Development of a Low Cost Household Level Biological Arsenic-Iron Removal Unit

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A Project report submitted to the Department of Civil Engineering of Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh in partial fulfillment of the requirements for the degree of

"Master of Science in Civil Engineering".

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Declaration

This is to certify that the project work entitled "Development of a Low Cost Household level Biological Arsenic-Iron Removal Unit" has been carried out by Md. Forhad Hossain, in the Department of Civil Engineering, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work has not been submitted anywhere for any award of degree or diploma.

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Approval

This is to certify that the project work submitted by Md. Forhad Hossain entitled as "Development of a low cost Household level Biological Arsenic-Iron Removal Unit" has been approved by the board of examiners for the partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering under Khulna University of Engineering & Technology, Khulna, Bangladesh in June, 2007.

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Abstract

The urban and rural water supply system in Bangladesh is mainly dependent on groundwater. Widespread arsenic contamination and presence of elevated level of iron in groundwater are the major water quality problem in Bangladesh. Thousands of people are reported to have already symptoms of severs arsenic poisoning and several millions are at risk of arsenic contamination from drinking tubewell water. A few number of costly household level arsenic and iron removal units are available in the contaminated areas but most of them are chemical dependent and complex in operation and maintenance. The socio-economic conditions of Bangladesh demands low-cost treatment systems that could be implemented in the rural areas at household levels. Although a few household level arsenic removal units have been developed and tested, little attempt has been made in the development of a low cost biological type arsenic-iron removal unit.

Considering the above points, a low cost bio-physicochemical treatment unit has been developed at laboratory scale for simultaneous arsenic and iron removal from groundwater. The biological fixed bed reactor using coconut husk along with iron-matrix, charcoal and sand filtration have combined the bio-physicochemical removal processes in a single system. The unit was developed by using locally available materials in Bangladesh. The developed unit consists of three buckets where arsenic-iron contaminated raw water was poured into the first one. In this bucket bio-oxidation took place. Arsenic-Iron concentrated raw water was oxidized by the bacteria. The bacteria were produced on coconut husk bed and form small particles by sorption onto $Fe(OH)_3$. In second bucket comparatively larger flocculated particles precipitated and settled at the top of the chamber and the removal of precipitated particles through sorption onto iron oxy hydroxides. Additional adsorption of escaped arsenic from the first bucket was done on the iron matrix layer in the second bucket. Other fine and coarse particles precipitated on charcoal and coarse sand. Final removal of bacteria and other fine particles were accomplished in the 3rd bucket. This bucket consists of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer.

Following the above technique, detail laboratory analysis and tests were carried out for nine different ratios of arsenic-iron concentrated synthetic raw water. Considering different hydro-geological conditions, modifications were made to the developed unit for field applications. The modified units were then installed and tested in different water quality conditions at the field level. The main findings drawn from this test were as follows:

(i) The raw water with arsenic concentration up to 500 ppb was treated with the laboratory and field treatment units satisfying Bangladesh standards (50ppb) without using any chemicals;

(ii) Maintaining a face velocity of 0.5 m^3/m^2-hr, appreciable iron removal efficiency over 90% was achieved through the treatment unit;

(iii) No sign of Total Coliform were detected in the treated water produced by the unit. It appeared that the units performed consistently well in eliminating bacteria;

(iv) Some selected water quality parameters of treated water (pH, Turbidity, Color, Mn, DO, EC) were determined at random basis and they were found within the acceptable limit of Bangladesh standard; and

(v) The operation and maintenance of the developed treatment units are simpler and more users friendly. It was observed that the clogging of the units were occured over six months for most of the cases. Clogging of the units was varied for different iron concentrations of the raw water.

The final finding was observed that the unit produced sparkling clear water with no arsenic and iron for continuous duration of six to ten months without any maintenance.

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Chapter One

Introduction

1.1 General

Arsenic contamination in groundwater is considered to be one of the greatest current environmental disasters in Bangladesh. The groundwater of the country was, in the past, considered to be a source of safe drinking water. Unfortunately it is now established that this water contains arsenic at concentrations higher than the safe limit set for drinking purpose. Presence of elevated levels of arsenic in groundwater has become a major concern in Bangladesh. Although arsenic contamination of water sources has been reported for a number of countries, the contamination scenario in Bangladesh appears to be the worst detected so far world-wide, both in terms of area and population affected. Arsenic pollution of groundwater is particularly challenging in Bangladesh since tubewell water extracted from shallow aquifers is the major source of drinking water for most of its population.

Until 1970s most rural people obtained and consumed water from the hand-dug wells, ponds, rivers or canals. These waters were usually consumed directly without any treatment. So epidemics of diarrhea, cholera and other water-borne diseases were very common. Hundreds of people particularly the infants died only because of drinking these unsafe waters. The idea of tapping groundwater, which seemed to be clean, plentiful and pathogen-free under anaerobic condition, was accepted and hand tubewells were considered reliable means for extracting groundwater at an affordable cost. In Bangladesh, ground water is available in adequate quantity in shallow aquifers for the development of low-cost tubewell based water supply system for scattered rural population because of the fact that ground water has for long been considered to be pure and free from pathogenic microorganism and safe to serve drinking purpose. Extraction of the ground water from shallow tubewells have been found to be the best option for rural and some urban water supply and Bangladesh has achieved a remarkable success by providing 97 % of the rural population with tubewell water (Progotir Pathey 2000, BBS and UNICEF), which is the highest population coverage by tubewell water in the region.

This tremendous achievement was overshadowed when in 1993 an alarming discovery revealed the presence of arsenic in ground water in Chapainawabgonj. However, at this success in water supply, it is unfortunate that the presence of arsenic in addition to iron in drinking water has emerged as a serious threat to public health. In recent years there has been widespread coverage in the media about the problems of arsenic in Bangladesh's drinking water. This has been an unforeseen consequence of a large-scale programme to replace contaminated surface water sources by 'safe' ground water. Over a period of about 20-25 years about four million wells have been installed to utilize the groundwater from deeper aquifer layers, typically less than 200m deep (UNICEF, 1999), never suspecting the presence of arsenic in the aquifers carrying the groundwater. Thousands of people are reported to have already symptoms of severs arsenic poisoning and several millions are at risk of arsenic contamination from drinking tubewell water (Ahmed, M.F. and Jahan, H. (2000)). Estimates of population exposed to arsenic concentration above the Bangladesh drinking water standard of 0.05 mg/L vary from about 20 million to over 36 million (DPHE/BGS/MML, 1999; EES/DCH, 2000).

On the other hand groundwater collected through hand pump tube wells in Bangladesh carries a high concentration of iron and in many locations the concentration is much higher than the acceptable limit. According to the Bangladesh Drinking Water Standards (1997) with WHO guideline values (1993) the iron concentration is 0.3 to 1.0 mg/l. It has been found that hand tube well water in 65 % of the area of Bangladesh contains iron in excess of 2 mg/l and in many acute iron problem areas; the concentration of dissolved iron is higher than 15 mg/l. This is probably because of the fact that alluvial deposits containing trace of iron compounds underlie most of the places and shallow hand pump tube wells are drilled in such deposits to collect water. Available information and evidence suggest that the source of arsenic in the ground water of Bangladesh is geologic. Arsenic released from arsenic-rich minerals in the upstream is believed to be mainly adsorbed on iron oxyhydroxide coated fine-grained soils, transported with sediments in river water and deposited in the floodplains in the lower reach of the river system. Arsenic content of soils in Bangladesh has been found to be directly related to its iron content.

Dissolution and desorption of arsenic from arsenic rich iron oxyhydroxides in reducing soil environment at low redox potential can be the possible causes of arsenic contamination of groundwater in Bangladesh. The presence of iron and arsenic in both soil and water suggests their coexistence. The distribution of iron and arsenic in soil in bore holes in highly affected area shows that concentrations of both iron and arsenic are higher in upper layers of soils and decrease with depth (Kubota, 1998).

Since, arsenic problem is a national problem for the country and it is an associate problem with iron in most of the areas, an attempt was taken to remove arsenic with iron by Co-precipitation and adsorption. The socio-economic conditions of Bangladesh demands low-cost as well as small-scale treatment systems that could be implemented in the rural areas at household or community levels. Although a number of community based arsenic and iron removal units have been developed and tested in the field but these units are reported to fail (UNICEF report 1998).

So, to save millions of people from arsenic poisoning it is important to provide suitable, user friendly and cost effective arsenic and iron removal process for the rural people of Bangladesh. Therefore, there is a serious need of developing a small scale household level arsenic and iron removal unit because the removal technologies so far tried for the rural people have potential but not tested thoroughly for adoption. Most of the rural people are illiterate and they developed the habit of drinking hand tubewells water during the last 30 years. So any change in their behavior needs more friendly approach technology. A few number of household level arsenic and iron removal units are available in the arsenic and iron contaminated areas but those are costly, chemical dependent, complex in operation and maintenance and of course out of the reach of the poor villagers.

Therefore, the developed Treatment Unit is chemical free, user friendly, simple in operation, reusable and cost effective to the users and would be used in highly arsenic and iron contaminated areas.

1.2 Objectives of the Project Work

Following are the major objectives of this project work:

- To develop a low cost and sustainable biological As-Fe removal unit by using locally available materials in Bangladesh following bio-oxidation, adsorption, co-precipitation and simple sand filtration technique.
- To study the performance of the developed unit in the laboratory for some selected water quality parameters with an optimum face velocity.
- To conduct field application of the modified unit in different hydro-geological conditions to study the field performance.
- To study the social acceptance and identify the problems of the developed unit at the field level.

1.3 Scope of the Study

To achieve the above-mentioned objectives the following tasks were carried out:

- Laboratory batch study with different options of unit processes for arsenic, iron and bacteria removal.
- Selection of the most appropriate unit processes for arsenic, iron and bacteria removal.
- Detail laboratory analysis, model tests and evaluation the removal efficiency of arsenic, iron and bacteria with synthetic raw water with optimum face velocity.
- Determination of the problems associated of the developed unit through long-term field monitoring and its subsequent modification.

1.4 Organization of the Project Paper

This project paper presents the detail analysis, results and findings of the study in six chapters and appendices as shown below. In addition a reference of related publications has also been presented.

Chapter 1: Represents brief introduction to the study along with its objectives and scope.

Chapter 2: Represents literature review concerning the present Arsenic and Iron contamination scenario of Bangladesh, occurrence of arsenic and iron, global arsenic problems, sources of arsenic, possible causes (hypothesis) and mobilization, effect of arsenic on health and behavior of arsenic in the environment. This chapter emphasizes the chemistry of arsenic and iron. The technologies and unit processes of arsenic, iron removal and biological concept are also discussed in this chapter.

Chapter 3: Briefly reviews the methodologies of this project work concerning the associated unit processes with the Treatment Unit and the detail design of the Treatment Unit for laboratory model test as well as the field applications. Both the laboratory and field experimental set up and determination of variable parameters, construction and monitoring of the Unit under different water quality and different hydro-geological conditions are also focused in this chapter.

Chapter 4: Represents the detail laboratory tests and analysis that had been carried out through Treatment Unit-Model to biological oxidation, iron-arsenic ratio for effective removal of arsenic through co-precipitation with iron, removal efficiency of bacteria and the performance study of the Unit –model at the laboratory.

Chapter 5: The performance studies of the field Units for different hydro-geological conditions are briefly discussed in this chapter.

Chapter 6: Beneficiaries' opinion and experiences from the field application, Engineering significance and Economic aspect for developing the Treatment Unit has discussed in this chapter.

Chapter 7: Major conclusions of the project works and recommendations for future study for the sustainable approach of the developed Unit to go for mass scale construction have been cited in this chapter.

Chapter Two

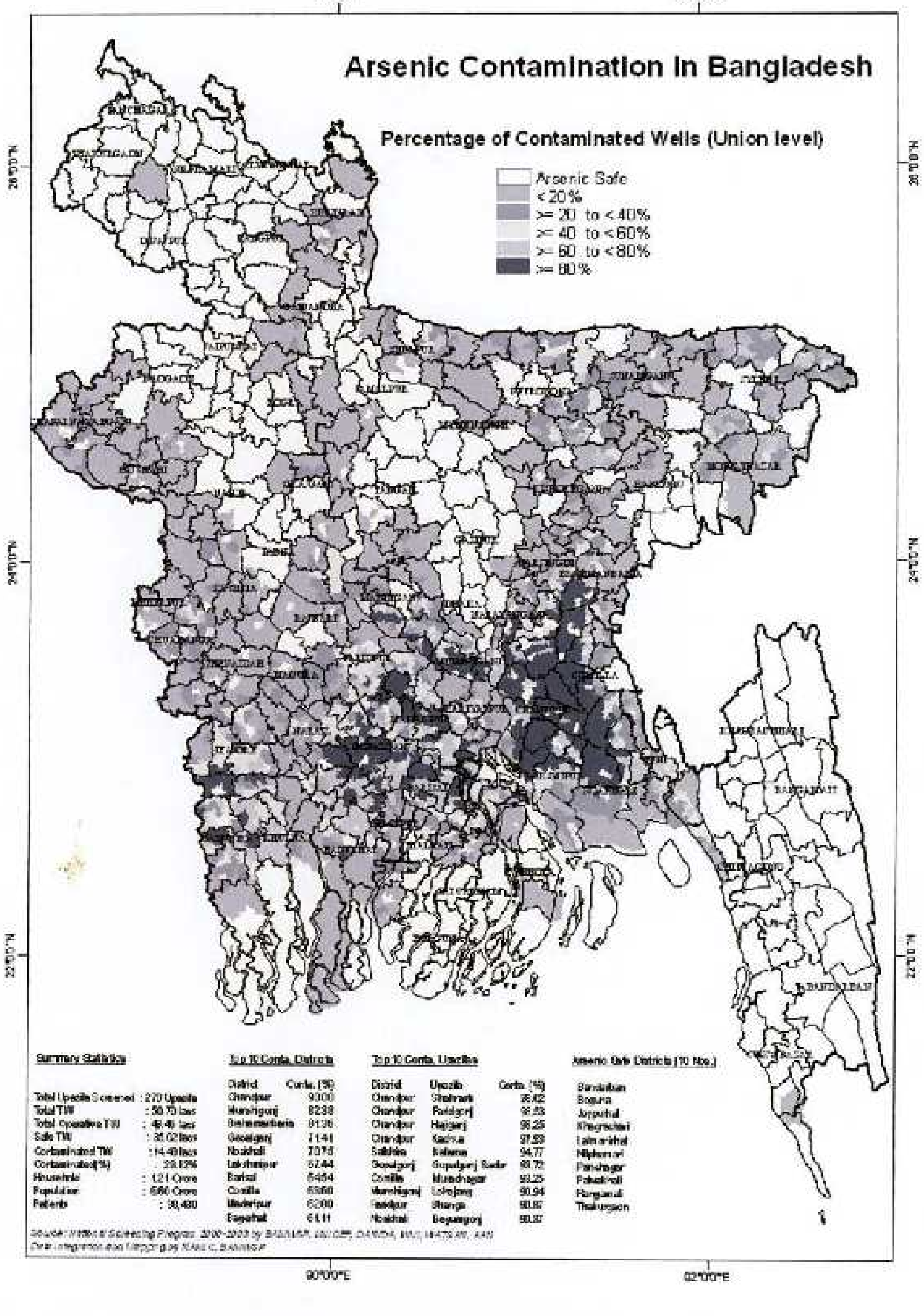
Literature Review

2.1.1 Arsenic & Iron pollution scenario of Bangladesh

Water is a universal solvent and capable of dissolving almost everything to a certain extent but the possibility of having arsenic at high concentration had never been considered seriously in the past. The success achieved for years in rural water supply in Bangladesh is on the verge of collapse. Most of the districts, 61 out of 64 in the country are now facing the problem of safe drinking water. The present scenario of the country to be best understood from the screening report of 270 Upazilas which has completed recently in a nation wide screening activities done by the various agencies namely BAMWSP, UNICEF, World Vision, WPP, Danida, and JICA & AAN. A through screening of 57,482 villages in 270 Upazilas shows that 50, 69,832 nos. of TW has tested in the field level. Out of them 14, 40,409 nos. of TW are found contaminated and 35, 02,816 nos. of TW are free from the contamination. The percent contamination is almost 30 %. The numbers of patient carrying arsenicosis are 38,480 nos. (NAMIC, BAMWSP, 2004). The arsenic contamination scenario of the country is represented in Figure-2.1.

Iron problem is acute in ground water in most of the districts of Bangladesh. Iron does not cause any direct health problem. Due to aesthetic reasons, rural people generally refuse to use tube well water in iron problem areas and they become more inclined to use unprotected surface water sources.

In a Survey conducted by UNICEF and the WHO in Bangladesh in 1976, it was found that the rate of diarrhoeal diseases in the iron prone areas is 53 % higher than that in the other areas (Ahmed, (1981). The overall iron concentration scenario of the country to be best understood from the studies done by DPHE/BGS/DFID (2000) (Figure-2.2).



Summary Statistics

Total Upazila Screened	: 270 Upazila
Total TW	: 50.70 lacs
Total Operative TW	: 49.46 lacs
Safe TW	: 35.02 lacs
Contaminated TW	: 14.40 lacs
Contaminated(%)	: 29.12%
Households	: 1.21 Crore
Population	: 6.60 Crore
Patients	: 38,430

Top 10 Conta. Districts

District	Conta. (%)
Chandpur	90.00
Munshiganj	82.38
Brahmanbaria	81.36
Gopalganj	71.41
Noakhali	70.75
Lakshmipur	67.44
Barisal	64.64
Comilla	63.60
Madaripur	62.00
Bagerhat	61.11

Top 10 Conta. Upazilas

District	Upazila	Conta. (%)
Chandpur	Shahrasti	98.42
Chandpur	Faridganj	96.53
Chandpur	Hajiganj	96.25
Chandpur	Kachua	97.53
Satkhira	Kalaroa	94.77
Gopalganj	Gopalganj Sadar	93.72
Comilla	Muradnagar	93.25
Munshiganj	Lohajang	90.94
Faridpur	Bhanga	90.87
Noakhali	Begumganj	90.87

Arsenic Safe Districts (10 Nos.)

- Bandarban
- Bogura
- Joypurhat
- Khagrachari
- Lalmonirhat
- Nilphamari
- Panchagar
- Patuakhali
- Rangamati
- Thakurgaon

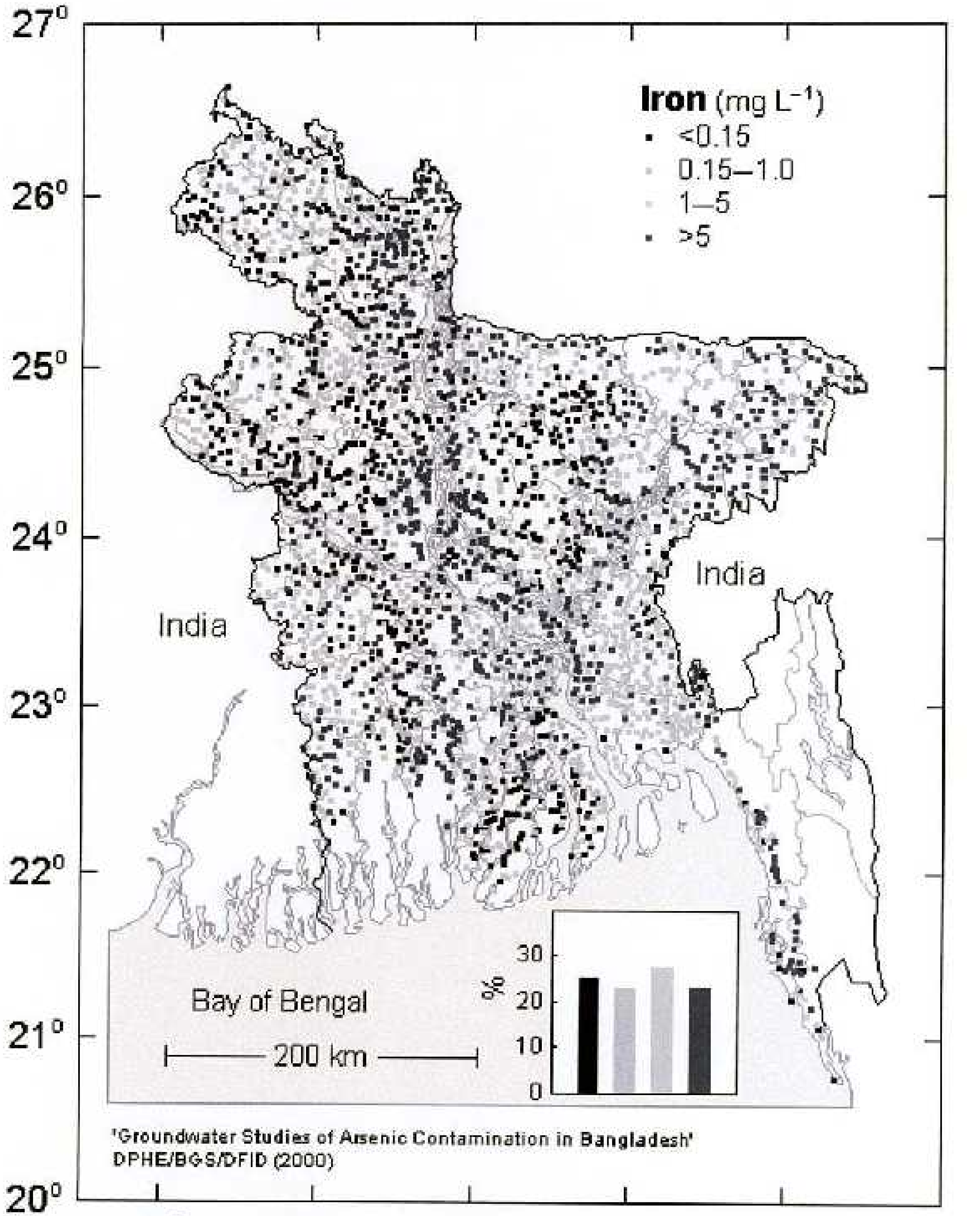
Source: National Screening Program 2000-2003 by BAMWSP, UNICEF, DANIDA, WVI, [illegible]
Data integration and Mapping by NAMIC, BAMWSP

Figure – 2.1: Arsenic contamination scenario of Bangladesh (NAMIC, BAMWSP (2004)).

The Arsenic distribution map above indicates that most As-rich regions are located in the central, south and southeastern parts of the country, while the northwestern and the uplifted areas of the north-central parts are least affected. Isolated "hot spots" are, however, encountered in the southwestern, northwestern, northeastern and north-central regions of Bangladesh. Based on the little data available from the Hill Districts, it seems that the wells in that region are mostly unaffected. The tube wells in large parts of Dhaka division, most of Chittagong division except the Hill Tracts area, significant parts of Rajshahi and Sylhet division and most parts of Khulna and Barisal divisions except the coastal areas are contaminated with arsenic. Highly affected districts include Sylhet, Sunamgonj, Comilla, B-Baria, Naraуngonj, Chandpur, Lakshmipur, Feni, Noakhali, Madaripur, Munshiganj, Bagerhat, Satkhira, Jessore, Jhenaidah, Chuadanga, Nawabganj, Manikganj, Faridpur, Khulna and Gopalganj. It has found that the Presence of arsenic in the coastal areas is low because of the fact that most of the groundwater in this saline area is extracted from arsenic-free deep aquifer. The Table (Table-2.1) below shows the top ten districts and upazilas with their percent arsenic contamination.

Table-2.1: Top ten District and Upazila with percent contamination of arsenic.

Top ten contaminated districts		Top ten contaminated upazilas		
Districts	% cont.	Districts	Upazilas	% cont.
Chandpur	93.00	Chandpur	Sharasti	98.62
Munshiganj	82.38	Chandpur	Faridganj	98.53
Brahmanbaria	81.36	Chandpur	Hajiganj	98.25
Gopalganj	71.41	Chandpur	Kachua	97.93
Noakhali	70.75	Satkhira	Kolaroa	94.77
Lakshmipur	67.44	Gopalganj	Gopalganj Sadar	93.72
Barisal	64.54	Comilla	Muradnagar	93.25
Comilla	63.60	Munshiganj	Lohajang	90.94
Madaripur	62.80	Faridpur	Bhanga	90.87
Bagerhat	61.11	Noakhali	Begumganj	90.37



'Groundwater Studies of Arsenic Contamination in Bangladesh'
DPHE/BGS/DFID (2000)

Figure-2.2: Iron contamination scenario of Bangladesh.

2.1.2 Characteristics of Arsenic

Arsenic, probably the oldest known human poison, has six characteristics

(Nriagu & Azcue, 1994):

- It is a virulent poison on acute ingestion, 76 mg arsenic (III) is considered to be lethal to adults.
- It is extremely toxic on long-term exposure to very low concentrations. The WHO acceptable skin cancer risk is calculated to be 0.17 µg arsenic/L of water (WHO, 1996).
- It is not visible in water and food. Even heavy contaminated water may be clear and colorless.
- It has no taste. Even heavy contaminated water may have a pleasant taste.
- It has no smell, even at deadly concentrations.
- It is difficult to analyze, even when occurring in water in concentrations double as high as the WHO guideline.

2.1.3 Causes of Arsenic Pollution in Bangladesh (The Hypotheses)

With regard to identification of source(s), current opinion favours to a natural geogenic source. It was earlier believed that natural source is from breakdown of the mineral pyrite. Recently, it has been established that the source of Arsenic in Bangladesh is from coatings on sediments grains (Ferrous-oxy-hydroxide). However, a number of plausible hypotheses have been put forward for the sources of arsenic found in the groundwater. The hypotheses initially proposed to explain the possible causes of arsenic contamination in Bangladesh include:

The surface coating hypothesis (PHED, 1991): Arsenic-rich coatings (c. 2% arsenic by weight) have been observed on the surface of quartz and biotite grains from sediment cores from the affected region. This has also been predicted to be the cause of Arsenic contamination in Bangladesh.

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The biotite hypothesis (Ghosh and De, 1995: The Arsenic is derived from Arsenic present as an impurity within the biotites found in some of the sediments. A variant of this is the heavy mineral hypothesis.

The phosphate hypothesis (Bagla and Kaiser, 1996): The high concentration of phosphate in the groundwater (assumed by Sen Gupta to be from the increase use of phosphate fertilizers) has desorbed Arsenic from the surface of pyrite.

The (arseno) pyrite oxidation hypothesis (Das et al., 1996): Arsenopyrite has been reported to be present in the West Bengal sediments. Oxidation of these minerals, which results when there is rapid diffusion of air through the unsaturated zone during the dry season, releases Arsenic from the pyrite. This can then be mobilized by the subsequent water level rise in the following wet season. This hypothesis is proven to be unauthenticated.

The reduction dissolution hypothesis (Bhattacharya et al., 1997., Bagla and Kaiser, 1996): The increasing number of flooded fields in recent years has increased the rate of Arsenic leaching because the decreased subsurface supply of oxygen is leading to anaerobic conditions and the dissolution of Arsenic- containing iron oxides.

It is too early to make any conclusions on the possible cause of Arsenic contamination in Bangladesh, However, based on the hypotheses so far received the following can be summarized as:

- Arsenic leaching from Chromate Copper Arsenic (CCA) treated electric poles used in Bangladesh.
- The use of Arsenic based pesticides.
- The use of Phosphate fertilizers.
- Oxidation of arsenopyrite or arsenic-rich pyrite minerals (Oxidation Hypotheses).
- Reduction of arsenic-rich iron-oxyhydroxides (Reduction Hypotheses).

The first three hypotheses did not get wider support in the absence adequate evidence and most scientists have settled down to remaining two hypothesis- oxidation hypothesis and reduction hypothesis (Ahmed, M.F, 2003).

2.1.4 Mobilization of Arsenic (Bangladesh Context)

Several hypotheses have been put forward to explain the problem of As-enrichment in ground waters of Bangladesh. Since its first discovery, use of fertilizers, pesticides, insecticides, waste disposal, As compound treated wooden poles etc. were blamed as the anthropogenic sources of As-enrichment in groundwater (NRECA, 1997). Regional occurrence of As in groundwater of Bangladesh is however not attributable to any anthropogenic activities, and the current status of knowledge indicates predominantly geogenic source and its release in groundwater through natural processes (Bhattacharya et al, 1997; Nickson et al., 1998, 2000, McArthur et al., 2006).

Oxidation of pyrite (FeS2) or arsenopyrite (FeAsS) was postulated as the dominant process for As mobilization due to lowering of water table following excessive pumping of groundwater (Mandal et al., 1996; Mallik and Rajagopal, 1996) that was widely accepted at the beginning. An alternate theory, known as the Fe oxyhydroxide reduction hypothesis, is now widely accepted as the principal mechanism of As mobilization in the ground waters of the alluvial aquifers of the GBM Delta plain (Bhattacharya et al., 1997, 2001; Ahmed et al., 1998b; Nickson et al., 2000; Routh et al., 2000; McArthur et al., 2001; Dowling et al, 2002; Anawar et al., 2003, McArthur et al., 2006).

Neither pyrite oxidation, nor competitive exchange of fertilizer-phosphate for sorbed arsenic, cause arsenic pollution of groundwater in the Ganges-Meghna-Brahmaputra deltaic plain. Indeed, pyrite in Bangladesh aquifers is a sink for, not a source of, arsenic. Pollution by arsenic occurs because FeOOH is microbially reduced and releases its sorbed load of arsenic to groundwater. The reduction is driven by microbial metabolism of buried peat deposits. Dissolved phosphorus comes mainly from FeOOH, as it is reductively dissolved, with subordinate amounts being contributed by degradation of human organic waste in latrines and fermentation of buried peat deposits. Dissolved ammonium in the aquifer derives predominantly from microbial fermentation of buried peat deposits, but significant amounts are contributed by unsewered sanitation. Ammonium ion is not, therefore, an infallible indicator of faecal contamination of groundwater. Reduction of FeOOH, and release of sorbed arsenic, serves as a generic model for arsenic contamination of aquifers where waters are anoxic, particularly where organic matter is abundant, *e.g.* in deltaic or fluvial areas that supported peat land during climatic optimums (J.M. McArthur, 2006)

2.1.5 Historical Review

Arsenic is derived from the Greek word for orpiment (Forbes, 1964). In the forth century B.C., Aristotle named arsenic sulfide as sandarach (Nriagu, 1994). The name is probably connected with the root sand or sard, meaning red. Ancient Indian cultures valued arsenic compounds during the age of Buddha. The magnitude of names for white arsenic in Sanskrit (Sankh and Sabala Kshara), Hindi (Sanbul-Khar, Sammal khar, Sankhyia sanbul, and Sankyhia), and Bengali (Sanka or Senko) suggest general familiarity and extensive use of this compound presumably in some nefarious ways (Bagachi, 1969).

The discovery of elemental arsenic is generally credited to the German Dominican scholar and alchemist Albertus Magnus (1193-1280) (Nriagu, 1994). His description of a substance (De Rebus Metallicis) in arsenic compounds is supposedly the first reference to the metallic form of arsenic (Nriagu, 1994). According to Berthelot (1893), metallic arsenic was first mentioned in the third or forth century by Zosimus, who referred to it as a second mercury that burns up to the "soul of the color" or white oxide. Geber (Jabir ibn Haiyan), an Arabian alchemist of the eight century, apparently produced arsenic from its sulfides, but his product was not recognized a metal (Parr, 1958). In 1641, Schorder, in his pharmacopoeia, divulged a procedure for obtaining elemental arsenic through the reduction of arsenious oxide with charcoal (Aitehinson, 1960). Meyer postulated that arsenic was first prepared by western alchemists in the thirteenth century. Later, in 1675, Leery obtained regales, a metallic arsenic, by heating arsine's oxide with soap and potash (Aitchinson, 1960). Brand, in 1733, carried out the first accurate experiments on the chemical nature of arsenic and showed that white arsenic was the clax or oxide of the element (Hunter, 1978).

2.1.6 Occurrence of Arsenic

Arsenic is found in everywhere in the environment. It is found in atmosphere, biosphere, hydrosphere, pedosphere and geosphere and transferred from one to another by natural processes or human activities such as mining, agriculture, industrial processes etc. Arsenic is mainly found in the form of its mineral compounds and widely distributed in air, water, soils and in rocks and earth crust.

The relative proportion of arsenic in rock, soil, water, biota and atmosphere with respect to soil is shown in the following Table and it may be seen that rocks and minerals are the main reservoirs of arsenic, which is mobilized in the other media of the environment by natural weathering processes, biological activity, volcanic eruption and anthropogenic activities.

Table-2.2: Ratios of Arsenic Concentrations in Natural Reservoir with respect to Soil (Mackenzie et al., 1979)

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

Arsenic is associated with igneous and sedimentary rocks, particularly with sulfidic ores. Natural phenomena such as weathering, biological activity and volcanic activity, together with anthropogenic inputs are responsible for the emission of arsenic into the atmosphere, from where it is redistributed on the earth's surface by rain and dry fallout. Arsenic is also mobilized by dissolution in water, with aquatic and soil sediment concentrations being controlled by a variety of input and removal mechanisms (Cullen and Reimer, 1989). There is general agreement that most anthropogenic atmospheric input is due to smelting operations and fossil fuel combustion, but still unresolved is the extent to which man's activities contribute to the overall arsenic cycle (Edlestein, 1985). The Figure below shows a comprehensive cyclic transfer of arsenic (Bhumbla and Keefer, 1994). In nature arsenic goes through the reactions of oxidation-reduction, precipitation-dissolution, adsorption-desorption and organic and biochemical methylation. All of these reactions control the mobilization and bio-accumulation of arsenic in the environment (Bhumbla and Keefer, 1994).

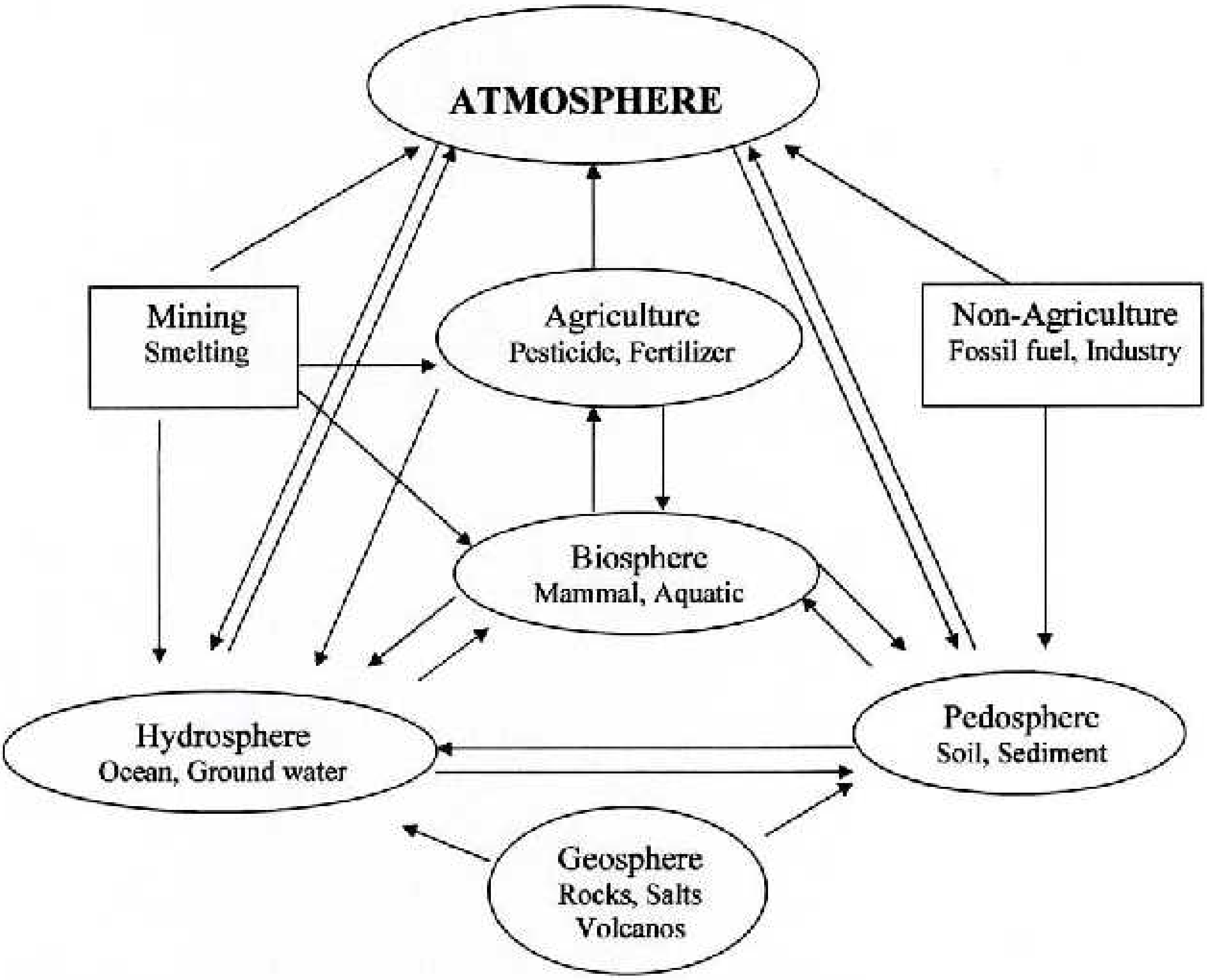

Figure- 2.3: The Environmental Cycle of Arsenic (Bhumbla & Keefer, 1994)

2.1.7 The Global Arsenic Contamination Scenario

The arsenic pollution of groundwater has become a major global disaster. Exploitation of groundwater from arsenic contaminated aquifers has resulted in mobilizing the arsenic and led to mass poisoning in the region, which is defined by the generic term arsenicosis (Rahman et al., 2001). Presence of arsenic from natural sources in the groundwater is not unusual and has been documented in many parts of the world. The state of arsenic contamination of drinking water and its consequences in selected countries have been described shortly in this section. It has been summarized from NAMIC, BAMWSP (DPHE, 2004), Ahmed (2002), Chowdhury (1997), Smith (1997), AAN (1997), Smedly and Kinniburgh (2002) and Giger et al. (2001).

Argentina:

- Water borne arsenicosis was as early as the beginning of the 20th century.
- The term "Bell Ville disease" was used to describe skin manifestations caused by As.
- Estimated 2 million people are exposed within about 1 km^2 affected area.
- Levels of arsenic in the range of <1 _5300µg/L with 7800µg/L in some pore waters were reported. Arsenic is mainly in the form of As (V).
- The source of contamination was found to be natural. The soil composition was favorable for polluting the sallow well the first notification of waters. Also high arsenic content was found in some river waters.
- Oxidizing, neutral to high pH, high alkalinity ground water condition, Holocene and volcanic ash type aquifers.

Hungary:

- Arsenic contamination has been identifies in groundwater in alluvial sediment in the southern part of the Great Hungarian Plain.
- About 110,000 km^2 area consists of quaternary sediment are arsenic affected.
- Population exposed to arsenic contamination is 29,000.
- Arsenic concentration in the range <2 – 176 µg/L.

Mexico:

- The Lagunera region of northern Mexico has been reported to have arsenic problems.
- The area affected is 32,000 km^2.
- A population of 1, 27,000 inhabitants have been drinking water containing 100-500 µg/L arsenic. Arsenic is mainly As(V).
- Volcanic sediment type aquifer having oxidizing, neutral to high pH groundwater condition.

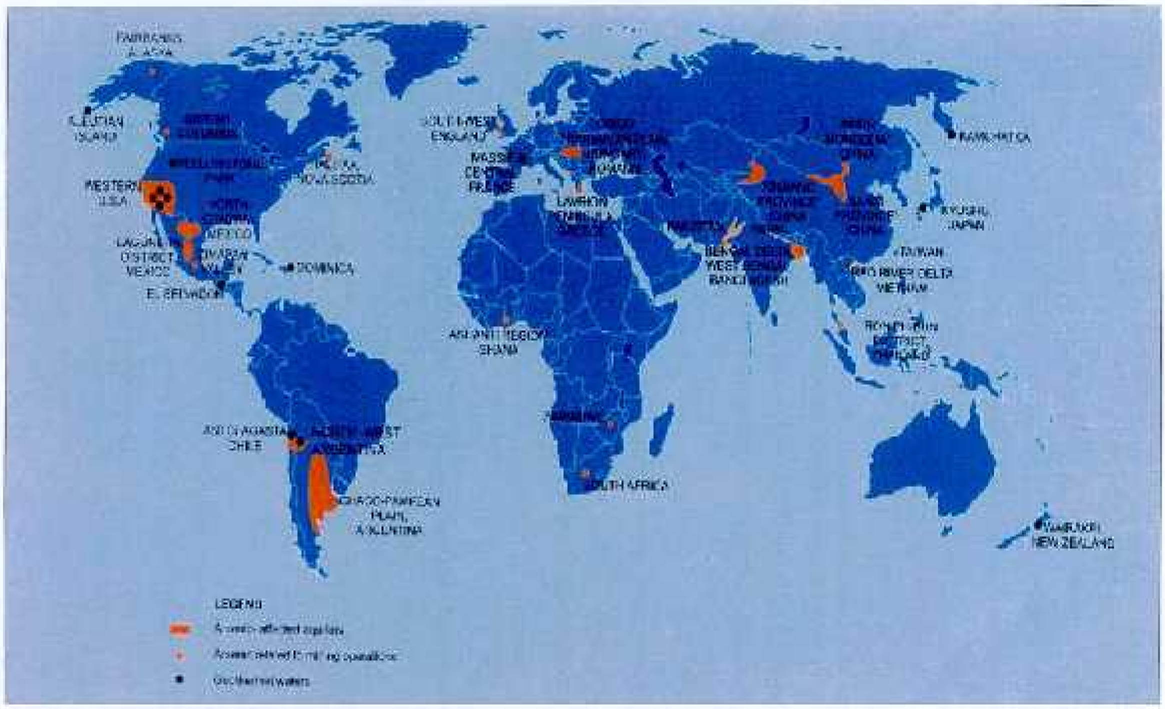

Figure - 2.4: Worldwide arsenic problem (After BGS and DPHE, 2001).

Nepal:

- Arsenic contaminated tubewell have been identified in 20 Terai districts.
- Estimated population exposed to arsenic exceeding 50 µg/L is 5,50, 000 (2.4% of the total population).
- Estimated population exposed to arsenic exceeding 10 µg/L is 3.19 million (13.6%).

Taiwan:

- The arsenic problem in Taiwan was reported since 1968, now best known and most studied case of arsenic contamination.
- It is Taiwan that gave arsenicosis the name "Black Foot Diseases".
- Survey of over 83,000 wells showed that 19% of the tube wells had arsenic over 50 µg/L.
- 1,00,000 inhabitants were exposed to well water containing arsenic 10-1820 µg/L, on an average about 500 µg/L for over 40 years.
- Studies in Taiwan provided data to develop dose-response relationships for skin, bladder and lung cancers.
- The contaminated aquifer is sediment type with shale.

Thailand:

- In 1996 arsenic is reported to occur in some shallow as well as deep tubewells in southern Thailand.
- Area affected is 100 km^2.
- The concentrations found are between 1 and 500 μg/L.
- Oxidation of arsenopyrite from former tin mining. Aquifer type includes dredged quaternary alluvium and mine tailings.

Inner Mongolia, P.R. China:

- The first case of arsenic poisoning was discovered in 1990.
- Many of the arsenic affected areas are located in the arid region (rainfall 200-300mm/yr)
- 90% of the well tested had arsenic at level higher than 50 μg/L.
- The highest concentration detected in the well water was 2400 μg/L.
- The arsenic contamination is combined with too high concentrations of fluoride.
- 35% of the 612 checked inhabitants were found arsenic lesions in a survey.
- More serious effects were detected including high cancer mortality.

USA:

- USA is probably the only (mildly) arsenic affected country which has carried out a nation wide survey of arsenic occurrence in drinking water.
- About 3,47,000 people had received public supplied water containing arsenic more than 50 μg/L.
- About 2.5 million people had received public supplied water containing arsenic more than 10 μg/L.
- Small water supplies serving 1,000 to 10,000 persons contaminated with arsenic exceeding 50 μg/L, 10 μg/L and 5 μg/L are estimated to be 1%, 7.5% and 13% respectively.
- Arsenic contaminated area in USA include about 2,00,000 km^2 in Arizona (arsenic up to 1300 μg/L), 5000 km^2 in California (arsenic in the range of 1-2600 μg/L) and 1300 km^2 in Nevada (arsenic up to 2600 μg/L).
- Studies from 1972 to 1982 showed correlation with specific skin alterations and neurological abnormalities.

West Bengal, India:

- The arsenic pollution is of geological origin and widespread in Holocene alluvium/deltaic sediment.
- The arsenic is mainly found in the groundwater pumped from intermediate depth. As a common rule, neither shallow nor deep aquifer show above permissible limit arsenic contents.
- High arsenic groundwater is characterized by high iron, calcium, magnesium and bicarbonate and by low chloride, sulfate and fluoride.
- About 3115 habitations, 15 non-municipal areas and 9 municipalities in 8 districts are found affected.
- The affected area is 23,000 km^2.
- About 5.31 million people are exposed to high arsenic content in drinking water.
- Estimated 3, 00,000 people are suffering from various stages of arsenicosis.

Vietnam:

- Arsenic in ground water was first detected in Hanoi in 1997, where arsenic content of 29% of the wells were above 0.05mg/L.
- Arsenic contamination of tubewell water has been found in the large deltas of the Mekong and Red rivers.
- In1999, UNICEF supported study in 7 provinces in the Red river Delta reported arsenic in 12% samples above 0.05 mg/l.
- Inmost affected district, ground water with average arsenic concentration of 430μg/L and maximum arsenic concentration of 3000μg/L is directly used as drinking water.
- Alarming levels of arsenic in the range of 2000 to 3000μg/L in ground water were found on both sides of the Red river.
- Arsenic concentration in water supply in Hanoi city is within the range of 25-91μg/L after treatment and 7-82μg/L at the tap water.
- Arsenic contamination is due to anoxic condition of the aquifer.

2.1.8 Sources of Arsenic

Natural Sources:

Arsenic bearing minerals are the primary natural sources of arsenic. There are more than 245 such minerals, mostly ores containing sulfide, along with copper, nickel, lead, cobalt and other metals as well as some oxides. The following Table provides a list of some important arsenic bearing minerals:

Table- 2.3: Naturally Occurring Minerals Containing Arsenic (NRCC, 1978)

Mineral	Formula	Mineral	Formula
Arsenite	As	Pearcite	$Ag_{16}As_2S_{12}$
Antimony arsenide	$AsSb$	Proustite	Ag_2AsS_3
Realger	AsS	Energite	Cu_3AsS_4
Orpiment	As_2S_3	Rathite	$Pb_3As_5S_{10}$
Arsenopyrite	$FeAsS$	Arsenolite	As_2O_3
Nicolite	$NiAsS$	Mutite	$Pb_5(PO_4,AsO_4)_3Cl$
Gersdorffite	$CoAsS$	Adamite	$Zn_2AsO_4(OH)$
Cobaltite	$CoAsS$	Erythrite	$Co_3AsO_4.8H_2O$
Smaltite	$(Co,Ni)As_x$	Annabergite	$N_{13}(AsO_4)_2.8H_2O$
Skutteridite	$(Co,Ni)As_x$	Scorodite	$(Fe.Al)AsO_4.2H_2O$
Loellingite	$FeAs_2$	Pharmacosiderite	$Fe_3(AsO_4)_2OH_3$
Tennantite	$Cu_{12}As_4S_{13}$	Olivenite	$Cu_2(AsO_4)OH$
Jordanite	$(Pb,Ti)_{13}As_7S_{23}$	Beaudanite	$PbFe_3(AsO_4)SO_4$

The most important ores of arsenic are Arsenopyrite or Mispickel ($FeAsS$), Realgar (As_4S_4), Orpiment (As_2S_3), Loellingite ($FeAs_2$), Nicolite ($NiAs$), Cobalt-glance ($CoAsS$), Nickel-glance ($NiAsS$), Smaltite ($CoAs_2$) and Arsenolite (As_2O_3). Among these, Arsenopyrite is probably the most common mineral. Arsenic occurs in uncontaminated soil at an average concentration of about 5 to 6 mg/kg, but this varies among geographic regions.

Anthropogenic Sources:

Recent estimates have placed the ratio of natural to anthropogenic inputs of arsenic at 60:40. The global production rates of arsenic compounds determined in recent surveys are shown in the following Table:

Table -2.4: Production Rates of the Main Arsenical Compounds (Alloway, 1990)

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

The anthropogenic influence on the level of arsenic in soils depends on the human activity, the distance from the pollution sources and the pollution dispersion pattern. Arsenic may accumulate in soil through use of arsenical pesticides, application of fertilizers, irrigation, and dust from the burning fuels and disposal of industrial and animal wastes (Sandberg and Allen, 1975). It is a natural contaminant in lead, zinc, gold and copper ores and can be released during the smelting process (Crecelious et al., 1974; Ragini et al., 1977; Rosehart and Lee, 1973).

2.1.9 Chemistry of Arsenic

a) Acid-Base Chemistry:

Apart from elementary arsenic with oxidation state of 0, arsenic is stable in the oxidation states of +5, +3 and -3, but generally found in water only in the trivalent and pentavalent states. The oxidation state is closely related to the arsenic immobilization and hence the release of arsenic from its geological formations into the water bodies and biosphere. Both the oxidation state and the release are determined by the soil and water pH, the redox potential, the in excess occurrence of sulfide, the occurrence of other ions as well as solids of especially iron and manganese (Dahi, 1997). The oxides of both As(III) and As(V) are soluble in water. The dissolution implies direct reaction with the water, hydration, where the oxides behave like non-metals and exhibit acidic character. As(III) forms arsenious acid and As(V) forms the arsenic acid. The two acids dissociate to form respectively arsenite and arsenate ions as shown in the following reactions with their equilibrium constants (Cherry et al., 1979):

Dissociation of Arsenious Acid:

$H_3AsO_3 = H^+ + H_2AsO_3^-$ pKa = 9.22
$H_2AsO_3^- = H^+ + HAsO_3^{2-}$ pKa = 12.13
$HAsO_3^{2-} = H^+ + AsO_3^{3-}$ pKa = 13.40

Dissociation of Arsenic Acid:

$H_3AsO_4 = H^+ + H_2AsO_4^-$ pKa = 2.20
$H_2AsO_4^- = H^+ + HAsO_4^{2-}$ pKa = 6.97
$HAsO_4^{2-} = H^+ + AsO_4^{3-}$ pKa = 11.53

Table -2.5: Arsenic Species and their Environmental Importance (Kartinen & Martin, 1995)

Sl.	Compounds	Example	Env. Significance / Dominant pH region
1	Trivalent Arsenic Oxidation State: +3	As (III)	Dominant under Anaerobic Condition 10 Times more Toxic than As (V)
	(Arsenite, Inorganic)	H_3AsO_3	pH = 0-9
		$H_2AsO_3^-$	pH = 10-12
		$HAsO_3^{2-}$	pH = 13
		AsO_3^{3-}	pH = 14
2	Pentavalent Arsenic Oxidation State: +5	As (V)	Dominant under Aerobic Condition 10 Times less Toxic than As (III)
	(Arsenate, Inorganic)	H_3AsO_4	pH = 0-2
		$H_2AsO_4^-$	pH = 3-6
		$HAsO_4^{2-}$	pH = 7-11
		AsO_4^{3-}	pH = 12-14

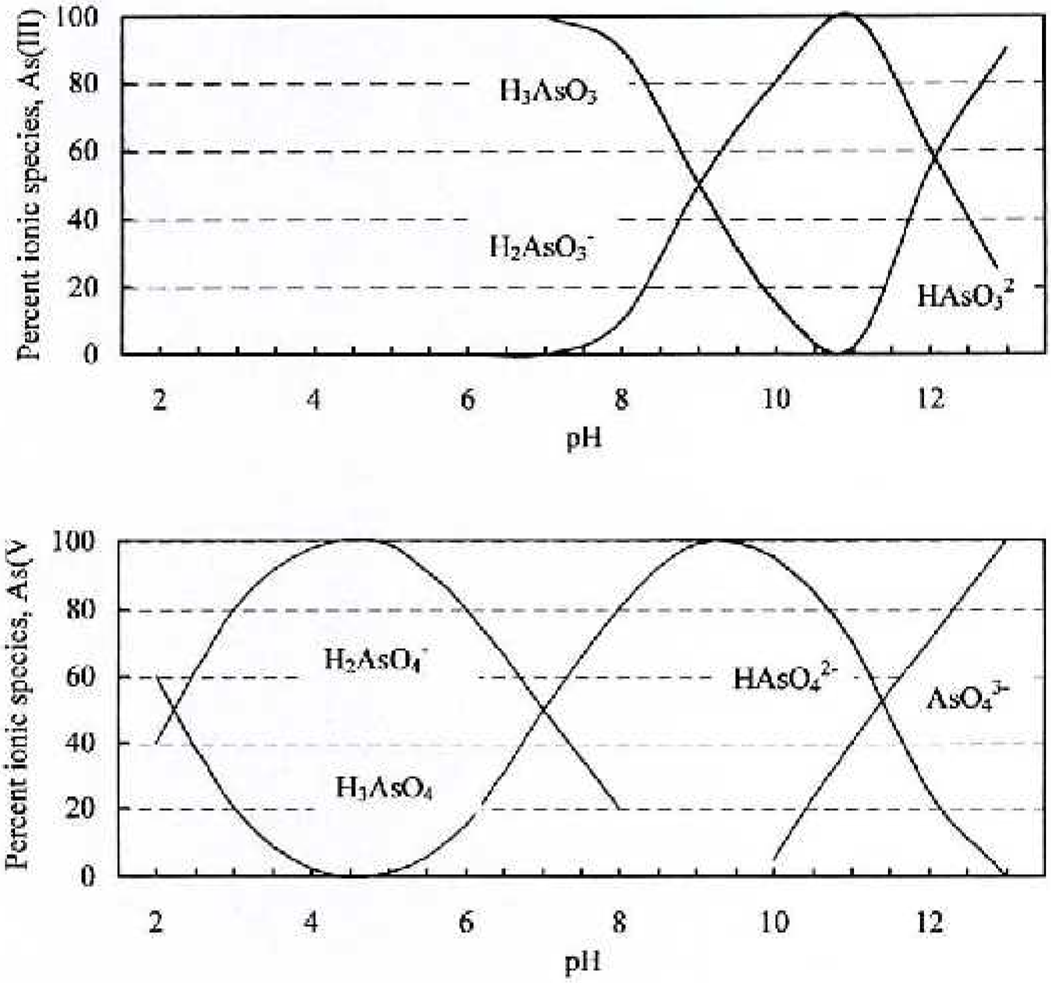

Figure - 2.5: Predominance Diagram of As(III) and As(V) as a Function of pH
(Gupta and Chen, 1978; Montgomery, 1985)

Within the range of natural waters (particularly groundwater), where pH is usually between 6 and 9, the trivalent inorganic arsenic is found as non-dissociated arseneous acid (H_3AsO_3); While the pentavelent arsenic is primarily found as the ionized forms ($H_2AsO_4^-$, $HAsO_4^{2-}$).

Oxidation Reaction of As(III) to As(V) :

Chlorine is widely used for oxidation purpose, but may lead to chlorinated by-products, namely trihalomethenes (THMs), from reactions with natural organic matter. Ozone, widely used in surface water treatment for oxidation and disinfection, is quite effective but is not feasible for a specific application with As(III) oxidation. Permanganate oxidizes As(III), ferrous and manganese ions specially and quickly. Chlorine and permanganate are able to oxidize arsenic (III) to (V) within a very short time, e.g., half an hour or even few minutes (Dahi, 1997).

$$H_3AsO_3 + {}^{1}/_{2}O_2 = H_2AsO_4^- + 2H^+$$

$$H_3AsO_3 + HClO = H_2AsO_4^- + 2H^+ + Cl^-$$

$$H_3AsO_3 + {}^{2}/_{3}MnO_4^- = H_2AsO_4^- + {}^{2}/_{3}MnO_2 + {}^{1}/_{3}H^- + {}^{1}/_{3}H_2O$$

Air oxidation of arsenic is very slow and can take weeks for oxidation (Pierce and Moore, 1982) but chemicals like chlorine and permanganate can widely oxidize arsenite to arsenate under wide range of conditions.

Arsenate Adsorption:

$$\equiv Fe(OH)^0 + AsO_4^{3-} + 3H^+ = \equiv FeH_2AsO_4^0 + H_2O$$

$$\equiv Fe(OH)^0 + AsO_4^{3-} + 2H^+ = \equiv FeHAsO_4^- + H_2O$$

$$\equiv Fe(OH)^0 + AsO_4^{3-} + H^+ = \equiv FeAsO_4^{2-} + H_2O$$

$$\equiv Fe(OH)^0 + AsO_4^{3-} = \equiv Fe(OH)AsO_4^{3-} + H_2O$$

Arsenite Adsorption:

$$\equiv Fe(OH)^0 + H_3AsO_3 = \equiv FeH_2AsO_3^0 + H_2O$$

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

$$\equiv FeH_2AsO_4^0 + PO_4^{3-} = \equiv FeH_2PO_4^0 + AsO_4^{3-}$$

$$\equiv FeHAsO_4^- + PO_4^{3-} = \equiv FeHPO_4^- + AsO_4^{3-}$$

$$\equiv FeAsO_4^{2-} + PO_4^{3-} = \equiv FePO_4^{2-} + AsO_4^{3-}$$

Precipitation and dissolution:

Precipitation – dissolution reaction are important mechanisms controlling mobility of arsenic in the subsurface. As an example, because arsenic often co precipitates with iron oxide, iron oxide may act as an arsenic source (case of dissolution) or a sink (case of precipitation) for ground water (USGS, 1999).

In Bangladesh, reductive dissolution of iron oxyhydroxides and consequent release of adsorbed arsenic could be an important mechanism of arsenic mobilization in the subsurface. Oxidative dissolution reactions (Bhumbla and Keefer, 1994) of arsenopyrite (FeAsS) are shown as follows:

$$4\,FeAsS + 11O_2 + 6\,H_2O = 4\,FeSO_4 + 4\,H_2AsO_3^- + 4H^+$$

$$4\,FeAsS + 13O_2 + 6\,H_2O = 4\,FeSO_4 + 4\,H_2AsO_4^- + 4H^+$$

Methylation Reactions:

Several fungi and bacterial species have been demonstrated to methylate inorganic arsenic by an initially reducing arsenate fraction to arsenite, which then is methylated and released to the environment (Kartinen and Martin 1995).

However, the concentration of methylated arsenic in the natural waters, whether ground or surface, is normally low. This is because the methylated arsenic is taken up by the biota where it undergoes metabolic conversion into organic arsenical. Compounds like arsenobetaine and arsenocholine, can thus be found in fish and crustaceans. These compounds do not have any toxicological significance. Upon consumption by man they are directly excreted through urine without any bio-transformation (Vahter, 1994).

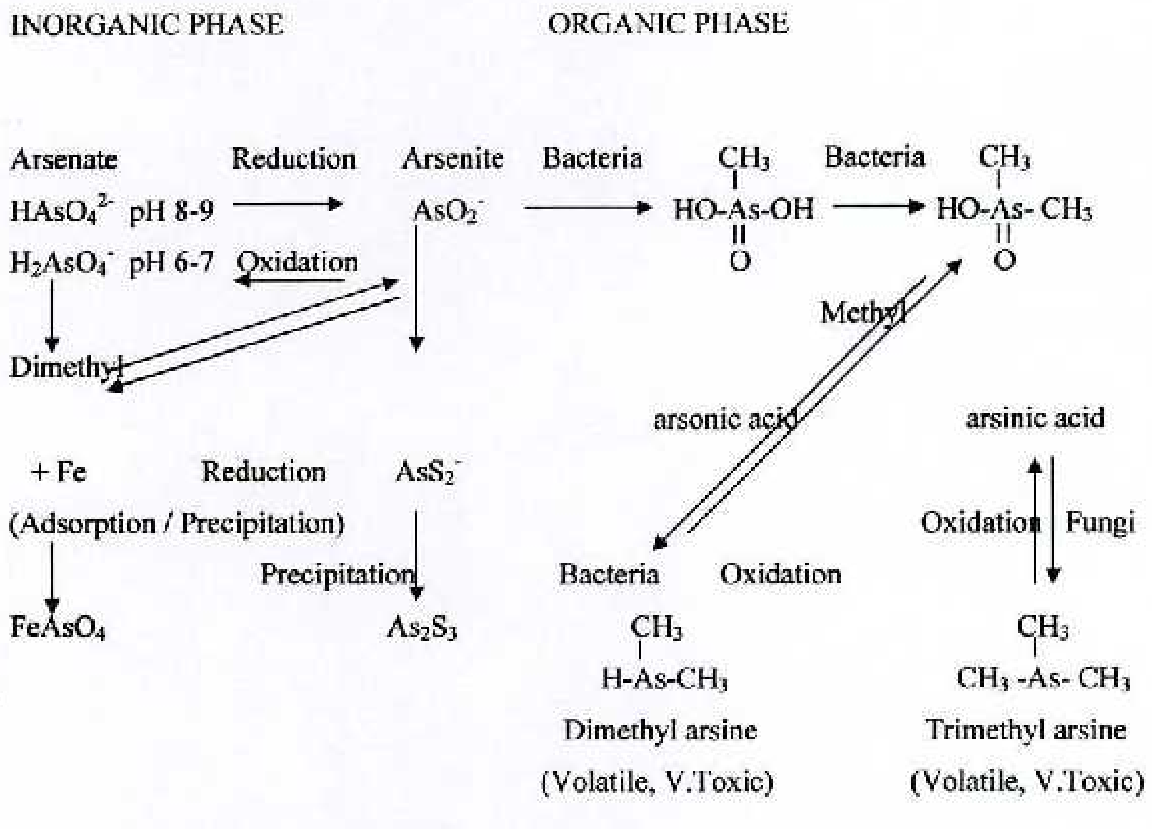

Figure- 2.6: Chemical Forms of Arsenic and their Transformations (Bhumbla & Keefer, 1994)

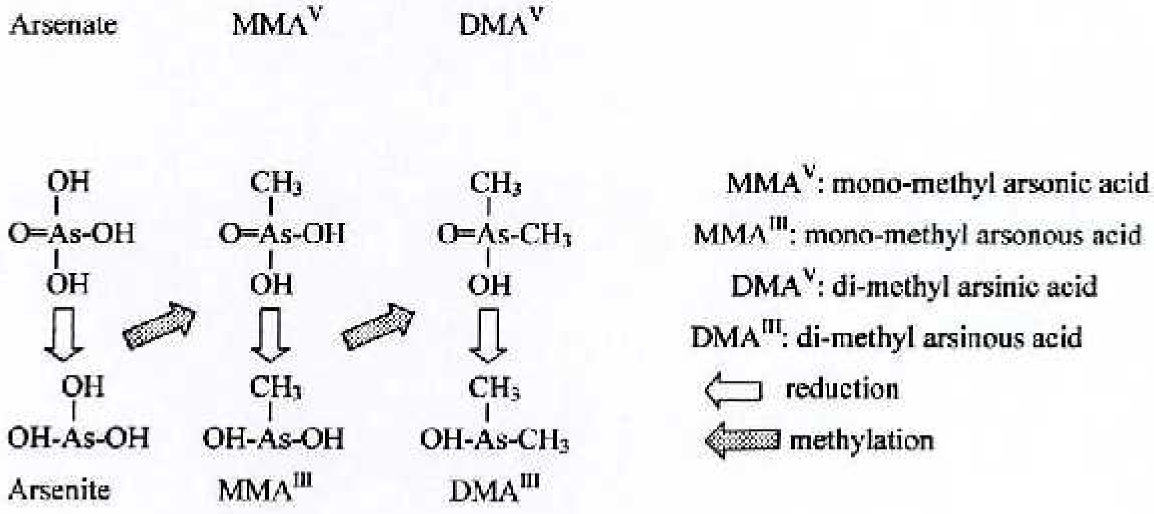

Figure- 2.7: Reduction and Methylation Reactions in the Metabolism of Arsenic (Suzuki, 2002)

2.1.10 Biological Concept for Arsenic Removal Process

Biological removal processes is the process where bacteria can play an important role in catalyzing many of the above processes. Relatively little is known about the potential for biological removal of arsenic from water.

Most arsenic removal technologies are most effective at removing the pentavalent form of arsenic (arsenate), since the trivalent form (arsenite) is predominantly non-charged below pH 9.2. Therefore; many treatment systems include an oxidation step to convert arsenite to arsenate. Oxidation alone doesn't remove arsenic from solution, and must be coupled with a removal process such as coagulation, adsorption or ion exchange.

Lehimans et al. (1998) conducted pilot studies to adopt biological filtration for removal of

As (III), the oxidation state where Arsenic is the most delicate to treat. For concentration as high as 400 µg/l, up to 90% reduction was achieved. An initial level of 75 µg/l even allows a final concentration below 10 µg/l. In addition, complete iron removal was achieved. They conclude that under optimized pH, temperature and oxygenation condition and with a sufficient initial iron concentration, biological filtration allows simultaneous elimination of As (III) and Iron.

Parknikar (1998) describes two types of metal-micro biological interactions that can be used for arsenic removal: i) microbial oxidation of As (III) to As (V) and its subsequent precipitation, and ii) bio-accumulation of arsenic by microbial biomass. The oxidation method can be operated in an immobilized reactor reservoir. A cheap source of organic substrate like sugarcane juice can be added along with iron fillings (Panikar, 1998). Iron fillings promote development of iron – oxidizing bacteria that oxidize iron at a rate 50 times faster than chemical oxidation of iron. Arsenic is then adsorbed on the ferric iron. Treated overflow of water typically contain arsenic< 0.05 mg/l for initial concentration up to 4.0 mg/l.

2.1.11 Technologies Used For Arsenic Removal in Bangladesh

General:

In the context of prevalence of high concentrations of arsenic in tubewell water, wide ranges of technologies have been tried for the removal of arsenic from drinking water. The most common technologies utilized the conventional processes of oxidation, co-precipitation and adsorption onto coagulated flocs, adsorption onto sorptive media, ion exchange and membrane techniques for arsenic removal. The conventional technologies have been scaled down to meet the requirements of households and communities and suit the rural environment. Some technologies utilized indigenous materials for arsenic removal. This article presents a short review of the processes and removal units used for arsenic removal in Bangladesh.

2.1.11.1 Unit Processes of Arsenic Removal

(a) Oxidation, Co-Precipitation and Adsorption:

Arsenic is present in groundwater in As(III) and As(V) forms in different proportions. Most treatment methods are effective in removing arsenic in pentavalent form and hence include an oxidation step as pretreatment to convert arsenite to arsenate. Atmospheric oxygen, hypo chloride and permanganate are commonly used for oxidation in developing countries.

Water treatment with coagulants such as alum, $Al_2(SO_4)_3.18H_2O$, ferric chloride, $FeCl_3$ and ferric sulfate $Fe_2(SO_4)_3.7H_2O$ are effective in removing arsenic from water. Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH. In both cases pentavalent arsenic can be more effectively removed than trivalent arsenic.

Arsenic adsorbed on aluminum hydroxide flocs as Al-As and on ferric hydroxide flocs as Fe-As complexes are removed by sedimentation. Filtration may be required to ensure complete removal of all flocs.

This process is effective in removing arsenic but associates with high operation costs of chemicals as well as frequent maintenance due to clogging of filter bed.

(b) Passive Sedimentation:

Passive sedimentation received considerable attention because of rural people's habit of drinking stored water from pitchers. Oxidation of water during collection and subsequent storage in houses may cause a reduction in arsenic concentration in stored water (Bashi Pani). Experiments conducted in Bangladesh showed zero to high reduction in arsenic content by passive sedimentation. Arsenic reduction by plain sedimentation appears to be dependent on water quality particularly the presence of precipitating iron in water. Ahmed et al., (2000) showed that more than 50% reduction in arsenic content is possible by sedimentation of tubewell water containing 380-480 mg/L of alkalinity as $CaCO_3$ and 8-12 mg/L of iron but cannot be relied to reduce arsenic to desired level. Most studies showed a reduction of 0 to 25% of the initial concentration of arsenic in groundwater. In rapid assessment of technologies, passive sedimentation failed to reduce arsenic to the desired level of 50 μg/L in any well (BAMWSP, DFID, Water Aid, 2001).

(c) In-situ Oxidation:

In-situ oxidation of arsenic and iron in the aquifer has been tried under DPHE-Danida Arsenic Mitigation Pilot Project. The aerated tubewell water is stored in a tank and released back into the aquifers through the tubewell by opening a valve in a pipe connecting the water tank to the tubewell pipe under the pump head. The dissolved oxygen in water oxidizes arsenite to less mobile arsenate and also the ferrous iron in the aquifer to ferric iron, resulting a reduction in arsenic content in tubewell water. Experimental results show that arsenic in the tubewell water following in-situ oxidation is reduced to about half due to underground precipitation and adsorption on ferric iron (Ahmed, 2001).

(d) Solar Oxidation:

SORAS is a simple method of solar oxidation of arsenic in transparent bottles to reduce arsenic content of drinking water (Wegelin et al., 2000). Ultraviolet radiation can catalyze the process of oxidation of arsenite in presence of other oxidants like oxygen (Young, 1996). Experiments in Bangladesh show that the process on average can reduce arsenic content of water to about one-third (Ahmed, 2001).

(e) Naturally Occurring Iron:

The use of naturally occurring iron precipitates in ground water in Bangladesh is a promising method of removing arsenic by adsorption. The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron [$Fe(OH)_2$] present in groundwater, have the affinity for the adsorption of arsenic. Only aeration and sedimentation of tubewell water rich in dissolved iron has been found to remove arsenic. The iron removal plants (IRP) in Bangladesh constructed on the principles of aeration, sedimentation and filtration have been found to remove arsenic without any added chemicals. The conventional community type IRP, depending on the above operating principles, more or less work as arsenic removal plants (ARP) as well. Results show that most IRPs can lower arsenic content of tubewell water to half to one-fifth of the original concentrations (Ahmed, 2001) level of 50 µg/L in any well (BAMWSP, DFID, Water Aid, 2001).

(f) Sorptive Filtration Media:

Several sorptive media have been reported to remove arsenic from water. These are activated alumina, activated carbon, iron and manganese coated sand, kaolinite clay, hydrated ferric oxide, activated bauxite, titanium oxide, silicium oxide and many natural and synthetic media. The efficiency of sorptive media depends on the use of oxidizing agent as aids to sorption of arsenic. Saturation of arsenic by different contaminants and components of water takes place at different times of operation depending on the specific sorption affinity of the medium to the given component. Saturation means that the efficiency in removing the desired impurities becomes zero.

Activated alumina (Al_2O_3) having good sorptive surface is an effective medium for arsenic removal. When water passes through a packed column of activated alumina, the impurities including arsenic present in water are absorbed on the surfaces of activated alumina grains. Eventually the column becomes saturated, first at its upstream zone and later the saturated zone moves downstream towards the bottom end and finally the column get totally saturated.

Regeneration of saturated alumina is carried out by exposing the medium to 4% caustic soda (NaOH), either in batch or by flow through the column resulting in high arsenic contaminated caustic waste water. The residual caustic soda is then washed out and the medium is neutralized with a 2% solution of sulfuric acid rinse. During the process about 5-10% alumina is lost and the capacity of the regenerated medium is reduced by 30-40% (Ahmed, 2001). The activated alumina needs replacement after 3-4 regeneration. Like coagulation process, pre-chlorination improves the column capacity dramatically.

(g) Ion Exchange:

The process is similar to that of activated alumina; just the medium is a synthetic resin of more well defined ion exchange capacity. The process is normally used for removal of specific undesirable cation or anion from water. As the resin becomes exhausted, it needs to be regenerated. The arsenic exchange and regeneration equations with common salt solution as regeneration agent are as follows:

Arsenic exchange

$2R\text{-}Cl + HAsO_4^{--} = R_2HAsO_4 + 2Cl^-$

Regeneration

$R_2HAsO_4 + 2Na^+ + 2Cl^- = 2R\text{-}Cl + HAsO_4^{--} + 2Na^+$

Where, R stands for ion exchange resin.

The arsenic removal capacity is dependent on sulfate and nitrate contents of raw water as sulfate and nitrate are exchanged before arsenic. The ion exchange process is less dependent on pH of water. The efficiency of ion exchange process is radically improved by pre-oxidation of As(III) to As(V) but the excess of oxidant often needs to be removed before the ion exchange in order to avoid the damage of sensitive resins. Development of ion specific resin for exclusive removal of arsenic can make the process very attractive.

Tetrahedron ion exchange resin filter tested under rapid assessment program in Bangladesh (BAMWSP, DFID and Water Aid, 2000) showed promising results in arsenic removal. The system needs pre-oxidation of arsenite by sodium hypochloride. The residual chlorine helps to minimize bacterial growth in the media. The saturated resins require regeneration by recirculating NaCl solution. The liquid wastes rich in salt and arsenic produced during regeneration require special treatment. Some other ion exchange resins were demonstrated in Bangladesh but sufficient field test results are not available on the performance of those resins.

(h) Membrane Techniques:

Membrane techniques like reverse osmosis, nanofiltration and electrodialysis are capable of removing all kinds of dissolved solids including arsenic from water (Ahmed, 2001). In this process water is allowed to pass through special filter media which physically retain the impurities present in water. The water, for treatment by membrane techniques, shall be free from suspended solids and the arsenic in water shall be in pentavalent form. Most membranes, however, cannot withstand oxidizing agent.

2.1.11.2 Arsenic Removal Units

(a) Bucket Treatment Unit:

The Bucket Treatment Unit (BTU), developed by DPHE-Danida Project is based on the principles of coagulation, co-precipitation and adsorption processes. It consists of two buckets, each 20 liter capacity, placed one above the other. Chemicals are mixed manually with arsenic contaminated water in the upper bucket by vigorous stirring with a wooden stick for 30 to 60 seconds and then flocculated by gentle stirring for about 90 seconds. The mixed water is then allowed to settle for 1-2 hours. The water from the top bucket is then allowed to flow into the lower bucket via plastic pipe and a sand filter installed in the lower bucket. The flow is initiated by opening a valve fitted slightly above the bottom of the upper bucket to avoid inflow of settled sludge in the lower bucket. The lower bucket is practically a treated water container.

The DPHE-Danida Project in Bangladesh distributed several thousands BTU units in rural areas. These units are based on chemical dosages of 200 mg/L aluminum sulfate and 2 mg/L of potassium permanganate supplied in crushed powder form. The units were reported to have very good performance in arsenic removal in both field and laboratory conditions (Sarkar et al., 2000). Extensive study of DPHE-Danida BTU under BAMWSP, DFID, and Water Aid (2001) rapid assessment program showed mixed results. In many cases, the units under rural operating conditions fail to remove arsenic to the desired level of 0.05 mg/L in Bangladesh (Ahmed, 2001). Poor mixing and variable water quality particularly pH, phosphate, nitrate, sulfate and chloride of groundwater in different locations of Bangladesh appeared to be the cause of poor performance in rapid assessment.

Bangladesh University of Engineering and Technology (BUET) modified the BTU and obtained better results by using 100 mg/L of ferric chloride and 1.4 mg/L of potassium permanganate in modified BTU units. The arsenic contents of treated water were mostly below 20 ppb and never exceeded 37 ppb while arsenic concentrations of tubewell water varied between 375 to 640 ppb (Ahmed, 2001). The BTU is a promising technology for arsenic removal at household level at low cost. It can be built by locally available materials and is effective in removing arsenic if operated properly.

(b) Stevens Institute Technology:

This technology also uses two buckets, one to mix chemicals (reported to be iron sulfate and calcium hypochloride) supplied in packets and the other to separate floc by the processes of sedimentation and filtration. The second bucket has a second inner bucket with slits on the sides to help sedimentation and keeping the filter sand bed in place. The chemicals form visible large flocs on mixing by stirring with stick. Rapid assessment showed that the technology was effective in reducing arsenic levels to less than 0.05 mg/L in case of 80 to 95% of the samples tested (BAMWSP, DFID, Water Aid, 2001). The sand bed used for filtration is quickly clogged by flocs and requires washing at least twice a week.

(c) BCSIR Filter Unit:

Bangladesh Council of Scientific and Industrial Research (BCSIR) has developed an arsenic removal system, which uses the process of coagulation, co-precipitation with an iron based chemical followed by sand filtration. The unit did not take part in a comprehensive evaluation process (Ahmed, 2001).

(d) Fill and Draw Units:

It is a community type treatment unit designed and installed under DPHE-Danida Arsenic Mitigation Pilot Project. It is 600 L capacity (effective) tank with slightly tapered bottom for collection and withdraws of settled sludge. The tank is fitted with a manually operated mixer with flat-blade impellers. The tank is filled with arsenic contaminated water and required quantity of oxidant and coagulants are added to the water. The water is then mixed for 30 seconds by rotating the mixing device at the rate of 60 rpm and left overnight for sedimentation. The water takes some times to become completely still which helps flocculation. The floc formation is caused by the hydraulic gradient of the rotating water in the tank. The settled water is then drawn through a pipe fitted at a level, few inches above the bottom of the tank and passed through a sand bed and finally collected through a tap for drinking purpose. The mixing and flocculation processes in this unit are better controlled to effectively higher removal of arsenic (Ahmed, 2001). The experimental units installed by DPHE-Danida Project are serving the clusters of families and educational institutions.

(e) Arsenic Removal Unit Attached to Tubewell:

The principles of arsenic removal by alum coagulation, sedimentation and filtration have been employed in a compact unit for water treatment in the village level in West Bengal, India. The arsenic removal plant attached to hand tubewell has been found effective in removing 90% arsenic from tubewell water having initial arsenic concentration of 300 μg/L (Ahmed, 2001). The treatment process involves addition of sodium hypochloride (Cl_2), and aluminum alum in diluted form, mixing, flocculation, sedimentation and up flow filtration in a compact unit. This process was found effective in removing arsenic but associated with high operation costs of chemicals as well as frequent maintenance due to clogging of filter bed.

(f) Chemical Packages:

In Bangladesh different types of chemical packages have been distributed in the forms of tea bags, small packets and powder of tablet form for the removal of arsenic from drinking water. The principals involved in arsenic removal by these chemicals involve oxidation, sorption and co-precipitation. Application methodology and efficiency of any of these chemicals have not been fully optimized by long experimentation. Quality assurance and dosage control in rural condition are extremely difficult. The residuals of added chemicals in water after treatment can do equal harm. The use of unknown chemicals and patented process without adequate information should be totally discouraged (Ahmed, 2001).

(g) Activated Alumina Based Units:

- BUET Activated Alumina
- Alcan Enhanced Activated Alumina
- ARU of Project Earth Industries Inc., USA
- Apyron Arsenic Treatment Unit

The BUET and Alcan activated alumina have been extensively tested in field condition in different areas of Bangladesh under rapid assessment and found very effective in arsenic removal (BAMWSP, DFID, Water Aid, 2001). The arsenic removal units (ARU) of Project Earth Industries Inc., USA used hybrid aluminas and composite metal oxides as adsorption media and were able to treat 200-500 Bed Volume (BV) of water containing 550 μg/L of arsenic and 14 mg/L of iron (Ahmed et al., 2000). The Apyron Technologies Inc. (ATI) also uses inorganic granular metal oxide based media that can selectively remove As(III) and As(V) from water. The Aqua-Bind ™ arsenic media used by ATI consists of non-hazardous aluminium oxide and manganese oxide for cost-effective removal of arsenic. The proponents claimed that the units installed in India and Bangladesh consistently reduced arsenic to less than 10μg/L (Ahmed, 2001).

(h) Granular Ferric Hydroxide:

M/S Pal Trockner (P) Ltd., India and Sidko Ltd., Bangladesh installed several Granular Ferric Hydroxide based arsenic removal units in India and Bangladesh. The Granular Ferric Hydroxide (Adsorb As®) is arsenic selective adsorbent developed by Technical University, Berlin, Germany. The unit requires iron removal as pretreatment to avoid clogging to filter bed. The proponents of the unit claim to have very high arsenic removal capacity and produces non-toxic spent granular ferric hydroxide (Ahmed, 2001).

(i) Read-F Arsenic Removal Unit:

Read-F is an adsorbent produced and promoted by Shin Nihon Salt Co. Ltd., Japan for arsenic removal in Bangladesh. Read-F displays high selectivity for arsenic ions under a broad range of conditions and effectively adsorbs both arsenite and arsenate without the need for pretreatment. The Read-F is Ethylene-vinyl alcohol copolymer (EVOH)-borne hydrous cerium oxide in which hydrous cerium oxide ($CeO_2.nH_2O$), is the adsorbent. The material contains no organic solvent or other volatile substance and is not classified as hazardous material. Laboratory test at BUET and field testing of the materials at 4 sites under the supervision of BAMWSP showed that the adsorbent is highly efficient in removing arsenic from groundwater (SNSCL, 2000).

(j) Iron Coated Sand:

BUET has constructed and tested iron coated sand based small-scale unit for the removal of arsenic from ground water. Iron coated sand has been prepared following a procedure similar to that adopted by Joshi and Choudhury (1996). The iron content of the iron coated sand was found to be 25 mg/g of sand. For raw water having both As(III) and As(V) of concentration 300μg/L when filtered through iron coated sand, it was found that 350 bed volume (BV) could be treated satisfying the Bangladesh drinking water standard of 50 ppb (Ali, 2001). The saturated medium is regenerated by passing 0.2N sodium hydroxide followed by washing with distilled water. No significant change in bed volume (BV) in arsenic removal was found after 5 regeneration cycles. It was interesting to note that iron coated sand is equally effective in removing both As(III) and As(V). Iron coated brick dust has also been developed in Bangladesh for arsenic removal from drinking water.

(k) Indigenous Filters:

There are several filters available in Bangladesh that use indigenous material as arsenic adsorbent. Red soil rich in oxidized iron, clay minerals, iron ore, iron scrap or fillings and processed cellulose materials are known to have capacity for arsenic adsorption. Some of the filters manufactured using these materials include:

- Sono 3-Kolshi Filter
- Garnet Home-made Filter
- Chari Filter
- Adarsha Filter
- Shafi Filter
- Bijoypur Clay/Processed Cellulose Filter

The Sono 3-Kolshi Filter uses zero valent iron fillings and coarse sand in the top Kolshi, wood coke and fine sand in the middle Kolshi while the bottom Kolshi is the collector of the filtered water (Khan et al., 2000). This unit has been found to be very effective in removing arsenic but the media was found contaminated with the growth of microorganism (BAMWSP, DFID and Water Aid, 2000). The one-time use unit becomes quickly clogged, if groundwater contains excessive iron.

The Garnet homemade filter contains relatively inert materials like brick chips and sand as filtering media. No chemical is added to the system. Air oxidation and adsorption on iron-rich brick chips and flocs of naturally present iron in groundwater could be the reason for arsenic removal from groundwater. The unit produced inadequate quantity of water and did not show reliable results in different areas of Bangladesh and under different operating conditions (Ahmed, 2001). The Chari filter also uses brick chips and inert aggregates in different Charis as filter media. The effectiveness of this media in arsenic removal is not known (Ahmed, 2001).

The Shafi and Adarsha filters use clay material as filter media in the form of candle. The Shafi filter was reported to have good arsenic removal capacity but suffered from clogging of filter media (Ahmed, 2001). The Adarsha filter participated in the rapid assessment program but failed to meet the technical criterion of reducing arsenic to acceptable level (BAMWSP, DFID and Water Aid, 2000). Bijoypur clay and treated cellulose were found to absorb arsenic from water (Khair, 2000).

(l) Cartridge Filters:

Filter units with cartridges filled with sorptive media or ion-exchange resins are readily available in the market. These units remove arsenic like any other dissolved ions present in water. These units are not suitable for water having high impurities and iron in water. Presence of ions having higher affinity than arsenic can quickly saturate the media requiring regeneration or replacement. Two household filters were tested at BUET laboratories, these are:

- Chiyoda Arsenic Removal Unit, Japan
- Coolmart Water Purifier, Korea

The Chiyoda Arsenic Removal Unit could treat 800 BV meeting the WHO guideline value of 10 μg/L and 1300 BV meeting the Bangladesh Standard of 50 μg/L when the feed water arsenic concentration was 300 μg/L (Ahmed, 2001). The Coolmart Water Purifier could treat only 20 L of water with a effluent arsenic content of 25 μg/L (Ahmed et al., 2000). The initial and operation costs of these units are high and beyond the reach of the rural people.

(m) MRT-1000 and Reid System Ltd.:

Jago Corporation Limited promoted a household reverse osmosis water dispenser MRT-1000 manufactured by B & T Science Co. Limited, Taiwan. This system was tested at BUET and showed a As(III) removal efficiency more than 80% (Ahmed, 2001). A wider spectrum reverse osmosis system named Reid System Limited was also promoted in Bangladesh. Experimental results showed that the system could effectively reduce arsenic content along with other impurities in water (Ahmed, 2001). The capital and operational costs of the reverse osmosis system would be relatively high.

(n) Low-pressure Nanofiltration and Reverse Osmosis:

Oh et al. (2000) applied reverse osmosis and nanofiltration membrane processes for the treatment of arsenic contaminated water applying low pressure by bicycle pump. A nanofiltration membrane process coupled with a bicycle pump could be operated under condition of low recovery and low-pressure range from 0.2 to 0.7 Mpa. Arsenite was found to have lower rejection than arsenate in ionized forms and water containing higher arsenite requires pre-oxidation for reduction of total arsenic acceptable level. In tubewell water in Bangladesh the average ratio of arsenite to total arsenic was found to be 0.25 (Ahmed, 2001). However, the reverse osmosis process coupled with a bicycle pump system operating at 4 Mpa can be used for arsenic removal because of its high arsenite rejection. The study concluded that low-pressure nanofiltration with pre-oxidation or reverse osmosis with a bicycle pump device could be used for the treatment of arsenic contaminated groundwater in rural areas (Oh et al., 2000).

2.1.12 Comparative Merits and Demerits of As Removal Technologies

The following Table summarizes the relative advantages and disadvantages of different arsenic removal technologies.

Table- 2.6: A Comparison of the Main Arsenic Removal Technologies (Ahmed, 2001)

Technologies	Advantages	Disadvantages
Oxidation-precipitation		
• Air Oxidation • Chemical Oxidation	• Simple and Low cost • Simple and Rapid process	• Less Removal Efficiency • Toxic Residual
Coagulation-Coprecipitation		
• Alum Coagulation • Iron Coagulation	• Easily Available Chemical • Effective Over Wider pH Range	• Produces Toxic Sludge • Relatively Costly Chemicals
Sorptive Techniques		
• Activated Alumina • Iron Coated Sand • Ion Exchange Resin	• Commercially Available • Plenty of Possibilities • High Removal Efficiency	• Produces Toxic Waste • High Technical O & M • Relatively High Cost
Membrane Techniques		
• Reverse Osmosis • Electrodialysis	• No Toxic Waste Produces • Capable of Removing Other Contaminants	• High Technical O & M • Toxic Waste Water Produces
• Microbial Processes	• Should be Less Costly	• Not Yet Fully Established

2.1.13 Health Implications of Drinking Arsenic Polluted Water

Acute arsenic exposures (high concentrations ingested over a short time period) can cause a variety of adverse effects (Frederick et al., 1994). The severity of the effect depends primarily on the level of exposure. Acute high dosage oral exposure to arsenic typically leads to gastrointestinal irritation accompanied by difficulty in swallowing, thirst, abnormally low blood pressure and convulsions. Death may occur from cardiovascular collapse.

The respiratory tract, nervous system and skin may be considered as the critical targets of prolonged arsenic exposures. Arsenic level in tissues and excreta are of limited importance on diagnosing chronic arsenic poisoning. The lethal dosage (LD_{50}) to humans is estimated at 1-4 mg As/kg body weight for an adult (Vallee et al., 1960, Winship, 1984). Short-term exposure to dosages of 500µg As/kg/d can cause serious blood pressure, nervous system disorder, gastro-intestinal irritation and other ill effects and also may led to short death. Short-term intake of dosages from 30-300µg As/kg/d does not cause serious effects in most people, but some may experience relatively mild effects (USEPA, 1993). Prolonged arsenic toxication results are shown in the following Table:

Table- 2.7: Arsenic Poisoning from Drinking Water

Sl	Main organ	Effects	Reference
1	Nervous system	Ataxia, Paralysis, peripheral neuropathy	Valle et al., 1960
2	Respiratory system	Nasal septum perforation, bronchitis, cancer	Luh et al., 1973
3	Skin	Melanosis, dermatitis, hyperkeratosis, cancer	Yeh,S., 1973
4	Heart	Heart and occlusive arterial disease	Hindmarsh, 1977
5	Liver	Liver cirrhoses and cancer	Zadivar, 1977

2.1.14 Drinking Water Standards for Arsenic

The Tolerable Daily Intake (TDI) is an estimate of the amount of substance per kg of body weight that can be ingested daily over a life time without appreciable health risk. For a proven human carcinogen chemical like arsenic it is accepted that the threshold value of TDI does not exist (Dahi, 1997). This is because; theoretically there will always be a probability of harmful effect, i.e., risk at any level of exposure. Estimated risks are normally based on 60 kg person, drinking 2 L of water per day, for a life time of 70 years. The WHO guideline value for substances in drinking water is the concentration corresponding to an upper bound estimate of an excess lifetime cancer risk of 10^5. In other words it is the concentration expected to give one additional cancer case per 100,000 people ingesting the water for 70 years.

On this basis the arsenic concentration for acceptable skin cancer risk is calculated to be 0.17µg/L. For practical limitation in available analysis methods, only a provisional guideline value of 10µg/L is established (Dahi, 1998). Thus the estimated excess lifetime skin cancer risk associated with exposure to 10µg/L drinking water concentration for a lifetime of 70 years is: $P = (10\mu g/L. 10^{-5}) / 0.17\mu g/L = 6.10^{-4}$; i.e., 6 additional skin cancer cases per 10,000 exposed. For comparison the national standards adopted are 10µg/L in the European Union, 25µg/L in Canada and 50µg/L in Bangladesh Standard.

2.2 Irons in Ground Water

2.2.1 General

The presence of iron in ground water is now considered to be a major problem throughout the world and produce numerous adverse effects. These problems are severe in the context of Bangladesh as groundwater is a vital source for the safe drinking water supply. In some places of Bangladesh the concentration of iron in ground water is at a much higher level than the limit acceptable to the rural people. People of those areas generally refuse to use tube well water and inclined to use pond and river waters.

2.2.2 Occurrence of Iron

The element iron is an abundant and widespread constituent of rocks and soils. Dissolved iron is found in ground water from wells located in shale, sandstone and alluvial deposits. In igneous rocks the principal minerals containing iron as an essential component include the pyroxenes, amphiboles, magnetite and the nesosilicates such as olivine. The composition of olivine ranges from Mg_2SiO_4 to Fe_2SiO_4 (forsterite to fayalite) with ferrous iron substituting freely for magnesium. Most commonly, the iron in igneous rocks is in the ferrous form but may be mixed with ferric iron as in magnetite Fe_3O_4 (Hem, 1970). Common mineral deposits of iron include ferric oxide and hydroxides such as hematite Fe_2O_3 and ferric hydroxide $Fe(OH)_3$. Sedimentary forms of iron include sulfides such as pyrite and marcasite; two minerals with identical chemical composition FeS_2 but different crystalline structures. Carbonates such as siderite $FeCO_3$ and mixed oxides such as m0agnetite Fe_3O_4. The ferrous oxides and sulfides are the usual sources of dissolved iron in ground water. Weathering of iron silicates can produce dissolved iron in near surface water. However, this is a relatively slow process. Ferrous iron Fe^{2+} is chemically reduced, soluble form that exists in a reducing environment (in absence of dissolved oxygen and low pH). Many ground waters are low in dissolved oxygen and are supersaturated with CO_2 owing to weathering of carbonate rocks or to increased CO_2 concentration in the soil gas. The lower pH value of ground water due to the presence of CO_2 and mineral acids and absence of dissolved oxygen creates favorable conditions to hold iron in high concentration in ground water as ferrous bicarbonate (Bell, 1965).

$$Fe^{2+} + 2\,CO_2 + 2\,H_2O \longrightarrow Fe(HCO_3)_2 + 2\,H^+$$

Upon exposure to the atmosphere dissolution of CO_2 from supersaturated ground water occurs, leading to an increase in pH value. At the same time aeration of the ground water occurs and increases the dissolved oxygen concentration. As a result rate of oxidation of soluble ferrous iron to insoluble ferric iron increases, which precipitates from solution as hydrous ferric oxides.

$$2\,Fe^{2+} + 4\,HCO_3^- + H_2O + \tfrac{1}{2}O_2 \longrightarrow 2\,Fe(OH)_3 + 4\,CO_2$$

The oxidation of iron in natural system is more complex than indicated by the above equation. Iron can also enter in water through solution or infusion of organic bodies such as wood, leaves and so forth. Iron is an essential element in both plant and animal metabolism.

2.2.3 Chemistry of Iron in Water

Iron Fe^{2+} is a chemically reduced soluble form that may exist in a reducing environment. Upon exposure to the atmosphere dissolution of CO_2 and H_2S from supersaturated ground water occurs leading to an increase in pH value. At the same time aeration of the ground water occurs and increases the dissolved oxygen concentration. Thus aeration and dissolution of CO_2 increases the rate of oxidation of soluble ferrous iron to insoluble ferric iron. But the oxidized and precipitated iron particles are so small in size that it is very difficult to separate them through sedimentation. Coagulation and flocculation are the process by which these small particles are allowed to grow or flocculate to sizes that settle at satisfactory velocities.

Solubility of Iron:

In the pH range encountered in natural waters, soluble ferrous iron consists primarily of Fe^{2+} and $FeOH^+$. While greatly limited in solubility at neutral pH, the aqueous ferric ions consists predominantly of $Fe(OH)_2^+$ and $Fe(OH)_4^-$ (O'Connor, 1971). In alkaline water which is devoid of sulfide, phosphate and organic hydroxide; ferrous carbonate, ferric hydroxide or mixture of them exist depending on the concentration of oxidizing agents and pH.

According to Ghosh, et al., (1966) in alkaline natural water, the solubility of ferrous iron is limited by the solubility of ferrous carbonate in the pH range of 6-9, above which the solubility equilibrium of ferrous hydroxide becomes limiting again. Theoretically iron that precipitates from a supersaturated solution of this type would be either ferrous carbonate or ferrous hydroxide depending on the pH. Under practical conditions, however, the precipitation of basic carbonates [e.g. $Fe(OH)_2.FeCO_3$] with somewhat different solubility characteristics is probable, especially in the pH range of 8 to 11.On aeration or by the addition of oxidizing agents; iron is oxidized from the ferrous to ferric form. Once oxidized, the solubility of iron is severely limited over a wide range of pH values from 4 to 13 by the solubility of ferric hydroxide. The following Figure shows plot of the solubility of Fe(III) in water having a concentration of total carbonic species 10^{-3} M (Stumm, 1964). To take advantage of this solubility restriction, the basic step in the removal of iron is oxidation of ferrous iron to ferric iron. Ferric ions generally have a stronger tendency to form complexes than ferrous ions. Complex formation of ferric ions with o-phosphate silicate and many organic bases is stable and very difficult to precipitate.

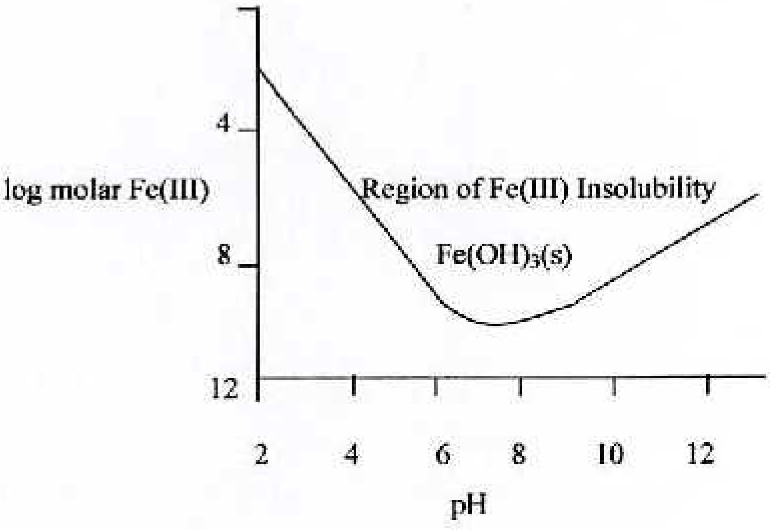

Figure - 2.8: Solubility of Fe(III) at 25^{0}C (Fair, Geyer and Okun, 1958)

The Kinetics of Iron Oxidation:

In the presence of dissolved oxygen, soluble ferrous iron Fe^{2+} oxidizes to ferric oxides or hydroxides. The stoichiometric relationship being (O'Connor, 1971) as follows:

$$Fe^{2+} + \frac{1}{4} O_2 + 2\,OH^- + \frac{1}{2} H_2O \longrightarrow 2\,Fe(OH)_{3(S)}$$

This indicates that 1 mg/L of oxygen will oxidize 7 mg/L of ferrous iron. So the oxygen demand and correspondingly the oxygen gas transfer requirements are very small. It is believed that the oxidation of ferrous iron proceeds stepwise through various ferrous-ferric species.

Effect of Fe^{2+} and Partial Pressure of O_2:

Ghosh et al., (1966) stated that the rate of ferrous iron oxidation is of the first order with respect to ferrous iron concentration (Fe^{2+}) and the partial pressure of oxygen (pO_2).

Thus the rate law constant

$$-d/dt\,(Fe^{2+}) = k_1(Fe^{2+})pO_2$$

It was also observed in the above study that the rate of iron oxidation remains unaffected by dissolved oxygen if the concentration exceeds 5 mg/L.

Effect of pH Value:

Usually ground water contains a high concentration of CO_2. The aeration not only results in the oxidation of ferrous iron but also serves to remove CO_2 resulting in an increase in pH. Oxidation of ferrous iron increases rapidly at pH of 7.0 or above and is very slow below 6.0. Reaction rates are strongly pH dependent. Stumm and Lee (1961) indicated that an increase of one pH unit, causes 100 fold increase in the rate of reaction i.e. there is a second order relationship between the rate of reaction and the hydroxyl ion concentration.

Therefore,

$$-d/dt\,(Fe^{2+}) = K\,(Fe^{2+})pO_2[OH^-]^2$$

Where, $d/dt\,(Fe^{2+})$ = Rate of Fe(II) oxidation, mol/L/min

Fe^{2+} = Ferrous ion concentration, mol/L

pO_2 = Partial pressure of oxygen, atmosphere

OH^- = Hydroxyl ion concentration, mol/L

K = Reaction rate constant=$8.0+(2.5) \times 10^{13}$ L^2/min/atmos/mol^2 at 20.5^0C

It has been observed that the half time for Fe^{2+} oxidation at pH 7.02 is approximately 4 minutes and at pH 7.24 it is around 2 minutes, implying complete (>99%) oxidation of Fe^{2+} in a relatively short time in well aerated water at pH values greater than 7.2 and alkalinity above 450 mg/L as $CaCO_3$ (Stumm and Lee, 1961).

Effect of Alkalinity:

Stumm and Lee reported that the reaction rates obtained in solutions of lower alkalinity tend to be of smaller magnitude and more scattered than those obtained in solutions of higher alkalinity.

Robinson and Dixon (1968) mentioned that in order to obtain complete oxidation of the ferrous iron, the bicarbonate alkalinity of the water should be in excess of 100 mg/L as $CaCO_3$. Generally, if the concentration of alkalinity reaches 130 mg/L as $CaCO_3$ all of the ferrous iron will be oxidized almost immediately and any further addition of chemicals would appear to be unnecessary. Low alkaline water needs some oxidizing agent ($KMnO_4$) without raising pH and alkalinity or some chemical additive (Na_2CO_3) to raise both pH and alkalinity.

Effect of Temperature:

The reaction rate is dependent on temperature. For a given pH value, the rate increases about 10 fold for a 15^0C increase in temperature, which is mainly caused by the change in $[OH]^-$ concentration due to temperature dependence of the ionization constant of water (Stumm et al., 1961).

Effect of Ionic Strength:

Sung and Forbes (1984) showed that the rate constant K is also a function of ionic strength and the presence of complex forming anions. They observed a linear variation (decrease) of the rate constant up to an ionic strength of 0.25 M in their study. At values greater than this, increasing ionic strength actually increases the rate constant.

Effect of Chloride and Sulfate:

Sung and Morgan (1980) observed that chloride and sulfate ions have a significant retarding influence on the rate constant in the pH range from 6.5 to 7.2. Later Sung and Forbes (1984) mentioned that for typical fresh water iron removal, chloro-complexes of iron could probably be ignored because of the effect of ionic strength and chloro-complexes may not be as important as the effects of temperature and pH.

Effect of Organic Matter:

Ferrous iron is capable of forming complexes with organic matter which is resistant to oxidation even in the presence of dissolved oxygen. The relative strength of such complexes has stability constants of approximately 10^4 (Theis and Singer, 1974).

Catalytic Effect:

For a given pH value and oxygen concentration, the addition of as little as 0.02 mg/L of Cu^{2+} reduces the oxygenation time by a factor of 5 (Stumm and Lee, 1961).

Sung and Morgan (1980) studied the effect of ferric hydroxide on the oxygenation of ferrous iron and stated that auto catalysis is noticeable only for pH around 7 and above. Cox, (1969) has described the use of contact bed oxidation in iron removal. The purpose of contact bed according to him is to facilitate oxidation of iron or manganese through the catalytic action of previously precipitated oxides of these minerals on the gravel or ore.

2.2.4 Existing Iron Removal Technologies

To remove soluble iron it is generally accepted that an oxidation process followed by a suspended solids removal process is most effective. Usually oxidation of soluble iron is accomplished by simple aeration or chlorination/potassium permanganate application. Coagulation – flocculation with sedimentation and filtration are employed as solid removal processes.

Ahmed (1987) developed a low-cost iron removal plant based on four major units, e.g. aeration channel, sedimentation and two brick chips adsorption chambers. Several plants were constructed and it was found to be effective in removing iron from No. 6 tube well with yielding capacity of 9 to 13 L/min. The plants have been found to be very effective in removing soluble iron from tubewell water in excess of 90 percent.

Ahmed (1987) conducted some studies on horizontal flow roughing filter for the removal of iron from water. It was observed that in a roughing filter of 0.4 m long with 4 to 10 mm filter grain size and a filtration rate of 0.4 m/hr, an average of over 92% iron removal could be achieved during a total run of 100 hours. It was also observed that the most important factor that affects the performance of a roughing filter is the increasing depth of penetration of iron sludge with time.

In 1986-87 UNICEF developed an improved iron removal plant consists of three units e.g. perforated Ferro cement channel, sedimentation chamber and brick chip filter. The plant was found to be effective in iron removal and the filter run was also satisfactory. A study by WHO, UNICEF and DPHE (1990) on these iron removal plants showed that iron removal was satisfactory. The iron concentration was reduced to around 1.5 ppm from 15 ppm with average cleaning period of 12 days (with minimum of 5 days). With the same interval of cleaning it has been observed that the higher the concentration in raw water the higher the concentration in treated water but it was not exceeded 2.5 ppm.

For the elimination of iron from hand pump tubewell water, Aowal (1981) proposed to introduce a spray aeration, a settling tank and a plain sand filter, all housed in a single chamber. Although an effective removal was achieved the length of run between cleaning was very short, less than 24 hours. The top layer of fine sand was needed to be removed, washed and dried for the next use, which is not easy.

Kibret (1986) has shown that dry filter is one of the alternatives that can be applied for iron removal and the process uses the self-purification capacities of iron bacteria. Investigation made on the pilot plants showed that iron removal process by dry filtration depends on the hydraulic load, filter depth, size of filter material, the development of the microorganisms and iron concentration in the raw water. Dry filter does not only remove iron but it also removes manganese, ammonia, and carbon dioxide and provides sufficient oxygen supply to the treated water. The results obtained from the test plants were not bellowing the standard limits except from the full-scale production plant. However, complete removal of iron by dry filter is feasible provided the best possible favorable combinations of the factors on which iron removal depends are found.

In 1985-86 over hundred iron removal units, which were originally designed by BUET under a research programme, were built at Sirajgonj and Comilla. These units are reported to fail due to following reasons (UNICEF report 1988):

- Lack of community participation in all activities of the project.
- Faulty construction of the unit.
- Lack of continued support and technical advice from DPHE/UNICEF.
- Difficulty in cleaning the filter due to short filter runs.
- Complicated design of the unit.

In 1988, DPHE with the help of UNICEF, Dhaka Bangladesh, designed and constructed iron removal plant for hand pump tubewells in different parts of Bangladesh. Those plants were also failed due to faulty design of sedimentation chamber, where flocs were gradually settled and mixed with treated water.

Wong (1984) has shown that processes in which oxidation is followed by removal of suspended solids can effectively remove soluble iron and manganese from water. He has developed three common processes for removing iron and manganese, e.g. (i) aeration-filtration (ii) chlorination-filtration and (iii) potassium permanganate-manganese greensand filtration.

Other processes such as ion exchange, chlorine dioxide filtration, stabilization with polyphosphates etc. have also been applied but with less frequency, owing to cost and operational considerations. Removal processes are selected on the basis of iron concentration and other conditions.

More specially, the methods used in the removal of iron are:

I) a) Aeration – Sedimentation – Filtration
   b) Chlorination – Sedimentation – Filtration
   c) Potassium permanganate – Manganese greensand filtration
II) Flocculation – Sedimentation
III) Manganese zeolite process
IV) Stabilization method

I) (a) Aeration – Sedimentation – Filtration Method:

This method was studied and developed by Wong (1984) and typically includes an aerator, retention tank and filters. Oxygen from the atmosphere reacts with iron in raw water to produce relatively insoluble salts of ferric oxide. This method is generally recommended for water with high concentration of iron above 5 mg/L. The rate of reaction depends on pH. It is more rapid at higher pH values. Retention time of several hours may be necessary after aeration depending on raw water characteristics. Sometimes sedimentation tanks with sludge collection and removal facilities are used instead of a simple retention tank if iron concentration is high. Pressure filters preferably with duel media of anthracite and sand are used to remove iron. The major disadvantage of this method is that the initial cost is too high.

I) (b) Chlorination – Sedimentation – Filtration Method:

The process consists of a chemical feed system, a small retention tank and filter. The process needs a pH adjustment system through feeding caustic soda and lime. The process generally recommended for removal of low iron concentration less than 2 mg/L.
Either gaseous chlorine or hypochlorite can be used as the oxidizing agent. The filters used in this process are similar to those used in aeration – filtration process (Wong, 1984).

I) (c) Potassium permanganate – Manganese greensand filtration Method:

The method is recommended for removal of low to moderate concentration up to 5 mg/L of iron. Equipment for this process is similar to that for chlorination – filtration process but differs in the primary oxidizing agent and the filter media. A 1-4% solution of $KMnO_4$ is continuously feed into the raw water line prior to filtration to reduce the amount of soluble iron going to the filter. Manganese treated greensand has the ability to oxidize and to filter. However, its oxidation capacity is limited and the bed must be regenerated with potassium permanganate after back wash. The process has an advantage in that the greensand can act as a buffer. If the feed of $KMnO_4$ does not oxidize all the soluble iron, the greensand will oxidize and filter it.

Major disadvantages of this process are high operational costs associated with chemical requirements and filter bed deterioration if the pH falls below 7.1. In some cases, chlorine is used in conjunction with $KMnO_4$ to reduce chemical costs (Wong, 1984).

II) Flocculation and Sedimentation Method:

Sung and Forbes (1984) pointed out that oxidation of soluble iron is not the entire picture in iron removal processes. When ferrous iron solution is oxygenated, there study showed that the precipitate is roughly concentrated in the sub-micron size range. To enhance the settling character they proposed to promote coagulation/flocculation before settling.

Owens (1963) has suggested using calcium hydroxide as the coagulant. Upon addition of lime iron hydroxide precipitates out in the suspended sludge blanket in a solid contact unit. This is very effective in the removal of colloidal particles.

III) Manganese zeolite process:

Manganese zeolite is made by coating natural greensand (glauconite) zeolite with oxides. Manganese dioxide removes soluble iron until it becomes degenerated. The filter is regenerated using potassium permanganate ($KMnO_4$).

$$\text{Z–MnO}_2 + \text{Fe}^{2+} \longrightarrow \text{Z–Mn}_2\text{O}_3 + \text{Fe}^{3+}$$
$$\text{Z–Mn}_2\text{O}_3 + \text{KMnO}_4 \longrightarrow \text{Z–MnO}_2 \text{ (Regeneration)}$$

Manganese zeolite filters are generally pressure type. Disadvantages of the regenerative batch process are the possibility of soluble manganese leakage when the bed is nearly degenerated and the waste of excess $KMnO_4$ needed to regenerate the greensand (Clark, 1977).

IV) Stabilization Method:

The alternative to iron removal is stabilization or dispersion. According to Clark et. al. (1977) sodium hexametaphosphates at dosages of 5 mg/(mg of Fe plus Mn) have been used for this purpose. While this treatment will stabilize iron in suspension, it reportedly is not suitable where iron concentration of 1 mg/L is exceeded. Moreover, when the water is heated, the polyphosphate will revert to orthophosphate and loose its dispersing properties. The application of polyphosphate must take place prior to aeration or chlorination because the polyphosphate do not effectively stabilize precipitated ferric hydroxide. Polyphosphate dosages are limited to less than 10 mg/L because the availability of phosphorus may stimulate bacterial growths in distribution systems.

2.3 Requisite of Different Filter

Slow Sand Filter

It consists of a layer of ungraded fine sand through which water is filtered at a low rate. In general, slow sand filters have filtration rates of up to 0.4 m/hour. The low filtration rate causes long detention times of the water above the sand and within the sand bed. This allows substantial biological activity. Slow sand filtration removes particles mainly at the surface of the sand bed. Because of the low hydraulic loading and smaller sand size found in slow sand filters, most of the solid particles are removed within the top 0.5 - 2 cm of sand. Filter sand should have an effective size between 0.15 and 0.35mm and uniformity co-efficient between 1.5 and 3.0.

Slow sand filters are more practical in the treatment of water with turbidity below 50 NTU, although higher turbidities can be tolerated for a few days. The best purification occurs when the turbidity is below 10 NTU. (Schulz and Okun, 1984).

Slow sand filters work through the formation of a gelatinous layer (or biofilm) called the hypogeal layer or *Schmutzdecke* in the top few millimetres of the fine sand layer. This layer consists of bacteria, fungi, protozoa, rotifera and a range of aquatic insect larvae. The *Schmutzdecke* is the layer that provides the effective purification in potable water treatment, the underlying sand providing the support medium for this biological treatment layer. As water passes through the *Schmutzdecke*, particles of foreign matter are trapped in the mucilaginous matrix and dissolved organic material is absorbed, absorbed and metabolised by the bacteria, fungi and protozoa. The water produced from a well-managed slow sand filter can be of exceptionally good quality with no detectable bacterial content.

Slow sand filters slowly lose their performance as the *Schmutzdecke* grows and thereby reduces the rate of flow through the filter. Eventually it is necessary to refurbish the filter. Two methods are commonly used to do this. In the first, the top few millimetres of fine sand is very carefully scraped off using mechanical plant and this exposes a new layer of clean sand. Water is then decanted back into the filter and re-circulated for a few hours to allow a new *Schmutzedecke* to develop. The filter is then filled to full depth and brought back into service. The second method, sometimes called wet harrowing, involves lowering the water level to just above the *Schmutzdecke*, stirring the sand and thereby suspending any solids held in that layer and then running the water to waste. The filter is then filled to full depth and brought back into service. Wet harrowing can allow the filter to be brought back into service more quickly.

In order to be effective, most literature insists that a constant flow of water passing through a slow sand filter is essential. This flow provides oxygen and food to the organisms that make up the '*schmutzdecke*' and biological zone living within the top part of the sand, which are responsible for much of the removal of disease-causing organisms. Under stagnant conditions, the biological can start to die - sometimes within several hours.

Rapid Sand Filter

It consists of a layer of graded sand or in some instances a layer of coarser filter media (e.g., anthracite) placed on top of a layer of sand, through which water is filtered. Rapid sand filtration is the flow of water through a bed of granular media, normally following settling basins in conventional water treatment trains. As its name suggests water in rapid sand filters passes quickly through the filter beds. The purpose of this filtration is to remove any particulate matter left over after flocculation and settling. The filter process operates based on two principles, mechanical straining and physical adsorption.

Sand filtration is a "physical-chemical process for separating suspended and colloidal impurities from water by passage through a bed of granular material. Water fills the pores of the filter medium, and the impurities are adsorbed on the surface of the grains or trapped in the openings." (Culp, page 91). The key to this process is the relative grain size of the filter medium. Effective size of filter sand is 0.55 mm and higher and uniformity coefficient 1.5 and lower.

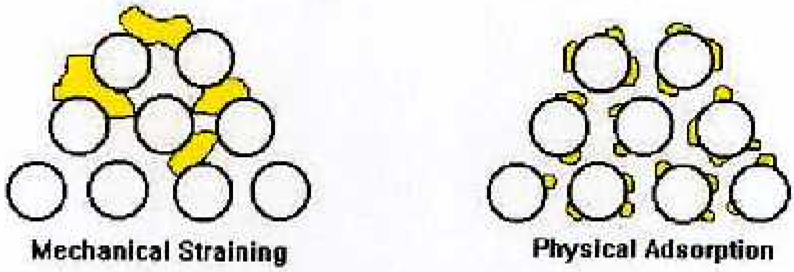

Figure - 2.9: Schematic of basic filtration principles by D. Schmitt

The main distinction from slow sand filtration is the fact that biological filtration is not part of the purification process in rapid filtration. Rapid filtration is used widely to remove impurities and remnants of flocculants in most water treatment plants. As a single process, it is not as effective as slow sand filtration in production of drinking water. Rapid sand filtration is contrasted to slow sand filtration by increased flow rate. In general, rapid sand filters which can see filtration rates of up to 21 m/hour. Physical straining is the most important mechanism present in rapid filters. Particles that are larger than the pore spaces between the sand grains are trapped - smaller solids however can pass through the filter. Rapid sand filtration removes particles over a substantial depth within the sand bed.

Chapter Three

Methodology

A brief description of the methodology that was followed in conducting the laboratory study and field application is given below:

3.1 Selected Processes for the Treatment Unit

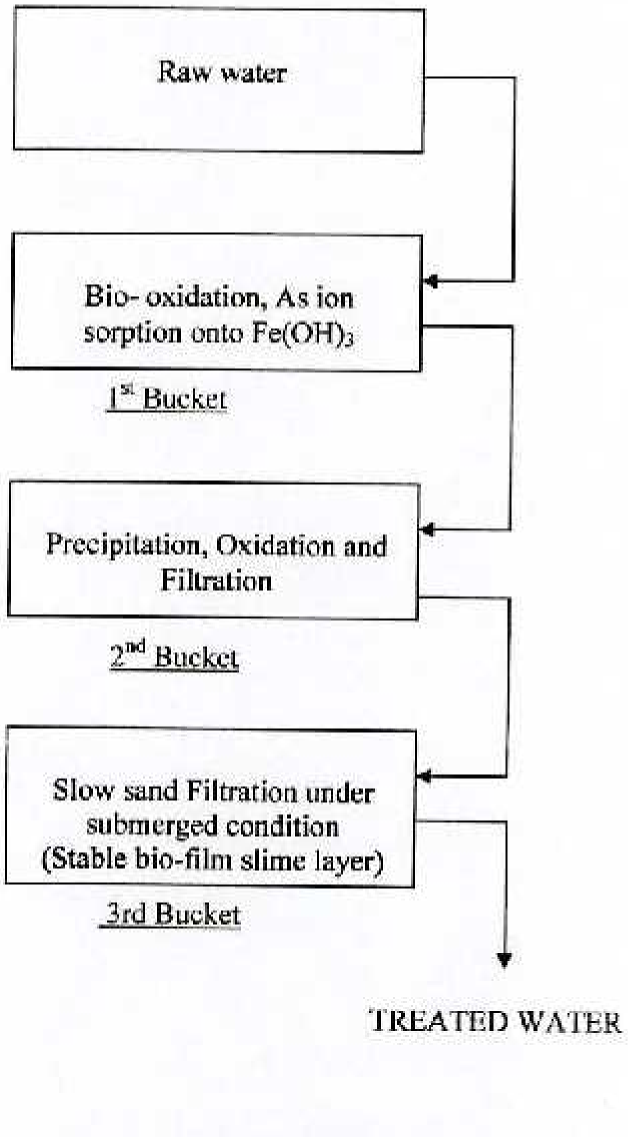

Figure-3.1: Flow diagram of the developed biological treatment Unit.

The Treatment Unit was a three chambered down flow process in series and they were-

- 1st Chamber:

Bio-Oxidation:

Arsenic-Iron concentrated raw water was oxidized by the bacteria which were produced on coconut husk bed and formed small particles by sorption and absorption.

- 2nd Chamber:

Sedimentation:

Comparatively larger flocculated particles precipitated and settled at the top of the 2nd chamber with a small detention time.

Filtration:

Removal of precipitated particles through sorption onto iron oxyhydroxides. Additional adsorption of escaped arsenic from the first bucket was done on the iron matrix layer in the second bucket. Other fine and coarse particles precipitated on charcoal and coarse sand.

- 3rd Chamber (Under submerged condition):

Filtration (Final removal of bacteria and other fine particles):

This chamber was constructed on the basis of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer. Partial treated water flowed at very slow rates through fine sands to retain suspended solids in the interstices between the sand grains. The pores in the sand bed acted as a minute sedimentation basin and curved flow paths around grains bring the fine particles and bacteria in contact with sand surfaces, where they adhere because of physical attraction and presence of gelatinous coating. During the filtration process, the coating of micro-organisms formed around the sand grains was responsible for the removal of organic matters and bacteria.

3.2 Design of the Treatment Unit

The design of the filter unit is important before its manufacturing. For designing the amount of water that can be filtered by the filter unit is to be mentioned. For family size filter unit should have the maximum capacity of filtration.

Beside that the following criteria were considered in the design of the Unit:

- Filter material should be available from local sources.
- The size of filters bed selected with due regard to the character of the raw water and rate of filtration.
- Lower rate and fine sand being used when bacterial pollution is serious.
- Filter materials should so graded that can prevented penetration and provide the flow of water towards the under drain.

3.3 Materials and Equipments for the Treatment Unit

The materials and equipments required for the development of the low cost As-Fe removal unit were-

1. Raw water (As-Fe)
2. Buckets
3. Plastic pipes
4. Taps
5. Sylhet sand
6. Local sand
7. Coconut husk
8. Cast iron dust
9. Charcoal
10. Gravel

3.4 Function of the Materials and Equipments

The function of the above materials and equipments are given below-

Synthesis Raw Water (As-Fe)

Arsenic and iron salts were used to prepare the synthetic raw water of different As-Fe concentration ratios for laboratory study.

Bucket

Three plastic buckets of capacity 35 liters each were used in the treatment Unit. The first two buckets are pre-treatment chamber and the last one is used for final treatment.

Plastic Pipes

Normally 5/8" diameter plastic pipes are used for connecting the buckets.

Tap

Suitable plastic taps are used for connecting the buckets with pipes and controlling the water flow from first to second and third bucket.

Sylhet Sand

Sylhet sands were used for making rapid sand filter bed with required depth to remove large flocculated particles.

Local Sand

Local sands acted as a filter bed while water passed through it, used for making slow sand bed with required depth and final removal of bacteria, iron, arsenic and other small colloidal particles.

Coconut Husk

A fixed bed bio-film layer used for oxidation of As (III) and conversion to As (V) as well as the absorption, co-precipitation for the removal of both As and Fe from raw water.

Cast iron Dust

The function of the iron dust was to produce iron with water and used for additional adsorption of escaped arsenic with water.

Charcoal

Used for the removal of color, odors, taste and arsenic.

Gravel

It is the normal nature of coconut husk to spread in water. Gravel was used over the coconut husk to compress the coconut husk bed, protect the floatation and thus maintained proper shape and size of the husk bed.

3.5 Dimension of the Filter Unit

3.5.1 Laboratory Study

The following dimensions were maintained in the developed unit for laboratory study and are shown in Figure-3.2 (a).

- Capacity of treated bucket= 35 liters
- Height of the gravel bed = 5 cm (Gravel size-19mm to 25 mm)
- Height of the coconut husk bed= 15 cm
  (Husk size-25 to 38mm, fresh rectangular shape)
- Height of the rapid sand filter bed= 7.50 cm at top and 10 cm at bottom
  (Sand size -#08 passing & #50 retain)
- Height of the iron matrix bed= 25 mm
  (Fresh Cast Iron of #08 passing & #30 retain)
- Height of the charcoal bed= 5 cm
  (Wooden Charcoal of #08 passing & #30 retain)
- Height of the slow sand filter bed= 12.5 cm
  (Sand size -#50 passing & #200 retain)
- Diameter of the plastic pipe= 16 mm

3.5.2 Field Application

Considering the different hydro-geological condition of the field, the laboratory model was modified for field application. To get better water quality the modified unit are shown in Figure-3.2 (b) and the modification are following:

- Capacity of treated bucket= 36 liters
- Height of the gravel bed = 5 cm
- Height of the of the coconut husk bed= 15 cm
- Height of the rapid sand filter bed= 7.50 cm at the top and bottom
- Height of the iron matrix bed= 6.25 cm
- Height of the charcoal bed= 3.75 cm
- Height of the slow sand filter bed= 15 cm
- Diameter of the plastic pipe= 16 mm

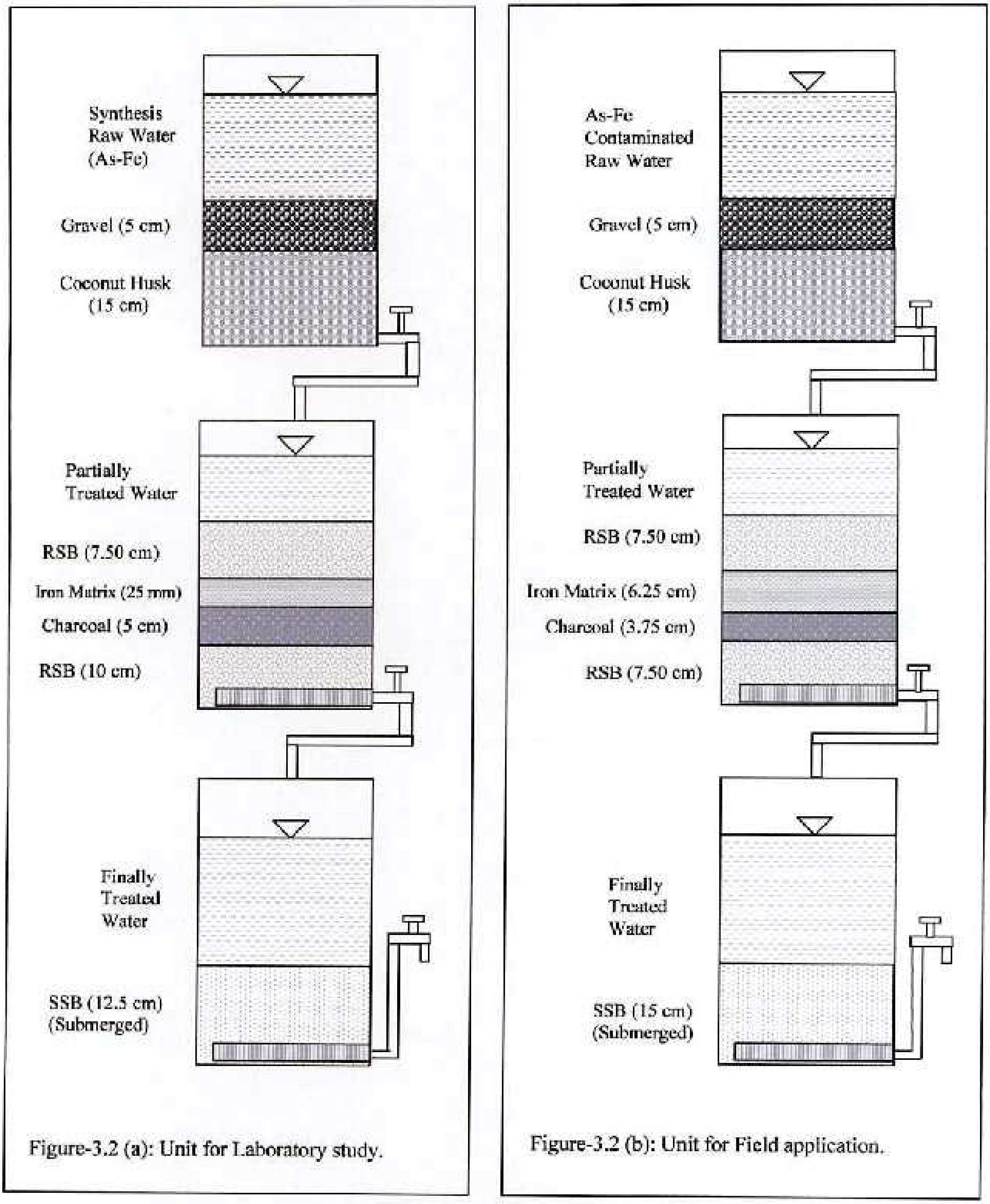

Figure-3.2 (a): Unit for Laboratory study.

Figure-3.2 (b): Unit for Field application.

Figure-3.2: Schematic diagram of developed As-Fe Removal Biological Fixed bed Reactor.

Figure-3.3: Coconut husk (Soaked & Dry) and Iron Scraps.

Figure- 3.4: Developed Treatment Unit (Laboratory Model)

Figure- 3.5: Developed Treatment unit used for fields' performance study.

3.6 Operation and Maintenance

The maintenance of the unit was vital for smooth running. The whole maintenance system was divided into the following parts:

- Bacterial growth on coconut husk bed in the first bucket.
- Placement of gravel over coconut husk to protect floating tendency of the husk in the first bucket.
- Ensuring air entering system in the buckets.
- Controlling flow of water from first to second and third bucket.
- Placement of different filter media in the second bucket.
- Ensuring submerged condition of slow sand filter bed in the third bucket.
- Observing the clogging of the filtering unit.

Coconut Husk Bed

The following steps were followed for bacterial growth in coconut husk bed:

- Coconut husk was submerged by pond water in a bucket about two to four weeks to produce bacteria. In that period the husk was washed thoroughly after every three to four days to reduce its color and odor. After confirming the reduction of odor it was placed as filter bed.
- It was fully saturated in water for the life period of the treatment Unit.

Velocity of Flow

Constant face velocity was maintained at the first and second tap junction for smooth running of the unit. The face velocity was kept around 0.5 m/h for better results.

Different Filter Beds in 2nd Bucket

Following steps were taken in filtering beds:

- Height of the different filter beds was maintained as per specification.
- The second bucket of the unit was moistened for Laboratory analysis but in case of field application it was avoided considering the self weight of the bucket.
- In case of clogging of rapid sand filter bed, scrapping off one inch thick layer and replaced by new sands.
- Determination of bacteria removal efficiency.

Air entering system

For proper oxidation a small hole was kept at the top of every bucket.

Clogging of the filtering unit

Copper net with small opening was provided in the tap junction point of the first bucket to protect the unusual entering of the rotten coconut husk.

Third bucket was the final part of the treatment unit. Special care was taken in this bucket in the time of construction of the unit and in the operation and maintenance.

- This bucket was simply a slow sand filter with submerged condition. The height of the sand filter bed was always kept below the height of the outlet tap.
- As the sand grain used in this bucket was very fine (size- #50 passing and #200 retain), a thin net cloth with very fine pores was used around the P.V.C filter pipe to protect clogging of filter pipe by unusual entrance of the sand grain.
- In case of filter bed clogging it was essential to refurbish the filter bed. The top few millimetres of fine sand was very carefully scraped off and this exposed a new layer of clean sand. Water was then decanted back into the filter and re-circulated for a few hours to allow a new *Schmutzedecke* to develop. The filter was then filled to full depth and brought back into service.
- Determination of the As, Fe, Color, Turbidity, Mn and bacteria removal efficiency.

Chapter Four

Laboratory Tests and Analysis

4.1 General

Detail laboratory tests and analysis were carried out through treatment unit-model to determine some important selected parameters. Arsenic adsorption mechanism is dependent on biological bio-film oxidation layer. The face velocity was kept constant through the treatment unit and different filter run were determined with different As-Fe ratios. The treatment unit was based on arsenic removal by bio-oxidation, adsorption and precipitation onto ferric hydroxides through sand filters. The bacteria in the first bucket which were produced biologically from coconut husk were used to oxidize arsenic. These were completely eliminated in the third bucket by the slow sand filtering system under submerged condition.

4.2 Preparation of Synthetic Raw Water

Arsenic (As_2O_3) and iron ($FeSO_4.7H_2O$) salts were added in tubewell water to prepare synthetic raw water for laboratory analysis. Tubewell water with arsenic and iron salt was immerged in a bucket for three to four days for proper mixing of the salts in water. After this period the water was tested to determine the concentrations of arsenic and iron of the synthetic raw water. Ten liters of synthetic raw water were prepared for every filter run. For the concentration of 500 ppb arsenic with 5 ppm iron, 0.013 gm of arsenic salt and 0.248 gm of iron salt was added in tubewell water.

Tubewell water was used for synthetic raw water preparation because groundwater naturally contains minerals and trace metals which are necessary for microbial growth. The biological As-Fe removal unit was followed bio-oxidation, adsorption, coprecipitation and filtration technique. Distilled water would also be used to prepare synthetic raw water. But considering the rate of microbial growth distilled water did not used for synthetic raw water preparation. Again in the field raw tubewell water was used for performance study. So, it was easy to study the developed laboratory model unit by using tubewell water to understand the field conditions.

4.3 Laboratory Model Study of the Treatment Unit

The laboratory tests and analysis were carried out through the filter unit for nine different As-Fe concentrated synthetic raw water. The raw, partially treated and final treated water were then tested for various selected water quality parameters according to the standard methods. The selected parameters were arsenic, iron, Color, Turbidity, Manganese, pH, DO, TC and FC.

The nine synthetic raw water ratios were:

1. Low As-Fe concentrated synthetic raw water.
   (Arsenic- 100 ppb, Iron- 1 ppm)
2. Low As-moderate Fe concentrated synthetic raw water.
   (Arsenic-100ppb, Iron-3 ppm)
3. Low As-High Fe concentrated synthetic raw water.
   (Arsenic-100 ppb, Iron-5 ppm)
4. Moderate As-low Fe concentrated synthetic raw water.
   (Arsenic-300 ppb, Iron-1 ppm)
5. Moderate As-Fe concentrated synthetic raw water.
   (Arsenic-300 ppb, Iron-3 ppm)
6. Moderate As-High Fe concentrated synthetic raw water.
   (Arsenic-300 ppb, Iron-5 ppm)
7. High As- low Fe concentrated synthetic raw water.
   (Arsenic-500 ppb, Iron-1 ppm)
8. High As- moderate Fe concentrated synthetic raw water.
   (Arsenic- 500 ppb, Iron- 3 ppm)
9. High As-Fe concentrated synthetic raw water.
   (Arsenic- 500 ppb, Iron- 5 ppm)

4.4 Relative Removal Efficiency of Arsenic and Iron

Arsenic removal efficiency for various concentration of iron in constant arsenic concentrations of synthetic raw water was observed. Iron removal efficiency for various concentration of arsenic in constant iron concentrations of synthetic raw water was also observed. Good arsenic and iron removal was achieved with this laboratory unit. The laboratory unit was run by nine different As-Fe concentrated synthetic raw water. The maximum arsenic concentration of the synthetic raw water was 500 ppb with 5 ppm iron. The minimum concentration of arsenic and iron was 100 ppb and 1 ppm respectively.

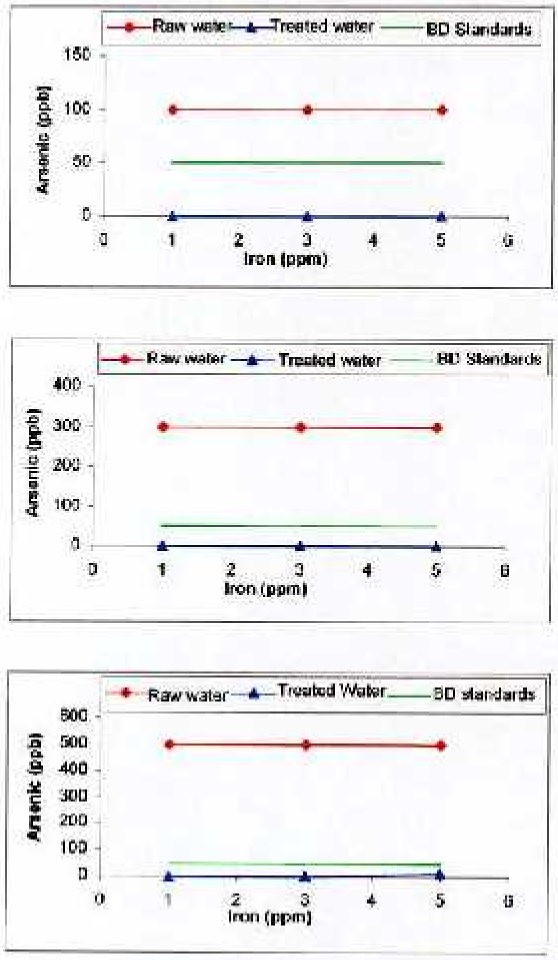

Figure-4.1: Removal Efficiency of Arsenic for different Iron concentrated raw and treated water with constant face velocity of the Laboratory unit.

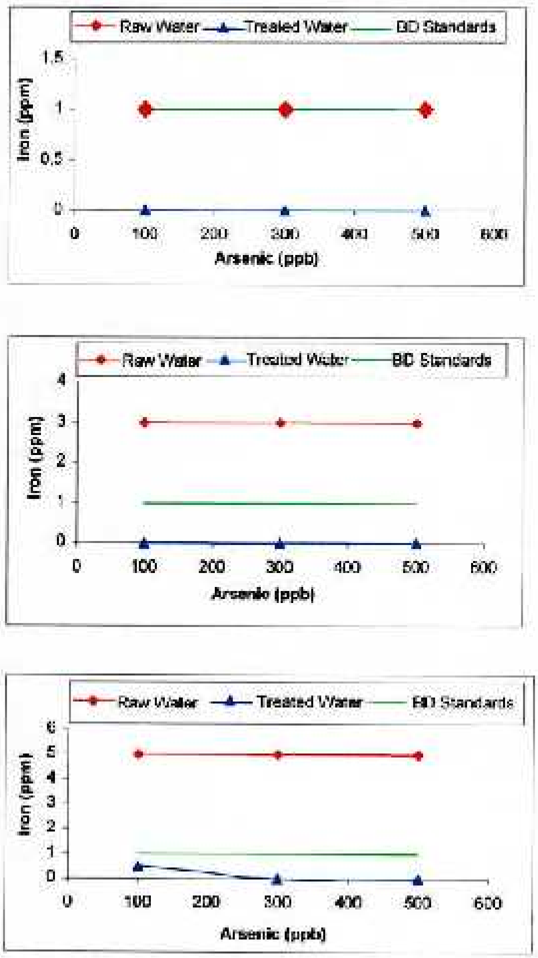

Figure-4.2: Removal Efficiency of Iron for different Arsenic concentrated raw and treated water with constant face velocity of the Laboratory unit.

In Figure 4.1 it has shown that 10 ppb of arsenic was observed once in the treated water. The initial concentration of arsenic and iron was 500 ppb and 5 ppm respectively in that run.

It has shown in Figure 4.2 that Iron concentration of 0.5 ppm was found in the treated water. In that run the synthetic raw water was in the ratio of As-Fe of 100 ppb and 5 ppm. As-Fe concentration came down to zero in the treated water for the other seven As-Fe concentration ratios passed through the unit.

It can be summarized that over 90% reduction of iron and arsenic was achieved for every concentration of As-Fe in the laboratory unit.

4.5 Bacteriological Growth and Removal Efficiency

Figure 4.3 illustrates the growth pattern of bacteria in the first bucket and the removal efficiency in second and third bucket. High bacteriological growth was observed in the first bucket of the laboratory unit to oxidize arsenic. Some bacteria were removed in second bucket as the filtering beds in this bucket were kept submerged for laboratory analysis. The final removal of the residual bacteria after second bucket was completely eliminated in the third bucket. This bucket acted as simple slow sand filtration system under submerged condition. During the bacteriological test no faecal coliform was noticed in the water of any bucket of the laboratory unit. So, the bacteriological removal efficiency of the laboratory unit was 100 percent.

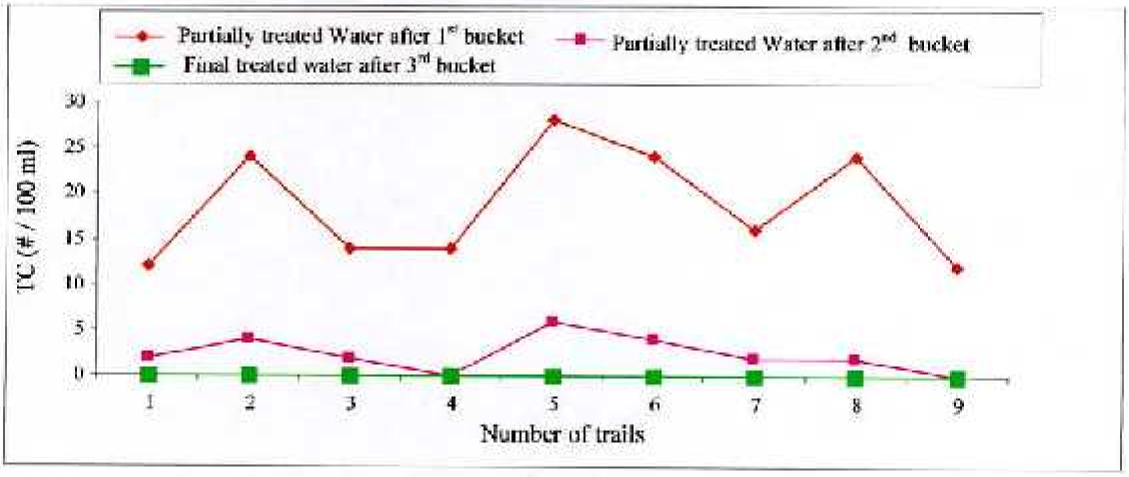

Figure-4.3: Removal efficiency of TC for the partial and final treated water of the Laboratory Unit

4.6 Removal Efficiency of Turbidity and Color

It can be seen from the Figure 4.4 and Figure 4.5 that the synthetic raw water and the partially treated water after 1st bucket exhibited high color and turbidity value. That was due to the variations of iron salt concentration in the synthetic raw water. The rotten coconut husk in the first bucket of the unit also increased turbidity and color value. The color and turbidity values of the partially treated water after 2nd bucket were declining in nature. It can be cleared from the Figure 4.4 that the removal of turbidity and color were started after passing the water in the second bucket. The acceptable limit of color and turbidity value for Bangladesh standards was found after passing the water in the third bucket. So, the color and turbidity removal efficiency of the laboratory unit was found sufficient for a constant face velocity.

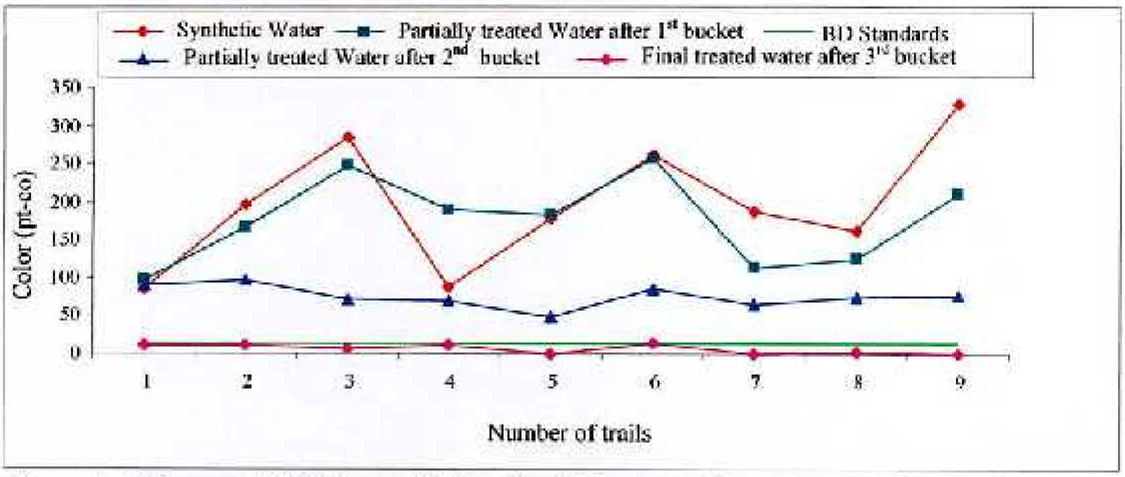

Figure-4.4: Removal Efficiency of Color for different As-Fe concentrated raw and treated water of the Laboratory unit with constant face velocity.

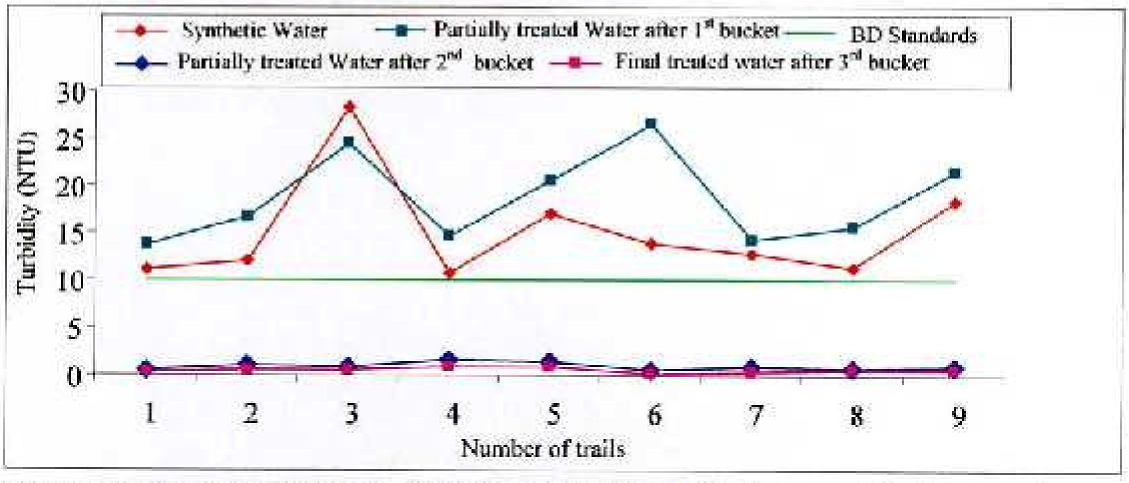

Figure-4.5: Removal Efficiency of Turbidity for different As-Fe concentrated raw and treated water of the Laboratory unit with constant face velocity.

4.7 Variation of pH and DO of Raw and Treated Water

Dissolved Oxygen concentrations of the partially treated water after passing 1st and 2nd bucket was gradually decreased. This may due to the fact that oxygen was consumed in the first bucket for bio-oxidation to oxidize arsenic. In the second bucket oxygen was also used for oxidation of arsenic. It can be observed from Figure 4.7 that an aerobic condition was occurred after passing the water in the 3rd bucket. The pH of synthetic raw water was decreased after passing through the 1st bucket. It was increasing in nature after passing through the 2nd and 3rd bucket. This may due to the presence of some calcium substances in the sand grain of the rapid and slow sand filter of the treatment unit. The variation of pH and DO of synthetic raw and treated water of the laboratory unit are shown in Figure 4.6 and Figure 4.7 as follows:

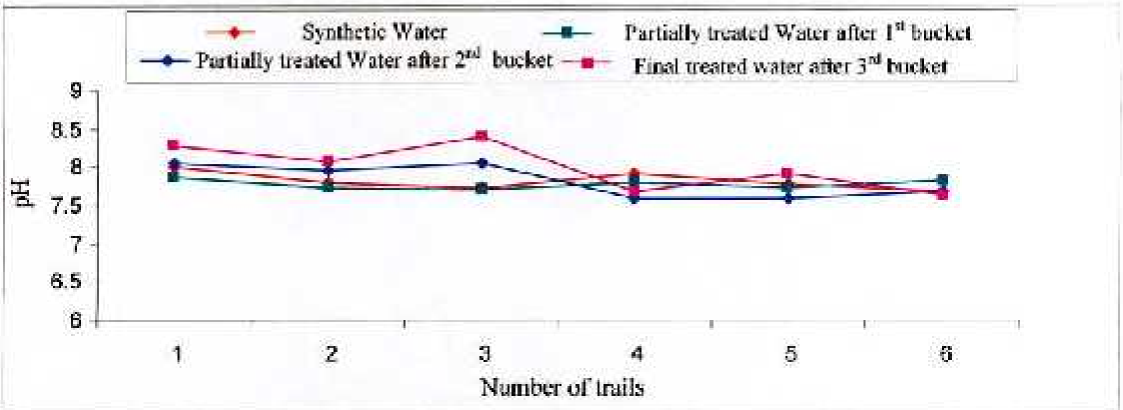

Figure-4.6: Variation of pH for different As-Fe concentrated raw and treated water of the Laboratory unit with constant face velocity.

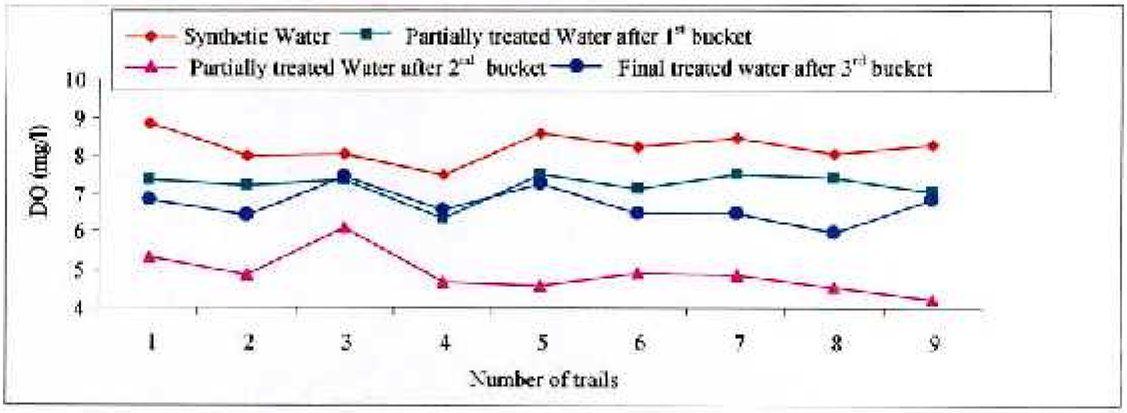

Figure-4.7: Variation of DO for different As-Fe concentrated raw and treated water of the Laboratory unit with constant face velocity.

4.8 Performance Study of the Laboratory Model Unit

The developed laboratory model unit was studied intensively for nine different As-Fe concentrated synthetic raw water. The performance study results of the laboratory model unit are represented in the following Table- 4.1:

Table No.-4 Laboratory Performance Study [illegible]

As	Fe
ppb	ppm
100	1
100	3
100	5
300	1
300	3
300	5
500	1
500	3
500	5

Chapter- Five

Results and Analysis of Field Application

5.1 General

Based on the laboratory performance three units were made for the field application. Three different fields were selected having tubewell water with different As-Fe concentration. Considering the different hydro-geological conditions of the field, the developed unit was modified for field application which was mentioned in Figure-3.2 in the previous chapter. A brief discussion was made with the tubewell owner about the operation and maintenance of the field unit before and after installation. The field tests and analysis were carried out by collecting water samples from the selected fields once in a week. Arsenic and Iron test were carried out frequently in the field instantly. The other selected parameters were tested in the laboratory as soon as collecting the samples from the fields. The removal efficiency and associated problems of field units were monitored regularly.

5.2 Application of the Field Unit

Field tests of the units were being conducted in three villages under Rupsha Upazila in Khulna district. The concentrations of iron and arsenic and the related other information for the selected sites is described as in Table-5.1

Table-5.1: Information about the selected field sites.

Field No.	01	02	03
Name of TW owner	Nur-Mohammed Sheikh	Binoy Krishna Halder	Modon Kumar Sarkar
Name of Village	Pithabhog	Taltala	Samontasena
Name of Union	Ghatbhog	T.S. Bahirdia	Naihati
Depth of TW	125 feet	245 feet	75 feet
Installation period	1987	1986	1988
First As detection period	2001	2001	2001
No. of User till 2001	60 nos. (12 H/H)	50 nos. (10 H/H)	20 nos. (2 H/H)
Present No. of User	06 nos.	04 nos.	03 nos.
Concentration of As	500 ppb upper	300 ppb Upper	100 ppb Upper
Concentration of Fe	5 ppm	5 ppm	3 ppm
Concentration type	High As-Fe	Moderate As-high Fe	Low As-moderate Fe
Unit installation Date	16.05.2006	29.06.2006	02.07.2006

5.3 Relative Arsenic and Iron Removal Efficiency

The applied field units showed sufficient removal efficiency both for arsenic and iron. It was observed from the field test results that the relative removal efficiency of arsenic and iron was different for different arsenic-iron concentrated raw water.

For the concentration of 500 ppb arsenic, the unit did not sustain for a long period. The unit filtered about 4800 liters of raw water on an average 40 liters per day in 122 days before reaching breakpoint. Considering the acceptable limit of Bangladesh the iron removal efficiency of the unit showed slightly poor compared to arsenic removal. With an initial iron concentration of 5 ppm the unit treated about 4000 liters of raw water in 102 days. The third bucket of this unit got clogged before reaching the break point of 50 ppb arsenic.

From the test results of second and third fields the removal efficiency of arsenic and iron was found sufficient. These field units showed expectable removal efficiency than the first one. It was found from the second field that the unit treated about 5200 liters of raw water containing arsenic and iron limit of 300 ppb and 5 ppm respectively in 8 months. The unit treated raw water on an average 20 liters per day. Clogging was noticed in this unit after running 223 days. After clogging, the bed materials in the first bucket of the unit were washed thoroughly. The top few millimeters sands from the second and third bucket was scrapped off and replaced by new sand. The unit was restart for treating raw water. In the respect of arsenic concentration the breakpoint of 50 ppb occurred after 254 days of its running.

Remarkable removal efficiency was observed from the third field unit. The unit showed smooth performance about ten months. In that period the unit treated about 5900 liters of raw water. The raw water in its tubewell of this field contained arsenic and iron concentration of 100 ppb and 3 ppm respectively. This unit treated raw water on an average 20 liters per day. No sign of clogging was noticed in its service period (297 days).

Both the tests of arsenic and iron were carried out frequently in the relevant three fields by test kit. The relative arsenic and iron removal efficiency for the field contained high As-Fe, moderate As-high Fe and low As-moderate Fe contaminated raw and treated water are shown in Figure- 5.1 (a), 5.1 (b), 5.1 (c) and Figure- 5.2 (a), 5.2 (b), 5.2 (c) respectively.

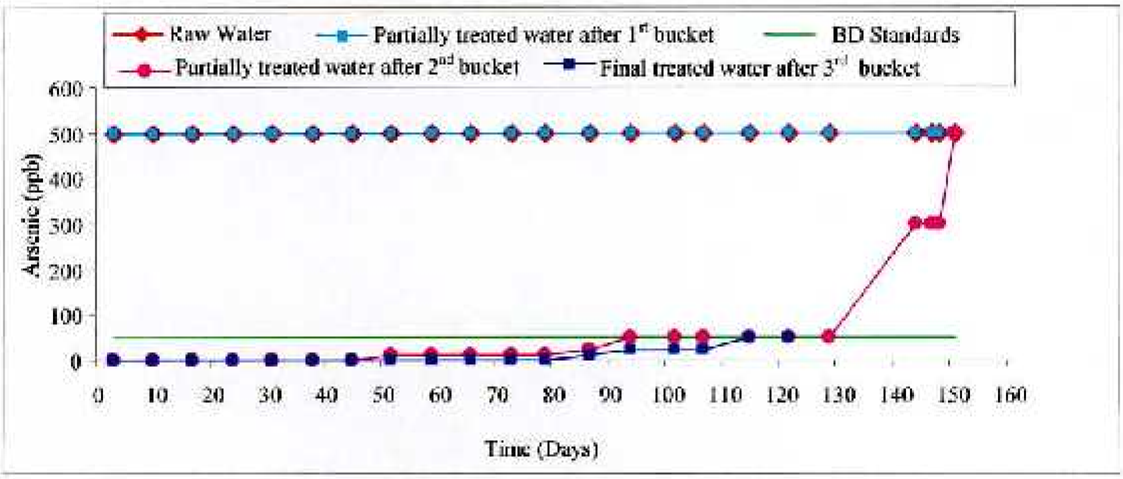

Figure-5.1 (a): Arsenic Removal Efficiency of the field unit for high As-Fe concentrated raw and treated water.

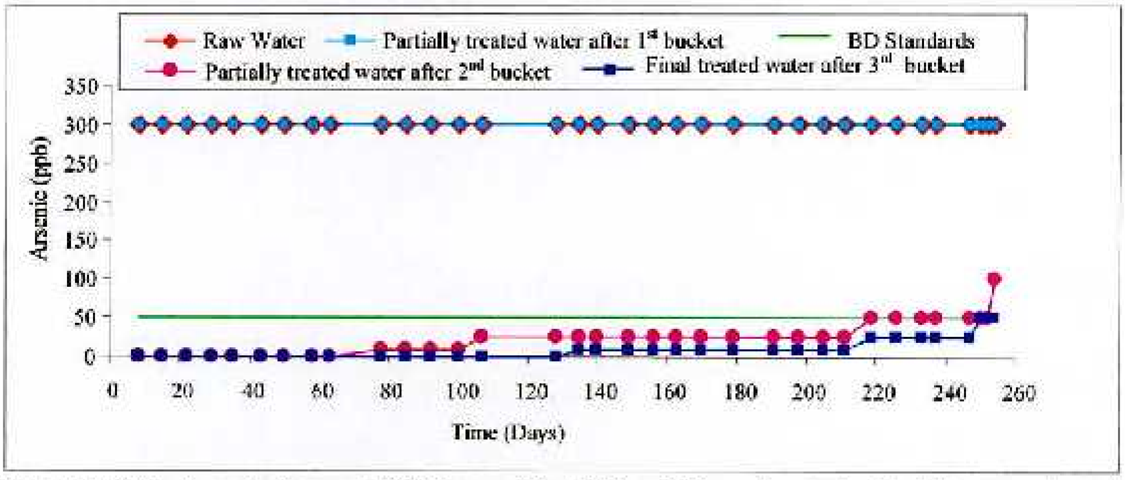

Figure-5.1 (b): Arsenic Removal Efficiency of the field unit for moderate As- high Fe concentrated raw and treated water.

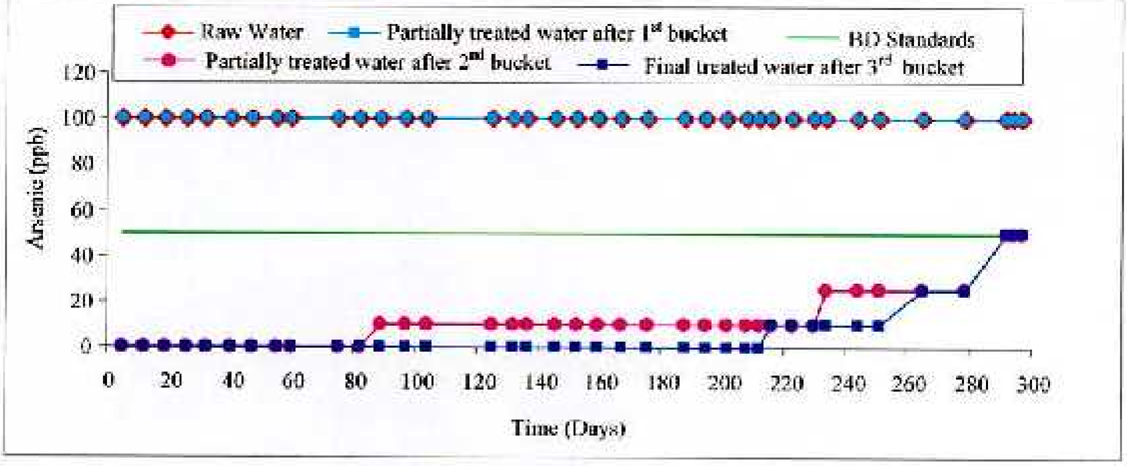

Figure-5.1 (c): Arsenic Removal Efficiency of the field unit for Low As- moderate Fe concentrated raw and treated water.

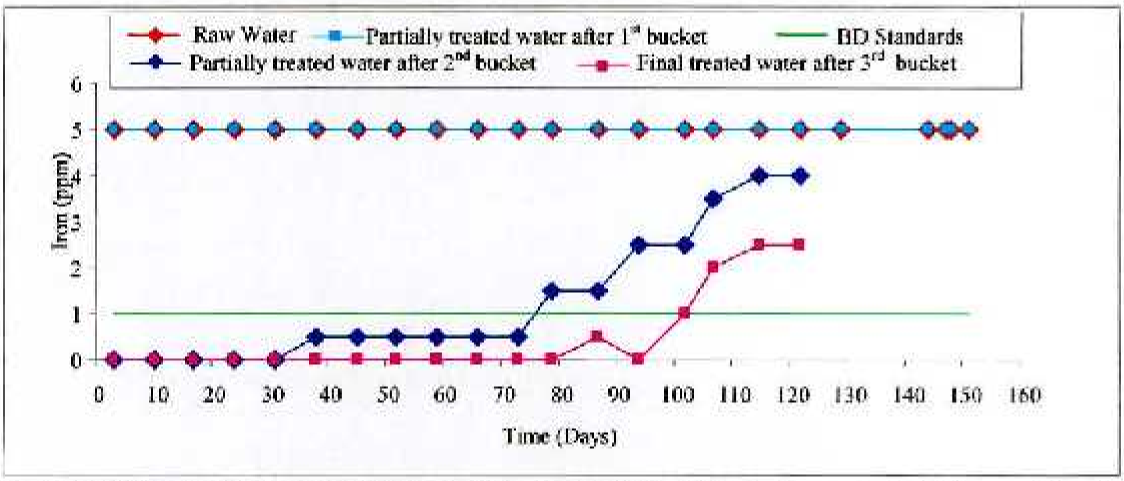

Figure-5.2 (a): Iron Removal Efficiency of the field unit for high As-Fe concentrated raw and treated water.

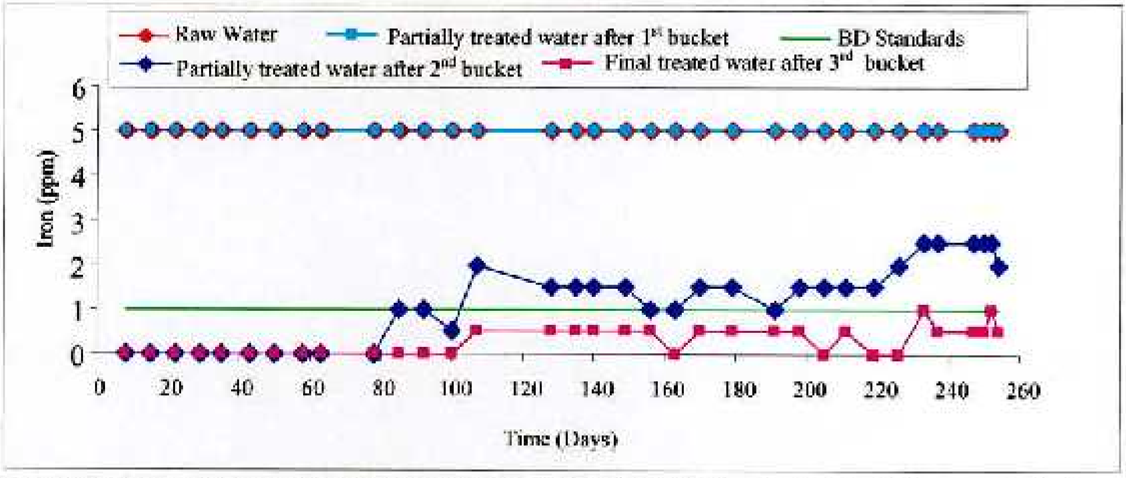

Figure-5.2 (b): Iron Removal Efficiency of the field unit for moderate As- high Fe concentrated raw and treated water.

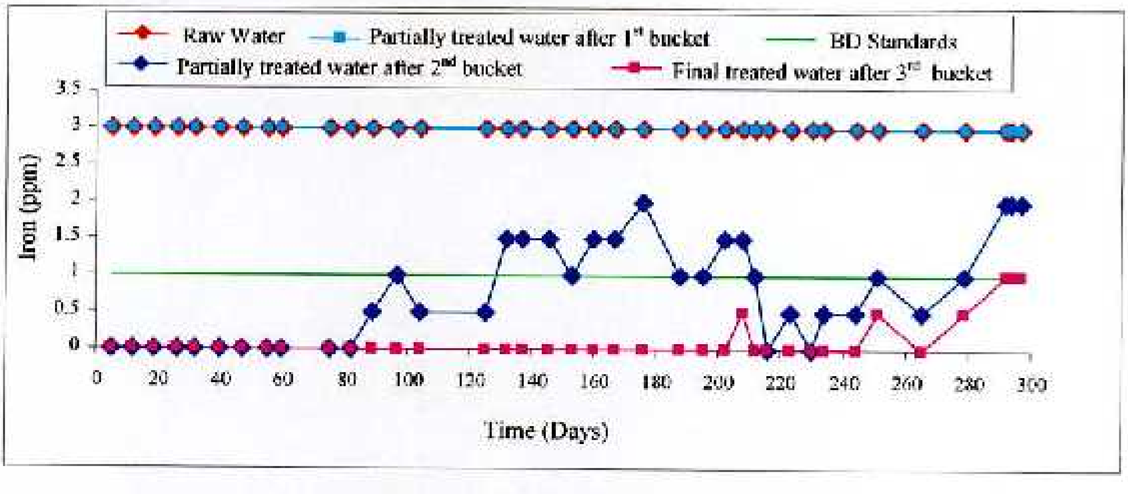

Figure-5.2 (c): Iron Removal Efficiency of the field unit for Low As- moderate Fe concentrated raw and treated water.

5.4 Bacteriological Growth and Removal Efficiency

The bacteriological removal efficiency was 100 percent for the field units that were in the similar pattern as found in the laboratory analysis. It was detected almost 25 numbers of total coliform per 100 ml of the water after passing 1st bucket in the field units. About 30 percent of TC after passing through first bucket was removed after passing water through the second bucket. The residual TC was completely eliminated after passing through the third bucket. It was confirmed from bacteriological test that the raw water was completely free from FC contamination. So, the field performance study of the bio-physicochemical treatment unit never detected any TC/FC in the treated water. The bacteriological growth and removal efficiency of the field units are shown in Figure -5.3 (a), 5.3 (b) and 5.3 (c) as follows:

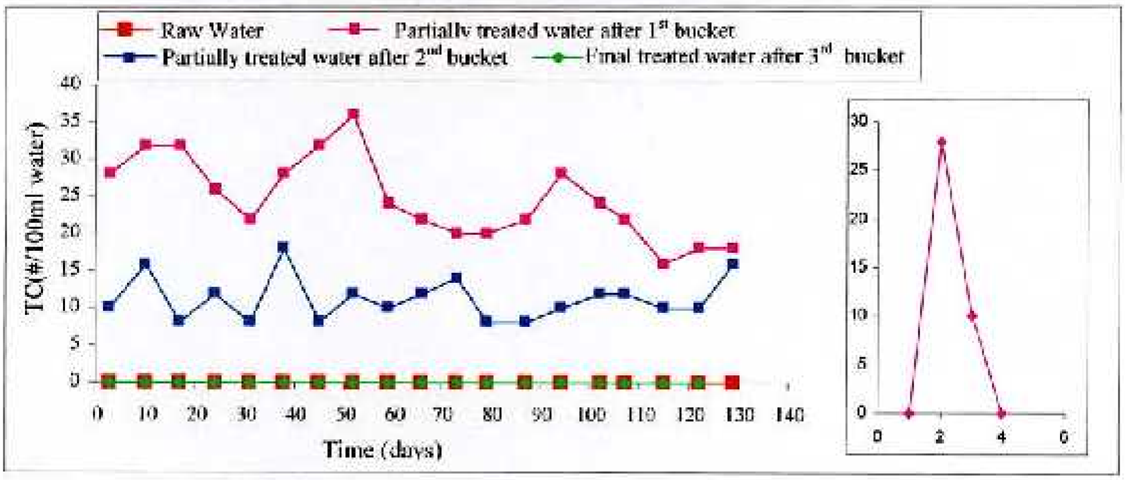

Figure-5.3 (a): Removal Efficiency of TC of the field unit for high As-Fe concentrated raw and treated water.

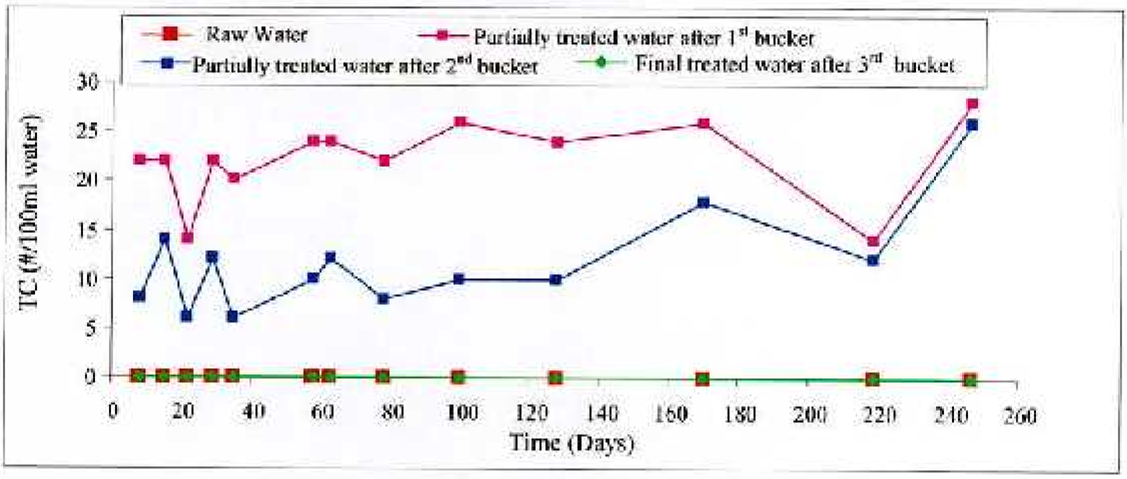

Figure-5.3 (b): Removal Efficiency of TC of the field unit for moderate As- high Fe concentrated raw and treated water.

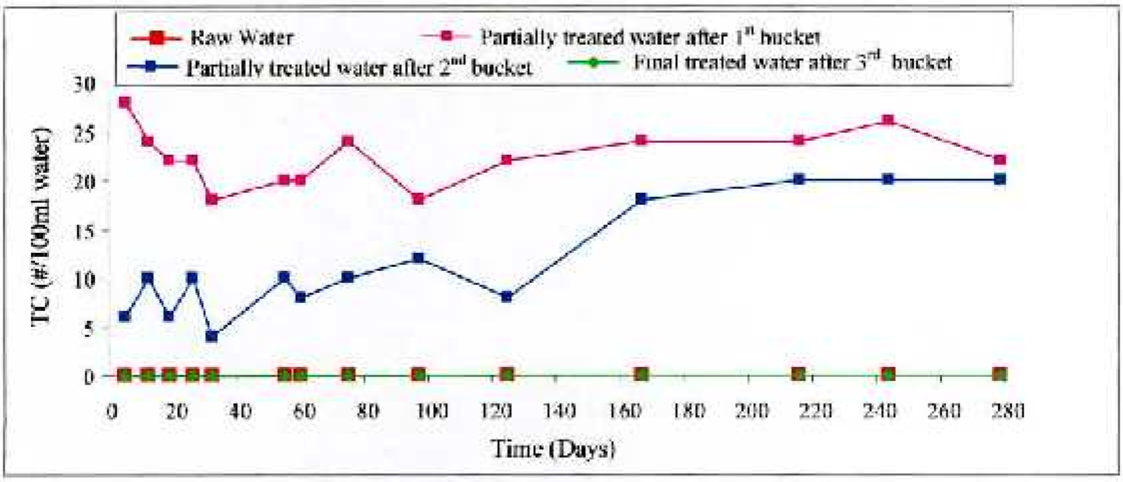

Figure-5.3 (c): Removal Efficiency of TC of the field unit for Low As- moderate Fe concentrated raw and treated water.

5.5 Color and Turbidity Removal Efficiency

Translucent and sparkling treated water was found in the field units although the raw water of the selected fields exhibited high color and turbidity value. It should be mentioned again that the raw water of the selected fields contained high iron. This high concentration of iron was responsible for being exhibiting high color and turbidity value. The results of highly As-Fe contaminated field site showed that the color and turbidity value of the treated water was within 15 pt-co units and 4 NTU respectively. These values were found less than 6 pt-co units and 2 NTU both for the low and moderately As-Fe contaminated field sites respectively. The color and turbidity concentrations of the raw water as well the removal efficiency of the developed field units are illustrated in Figure- 5.4 (a), 5.4 (b), 5.4 (c) and Figure-5.5 (a), 5.5 (b), 5.5 (c) respectively for the relevant field conditions.

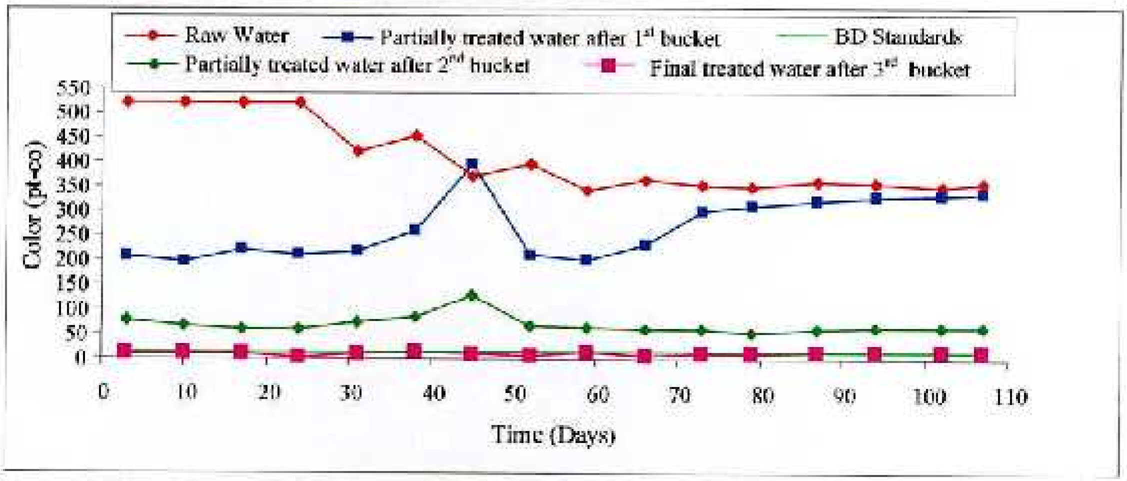

Figure-5.4 (a): Removal Efficiency of Color of the field unit for high As-Fe concentrated raw and treated water.

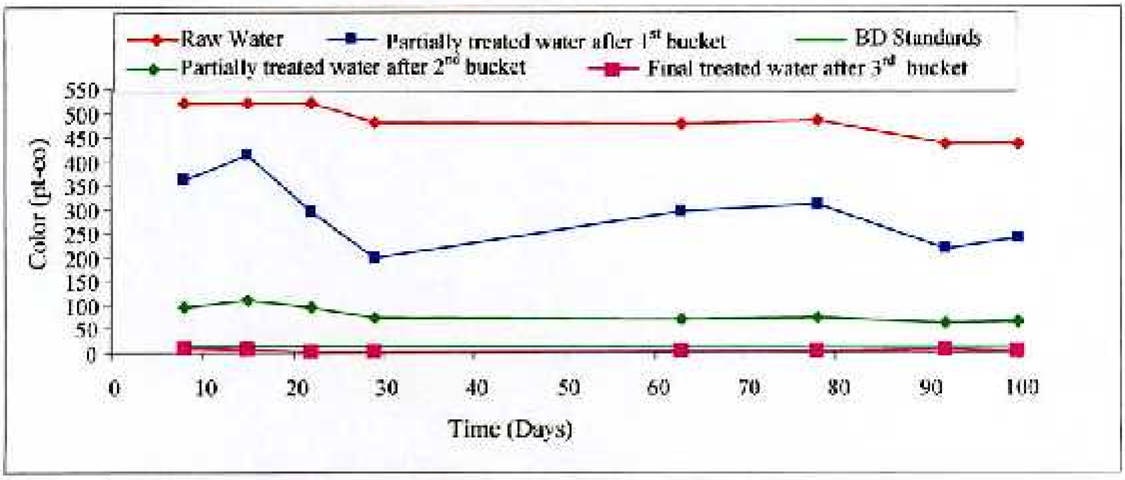

Figure-5.4 (b): Removal Efficiency of Color of the field unit for moderate As- high Fe concentrated raw and treated water.

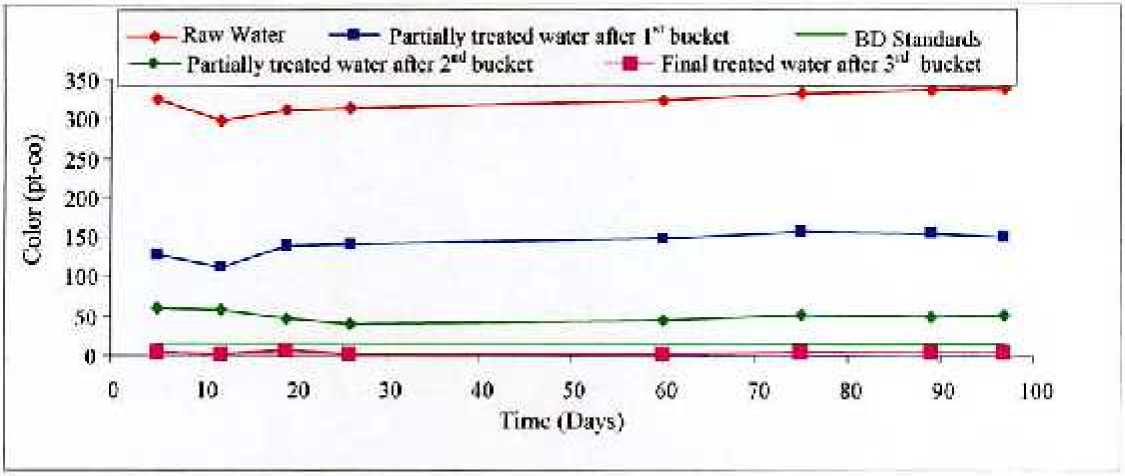

Figure-5.4 (c): Removal Efficiency of Color of the field unit for Low As- moderate Fe concentrated raw and treated water.

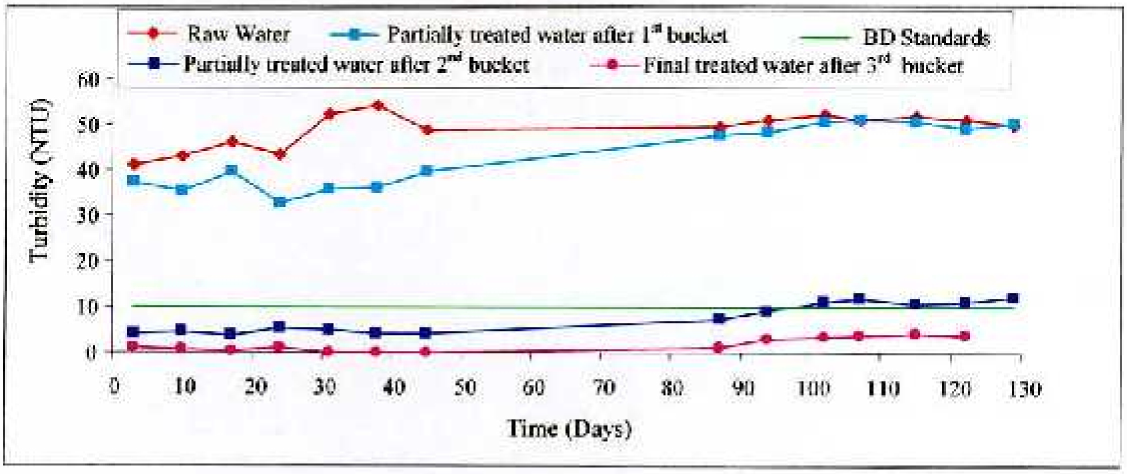

Figure-5.5 (a): Turbidity Removal Efficiency of the field unit for high As-Fe concentrated raw and treated water.

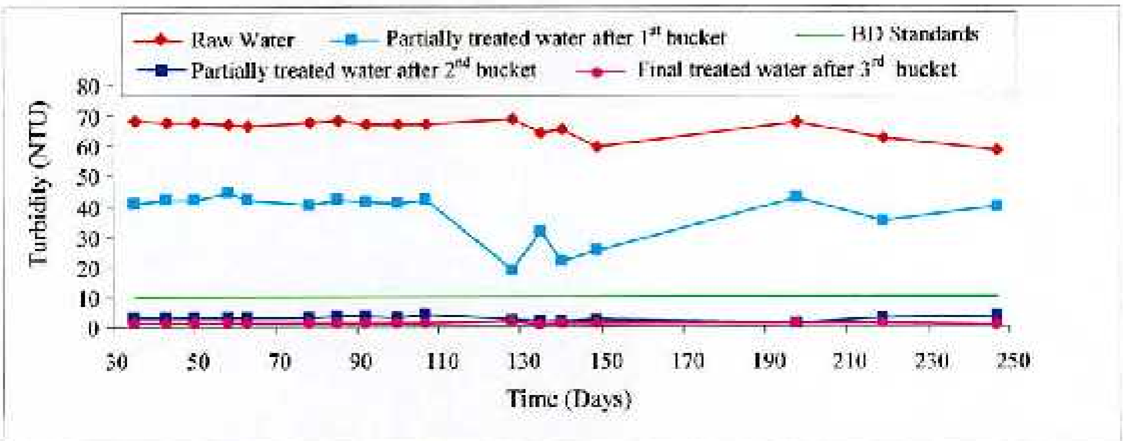

Figure-5.5 (b): Turbidity Removal Efficiency of the field unit for moderate As- high Fe concentrated raw and treated water.

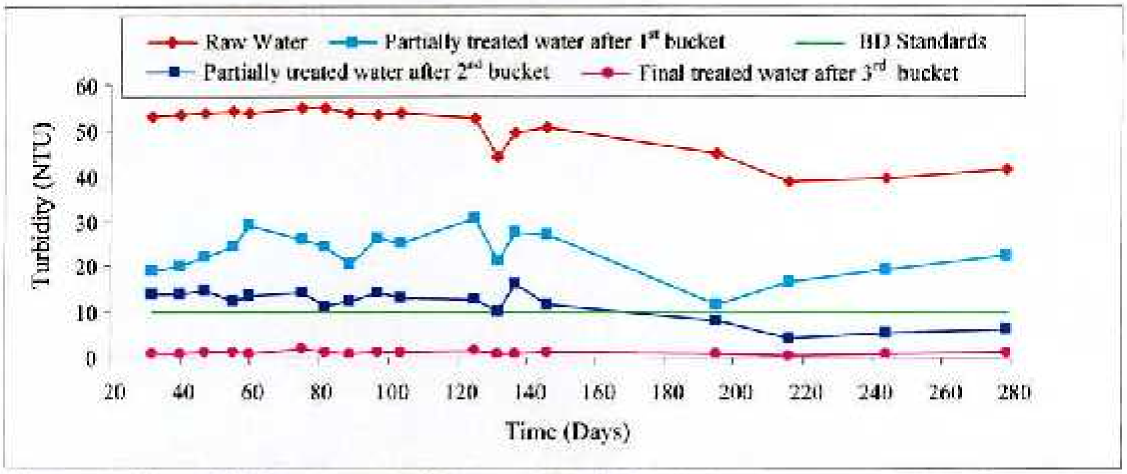

Figure-5.5 (c): Turbidity Removal Efficiency of the field unit for Low As- moderate Fe concentrated raw and treated water.

5.6 Variation of pH and Dissolved Oxygen

Dissolved oxygen level at different stages of the treatment units showed that aerobic condition was prevailing throughout the whole treatment operations in the field applications. It was observed that the treated water of all the three units always showed a value greater than almost 6 mg/l. An increasing nature of pH of the treatment units were observed in the field applications. The pH level at different stages of the treatment units always noticed alkaline conditions. The observed pH value of the treated water of the field units was always in between 6.5 to 8.5. The variations of pH and DO of the raw and treated water are shown in Figure- 5.6 (a), 5.6 (b), 5.6 (C) and Figure- 5.7 (a), 5.7 (b), 5.7 (c) for different field conditions.

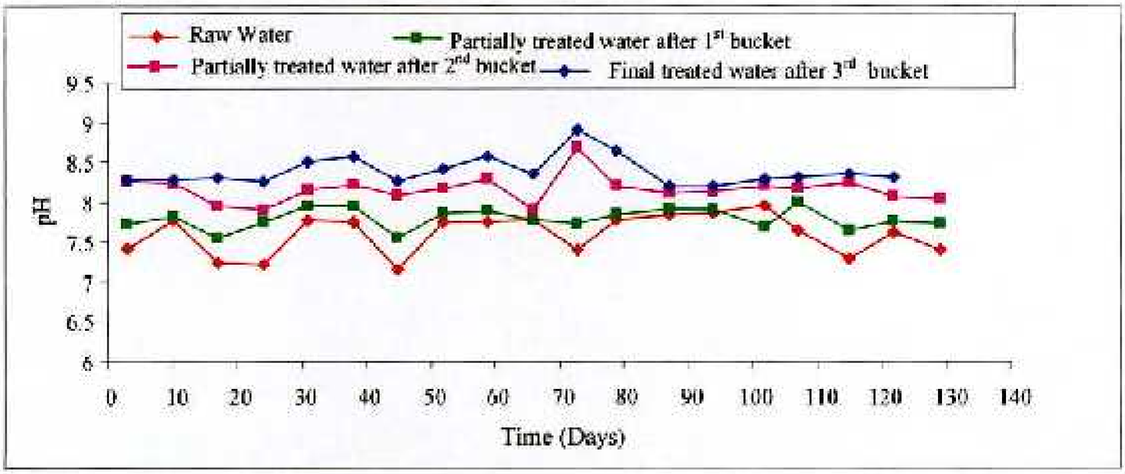

Figure-5.6 (a): Variation of pH of the field unit for high As-Fe concentrated raw and treated water.

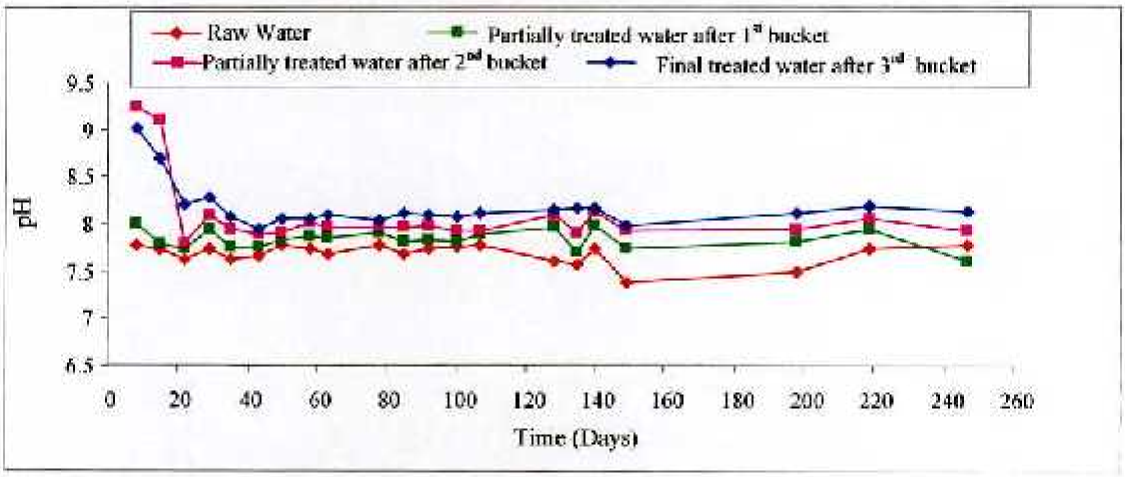

Figure-5.6 (b): Variation of pH of the field unit for moderate As- high Fe concentrated raw and treated water.

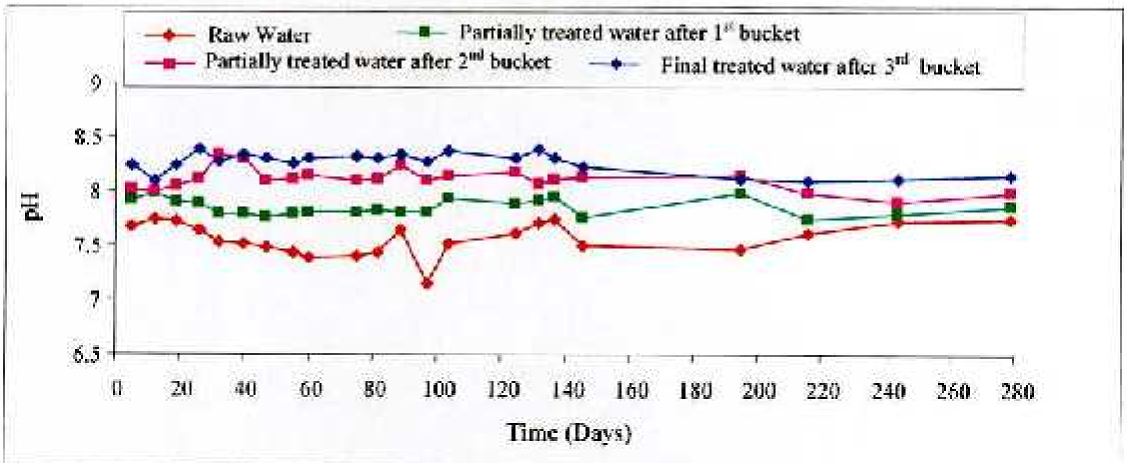

Figure-5.6 (c): Variation of pH of the field unit for Low As- moderate Fe concentrated raw and treated water.

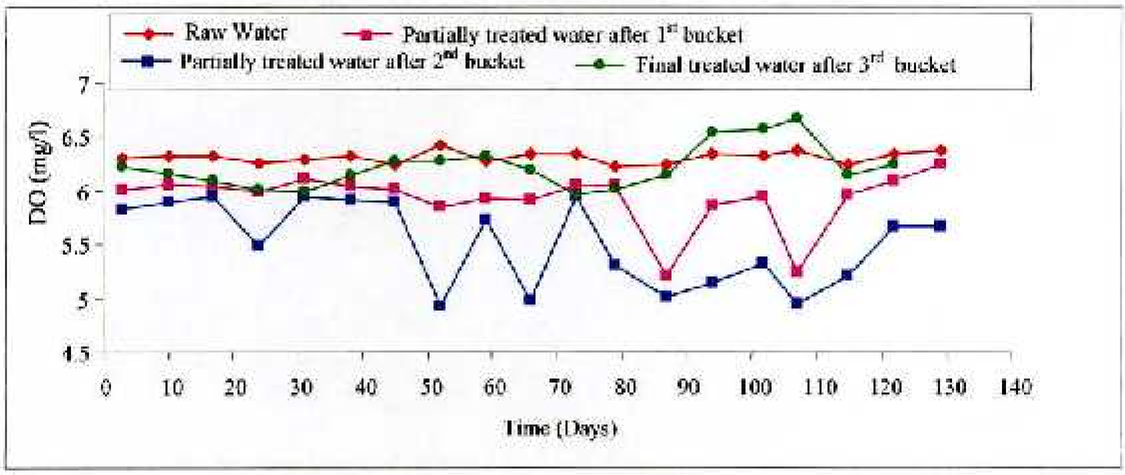

Figure-5.7 (a): Variation of DO of the field unit for high As-Fe concentrated raw and treated water.

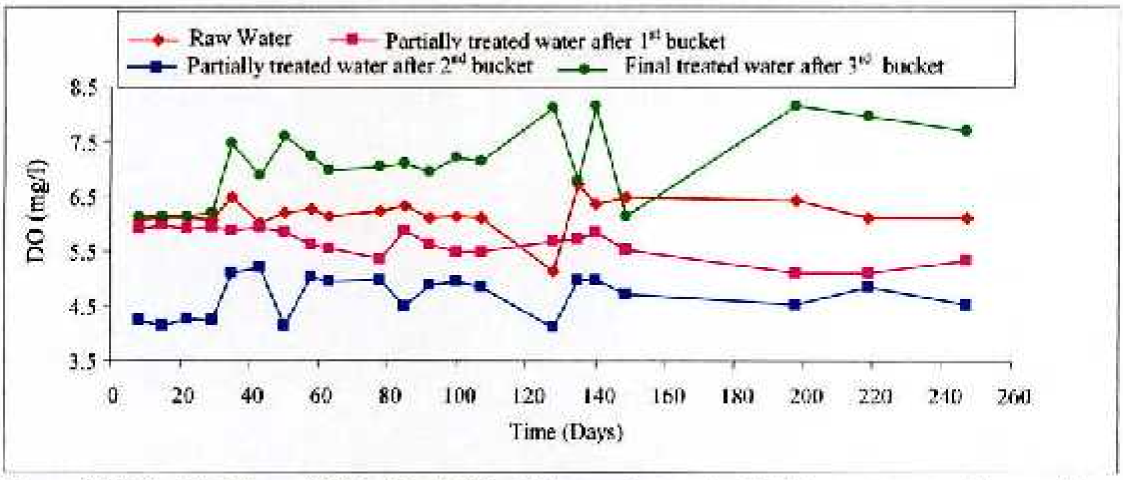

Figure-5.7 (b): Variation of DO of the field unit for moderate As- high Fe concentrated raw and treated water.

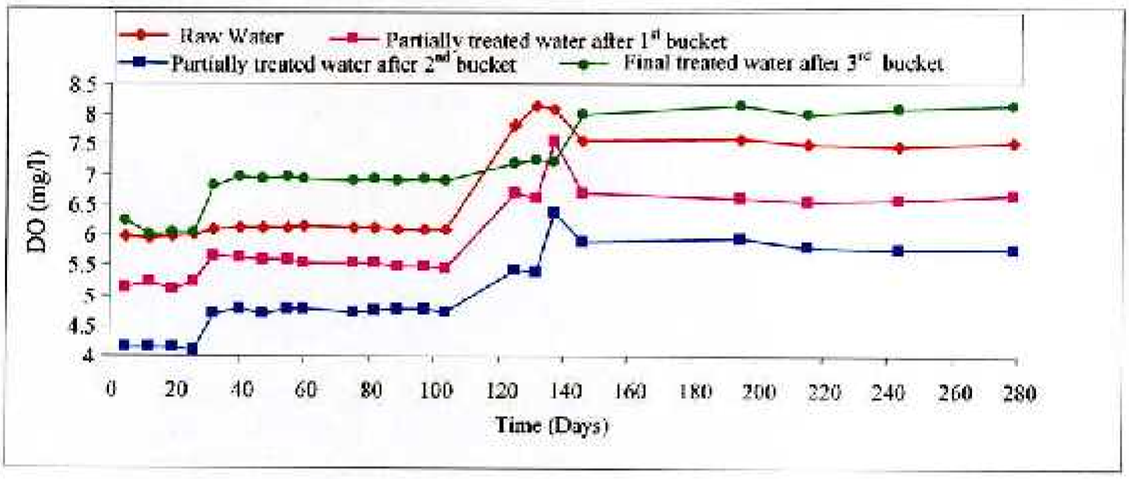

Figure-5.7 (c): Variation of DO of the field unit for Low As- moderate Fe concentrated raw and treated water.

5.7 Field Performance Study and Test Results

The field performance study was carried out intensively. The fields were selected considering the different hydro-geological conditions. Depending upon the As-Fe concentrations in its tubewell, the selected three fields were categorized as high As-Fe, moderate As-high Fe and low As-moderate Fe concentrated fields. The field performance study and test results of the applied units at the selected fields are represented in tabular form in following Table-5.2, 5.3 and 5.4.

Table -5.2: Field performance study and test results for high As-Fe concentration field site

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (μS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 16.05.2006 Name of the H/H chief: Nur-mohammad Sk Vill: Pirhabhog Union: Ghatbhog	19.05.06	Raw	500 D	5.0	41.3	6.31	7.41	1742	520 over	0.49	0	0
		After 1st bucket	500 D	5.0	37.2	6.01	7.72	1716	206	0.175	28	0
		After 2nd bucket	0	0	4.11	5.84	8.27	1256	77	0.053	10	0
		After 3rd bucket	0	0	1.10	6.22	8.29	1362	12	0.014	0	0
	26.05.06	Raw	500 D	5.0	43.0	6.32	7.77	1723	520 over	0.56	0	0
		After 1st bucket	500 D	5.0	35.4	6.06	7.82	1712	198	0.194	32	0
		After 2nd bucket	0	0	4.52	5.89	8.24	1286	68	0.059	16	0
		After 3rd bucket	0	0	0.49	6.16	8.29	1397	11	0.011	0	0
	02.06.06	Raw	500 D	5.0	46.2	6.32	7.25	1758	520 over	0.67	0	0
		After 1st bucket	500 D	5.0	39.8	6.05	7.56	1713	223	0.168	32	0
		After 2nd bucket	0	0	3.94	5.94	7.94	1234	59	0.072	08	0
		After 3rd bucket	0	0	0.42	6.10	8.31	1368	09	0.018	0	0
	09.06.06	Raw	500 D	5.0	43.5	6.26	7.21	1742	520 over	0.51	0	N.D
		After 1st bucket	500 D	5.0	32.6	5.99	7.76	1721	210	0.157	26	N.D
		After 2nd bucket	0	0	5.25	5.49	7.91	1269	59	0.061	12	N.D
		After 3rd bucket	0	0	1.10	6.01	8.26	1320	04	0.018	0	N.D
	16.06.06	Raw	500 D	5.0	52.26	6.29	7.78	1728	420	0.64	0	N.D
		After 1st bucket	500 D	5.0	35.61	6.12	7.94	1723	219	0.21	22	N.D
		After 2nd bucket	0	0	4.89	5.94	8.15	1264	75	0.072	08	N.D
		After 3rd bucket	0	0	0.12	6.00	8.51	1362	11	0.011	0	N.D
	23.06.06	Raw	500 D	5.0	54.20	6.32	7.74	1759	452	0.61	0	N.D
		After 1st bucket	500 D	5.0	36.29	6.05	7.96	1711	259	0.24	28	N.D
		After 2nd bucket	0	0.50	4.42	5.91	8.21	1305	84	0.061	18	N.D
		After 3rd bucket	0	0	0.16	6.15	8.57	1326	14	0.014	0	N.D
	30.06.06	Raw	500 D	5.0	48.96	6.24	7.16	1764	373	0.372	0	N.D
		After 1st bucket	500 D	5.0	39.68	6.02	7.56	1732	396	0.351	32	N.D
		After 2nd bucket	0	0.50	4.27	5.90	8.09	1123	127	0.015	08	N.D
		After 3rd bucket	0	0	0.19	6.28	8.25	1284	09	0.011	0	N.D
	07.07.06	Raw	500 D	5.0	N.D	6.42	7.74	1741	397	0.50	0	N.D
		After 1st bucket	500 D	5.0	N.D	5.85	7.85	1710	212	0.197	36	N.D
		After 2nd bucket	10 U	0.50	N.D	4.92	8.18	1298	69	0.042	12	N.D
		After 3rd bucket	0	0	N.D	6.27	8.41	1321	08	0.011	0	N.D
	14.07.06	Raw	500 D	5.0	N.D	6.28	7.76	1764	342	0.63	0	N.D
		After 1st bucket	500 D	5.0	N.D	5.93	7.88	1723	201	0.187	24	N.D
		After 2nd bucket	10 U	0.50	N.D	5.74	8.29	1229	63	0.024	10	N.D
		After 3rd bucket	0	0	N.D	6.32	8.57	1294	13	0.011	0	N.D
	21.07.06	Raw	500 D	5.0	N.D	6.34	7.77	1723	363	0.52	0	N.D
		After 1st bucket	500 D	5.0	N.D	5.92	7.78	1706	231	0.26	22	N.D
		After 2nd bucket	10 U	0.50	N.D	4.97	7.91	1301	61	0.020	12	N.D
		After 3rd bucket	0	0	N.D	6.19	8.34	1362	06	0.016	0	N.D
	28.07.06	Raw	500 D	5.0	N.D	6.35	7.39	1751	354	0.59	0	0
		After 1st bucket	500 D	5.0	N.D	6.04	7.73	1723	301	0.19	20	0
		After 2nd bucket	10 U	0.50	N.D	5.94	8.69	1256	61	0.031	14	0
		After 3rd bucket	0	0	N.D	5.97	8.91	1326	10	0.016	0	0
	03.08.06	Raw	500 D	5.0	N.D	6.23	7.78	1706	351	0.53	0	N.D
		After 1st bucket	500 D	5.0	N.D	6.04	7.84	1692	311	0.21	20	N.D
		After 2nd bucket	10 U	0.50	N.D	5.31	8.20	1284	54	0.019	08	N.D
		After 3rd bucket	0	0	N.D	6.01	8.64	1302	10	0.015	0	N.D

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 16.05.2006 Name of the H/H chief: Nur-mohammad Sk. Vill: Pithabhog Union: Ghatbhog	11.08.06	Raw	500 D	5.0	49.67	6.24	7.84	1721	359	0.58	0	N.D
		After 1st bucket	500 D	5.0	47.58	5.20	7.91	1703	321	0.18	22	N.D
		After 2nd bucket	25 D	1.5	7.21	5.01	8.10	1268	61	0.016	08	N.D
		After 3rd bucket	10 U	0.5	1.29	6.15	8.19	1301	14	0.014	0	N.D
	18.08.06	Raw	500 D	5.0	51.21	6.35	7.85	1703	356	0.54	0	N.D
		After 1st bucket	500 D	5.0	48.35	5.87	7.91	1684	328	0.21	28	N.D
		After 2nd bucket	50 D	1.5	9.24	5.14	8.12	1273	66	0.019	10	N.D
		After 3rd bucket	25 U	0	3.23	6.54	8.19	1298	16	0.015	0	N.D
	26.08.06	Raw	500 D	5.0	52.26	6.33	7.94	1712	351	0.57	0	N.D
		After 1st bucket	500 D	5.0	50.64	5.94	7.69	1695	331	0.34	24	N.D
		After 2nd bucket	50 D	2.5	11.10	5.32	8.20	1284	66	0.024	12	N.D
		After 3rd bucket	25 U	1.0	3.61	6.57	8.29	1308	15	0.019	0	N.D
	31.08.06	Row	500 D	5.0	51.29	6.37	7.64	1716	358	0.60	0	N.D
		After 1st bucket	500 D	5.0	51.11	5.24	7.99	1682	335	0.33	22	N.D
		After 2nd bucket	50 D	2.5	11.94	4.95	8.18	1282	64	0.021	12	N.D
		After 3rd bucket	25 U	2.0	3.94	6.67	8.31	1299	15	0.018	0	N.D
	08.09.06	Raw	500 D	5.0	51.94	6.24	7.28	1701	N.D	0.60	0	N.D
		After 1st bucket	500 D	5.0	50.67	5.97	7.64	1658	N.D	0.39	16	N.D
		After 2nd bucket	50 D	3.5	10.61	5.21	8.23	1278	N.D	0.040	10	N.D
		After 3rd bucket	50 D	2.5	4.13	6.14	8.35	1294	N.D	0.032	0	N.D
	15.09.06	Raw	500 D	5.0	51.17	6.34	7.61	1706	N.D	0.61	0	0
		After 1st bucket	500 D	5.0	49.28	6.10	7.74	1678	N.D	0.41	18	0
		After 2nd bucket	50 D	4.0	11.34	5.67	8.05	1263	N.D	0.065	10	0
		After 3rd bucket	50 D	2.5	3.96	6.24	8.30	1293	N.D	0.042	0	0
	22.09.06	Raw	500 D	5.0	49.91	6.37	7.39	N.D	N.D	N.D	0	0
		After 1st bucket	500 D	5.0	50.21	6.24	7.72	N.D	N.D	N.D	18	0
		After 2nd bucket	50 D	4.0	12.24	5.67	8.04	N.D	N.D	N.D	16	0
		After 3rd bucket	Filtration System Clogged									
	07.10.06	Raw	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	500 D	4.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	Filtration System Clogged									
	10.10.06	Raw	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	300 U	4.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	Filtration System Clogged									
	11.10.06	Raw	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	Filtration System Clogged									
	14.10.06	Raw	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	500 D	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	Filtration System Clogged									

Table-5.3: Field performance study and test results for moderate As-high Fe concentration field site

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 29.06.2006 Name of the H/H chief: Binoy Krishna halder, Vill: Talbala Union: T.S.Bahirdia	07.07.06	Raw	300 U	5.0	N.D	6.09	7.77	1041	520 over	0.637	0	0
		After 1st bucket	300 U	5.0	N.D	5.93	8.00	1086	363	0.770	22	0
		After 2nd bucket	0	0	N.D	4.24	9.23	927	97	0.053	08	0
		After 3rd bucket	0	0	N.D	6.14	9.01	1024	10	0.014	0	0
	14.07.06	Raw	300 U	5.0	N.D	6.11	7.74	1125	520	0.521	0	0
		After 1st bucket	300 U	5.0	N.D	5.99	7.79	1024	412	0.691	22	0
		After 2nd bucket	0	0	N.D	4.14	9.10	897	112	0.058	14	0
		After 3rd bucket	0	0	N.D	6.13	8.69	1061	06	0.011	0	0
	21.07.06	Raw	300 U	5.0	N.D	6.12	7.62	1101	520	0.662	0	0
		After 1st bucket	300 U	5.0	N.D	5.91	7.73	1097	297	0.784	14	0
		After 2nd bucket	0	0	N.D	4.28	7.79	985	95	0.049	06	0
		After 3rd bucket	0	0	N.D	6.16	8.21	1028	04	0.011	0	0
	28.07.06	Raw	300 U	5.0	N.D	6.08	7.74	1167	481	0.541	0	N.D
		After 1st bucket	300 U	5.0	N.D	5.96	7.94	1192	201	0.741	22	N.D
		After 2nd bucket	0	0	N.D	4.23	8.10	964	73	0.050	12	N.D
		After 3rd bucket	0	0	N.D	6.20	8.28	1094	04	0.012	0	N.D

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 29.06.2006 Name of the H/H chief: Binoy Krishna halder Vill: Taltala Union: T.S.Bahirdia	03.08.06	Raw	300 U	5.0	68.6	6.50	7.63	1036	N.D	N.D	0	N.D
		After 1st bucket	300 U	5.0	40.8	5.88	7.76	1014	N.D	N.D	20	N.D
		After 2nd bucket	0	0	3.02	5.10	7.94	987	N.D	N.D	06	N.D
		After 3rd bucket	0	0	1.16	7.47	8.07	941	N.D	N.D	0	N.D
	11.08.06	Raw	300 U	5.0	67.9	6.01	7.66	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	42.0	5.94	7.76	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	0	0	3.12	5.21	7.89	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.06	6.89	7.94	N.D	N.D	N.D	N.D	N.D
	18.08.06	Raw	300 U	5.0	67.6	6.21	7.77	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	42.3	5.84	7.84	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	0	0	3.18	4.13	7.91	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	0.98	7.61	8.06	N.D	N.D	N.D	N.D	N.D
	26.08.06	Raw	300 U	5.0	66.9	6.28	7.74	N.D	N.D	N.D	0	0
		After 1st bucket	300 U	5.0	44.12	5.64	7.86	N.D	N.D	N.D	24	0
		After 2nd bucket	0	0	3.18	5.06	8.01	N.D	N.D	N.D	10	0
		After 3rd bucket	0	0	1.00	7.24	8.06	N.D	N.D	N.D	0	0
	31.08.06	Raw	300 U	5.0	66.74	6.16	7.69	N.D	476	0.638	0	N.D
		After 1st bucket	300 U	5.0	42.10	5.58	7.85	N.D	295	0.724	24	N.D
		After 2nd bucket	0	0	3.09	4.94	7.97	N.D	69	0.052	12	N.D
		After 3rd bucket	0	0	0.97	6.99	8.10	N.D	05	0.016	0	N.D
	15.09.06	Raw	300 U	5.0	67.8	6.24	7.77	1091	483	0.599	0	N.D
		After 1st bucket	300 U	5.0	40.25	5.37	7.91	1026	311	0.712	22	N.D
		After 2nd bucket	10 U	0	3.18	4.97	7.96	967	75	0.054	08	N.D
		After 3rd bucket	0	0	1.04	7.05	8.04	925	04	0.016	0	N.D
	22.09.06	Raw	300 U	5.0	68.2	6.34	7.68	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	42.09	5.89	7.81	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.0	3.64	4.51	7.97	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.15	7.10	8.11	N.D	N.D	N.D	N.D	N.D
	29.09.06	Raw	300 U	5.0	66.91	6.11	7.74	N.D	436	0.625	N.D	N.D
		After 1st bucket	300 U	5.0	41.21	5.64	7.84	N.D	219	0.711	N.D	N.D
		After 2nd bucket	10 U	1.0	3.61	4.89	7.99	N.D	62	0.059	N.D	N.D
		After 3rd bucket	0	0	1.10	6.94	8.09	N.D	06	0.017	N.D	N.D
	07.10.06	Raw	300 U	5.0	67.4	6.14	7.76	N.D	435	0.623	0	0
		After 1st bucket	300 U	5.0	40.94	5.51	7.81	N.D	241	0.709	26	0
		After 2nd bucket	10 U	0.50	3.14	4.94	7.93	N.D	66	0.061	10	0
		After 3rd bucket	0	0	0.92	7.21	8.07	N.D	05	0.016	0	0
	14.10.06	Raw	300 U	5.0	66.9	6.11	7.77	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	42.00	5.49	7.88	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	2.00	3.98	4.84	7.92	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0.50	1.10	7.13	8.12	N.D	N.D	N.D	N.D	N.D
	04.11.06	Raw	300 U	5.0	68.7	6.15	7.61	1035	N.D	N.D	0	N.D
		After 1st bucket	300 U	5.0	18.6	5.70	7.97	966	N.D	N.D	24	N.D
		After 2nd bucket	25 D	1.5	2.10	4.11	8.09	917	N.D	N.D	10	N.D
		After 3rd bucket	0	0.5	1.88	8.10	8.15	883	N.D	N.D	0	N.D
	11.11.06	Raw	300 U	5.0	64.1	6.74	7.57	1053	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	31.5	5.74	7.70	1020	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	1.72	4.99	7.90	986	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	0.78	6.78	8.17	915	N.D	N.D	N.D	N.D
	16.11.06	Raw	300 U	5.0	65.2	6.37	7.74	1025	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	21.6	5.84	7.99	987	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	2.00	4.97	8.14	913	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	1.34	8.14	8.16	894	N.D	N.D	N.D	N.D
	25.11.06	Raw	300 U	5.0	59.8	6.51	7.39	1097	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	25.3	5.53	7.74	946	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	2.52	4.72	7.93	952	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	0.89	6.13	7.99	951	N.D	N.D	N.D	N.D
	02.12.06	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	09.12.06	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 29.06.2006 Name of the H/H chief Binoy Krishna halder. Vill: Taltala Union: T.S.Bahirdia	16.12.06	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	0	0
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	26	0
		After 2nd bucket	25 D	1.5	N.D	N.D	N.D	N.D	N.D	N.D	18	0
		After 3rd bucket	10 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	0	0
	25.12.06	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	06.01.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	13.01.07	Raw	300 U	5.0	67.9	6.42	7.49	1044	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	42.6	5.11	7.81	1011	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	1.16	4.52	7.95	947	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0.5	0.92	8.16	8.12	958	N.D	N.D	N.D	N.D
	20.01.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	26.01.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 U	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	30.01.07	Raw	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	Filtration System Clogged Need Washing									
		After 2nd bucket	Filtration System Clogged Need Washing									
		After 3rd bucket	Filtration System Clogged Need Washing									
	03.02.07	Raw	300 U	5.0	62.3	6.11	7.74	1038	N.D	N.D	0	0
		After 1st bucket	300 U	5.0	35.2	5.12	7.94	1001	N.D	N.D	14	0
		After 2nd bucket	50 D	1.5	2.65	4.84	8.05	964	N.D	N.D	12	0
		After 3rd bucket	25 U	0	1.10	7.96	8.19	987	N.D	N.D	0	0
	10.02.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 D	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	25 U	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	17.02.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 D	2.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	25 U	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	21.02.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 U	2.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	25 U	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	03.03.07	Raw	300 U	5.0	58.4	6.11	7.78	1112	N.D	N.D	0	0
		After 1st bucket	300 U	5.0	39.6	5.34	7.61	1089	N.D	N.D	28	0
		After 2nd bucket	50 U	2.5	3.41	4.54	7.92	984	N.D	N.D	26	0
		After 3rd bucket	25 U	0.5	0.54	7.69	8.14	925	N.D	N.D	0	0
	06.03.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 U	2.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	08.03.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 U	2.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	10.03.07	Raw	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	300 U	5.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	100 D	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 U	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Table-5.4: Field performance study and test results for low As-moderate Fe concentration field site

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 02.07.2006 Name of the H/H chief: Modon Kumar Samakar Vill: Samontasena Union: Naihati	07.07.06	Raw	100 U	3.0	N.D	5.97	7.67	1324	325	0.398	0	0
		After 1st bucket	100 U	3.0	N.D	5.12	7.92	1369	127	0.547	28	0
		After 2nd bucket	0	0	N.D	4.15	8.01	946	61	0.124	06	0
		After 3rd bucket	0	0	N.D	6.24	8.24	1064	04	0.012	0	0
	14.07.06	Raw	100 U	3.0	N.D	5.95	7.74	1369	298	0.381	0	N.D
		After 1st bucket	100 U	3.0	N.D	5.21	7.98	1384	113	0.528	24	N.D
		After 2nd bucket	0	0	N.D	4.15	8.00	954	58	0.131	10	N.D
		After 3rd bucket	0	0	N.D	6.01	8.09	1014	03	0.012	0	N.D
	21.07.06	Raw	100 U	3.0	N.D	5.98	7.73	1325	311	0.365	0	N.D
		After 1st bucket	100 U	3.0	N.D	5.11	7.91	1645	140	0.132	22	N.D
		After 2nd bucket	0	0	N.D	4.14	8.05	975	46	0.042	06	N.D
		After 3rd bucket	0	0	N.D	6.03	8.25	1101	06	0.011	0	N.D
	28.07.06	Raw	100 U	3.0	N.D	5.99	7.64	1397	315	0.512	0	0
		After 1st bucket	100 U	3.0	N.D	5.22	7.89	1364	142	0.164	22	0
		After 2nd bucket	0	0	N.D	4.09	8.12	991	41	0.061	10	0
		After 3rd bucket	0	0	N.D	6.02	8.39	1054	03	0.009	0	0
	03.08.06	Raw	100 U	3.0	53.2	6.09	7.53	1394	N.D	N.D	0	N.D
		After 1st bucket	100 U	3.0	19.1	5.56	7.79	1351	N.D	N.D	18	N.D
		After 2nd bucket	0	0	14.0	4.70	8.34	984	N.D	N.D	04	N.D
		After 3rd bucket	0	0	0.74	6.82	8.27	1056	N.D	N.D	0	N.D
	11.08.06	Raw	100 U	3.0	53.4	6.12	7.52	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	20.0	5.62	7.79	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	0	0	13.9	4.78	8.31	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	0.81	6.95	8.34	N.D	N.D	N.D	N.D	N.D
	18.08.06	Raw	100 U	3.0	54.0	6.11	7.49	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	22.0	5.61	7.76	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	0	0	14.9	4.71	8.10	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.15	6.94	8.31	N.D	N.D	N.D	N.D	N.D
	26.08.06	Raw	100 U	3.0	54.25	6.11	7.44	N.D	N.D	N.D	0	0
		After 1st bucket	100 U	3.0	24.5	5.59	7.79	N.D	N.D	N.D	20	0
		After 2nd bucket	0	0	12.32	4.79	8.12	N.D	N.D	N.D	10	0
		After 3rd bucket	0	0	1.10	6.97	8.26	N.D	N.D	N.D	0	0
	31.08.06	Raw	100 U	3.0	54.0	6.14	7.39	N.D	323	0.518	0	N.D
		After 1st bucket	100 U	3.0	29.0	5.55	7.81	N.D	148	0.171	20	N.D
		After 2nd bucket	0	0	13.65	4.79	8.14	N.D	44	0.063	08	N.D
		After 3rd bucket	0	0	0.94	6.94	8.31	N.D	03	0.012	0	N.D
	15.09.06	Raw	100 U	3.0	55.01	6.13	7.41	1396	331	0.542	0	N.D
		After 1st bucket	100 U	3.0	26.01	5.53	7.80	1349	157	0.169	24	N.D
		After 2nd bucket	0	0	14.20	4.74	8.10	964	51	0.054	10	N.D
		After 3rd bucket	0	0	1.95	6.89	8.32	997	04	0.012	0	N.D
	22.09.06	Raw	100 U	3.0	55.15	6.11	7.44	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	24.41	5.54	7.82	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	0	0	11.21	4.76	8.11	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.12	6.94	8.31	N.D	N.D	N.D	N.D	N.D
	29.09.06	Raw	100 U	3.0	53.9	6.10	7.64	N.D	337	0.551	N.D	N.D
		After 1st bucket	100 U	3.0	20.62	5.49	7.81	N.D	154	0.171	N.D	N.D
		After 2nd bucket	10 D	0.5	12.41	4.79	8.24	N.D	49	0.061	N.D	N.D
		After 3rd bucket	0	0	0.91	6.91	8.34	N.D	05	0.011	N.D	N.D
	07.10.06	Raw	100 U	3.0	53.5	6.10	7.14	N.D	339	0.541	0	0
		After 1st bucket	100 U	3.0	26.5	5.49	7.81	N.D	151	0.174	18	0
		After 2nd bucket	10 D	1.00	14.5	4.77	8.10	N.D	51	0.071	12	0
		After 3rd bucket	0	0	1.15	6.94	8.28	N.D	04	0.014	0	0
	14.10.06	Raw	100 U	3.0	54.0	6.10	7.51	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	25.1	5.44	7.94	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 D	0.5	13.25	4.74	8.15	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.28	6.91	8.37	N.D	N.D	N.D	N.D	N.D
	04.11.06	Raw	100 U	3.0	52.5	7.82	7.61	715	N.D	N.D	0	N.D
		After 1st bucket	100 U	3.0	30.6	6.71	7.89	708	N.D	N.D	22	N.D
		After 2nd bucket	10 D	0.5	12.6	5.41	8.17	700	N.D	N.D	08	N.D
		After 3rd bucket	0	0	1.74	7.19	8.30	662	N.D	N.D	0	N.D
	11.11.06	Raw	100 U	3.0	44.2	8.15	7.71	710	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	21.4	6.62	7.92	718	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	10.1	5.40	8.06	660	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	0.68	7.26	8.39	610	N.D	N.D	N.D	N.D

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 02.07.2006 Name of the H/H chief: Modon Kumar Sarnakar Vill: Samontasena Union: Naihati	16.11.06	Raw	100 U	3.0	49.6	8.10	7.74	718	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	27.5	7.58	7.95	713	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	16.3	6.37	8.12	684	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	0.74	7.23	8.30	619	N.D	N.D	N.D	N.D
	25.11.06	Raw	100 U	3.0	50.8	7.56	7.50	755	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	27.2	6.69	7.76	741	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	11.6	5.90	8.13	703	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	1.09	8.01	8.23	619	N.D	N.D	N.D	N.D
	02.12.06	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	09.12.06	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	16.12.06	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	0	0
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	24	0
		After 2nd bucket	10 U	1.5	N.D	N.D	N.D	N.D	N.D	N.D	18	0
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	0	0
	25.12.06	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	06.01.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	13.01.07	Raw	100 U	3.0	44.9	7.59	7.46	719	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	11.5	6.62	7.99	714	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.0	7.99	5.94	8.14	600	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	0.69	8.14	8.11	657	N.D	N.D	N.D	N.D
	20.01.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	26.01.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	30.01.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	1.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	0	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	03.02.07	Raw	100 U	3.0	38.6	7.50	7.61	723	N.D	N.D	0	0
		After 1st bucket	100 U	3.0	16.50	6.55	7.74	716	N.D	N.D	24	0
		After 2nd bucket	10 U	1.0	4.11	5.81	7.98	598	N.D	N.D	20	0
		After 3rd bucket	10 D	0	0.58	8.00	8.10	669	N.D	N.D	0	0
	10.02.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	17.02.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	10 U	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	21.02.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	03.03.07	Raw	100 U	3.0	39.5	7.47	7.72	729	N.D	N.D	0	0
		After 1st bucket	100 U	3.0	19.3	6.57	7.79	711	N.D	N.D	26	0
		After 2nd bucket	25 D	0.5	5.25	5.76	7.91	597	N.D	N.D	20	0
		After 3rd bucket	10 U	0	0.72	8.10	8.12	662	N.D	N.D	0	0
	10.03.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 D	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	10 U	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Name & Address	Date	Water Type	As (ppb)	Fe (ppm)	Tur (NTU)	DO (mg/l)	pH	EC (µS/cm)	Color (pt-co)	Mn (ppm)	TC (#/100ml)	FC (#/100ml)
Option installation date: 02.07.2006 Name of the H/H chief: Modon Kumar Samokur Vill: Samontasera Union: Nuihati	24.03.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	25 U	0.5	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	25 D	0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	07.04.07	Raw	100 U	3.0	41.6	7.54	7.74	723	N.D	N.D	0	0
		After 1st bucket	100 U	3.0	22.4	6.66	7.85	716	N.D	N.D	22	0
		After 2nd bucket	25 U	1.0	6.32	5.76	7.98	590	N.D	N.D	20	0
		After 3rd bucket	25 D	0.5	1.15	8.15	8.15	669	N.D	N.D	0	0
	20.04.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 D	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	22.04.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 U	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 D	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
	25.04.07	Raw	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 1st bucket	100 U	3.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 2nd bucket	50 U	2.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D
		After 3rd bucket	50 U	1.0	N.D	N.D	N.D	N.D	N.D	N.D	N.D	N.D

Chapter- Six

6.1 Beneficiaries' opinion and Experience from the field application

The field-testing started on 16th June, 2006 with installation of one unit in one household in Pithabhog village (field-1). The arsenic and iron concentrations in the tubewell located at this household was 500 ppb and 5 ppm respectively. On 29th July, 2006 and 2nd August 2006, two more units were installed at two other households in another two villages (field -2 & field-3). The arsenic concentrations in the tubewells located at these households were 300 ppb and 100 ppb respectively. The concentrations of iron detected in that tubewells were 5 ppm and 3 ppm respectively. The operation of the biological As-Fe removal unit was explained to the people of these households.

It can be mentioned that the presence of high level of arsenic in many of the tubewells in these villages was confirmed in October, 2001. The screening activity was conducted by BAMWSP, DPHE. People became very enthusiastic after receiving the proposal of installation some household level biological As-Fe removal units on a test basis. Considering the different hydro-geological conditions of the fields only three units were supplied in three different households. Many households in these villages requested to provide more units as they were also suffering from the poisonous elements (As-Fe).

After four to nine months of operation, the units appeared to have become very popular with the people in that selected villages. Many of them came to inspire for providing more unit. People in general were very eager to use these units. This was particularly true among the people who were more aware about the adverse effects of arsenic. This was evidenced by requests for many more units by the people. Many people showed their willingness to pay for the unit (which were supplied free of cost for field performance study). The easy operation and maintenance was one aspect that appeared to have made the units popular. Apart from the arsenic-iron removal efficiency of the units, the aspect that impressed people most was the clarity of water produced by the units. Many households identified this aspect as the primary reason for using the unit. With relatively high iron content (upto about 5 mg/L), raw water from every tubewell in the selected household showed high turbidity (resulting from precipitated iron flocs). The units were very effective in removing the iron content of water (along with arsenic) and the clear water produced was very attractive aesthetically. It was another interesting aspect regarding use of these units.

Survey of the three households revealed that on an average most of them treated two buckets (20 liters) of water daily. This water was used primarily for drinking and cooking. One household (Field -1, Taltala village) reported to have treated about three to four buckets daily. This unit was clogged within four months for treating so much water daily. This was due to the fact that the household was supplying water to a number of surrounding households. The households informed that it was difficult for women in the households to pour the water in the upper bucket. They suggested that if the upper bucket was placed at a lower height, it would be easier for them to pour.

During field visits, it was observed that the instructions for operation of the units were not strictly followed by all the users. For example the flow control (about 0.5 m/h) instructions were not always followed because many felt it was too slow to fill the collection pitcher. They tried to increase the water flow for quick collection of the treated water as their desired. It should be mentioned that the arsenic and iron removal efficiency did not appear to have been affected much by this action.

Water samples were collected during the field visits from the selected fields. Arsenic and iron were tested in the spot instantly by field test kits. Results of field testing of the units are summarized in Table- 5.2, 5.3 and 5.4. These results showed significant reduction of iron and arsenic concentrations in the treated water. Arsenic concentration came down to below 10 ppb in most cases from an initial concentration of 500 ppb. Good iron removal was achieved in the field units. Average manganese concentrations in the treated water were about 0.02 mg/L, far below the drinking water standard of 0.10 mg/L for Bangladesh.

The users were very happy with the performance of the units. The major advantage of the units was that it did not require any additional chemicals. The only maintenance required for the units was washing of the rapid sand filter in the second bucket and the slow sand filter in the third bucket in order to maintain reasonable flow rate through the units. The major concern for the units was clogging of the sand filter bed in the second and third bucket.

The iron content of 5 ppm in its tubewell of the first field (Pithabhog village) unit was clogged within four months of operation. In a similar time the breakpoint for arsenic was also observed in the unit. A reasonable flow rate (around 0.5 m/h) was not always maintained by the household in its service period.

In the second field (Taltala village) the iron content was also 5 ppm in its tubewell. The unit was clogged after seven months of operation. It was interesting that all the three buckets got clogged in the same time. Gravels and coconut husk bed from the first bucket of the unit was drawn. After washing properly with clean water, the coconut husk bed was placed in the first bucket. To protect the floatation of the husk bed gravel was placed properly over the husk bed. Top few millimetres sand was scraped off very carefully from the sand bed of second and third bucket and this exposed by new layer of clean sand. This action was introduced both for the rapid and slow sand filter bed in the second and third bucket respectively. The taps and joint pipes were also cleaned properly. Water was then decanted back into the filter and re-circulated for a few hours to allow a new *Schmutzedecke* to develop. The filter was then filled to full depth and brought back into service. The breakpoint was noticed about one and half month of operation from next installation.

The clogging of the third field (Samontasena village) unit did not occur before reaching breakpoint like first and second ones. The concentrations of iron and arsenic in its tubewell of the third field unit were 3 ppm and 100 ppb respectively. Monitoring of this unit suggests that about ten months (297 days) of operation it has reached the breakpoint of 50 ppb arsenic. The lower concentration limit of arsenic and iron was the cause of running this unit smoothly without any maintenance. It should be mentioned that this type of filtration unit requires regular monitoring to determine the breakpoint of arsenic in the treated water.

Arsenic toxicity has no known effective treatment. Drinking of arsenic free water can help arsenic affected people at early stage of ailment to get rid of the symptoms of arsenic toxicity. Therefore, the most important measure needed is to prevent further exposure of population by providing them with arsenic-free safe drinking water. In view of the overwhelming dependence of the population on groundwater, development of suitable treatment systems for arsenic removal from groundwater appears to a promising option for providing safe water to the rural population. Socio-economic conditions of Bangladesh demands low-cost as well as small-scale treatment systems. The community participation in our country has never been remarkably successful. So, the systems could be implemented at household level.

It can be summarized from the above discussion that the developed unit has a good potential in the context of both arsenic and iron contaminated areas. No additional chemicals required were the main benefits declared by the users. The simple operation, less maintenance and the clarity of the treated water was also the key cause for using the unit at household level. A little shortening of height of the unit could be the better option to provide as arsenic-iron removal household based unit in the contaminated areas.

6.2 Engineering significance and Economic aspect

The developed unit consists of three buckets where arsenic-iron contaminated raw water was poured into the first one. In this bucket bio-oxidation took place. Arsenic-Iron concentrated raw water was oxidized by the bacteria. The bacteria were produced on coconut husk bed and form small particles by sorption onto $Fe(OH)_3$. In second bucket comparatively larger flocculated particles precipitated and settled at the top of the chamber and the removal of precipitated particles through sorption onto iron oxy hydroxides. Additional adsorption of escaped arsenic from the first bucket was done on the iron matrix layer in the second bucket. Other fine and coarse particles precipitated on charcoal and coarse sand. Final removal of bacteria and other fine particles were accomplished in the 3rd bucket. This bucket consists of simple methodological technique of slow sand filtration under submerged condition i.e. stable bio-film slime layer. Partial treated water flow at a very slow rate through fine sands to retain suspended solids.

Following the above technique, detail laboratory analysis and tests were carried out for nine different ratios of arsenic-iron concentrated synthetic raw water. It was observed from the laboratory tests that the removal efficiency was sufficient for both arsenic and iron of different ratios. The water quality of relevant selected parameters in the treated water was also found satisfactory. The selected water quality parameters of the laboratory unit were within the acceptable limit of Bangladesh standards.

The laboratory unit was modified considering the different hydro-geological conditions of the field. Three units were constructed following the modification for field performance study. The modified field units were applied at Pithabhog, Taltala and Samontasena villages under Rupsha Upazila in Khulna district. The units showed very good removal efficiency of arsenic and iron. Arsenic concentrations in the treated water were found to be mostly below 10 ppb; while the maximum arsenic concentration in raw water was over 500 ppb. The iron concentration of the raw water was 5 ppm and after final treating it was found below 1 ppm. No sign of TC & FC were detected in the treated water. The water after 1st bucket contained a numerous TC of merely 25 numbers per 100 ml of water. Those were produced from the coconut husk bed to oxidize arsenic. Average manganese concentrations of about 0.50 mg/l were observed in the raw water of its tubewell in the selected fields. After treating the concentrations came down to almost 0.02 mg/l, far below the drinking water standard of 0.10 mg/L for Bangladesh.

Clogging of the slow sand filter in the 2^{nd} and 3^{rd} bucket was a major concern for the units. It was observed that the clogging of the units were not frequent for all concentration of iron. Clogging of the field units were varied for different iron concentrations. A brief discussion regarding clogging was made in section 6.1.

The total cost of constructing the household level biological As-Fe removal unit was about Tk. 1250/-. The cost of each plastic bucket is around Tk. 70/-. The mild steel frame for holding the unit costs around Tk. 400/-. Fresh CI scraps of about 7.5 kg were used in the unit cost Tk. 150/-. The cost of all other locally available materials used for constructing the unit is Tk. 150/-.

The most important point behind the cost is that the unit is reusable. After reaching breakpoint of arsenic and iron the bed materials could be replaced by new materials. Thus the unit could be replaced easily for treating raw water. The replacing cost is not more than Tk. 400/.

The developed household level biological As-Fe removal Unit is more economical than the other available Arsenic –Iron removal processes because of the following:

- A biological treatment Unit without using any additional chemicals.
- Materials used in the Unit are locally available.
- A complete biological Unit for Arsenic, Iron and bacteria removal.
- A treatment Unit of ease in Operation and Maintenance.
- A low cost treatment Unit for the As-Fe affected rural people.
- A reusable treatment Unit.

Due to the carcinogenic potential of chronic arsenic exposure, public water systems worldwide are in need of cost-effective technologies to remove arsenic from drinking water (ASCE / January, 2006). The problem of treatment of groundwater for arsenic removal arises from the requirement for its removal to very low levels to meet the stringent drinking water quality standards and guideline value. Arsenic removal technologies have improved significantly during the last few years but reliable, cost effective and sustainable treatment technologies are yet to be identified and further developed to meet the requirements (M. F Ahmed, 2003).

The entire household based arsenic treatment technologies available in our country are concentrated arsenic at some stage of treatment in different media especially iron media. It appeared that the technologies performed consistently well in reducing arsenic but they have no resistant to microbial growth. The major issues relating to the prospects for the technologies and for sustainable use are the risk of bacteriological contamination and the acceptability of the technologies to prospective users (Sutherland et al. 2001).

The good achievement for the developed household level biological As-Fe removal unit is that the treated water produced in the unit is completely free from bacteriological contamination. The major findings from the field units are the clarity of the treated water. It has observed that all the three units produced sparkling clear water with no arsenic and iron.

So, from the engineering point of view it could be concluded that the developed unit is cost effective, sustainable and user-friendly treatment unit which could be used in the arsenic-iron prone rural areas of Bangladesh.

Chapter- Seven

7.1 Conclusion

The project works focused on the development of a low cost household level biological As-Fe removal Unit. Detailed laboratory model analysis and tests were carried out to determine some important optimum design parameters of the Treatment Unit for practical field application. Considering different hydro-geological conditions, modifications were made to the developed Unit for field applications. The Modified Units were then installed and tested in different water quality conditions at the field level. The performances of the field Units were studied with respect of bacteriological growth, removal efficiency of arsenic, iron and bacteria. Breakpoint of arsenic and clogging of the field Units were a major part of the field performance study. Identifications of beneficiaries' opinion (i.e. social acceptance) for determining the problems in operation and maintenance of the Units have been carried out. The engineering significance and economic aspect for developing the Unit has also been focused thoroughly. The main findings drawn from this study are as follows:

(1) Over 90% arsenic removal was achieved without using any additional chemicals through bio-oxidation, adsorption, co-precipitation and filtration process in the developed Treatment Unit.

(2) Appreciable iron removal efficiency over 90% was observed while the face velocity was maintained around 0.4 m^3/m^2-hr.

(3) During field performance study of the modified bio-physicochemical Treatment Unit, no TC/FC in the treated water was detected.

(4) The clogging of the developed Unit was dependent on the iron concentration of raw water. The clogging and maintenance were not frequent and the cleaning procedures were simple.

(5) The developed Unit was capable of treating about 4000L to 6000L of raw water containing arsenic concentration of 100 to 500 ppb and iron concentration of about 3 to 5 ppm.

(6) The duration of service of the developed Unit is six to nine months depending on the iron concentrations in the raw water.

(7) Translucent and sparkling treated water was produced in the developed Unit. The treated water had the color value always less than 15 pt-co unit and turbidity value less than 4 NTU for high iron (>5 ppm) concentrated raw water. The color and turbidity value was always less than 6 pt-co unit and within 2 NTU for moderate iron (3 to 5 ppm) concentrated raw water respectively.

(8) Dissolved oxygen level at different stages of treatment processes showed that aerobic condition was prevailing throughout the whole treatment operations.

(9) Average manganese concentrations of about 0.50 mg/l were observed in the raw water of its tubewell in the selected fields. After treating the concentrations came down to almost 0.02 mg/l, far below the drinking water standard of 0.10 mg/L for Bangladesh.

(10) The construction cost of the developed Unit was around Tk.1250.00 and the replacing cost was around Tk. 400.00.

7.2 Recommendation

7.2.1 General

There is a wide variation of hydro-geological conditions in Bangladesh. The water quality parameters in groundwater and their concentration ratios are not same in all the places. They vary significantly from place to place. Therefore, it was significantly needed to study the performances of the developed Treatment Unit under various water quality conditions.

During intensive field visits for a period over nine months, it was observed that the flow control (about 0.5 m/h) instructions were not strictly followed by the users. They felt that it was too slow to fill the collection pitcher. So, they tried to increase the water flow for quick collection of the treated water as their desired. It should be mentioned that the arsenic and iron removal efficiency did not appear to have been affected much by this action rather the units get clogged earlier. The beneficiaries informed the difficulty for pouring the raw water in the upper bucket. They suggested placing the upper bucket at a lower height which would be easier for them to pour.

So, it is recommended that the developed treatment unit should be a lower height accepting the user's suggestion. Another important point is to provide the fixed flow control device to control the water flow which should increase the duration of service of the treatment unit.

7.2.2 Recommendation for future work:

1. To study on performances of the developed Unit in mass scale under various water quality conditions.
2. To study on quick filling the collection pitcher.
3. Further study on clogging after replacing bed materials.
4. To study on reduction of the height of the treatment Unit.
5. To study on provision for fixed flow control device.

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