	Percentage removal	Remarks
1	100	73	7	66	90	Tube well 1
2	200	75	7	68	91	
3	300	85	8	77	91	
4	400	70	10	60	86	
5	500	118	21	97	82	Tube well 2
6	600	115	30	85	74	
7	700	110	19	91	83	
8	800	172	19	153	89	Tube well 3
9	900	172	20	152	88	
10	1000	189	22	167	88	
11	1100	203	25	178	88	Tube well 4
12	1200	220	25	195	89	
13	1300	203	31	172	85	
14	1400	198	18	180	91	

4.2.3 Comparative Study of Filters A and B in Arsenic Removal

In principle both the filters are same. Only difference is the size. 5 and 2 kgs of iron nails are kept in Filter A and Filter B respectively. The results of second cycle study and field study indicated that both the filters are efficient to remove arsenic in the water having As concentration below 200 ppb. Once the concentration of As in water increases 200 ppb, the effluent As concentration of filter B crosses 50 ppb. But the Filter A is efficient for the water having As concentration up to 400 ppb. The reason behind may be the difference in mass of iron nails. More nails in Filter A produces more ferric hydroxide, which allows more adsorption of Arsenic molecules. The Figure 4.3 shows the comparison of removal efficiencies of both the filters during the second cycle of study.

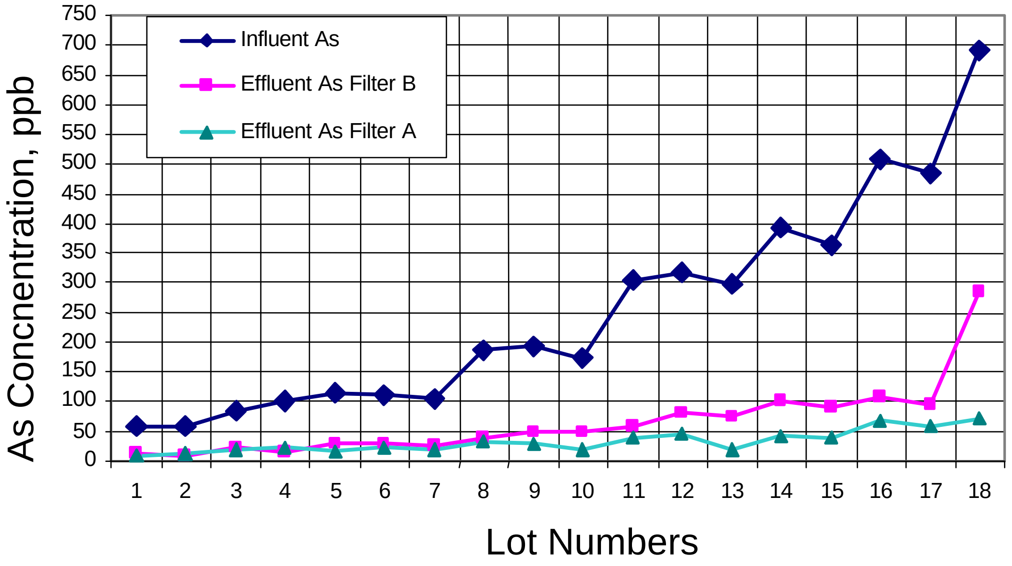

Figure 4.3 Arsenic removal in Filters A and B

4.3 Iron

Iron removal efficiency of Filters was tested as part of the study. But for this study no any iron were added in the water. The removal of naturally available iron was measured in both raw and filtered water.

The principle of arsenic removal mechanism is adsorption of Arsenic on iron particles.(flocs). The flocs of iron loaded with Arsenic are then removed by mechanical straining when passing through sand bed. Therefore iron removal is essential for Arsenic removal. But aeration of water is needed to remove the dissolved Iron (ferrous).

4.3.1 Efficiency of Filters in Iron Removal

The iron removal efficiencies of filters were tested in each of the three cycles of study.

Groundwater was used in first cycle of test. The Iron concentration of raw water in this cycle was varied between 1 to 2 mg/l.

The average iron removal efficiency of both filters is only about 50%. Maximum of 64.1% iron removal was achieved in the experiments. But the effluent iron concentration remained above WHO guideline value of 0.3 mg/l.

Average iron concentration of effluent water is 0.66 mg/l and 0.62 mg/l in Filter A and Filter B respectively. Both the filters showed almost same iron removal efficiency. The table 4.7 shows the iron removal in both filters during first cycle.

Table 4.7 Profile of iron concentration in filter A (First cycle)

Date	Iron Concentration in Raw Water, ppm	Iron Concentration in Filter A. ppm		Iron Concentration in Filter B, ppm	
		Effluent	Removal	Effluent	Removal
4-Aug	1.10	0.52	0.58	0.52	0.58
6-Aug	1.37	0.85	0.52	0.85	0.52
13-Aug	1.40	0.42	0.98	0.52	0.88
18-Aug	1.38	0.45	0.93	0.50	0.88
20-Aug	1.56	0.90	0.66	0.56	1.00
23-Aug	1.40	0.71	0.69	0.62	0.78
27-Aug	1.20	0.53	0.67	0.62	0.58
8-Sep	1.07	0.54	0.53	0.58	0.49
10-Sep	1.20	0.75	0.45	0.70	0.50
13-Sep	1.40	0.60	0.80	0.70	0.70
17-Sep	1.20	0.70	0.50	0.70	0.50
Average	1.30	0.63	0.67	0.62	0.68

As per WHO Guideline and Nepal's proposed standard, the iron concentration in drinking water should be less than or equal to 0.3 mg/l. But effluent of both the filters, in first cycle, has iron concentration more than above value. The probable cause for lesser iron removal may be due to inadequate aeration. In absence of enough oxygen, the iron in water remains in ferrous state, which is soluble in water. The filter under study can not remove the soluble iron effectively. To remove the iron from water, it must be converted to ferric state. When iron changes to ferric state, it produces gelatinous floc. The floc are then removed by passing the water through sand layer. It simply indicates that the rate of floc formation is directly proportional to iron removal from water.

Oxygen is necessary to convert the ferrous in to ferric,. To oxidize the ferrous iron in to ferric, the water must be kept in touch of air or oxygen. This process is called aeration. The filter designed may not have enough aeration facilities, which may be the main cause for lesser removal of iron from water.

The second cycle of test was carried out using tap water. The concentration of iron in tap water was very low. The concentration of water varies between 0.21 to 0.35 mg/l. The Iron concentration of filtered water varied between 0.08 to 0.19 mg/l. Irrespective of the configuration, the Iron concentration of filtered water in both the filters are found almost same. The detail of Iron concentration in both the filters is given in Table 4.8.

Table 4.8 Profile of iron concentration in filters A and B (Second cycle)

S.N.	Lot No.	Filter A				Filter B			
		In, ppm	Out, ppm	Removal ppb	% Removal	In, ppm	Out, ppm	Removal ppb	% Removal
1	1	0.21	0.17	0.04	19	0.21	0.16	0.05	24
2	2	0.27	0.15	0.12	44	0.27	0.16	0.11	41
3	3	0.25	0.13	0.12	48	0.25	0.11	0.14	56
4	4	0.29	0.13	0.16	55	0.29	0.11	0.18	62
5	5	0.3	0.1	0.2	67	0.3	0.09	0.21	70
6	6	0.22	N/D			0.22			
7	7	0.09	0.09			0.09	0.09		
8	8	0.32	0.13	0.19	59	0.32	0.13	0.19	59
9	9	0.35	0.1	0.25	71	0.35	0.19	0.16	46
10	10	0.26	0.08	0.18	69	0.26	0.08	0.18	69
11	11	N/D	N/D			N/D	N/D		
12	12	N/D	N/D			N/D	N/D		
13	13	0.31	0.11	0.2	65	0.31	0.13	0.18	58
14	14	N/D	N/D			N/D	N/D		
15	15	0.34	0.19	0.15	44	0.34	0.2	0.14	41
16	16	N/D	N/D			N/D	N/D		
17	17	0.27	0.18	0.09	33	0.27	0.16	0.11	41
18	18	0.27	0.16	0.11	41	0.27	0.16	0.11	41

The raw water used in the field for the experiments contained 1.2 to 1.75 mg/l Iron concentration. In each of the tube well, the raw water and filtered water were collected and tested for Iron concentration. Both the filters removed Iron concentration of raw water to very low concentration. The concentration of Iron in all the filtered water is found less than 0.3 mg/l, which is the guide line value for the Iron concentration in Nepal. The detail about the Iron concentration in raw and filtered water collected from the field is given in the Table 4.9.

Table 4.9 Profile of iron concentration in Filters A and B (Field test)

S.N.	Tube wells	Filter A				Filter B			
		In, ppm	Out, ppm	Removal	% Removal	In, ppm	Out, ppm	Removal	%Removal
1	1	1.75	0.2	1.55	89	1.75	0.22	1.53	87
2	1	1.75	0.2	1.55	89	1.75	0.22	1.53	87
3	2	1.39	0.15	1.24	89	1.39	0.15	1.24	89
4	2	1.39	0.15	1.24	89	1.39	0.15	1.24	89
5	3	1.20	0.10	1.10	92	1.20	0.09	1.11	93
6	3	1.20	0.10	1.10	92	1.20	0.09	1.11	93

4.4 Coliforms Removal

The filter under study is actually the combination of Bio sand filter (Also called Canadian Water Filter, CWF) and Three pitcher arsenic removal filter (3-Kolshi Filter). The top portion of the filter is responsible for the removal of arsenic, where as lower portion (Fine sand) is responsible for the removal of micro organisms. Biological layer, known as *schumze deck*, is mainly responsible for the removal of micro organisms from raw water. Some larger species of organisms like eggs of worm, cyst etc are removed by mechanical straining in sand layer. Other small species are removed by biological activities in the bio film layer. About 2 to 3 weeks of time is required to form full fledge bio film layer on the surface of find sand.

The coliforms tests were performed during first and second cycle of study. Due to some practical difficulties, this test could not be performed in field.

In first cycle of study, on an average 87.5% removal of Total coliforms and 82% removal of E-coli was found in filter no A. Similarly, 82.5% removal of total coliforms and 71.3% removal of E-coli were found in filter B. The total coliforms and E-coli in the influent, effluent and % removal in Filters A and B during first cycle are presented in Table 4.10 and 4.11 respectively.

Table 4.10 Coliforms and E-coli in Filter A

S.N.	Date	T .coliforms			E. Coliforms		
		In	Out	Removal %	In	Out	Removal %
1	8-Aug-04	500.0	80	84.0	20	4	80.0
2	19-Aug-04	500.0	52	89.6	12	3	75.0
3	27-Aug-04	180.0	20	88.9	8	1	87.5
4	10-Sep-04	300.0	40	86.7	30	5	83.3
5	12-Sep-04	200.0	25	87.5	20	4	80.0
6	17-Sep-04	350.0	40	88.6	15	2	86.7
7	22-Sep-04	500	65	87.0	16	3	81.3
	Average			87.5			82.0

Note: 500 means TNTC, for calculation it is assumed as 500

Table 4.11 Coliforms and E-coli in filter B

S.N.	Date	T .coliforms			E. Coliforms		
		In	Out	Removal %	In	Out	Removal %
1	8-Aug-04	500	75	85.0	20	6	70.0
2	19-Aug-04	500	53	89.4	12	5	58.3
3	27-Aug-04	180	56	68.9	8	2	75.0
4	10-Sep-04	300	75	75.0	30	13	56.7
5	12-Sep-04	200	30	85.0	20	2	90.0
6	17-Sep-04	350	55	84.3	15	2	86.7
7	22-Sep-04	500	50	90.0	16	6	62.5
	Average			82.5			71.3

In second cycle of study, 10 tests were performed for coliforms in each filter. But among ten tests, the fecal coliform in raw water was observed in only one test.

Three number of colony of fecal coliform in raw water was observed in raw water. The effluent of both filters did not developed any colonies. But the raw water in each of the test showed the dense colonies of total coliforms. The total coliforms test for raw water and filtered water from both the filters were done and the results are presented in the Table 4.12. Assuming 500 colonies for TNTC, when it was difficult to count, the removal efficiency is found more than 90%. However the complete removal of coliforms could not be achieved.. Average removal of total coliforms in Filter A and B is found 94 and 95% respectively.

Table 4.12 Total Coliforms removal in Filters A and B

Lot No.	Filter A				Filter B			
	Inlet	Outlet	Removal	% Removal	Inlet	Outlet	Removal	% Removal
1	500	20	480	96	500	15	485	97
2	500	40	460	92	500	38	462	92
3	200	10	190	95	200	12	188	94
4	500	40	460	92	500	30	470	94
8	500	20	480	96	500	15	485	97
9	500	30	470	94	500	25	475	95
13	500	50	450	90	500	35	465	93
15	300	20	280	93	300	20	280	93
17	300	20	280	93	300	15	285	95
18	300	20	280	93	300	15	285	95

4.5 Flow Rate

Compare to other household Arsenic removal technology, the filters used in this study have very satisfactory flow rate. This filter was designed as intermittent flow filter. The average flow rate, when the filters are in use, was never found less than 10 l/hr. The flow rate in the filter is proportional to the water level above the outlet pipe. Higher the water level, the higher is the hydraulic head, which leads to higher Darcy flux through sand, which in turn gives higher flow rate.

During experiment, it is found that the flow rate goes on decreasing as the time passes. This may be due to the clogging of voids in sand layer. The floc of ferric hydroxide goes on accumulating on the surface of fine sand, which reduces the flow rate.

The rate of flow through filter was found higher at beginning and decreased gradually. As the time passes, the head available on sand filter goes on decreasing which resulted reduced flow rate. The rate of filtration measured after making the diffuser box full with raw water are presented in Figures 4.4 for Filters A and B.

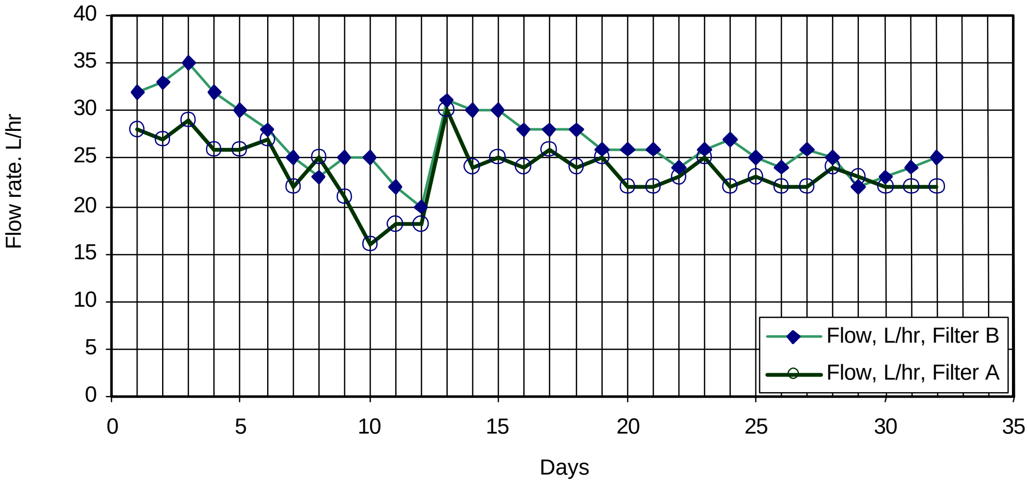

Figure 4.4: Flow rate profile in Filters A and B in first cycle

Note: The filters were cleaned on 12th day.

The flow rate was calculated by recording the time required to collect 2 liters of filtered water. The flow rate is obviously high in the beginning because the rate was calculated when diffuser box was full (5 minute after making full).

The flow rate of both filters decreased as the water level above the sand decreased. The flow rate was higher at beginning and slowly decreased later on. This fact is true for Filter A. But in filter B, the flow rate increases up to nearly initial 15 minutes. After reaching maximum, it again decreased slowly. To know the pattern of flow, the quantity of water at every 5 minute interval was measured. The pattern measured on 14th August 2004, is presented in Figure 4.5.

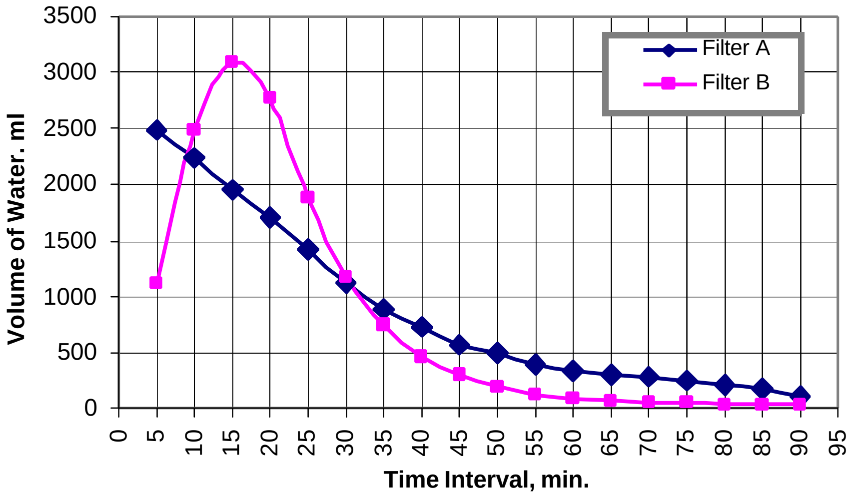

Figure 4.5: Flow pattern of Filters A and B

The flow rate measured in second cycle of study showed more or less same result as of first cycle. The flow rates measured with full diffuser box in both the filters is illustrated in the Figure 4.6.

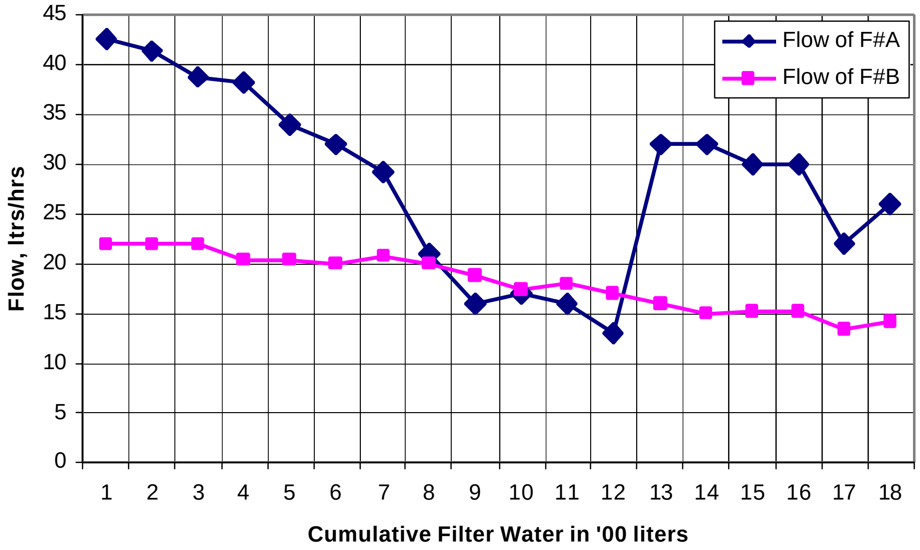

Figure 4.6 Filter's flow rates in second cycle

4.6 Turbidity

Turbidity is one of the very important quality parameter. Turbidity may not have direct health impact, but it is more associated with the social acceptance of water.

The water quality standard of Nepal emphasizes to have the turbidity of drinking water below 5 NTU.

The filters, under study were found very excellent in term of turbidity removal. On an average the turbidity of raw water was found 12.1 NTU. But the turbidity of filtered water was always less than 1 NTU. The average effluent turbidity are 0.8 NTU for Filter A and 0.9 NTU for Filter B.

The turbidity of raw water used for second cycle of test was very low. On an average the turbidity of raw water was 4 NTU. Obviously the turbidity of effluent water was also very less. In the entire test it was below 1NTU. On an average it was 0.5 NTU.

The removal percentage of turbidity is 92.56 for Filter A and 91.74 for filter B. The bar chart showing the average turbidity of influent and effluent water is given in Figure 4.8.

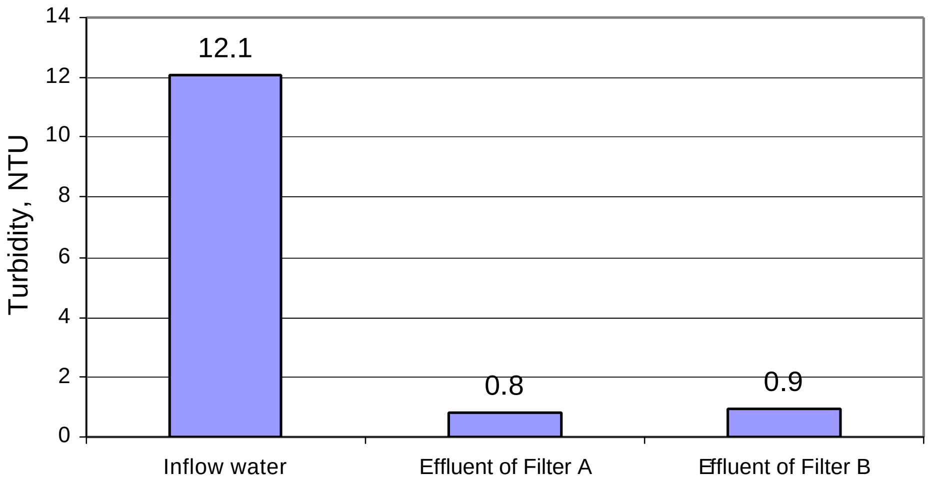

Figure 4.7 Average turbidity in Filters A and B

4.7 pH

The pH of influent and effluent water was also measured as a supporting parameter for study. The raw water used was slightly alkaline. The average influent pH is 7.8. The average effluent pH is about 7.85.

4.8 Temperature

The temperature of effluent water was less than that of the influent water. On an average there was a difference of 1.7 to 2 degree in inflow and out flow water of filters.

CHAPTER V

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The efficiencies of Filters A and B in removing Arsenic, Iron, Turbidity and microbial contaminants were studied in laboratory as well as field. In light of results obtained, following conclusions are drawn.

- Both the Filters are efficient to remove Arsenic content in water. Average removal efficiency of Filter A and B are 85 and 76 percent respectively.
- Filter A (with 5 kg nails) is more efficient to remove arsenic up to 400 ppb and Filter B (with 2 kg of nails) is efficient to remove arsenic up to 200 ppb.
- The water quality of filtered water (Arsenic concentration) meets Nepal Interim standard.
- The concentration of Arsenic in filtered water is found to exceed Nepal's interim standard of 50 ppb, when the raw water concentration of arsenic exceeded 400 ppb and 200 ppb in Filters A and B respectively.
- The efficiency of both the filters is found to be hindered when phosphate concentration in raw water is high.
- Removal efficiency of Filters are found to be higher in natural groundwater.
- Iron removal efficiency of both Filters is quite satisfactory. Iron concentration in raw water up to 1.75 mg/l is reduced to 0.25 mg/l.
- The average removal of Total Coliforms in the filters are 94%.
- Both the filters are found excellent in removing the turbidity. Raw water with average turbidity of 12 NTU was always reduced to turbidity less than 1 NTU.
- The flow rate of both the filters is very satisfactory. Average flow rates of filters are 10 l/hr. This rate of filtration is more than enough for average Nepali family size.
- Filter needs cleaning after filtering about 1000 liters of water. But the rate of clogging depends on many parameters such as turbidity etc.

- Filter A is easier in handling than Filter B. But, Filter B is cheaper than Filter A.

5.2 Recommendations

The filters under study are very much user friendly and efficient to remove Arsenic contamination of drinking water. Filter A is useful to treat arsenic contaminated water up to 400 ppb. Similarly, Filter B can be used to treat arsenic concentration level up to 200 ppb. Since the filter is efficient in removing Arsenic, Iron and Turbidity, it may be adopted as one of the best household technology in treating drinking water in Arsenic prone Terai area. Considering the fact that, the arsenic concentration in more than 90% of tube wells in Nepal is below 400 ppb, probably this filter is the best solution to cope with present arsenic problem.

This filter will also address the problem of microbial contamination of drinking water. During normal condition, this filter may be one of the easy solutions for the prevention of water borne diseases. However, it is advisable to use disinfectants like chlorine during epidemic and rainy season to make water safe from microbial contamination.

5.3 Areas for Further Study

There are still some areas in which detail study is required. Some of them are as follow:

- More study is needed to treat water containing more than 400 ppb arsenic. For this some modification in filter may be necessary.
- More detail and in depth study on removal of microbial contamination is required.
- The determination of efficiency of filter in continuous flow is desirable.
- Study on the elements which may interfere the removal efficiency of filter should be carried out.

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APPENDICES

Appendix- A: Main Data Sheets

Appendix-B: Photographs

Appendix-C: Arsenic Remediation Technologies

Appendix-A

Experiment results in First Cycle

Filter A

Depth of Sand: 16 cm
Weight of nails: 5 kgs

S.N.	Date	As Added ppb	Water, litres		Arsenic, Ugl/l		As removal		Iron, mg/l		Iron removal		Turbidity,NTU		pH		Temp., Deg		T.coli forms		E.Coliforms		Remarks
			Volume,l	Rate, l/hr	In	Out	ppb	%	In	Out	ppm	%	In	Out	In	Out	In	Out	In	Out	In	Out	
1	28-Jul-04		Filter Installation																				
2	29-Jul-04		Chlorination																				
3	30-Jul-04																						
4	31-Jul-04		←						Saturday														→
5	4-Aug-04	100	30	26.0	94.0	50.0	44.0	46.8	1.1	0.5	0.6	52.7	12.0	0.9	8.00	8.00	25.6	23.9					
6	6-Aug-04	100	30	27.0	70.0	25.0	45.0	64.3	1.4	0.9	0.5	38.0	12.0	0.7	7.90	8.00	25.8	23.8					
7	13-Aug-04	150	30	17.0	110.0	60.0	50.0	45.5	1.2	0.5	0.7	56.7	12.0	1.0	N/D	N/D	26.1	24.5					
8	18-Aug-04	200	40	30.0	125.0	62.0	63.0	50.4	1.3	0.5	0.8	61.5	13.0	0.6	7.4	7.9	26.2	23.4					
9	20-Aug-04	200	30	25.0	114.0	70.0	44.0	38.6	1.6	0.9	0.7	42.3	12.0	1.0	7.7	7.8	24.1	23.0					
10	23-Aug-04	200	40	26.0	102.0	61.0	41.0	40.2	1.4	0.7	0.7	49.3	14.0	0.9	7.8	7.9	25.0	23.4					
11	27-Aug-04	200	30	25.0	119.0	60.0	59.0	49.6	1.2	0.5	0.7	55.8	14.0	1.0	7.8	7.9	26.1	242.0	180.0	20.0	8.0	1.0	
12	8-Sep-04	250	40	22.0	104.0	73.0	31.0	29.8	1.1	0.5	0.5	49.5	13.0	0.7	7.9	8.1	25.8	23.90					
13	10-Sep-04	250	30	23.0	108.0	54.0	54.0	50.0	1.2	0.8	0.5	37.5	12.0	1.0	7.6	7.8	23.2	24.4	300.0	40.0	30.0	5.0	
14	13-Sep-04	200	40	22.0	86.0	70.0	16.0	18.6	1.4	0.6	0.8	57.1	12.0	0.8	7.9	8.0	23.3	24.0					
15	17-Sep-04	100	40	24.0	91.0	75.0	16.0	17.6	1.2	0.7	0.5	41.7	10.0	0.9	7.7	7.9	23.5	23.0	350.0	40.0	15.0	2.0	
					1123.0	660.0	463.0	451.3	14.0	7.1	6.9	542.2	136.0	9.5	77.69	79.30	274.7	479.3					
			Average		102.09	60	42.091	41.229	1.273	0.647	0.625	49.14	12.36	0.859	7.063	7.209	24.97	43.57					

Note: As test by AAS

Appendix-A

Experiment results in First Cycle
Filter B

Depth of Sand: 12 cm
Weight of nails: 2 kgs

S.N.	Date	As Added ppb	Water, litres		Arsenic, Ugl/l		As removal		Iron, mg/l		Iron removal		Turbidity,NTU		pH		Temp., Deg		T.coli forms		E.Coliforms		Remarks
			Volume,l	Rate, l/hr	In	Out	ppb	%	In	Out	ppm	%	In	Out	In	Out	In	Out	In	Out	In	Out	
1	28-Jul-04		Filter Installation																				
2	29-Jul-04		Chlorination																				
3	30-Jul-04																						
4	31-Jul-04		◄						Saturday														►
5	4-Aug-04	100	30	32.0	94.0	50.0	44.0	46.8	1.1	0.52	0.6	52.7	12.0	0.8	8.00	8.00	25.6	24.0					
6	6-Aug-04	100	30	28.0	70.0	62.0	8.0	11.4	1.4	0.85	0.5	38.0	12.0	0.7	7.90	8.00	25.8	23.8					
7	13-Aug-04	150	30	25.0	110.0	72.0	38.0	34.5	1.2	0.52	0.7	56.7	12.0	0.7	N/D	N/D	26.1	24.6					
8	18-Aug-04	200	40	31.0	125.0	74.0	51.0	40.8	1.3	0.50	0.8	61.5	13.0	1.0	7.4	7.4	26.2	23.9					
9	20-Aug-04	200	30	30.0	114.0	82.0	32.0	28.1	1.6	0.56	1.0	64.1	12.0	1.0	7.7	7.7	24.1	23.8					
10	23-Aug-04	200	30	28.0	102.0	58.0	44.0	43.1	1.4	0.62	0.8	55.7	14.0	0.8	7.8	7.8	25.0	24.2					
11	27-Aug-04	200	28	26.0	119.0	62.0	57.0	47.9	1.2	0.62	0.6	48.3	14.0	1.2	7.8	7.8	26.1	24.5	180.0	20.0	8.0	1.0	
12	8-Sep-04	250	40	26.0	104.0	54.0	50.0	48.1	1.1	0.58	0.5	45.8	13.0	1.0	7.9	7.9	25.8	24.20					
13	10-Sep-04	250	30	24.0	108.0	71.0	37.0	34.3	1.2	0.70	0.5	41.7	12.0	0.7	7.6	7.6	23.2	23.6	300.0	40.0	30.0	5.0	
14	13-Sep-04	200	40	27.0	86.0	72.0	14.0	16.3	1.4	0.70	0.7	50.0	12.0	0.9	7.9	7.8	23.3	23.4					
15	17-Sep-04	100	40	25.0	91.0	61.0	30.0	33.0	1.2	0.70	0.5	41.7	10.0	0.5	7.7	7.7	23.5	23.0	350.0	40.0	15.0	2.0	
Average					102.09	65.273	36.818	36.064	1.273	0.62	0.648	50.93	12.36	0.845	7.063	7.064	24.97	23.91					

Note: As test by AAS

ARSENIC AND IRON REMOVAL IN SECOND CYCLE

FILTER A

S.N.	Date	Lot No	Volume	Arsenic Concentration				Iron Concentration			
				In	Out	Removal	Percentage	In	Out	Removal	Percentage
1	1/7/61	1	100	59	11	48	81	0.21	0.17	0.04	19
2	2/7/61	2	100	58	12	46	79	0.27	0.15	0.12	44
3	3/7/61	3	100	84	19	65	77	0.25	0.13	0.12	48
4	12/7/61	4	100	103	22	81	79	0.29	0.13	0.16	55
5	13-7-61	5	100	116	17	99	85	0.3	0.1	0.2	67
6	14-7-61	6	100	110	24	86	78	0.22	0.15	0.07	32
7	15-7-61	7	100	106	21	85	80	0.09	0.09	0	0
8	16-7-61	8	100	186	34	152	82	0.32	0.13	0.19	59
9	17-7-61	9	100	194	28	166	86	0.35	0.1	0.25	71
10	18-7-61	10	100	175	19	156	89	0.26	0.08	0.18	69
11	19-7-61	11	100	305	40	265	87	-			
12	20-7-61	12	100	319	45	274	86	-			
13	22-7-61	13	100	298	21	277	93	0.31	0.11	0.2	65
14	24-7-61	14	100	394	43	351	89	-	0		
15	25-7-61	15	100	365	39	326	89	0.34	0.19	0.15	44
16	26-7-61	16	100	509	68	441	87	-			
17	1/8/61	17	100	485	58	427	88	0.27	0.18	0.09	33
18	12/8/61	18	100	690	73	617	89	0.27	0.16	0.11	41
	Average			253	33	220	85	0.27	0.13	0.13	46

Appendix-A

ARSENIC AND IRON REMOVAL IN SECOND CYCLE
FILTER B

S.N.	Date	Lot No	Volume	Arsenic Concentration				Iron Concentration			
				In	Out	Removal	Percentage	In	Out	Removal	Percentage
1	01/07/61	1	100	59	12	47	80	0.21	0.19	0.02	10
2	02/07/61	2	100	58	10	48	83	0.27	0.15	0.12	44
3	03/07/61	3	100	84	24	60	71	0.25	0.15	0.1	40
4	12/07/61	4	100	103	18	85	83	0.29	0.19	0.1	34
5	13/7/61	5	100	116	31	85	73	0.3	0.1	0.2	67
6	14/7/61	6	100	110	28	82	75	0.22	0.16	0.06	27
7	15/7/61	7	100	106	27	79	75	0.09	0.05	0.04	44
8	16/7/61	8	100	186	38	148	80	0.32	0.13	0.19	59
9	17/7/61	9	100	194	48	146	75	0.35	0.21	0.14	40
10	18/7/61	10	100	175	49	126	72	0.26	0.1	0.16	62
11	19/7/61	11	100	305	58	247	81	-			
12	20/7/61	12	100	319	82	237	74	-			
13	22/7/61	13	100	298	76	222	74	0.31	0.11	0.2	65
14	24/7/61	14	100	394	103	291	74	-	0		
15	25/7/61	15	100	365	93	272	75	0.34	0.22	0.12	35
16	26/7/61	16	100	509	107	402	79	-			
17	01/08/61	17	100	485	95	390	80	0.27	0.2	0.07	26
18	12/08/61	18	100	690	285	405	59	0.27	0.2	0.07	26
	Average			253	66	187	76	0.27	0.15	0.11	41

PHOTOGRAPHS

Photo 1 Photograph of Filter A & B

Photo 2 Top view of Filter A

PHOTOGRAPHS

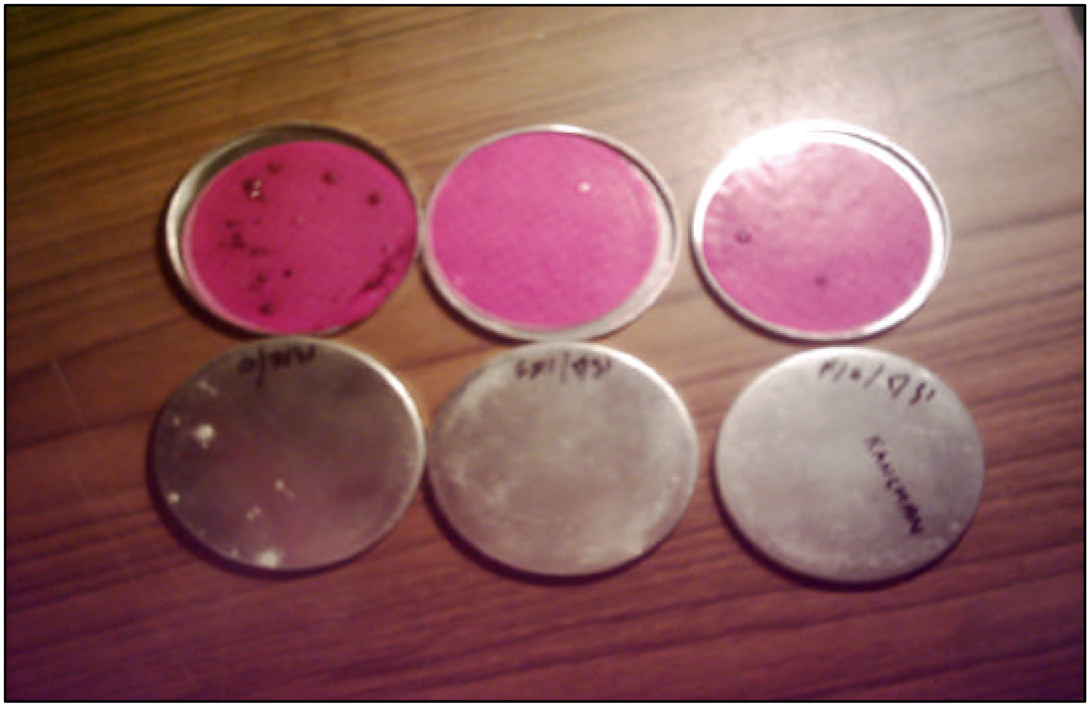

Photo 3 Coliforms Colonies on Membrane Filters

Photo 4 Student working in Lab

PHOTOGRAPHS

Photo 5 Working in Environment Laboratory

Photo 6 Iron test by UV Spectrophotometer

PHOTOGRAPHS

Photo 7 Field Test of Filter A

Photo 8 Field Test of Filter B

PHOTOGRAPHS

Photo 9 Student with House owner

Photo 10 Field Assistant and House owner

Appendix- C

ARSENIC REMEDIATION TECHNOLOGIES

Some of the technologies adopted for the removal of Arsenic from drinking water are listed below. This list is copied from the internet.

I. Oxidation

1.1. Simple Aeration

1.2. Solar Oxidation (SORAS)

1.3. UVFeOx (CRC, Australia)

1.4. Solar Oxidation/Reduction

II. Coagulation/ co-precipitation

2.1 Passive Precipitation/Sedimentation (taking advantage of naturally-occurring Fe and/or Mn precipitation)

2.2. Coagulation with Metal Salts

2.3. Tea Bag

2.4. Bucket Treatment Unit

2.5. Pilot Plant (PHED)

2.6. Candle Filter in Plastic Bucket (PHED)

2.7. Household Sand-Gravel G.I. Filter (PHED)

2.8. Hand-pump-attached Arsenic Removal System (PHED)

2.9. STAR Household Co-precipitation Filtration (Stevens Institute of Technology)

2.10. Oxidation of Ferrous Iron in Acidic Conditions (N.M. State University)

2.11. Enhanced Iron Co-precipitation (Hydro Solutions and Purification Inc.)

III. Sedimentation

IV. Filtration

4.1. "Safi" Filter

4.2. Filter #1 of Indigenous Raw Materials -- Coconut Coir, Shell and Husk (Allergy Env. Research & Skin Care Institute)

4.3. Filter #1 of Indigenous Raw Materials -- Bangladesh Center for Science and Industrial Research (BCSIR)

4.4. Simple Filter

V. Adsorption

5.1. Apyron Technologies Inc.

5.2. AMAL Hand-pump Filter with Activated Alumina (West Bengal Engineering College / Water for People)

5.3. AMAL Household-attached Arsenic Removal with Activated Alumina (West Bengal Engineerin College)

5.4. Simple Filter with Zero Valent Iron

5.5. Iron Filings and Sand (AsRT) (University of Connecticut)

5.6. Iron Filings in Jerry Can (University of Colorado - Denver)

5.7. 3-Kalshi

5.8. Design 5 (University of Toronto)

5.9. Ferric Oxyhydroxide + Settling (New Zealand-Bangladesh Bilateral Development Program)

5.10. Ferric Hydroxide-Coated Newspaper Pulp (Khair)

5.11. Granular Ferric Hydroxide in a Packed Bed (Driehaus, Germany)

5.12. Solmotex

5.13. GraMet Ferlat - Silica and Iron Adsorbent (Germany)

5.14. Molybdate Impregnated Chitosan Beads

5.15. Laterite

5.16. Ligand Reaction Based Ceramic Arsenic Removal Technology (EDA/Luxor)

5.17. Modified Clay Absorbent Tube

5.18. Other Adsorbents

VI. Ion exchange

6.1. Tetratreat (Tetrahedron)

6.2. Perfix

6.3. Krudico Anion Exchange POU Filter

6.4. Anion Exchange with Chloride Strong Base Resins (Clifford, University of Houston)

6.5. Sideko Ion Exchange System (Harbeusser, Germany)

VII. Membrane/Reverse osmosis

7.1. HVR Membrane Distillation POU Purifier

7.2. Ferric coagulation + microfiltration (Clifford, 1998)

VIII. Biological

8.1. Biological Filtration

8.2. Chemical and Biological Treatment with Duck Week and Jute Root

(Based on:http://web.mit.edu/murcott/www/arsnic/templates)