

# UNESCO-IHE INSTITUTE FOR WATER EDUCATION



## Optimization of IHE family filter for manganese removal under laboratory conditions

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# **Optimization of IHE family filter for manganese removal under laboratory conditions**

Master of Science Thesis

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The findings, interpretations and conclusions expressed in this study do neither necessarily reflect the views of the UNESCO-IHE Institute for Water Education, nor of the individual members of the MSc committee, nor of their respective employers.

## Abstract

High amount of arsenic (As) ( $>10$  mg/l) in groundwater is of environmental concern due to its toxicity and carcinogenicity. Other contaminant like manganese (Mn) is found naturally in groundwater, but levels can be increased by underground pollution sources. Mn may become noticeable in water at levels greater than 0.1 mg/l. At this level, the water may leave black deposits on distribution lines and stain plumbing fixtures. Chronic exposure to high levels of Mn ( $>0.4$  mg/l) can be harmful to the nervous system; a disorder similar to Parkinson's disease can result. On-going research at IHE has shown that IOCS can be effectively used to remove arsenic, Fe (iron), etc. and can be regenerated to restore its adsorptive capacity after exhaustion. However, the studies showed poor performance of IHE family filter (using IOCS) in terms of Mn removal ranging from no removal at all to increased concentration of manganese in the filtrate when high amounts of  $\text{NH}_3$  occur in the ground water. The goal of this research was to optimize IHE family filter with focus on manganese removal under laboratory conditions.

The methodology adopted in this study, included intensive literature review, field studies in Nepal, lab experiment and analysis of lab results. The lab experiment included lab filter set-ups, model water preparation, operation of filters, samples collection and water quality analysis. Different IHE family filters were run with i) an Aquamandix layer on top of IOCS, ii)  $\text{CaCO}_3$  layer at the bottom of IOCS, iii) post sand filter with local sand to optimise the filters in terms of manganese removal efficiency.

In the sample collected from Nepal, quality parameters As, Fe and Mn were observed to be in the range of  $2\text{ }\mu\text{g/l} - 235\text{ }\mu\text{g/l}$ ,  $0.28\text{ mg/l} - 4.56\text{ mg/l}$  and  $0.2\text{ mg/l} - 0.99\text{ mg/l}$  respectively. Highest concentration of ammonium obtained was  $3.78\text{ mg/l}$ . The observed ground water quality was used as reference for preparing model water. The average concentrations of parameters such as As, Fe, Mn and  $\text{NH}_4^+$  in feed water were respectively  $200\text{ }\mu\text{g/l}$ ,  $5\text{ mg/l}$ ,  $1\text{ mg/l}$  and  $4\text{ mg/l}$ .

The average rate of capacity reduction in the filter with IOCS (Filter 1) was  $0.94\text{ l/h}$  in 100 days and that of the filters with  $\text{CaCO}_3$  (Filter 2) and Aquamandix (Filter 3) were  $0.65\text{ l/h}$  per day and  $0.28\text{ l/h}$  in 100 days respectively.

In filter 1 and filter 2, the removal efficiency of As and Fe were 94% - 99% and about 90 % respectively for one week, later the removal efficiencies dropped. Nevertheless, these filters could not improve Mn removal efficiency. Filter 3 equipped with a polishing layer of Aquamandix on the top of IOCS consistently removed As, Fe and Mn below the WHO standards throughout the experimental period. However, the filtrate of Filter 3 had high amount of  $\text{NO}_2$ . Average nitrite concentration in filtrate of the Filters 1, 2 and 3 were  $0.4\text{ mg/l}$ ,  $1.75\text{ mg/l}$  and  $2.15\text{ mg/l}$  respectively. Polishing sand layer placed on top of IOCS in the Filter 1, removed micro-flocs of Fe with attached As. Post sand filter installed in series to the Filter 1 removed As, Fe,  $\text{NH}_4^+$  and  $\text{NO}_2$  below WHO and Nepal standards. The main cause of high concentration of nitrite is likely the unavailability of sufficient oxygen for survival of nitrobacter.

Some recommendations such as; long-term monitoring of the performance of the IHE family filter with polishing layer of Aquamandix in field condition to determine the breakthrough period is proposed.

**Key words:** Arsenic, IHE family filter, manganese, Aquamandix

This MSc thesis is dedicated to;  
My parents Dwarika Nath Shrestha and Chandra Badan Shrestha

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## List of Abbreviations

As	Arsenic
BDP	Bengal Delta Plain
CBS	Central Bureau of Statistics
DOC	Dissolved Organic Carbon
DWSS	Department of Water Supply and Sewerage
EU	European Union
Fe	Iron
IARC	International Agency for Research on Cancer
IOCP	Iron Oxide Coated Pumice
IOCS	Iron Oxide Coated Sand
MCL	Maximum Contaminant Level
mg/l	Milligram per litre
Mn	Manganese
NGO	Non-governmental Organization
O&M	Operation and Maintenance
POU	Point-of-Use
SMCL	Secondary Maximum Contaminant Level
TOC	Total Organic Carbon
UNICEF	United Nations Children's Fund
USEPA	United States Environment Protection Agency
WHO	World Health Organization
µg/l	Microgram per litre
µm	Micrometer
MCLG	Maximum Contaminant Level Goals

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# 1. INTRODUCTION

## 1.1 Background

Quality of ground water is becoming an emerging issue in the water supply and health sectors. The ground water in the past was considered safe for drinking purpose but now it came to be known that many shallow tube wells contain arsenic at concentrations higher than the safe limit set for drinking purpose by World Health Organisation (WHO) in 1993.

In order to produce drinking water of good quality, besides arsenic, other contaminants should be removed if present in ground water. Two of these contaminants, which can cause problems to consumers, are the metals – iron and manganese. Manganese is a mineral that naturally occurs in rocks and soil and usually coexist with iron (Petrusevski *et al.*, 2007). The most common sources of manganese in groundwater are naturally occurring, for example from weathering of iron and manganese bearing minerals and rocks (dissolution of the reduced form  $Mn^{2+}$ ). Industrial effluent (the iron and steel industry acid), mining, drainage, sewage may also contribute iron and manganese to local groundwater. The WHO health based guideline value for manganese in drinking water is 0.4 mg/l to protect against manganese toxicity (WHO, 2004).

High concentrations of arsenic in groundwater have been discovered in many parts of the world including Argentina, Bangladesh, Chile, China, Hungary, West Bengal (India), Nepal, Pakistan, Thailand, Vietnam, Mongolia, Mexico, USA, and Canada. Bangladesh is the worst in terms of the number of people exposed to contamination. At an international conference on arsenic contamination in Bangladesh in 2004, experts revealed that despite a seven-year effort, Bangladesh still tops the list of 23 arsenic affected countries with 85 million people exposed to the poison (Khan, 2004b).

The United States Environment Protection Agency (USEPA) and International Agency for Research on Cancer (IARC) have specified arsenic as known human carcinogen. Arsenic has long been recognized as toxin and carcinogen, and it is becoming a serious threat to public health particularly in the rural areas of Bangladesh. It has been reported that long-term exposure to arsenic in drinking water causes increased risks of skin, lungs, bladder and kidneys cancer. It also leads to other skin-related problems such as hyperkeratosis and changes in pigmentation (Adeel and Ali, 2002).

Nepal is a mountainous country with 47% of its population (around 11 million people) living on the flat land in the south Terai region (CBS, 2002). About 90% of the people in the Terai region depend on ground water as their major source of drinking water. The blanket test in 20 district of Terai region of Nepal showed 2.8% tube wells exceeded arsenic levels of 50  $\mu\text{g/l}$  and 13% tube wells above WHO guideline of 10  $\mu\text{g/l}$  (NASC/UNICEF, 2007).

Arsenic-induced health problems are imminent in Nepal. Many people who have been consuming high concentration of arsenic might be facing high mortality from skin and internal cancers (Panthi *et al.*, 2006). 2.6 % of the population, exposed to arsenic contaminated water with a concentration more than 50 µg/l, has a prevalence of arsenicosis (Shrestha *et al.*, 2003)

The potential health risk due to arsenic contaminated drinking water is profound as 48.4% (about 13 million) of the total population of the country inhabits the Terai region. It is estimated that arsenic contamination could affect more than 1.4 million populations across 20 Terai districts using estimated one million tube wells (Lawoti, 2006). Since 90% of population in the Terai region of Nepal depends on ground water for drinking, cooking and cleaning purposes. Realising the need to address this serious health issue, number of governmental and nongovernmental organizations have initiated tube well testing and mitigation programmes since early 2000.

Arsenic contamination in Nepal is not as widespread as in West Bengal and Bangladesh. However, studies indicate the seriousness of the problem in some areas of Terai. As geological source for the Bengal and Indus Basins primarily originated in the Himalayas and geochemical process is responsible for transforming arsenic from its mineral form, into a soluble toxic element, more studies in Nepal can be benefited by national policy makers and other countries in this region (Shrestha *et al.*, 2003).

Drinking arsenic free water can be the only solution for those people living in the affected area to prevent arsenic poisoning. Improvement of quality of the ground water is undoubtedly urgently required to protect health and wellbeing of rural people in Nepal. The socioeconomic aspect of rural part of Nepal demands low cost and small-scale treatment system that could be implemented at household level. Water treatment at the household level can be considered as a potential alternative for safe water supply for the rural part of the affected areas. Arsenic removal by affordable point of use (POU) system seems to be only feasible short-term solution. In the rural Terai region of Nepal, there is no centralized water supply systems and people are dependent on hand tube wells for drinking water consumption consequently needed POU system.

UNESCO-IHE, Institute for Water Education, Delft, The Netherlands is committed to contribute significantly in the sector of infrastructure, hydraulics and environmental issues. For several years, UNESCO-IHE has been working on the development of technology (family filter) using iron oxide coated sand (IOCS) as an arsenic adsorbent. IHE family filter is a simple and POU treatment unit that does not require any chemicals and power supply, which has proven high arsenic removal capacity in long-term as demonstrated in field-testing in Bangladesh (Petrusevski *et al.*, 2002).



## 1.2 Problem identifications

There are several water treatment technologies for removal of arsenic from ground water. The treatment processes used for arsenic removal such as coagulation–sedimentation–filtration, ion exchange process, membrane filtration are not appropriate for point of use system because of their high investment cost and need of well-trained personnel for its operation. These techniques are suitable for large treatment plants.

In 2004, as part of a project supported by the Dutch Government that includes 3 MSc. studies, 12 IHE family filters had been produced and tested under field conditions of rural Bangladesh by installing them in different locations. According to Khan (2004a), Sallehuddin (2005) and Barua (2006), the removal efficiency of the IHE Family filter regarding arsenic removal was nearly 100% satisfying the WHO guideline value of 10µg/l during long-term field testing of 2 years period after installed in 2004. Although this filter removed also iron very efficiently (95 - 100%), removal of manganese was not satisfactory in ground water with high ammonia (>3.76 mg/l).

The previous studies on removal of manganese by IHE family filter in Bangladesh had shown contradictory results. The studies showed poor long-term and short-term performance of IHE family filter in terms of manganese removal efficiency ranging from less removal to increased concentration of manganese in the filtrate when testing ground water with high  $\text{NH}_4^+$  concentration. The Section 2.7 shows the detail about the comparison of three previous MSc studies.

During field test, Sallehuddin (2005) examined effects of different measures like occasional chlorination, pre-treatment of raw water by simple aeration followed by flocculation and sedimentation, post sand filtration, addition of local materials (either 7 – 15 cm layer of local sand or 15 cm layer of brick chips on top of filter media), occasional filter media washing and introducing limestone layer in the filter. Some of the measures have no beneficial effects on manganese removal and some have only short-term effects on manganese removal efficiency (7% -99%). Precautions were also needed for pre-treatment of raw water. He recommended to further optimize the design of the IHE family filter to increase manganese removal efficiency.

Barua (2006) has continued study in Bangladesh to further optimize the IHE family filter regarding manganese removal. In his study, he examined effect of daily draining of the filter, occasional chlorination and filter media washing, addition of lime stone layer, post sand filtration and prolonged draining along with feed water storage etc. He found that arsenic was satisfactorily removed below WHO standard of 10 µg/l in most of the filters containing IOCS media. In addition, the measures lowered the manganese concentration in the filtrate by 57-80%. However, the effect was short living. Manganese concentration in filtrate of some filters was found to be higher than in ground water. Manganese released from the media occurred when dealing with groundwater having ammonia content more than 0.8 mg/l. He found the filter equipped with iron oxide coated pumice (IOCP) had the same manganese concentration

in filtrate as feed water. Daily draining of filters was found to be effective for manganese removal at sites where ammonium concentration was low. At high ammonia content in ground water ( $>2$  mg/l) created aerobic-anoxic condition within the IHE family filter.

### 1.3 Goal & Objectives of the research

The goal of the research is to optimize IHE family filter with focus on manganese removal under laboratory conditions.

The specific objectives are;

1. To screen ground water quality of a selected area of Parsa district in Terai region of Nepal (by collecting and analyzing a number of samples from tube wells);
2. To study the hydraulic capacity of the IHE family filter when treating water with high iron, arsenic and ammonium contents;
3. To monitor the performance of the filter under laboratory condition in terms of arsenic, manganese and iron removal efficiency by treating model water with high and no ammonium concentrations;
4. To study the effect of introducing the polishing layers of Aquamandix and calcium-carbonate in IHE family filter and polishing sand filter for manganese removal and overall filtrate quality; and
5. To study the ammonium removal phenomenon.

## 2. LITERATURE REVIEW

### 2.1 Arsenic in general

Arsenic contamination in groundwater has been reported in more than 20 different countries of the world. Long-term exposure to arsenic via drinking-water causes cancer of the skin, lungs, urinary bladder, and kidney, as well as other skin changes such as pigmentation changes and thickening (hyperkeratosis) (WHO, 2001). The WHO guideline for arsenic is 10 µg/l.

#### 2.1.1 Properties and chemistry of Arsenic

Arsenic is a chemical element and atomic number 33. Its atomic mass is 74.92 and ionic charge is (3-). This is a notoriously poisonous metalloid that has many allotropic forms: yellow (molecular non-metallic) and several black and grey forms (metalloids) are a few that are seen. Arsenic and its compounds are used as pesticides, herbicides, insecticides and various alloys. (Wikipedia, 2008)

Arsenic can occur in the environment in four different oxidation states (-3, 0, +3 and +5). However, arsenic presents in aqueous environment as  $\text{As}^{3+}$  and  $\text{As}^{5+}$  oxidation states. Due to its higher stability and solubility, the arsenite is difficult to be removed as compared to arsenate by simple adsorption and precipitation process. In oxidising environments, the principal mechanism of As migration is its adsorption to iron (III) oxide and hydroxides. The adsorption affinity is higher for As (V) than for As (III) within a pH range of 6 – 9. The reason is that, As (V) occurs as charged species whereas, As (III) is neutral in this pH range (Manning and Goldberg, 1996).

Arsenic can be introduced into groundwater from natural and anthropogenic source. In some aquifers, desorption of As can be caused by increasing pH after dissolution of silicates or after reductive dissolution of Fe carbonates due to cation exchange. This desorption may take place even in oxidised environments where Fe (III) hydroxides are stable. Available literature seems to agree on the fact that redox reactions involving As, Fe and S appear to be essential factors in determining arsenic fate and transport in contaminated environments (Nickson *et al.*, 2000).

#### 2.1.2 Toxicity and health effects of Arsenic

The United States Environment Protection Agency (USEPA) and International Agency for Research on Cancer (IARC) have specified arsenic as known human carcinogen. Also in some cases, there will be pain in inhaling (Bronchitis), Vomiting and Diarrhoea (Gastroenteritis). The manifestations of arsenicosis are clearer in the second stage with black

and white spots on the skin (leukomelanosis), palms and soles are affected by hard nodules (Hyperkeratosis), swelling of legs, Peripheral Neuropathy and complications of kidney and liver. Finally it also turns to cancer in skin, lungs, kidneys, liver and other organs (Petrusevski et al., 2007). These effects have been demonstrated in many studies in different parts of the world.

According to the health survey conducted so far, a very rough estimation of about 20,000 Nepalese people may prevalence of arsenicosis (Panthi *et al.*, 2006). Further health survey should be conducted with the initiation from the Ministry of Health in all arsenic vulnerable areas and a separate recording system should be developed in all health institutions for identification, treatment and monitoring of arsenicosis patients.

### 2.1.3 Removal of Arsenic

There are a number of arsenic removal technologies that are available worldwide. Arsenic removal technologies can be categorized according to their removal as follows;

- Coagulation/co-precipitation using coagulants or lime
- Adsorption on different media
- Membrane separation
- Ion exchange
- Biological

However, not all of the above-mentioned treatment technologies have found useful application for removal of arsenic from ground water (Johnson *et al.*, 2001).

Some arsenic removal processes are;

#### ***Coagulation/co-precipitation***

In the coagulation –flocculation process, aluminium sulphate, or ferric chloride is added and dissolved in water under efficient stirring for one or few minutes. Aluminium or ferric hydroxide micro flocs are then formed rapidly.

Coagulation/co-precipitation can successfully achieve removal of As (V), according to laboratory and pilot test studies, more than 90 percent of As (V) concentration can be removed. Arsenic compounds are removed from water by adsorption on hydroxide flocs. The source of the hydroxide flocs can be coagulants such as aluminium sulphate, alum,  $(\text{Al}_2(\text{SO}_4)_3 \cdot 18\text{H}_2\text{O})$ , ferric chloride  $(\text{FeCl}_3)$  and ferric sulphate  $(\text{Fe}_2(\text{SO}_4)_3 \cdot 7\text{H}_2\text{O})$  etc (Edwards, 1994). Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and they are effective over a wide range of pH. The removal efficiencies for arsenic decrease above pH 8 with ferric chloride and above pH 7 with alum. For the coagulation process oxidation of As (III) to As (V), enhance the removal of arsenic.

The limitation of the co-precipitation processes are;

- Inappropriate for most small system due to high costs and need well trained operators
- Toxic Sludge disposal is problematic

### ***Lime softening***

In lime softening (LS) metal salts are primarily used to remove calcium and magnesium cations from solution. The process is based on addition of lime or NaOH that increases the pH of the solution, thereby causing a shift in the carbonate equilibrium and the formation of calcium carbonate  $\text{CaCO}_3$  and magnesium hydroxide  $\text{Mg}(\text{OH})_2$  precipitates. Arsenic can be removed by sorption and/or co precipitation through lime softening with solids such as  $\text{Mg}(\text{OH})_2$ ,  $\text{Mn}(\text{OH})_2$  and  $\text{CaCO}_3$  formed during softening or precipitation of arsenic bearing solids such as  $\text{Ca}_3(\text{AsO}_4)_4$  and  $\text{Mn}(\text{AsO}_4)_2$ . As(III) or As(V) removal by LS is pH dependent. As(V) or As (III) removal by co precipitation with calcium carbonate (i.e., below a pH of 10.5) is poor (less than 10%). Oxidation of As(III) to As(V) prior to LS treatment and  $\text{pH} \geq 11$  will increase removal efficiencies if As(III) is the predominant form. The optimum pH for As(V) removal by softening is approximately 10.5 and the optimum pH for removal of As(III) is approximately 11.0 (EPA, 1999; EPA, 2003; Petrusevski and Sharma, 2005).

### ***Membrane technology***

Membrane techniques like reverse osmosis, nano-filtration and electro dialysis are capable of removing dissolved solids from water. In this process, water is allowed to pass through a special membrane, which physically can retain impurities larger than the membrane pore opening present in water. The membrane process treatment performance is dependent on the quality of the feed water and the desired quality of the product water (EPA, 2003). techniques show a good removal of arsenic (V) from water.

The limitations of the membrane technology are;

- Oxidation of As(III) to As(V) recommended
- Costly and troublesome in operation
- Requires extensive pre-treatment of the water
- Problem with fouling of the membrane
- Increase salinity and arsenic concentration in brine

### ***Ion exchange***

The ion exchange (IE) is a physical/chemical process by which an ion on the solid phase is exchanged for an ion in the feed water. This 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 efficiency of the 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. Sulphates and nitrates may lower the charge on arsenic depending on pH. (Ahmed *et al.*, 2000).

### ***Activated alumina***

Activated Alumina is a granulated form of aluminium oxide ( $\text{Al}_2\text{O}_3$ ) with very high internal surface area, in the range of  $200\text{-}300\text{m}^2/\text{g}$ . Activated alumina is formed by the thermal dehydration ( $250^\circ\text{C}$  to  $1150^\circ\text{C}$ ) of an aluminium hydroxide  $\text{Al}(\text{OH})_3$  such as, gibbsite, bayerite, etc (Barua, 2006; HARVARD, 2006).

The process involves water passing through a packed column of activated alumina, the impurities including arsenic present in water are adsorbed on the surface of activated alumina grains. Eventually the column becomes saturated, first at its upstream zone followed by the column-saturated zone. Regeneration of the 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 wastewater. The residual caustic soda is then washed out and the medium is neutralised with 2 % solution of sulphuric acid rinse. During the process about 5 – 10 %, alumina is lost and the capacity of the regenerated medium is reduced by 30 – 40 %. The mechanism of Al- loss is enhanced by dissolution due to hydrolysis. The activated alumina needs replacement after 3 – 4 regeneration cycles (Ahmed *et al.*, 2000).

The limitations of adsorption with ion exchange are;

- Oxidation of As(III) to As(V) recommended.
- Strong pH dependence
- Reduction of adsorption capacity significantly with each regeneration cycle
- High concentrated waste streams-disposal of brine

### ***Granular ferric hydroxide***

The Granular Ferric Hydroxide (GFH) is a selective adsorbent capable of adsorbing of arsenic on a granular ferric hydroxide fixed bed reactor. This unit requires removal of iron prior to treatment to avoid clogging of the filter bed. The proponents of this unit claim that it has high arsenic removal efficiency and produces toxic granular ferric hydroxide. (Ahmed *et al.*, 2000). The adsorption capacity of the GFH is  $1\text{-}10\text{ gAs/kg adsorbent}$  and has 5-20 times longer life time in comparison to activated alumina.

### ***Iron oxide coated sand (IOCS)***

Iron oxide coated sand (IOCS) consists of sand grains coated with ferric hydroxide that are used in fixed bed reactors. demonstrated that IOCS is equally effective in removing both As (III) and As (V) (Joshi and Chaudhari,(1996). Recent studies conducted with IOCS media have revealed that the affinity of this media for arsenic is remarkable. IOCS can produce arsenic-free water (below  $10\text{ }\mu\text{g As/l}$ ) from groundwater with high arsenic concentrations,

irrespective of the arsenic speciation. This feature allows IOCS to treat much higher bed volumes without the need for pre-oxidation or pH adjustment (Petrusevski *et al.*, 2002).

Several studies have been carried out at UNESCO-IHE (The Netherlands) on arsenic mitigation by using IOCS, originating from ground water treatment plants in the Netherlands as their by-product. Arsenic, iron and phosphates could be removed very effectively (Petrusevski *et al.*, 2002).

### ***Manganese dioxide coated media (MDCS)***

Manganese dioxide coated sand (MDCS) is a media that has been used for arsenic removal. This media can remove both arsenic (III) and arsenic (V) due to the oxidation potential of  $MnO_2$ . Studies have been shown that the MDCS can remove arsenic from water by adsorption of the arsenate ions on to  $MnO_2$  surface (Bajpai and Chaudhari, 1999). The main removal mechanism is the oxidation of arsenite by manganese dioxide in to arsenate and adsorption of arsenate and released Mn during oxidation to manganese dioxide ( $MnO_2$ ). The equation below shows the oxidation reaction (Bajpai and Chaudhari, 1999).



The released  $Mn^{2+}$  ions adsorb onto the manganese dioxide, giving it a positive surface charge and leading to an enhancement in the removal (adsorption) of arsenate present initially or produced as a result of the arsenite oxidation.

### ***Iron oxide coating pumice (IOCP)***

Due to the large surface area, availability and a low price, different studies are investigated the efficiency of the IOCP for arsenic removal. In UNESCO-IHE (The Netherlands), pilot test showed a good adsorption of arsenic but IOCP has lower arsenic adsorption removal capacity than that of IOCS.

### ***Microbial processes***

Several bacteria are capable of oxidising arsenite to arsenate thereby eliminating the need for the use of oxidants in other treatments. Biological treatment of arsenic is based on the theory that microorganisms that act directly on arsenic species or create ambient conditions that cause arsenic to precipitate/co-precipitate from water. During biological treatment, the micro organisms cannot only change arsenic speciation, but can also remove arsenic at various conditions of temperature, pH, etc (EPA, 2002). The exact removal mechanism involved is still unclear.



## 2.2 Manganese in general

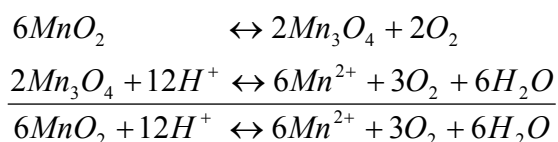
Manganese is one of the abundant materials in the earth's crust. Manganese comprises about 0.1% of the Earth's crust (Petrusevski *et al.*, 2007). Crustal rock is a major source of manganese found in the atmosphere (Howe *et al.*, 2005). Manganese is a mineral that naturally occurs in rocks and soil as ores and usually coexist with iron. It exists in well water as a groundwater mineral, but may also be present due to underground pollution sources. Manganese is an essential trace element in animal nutrition and is believed to be an essential trace mineral in human nutrition, as well. However, chronic exposure to high doses may be harmful (Leach and Harris, 1997; USEPA, 2003). Manganese is commonly found dissolved in borehole waters. It may become noticeable in water at concentrations greater than 0.1 mg/l by imparting odour, taste or staining of plumbing fixtures and turbidity to the water (WHO, 2004). The WHO guideline for manganese is 0.4 mg/l.

### 2.2.1 Properties and chemistry of Manganese

Manganese is a metallic element with atomic number 25 and an atomic weight of 54.94 daltons. Manganese exists in the oxidation states  $Mn^{2+}$  or Mn (II) and  $Mn^{3+}$  or Mn (III) (PDR, 2007).

Mn (II) in aqueous solutions is stable at pH values below 9 because of its very low rate of oxidation. Therefore, in the range of pH 6 to 9 of most natural waters, Mn (II) if presents remains stable. Mn (II) oxidation results in the formation of Mn oxides which occur as coating on the soil and sediment particles and as discrete particles (Buamah *et al.*, 2008b; Ehrlich, 1996). Mn (III) is thermodynamically unstable in aqueous solutions, being easily reduced to Mn (II) and can even undergo dis-proportionation reaction in the absence of reducing agents (Buamah *et al.*, 2008b; Cotton and Wilkinson, 1967). Mn (III) does not occur in soluble form except in the presence of strong complexing agents such as humic acids or other organic acids (Buamah *et al.*, 2008b; Kostka *et al.*, 1995). Mn (III) and Mn (IV) primarily form insoluble oxides and hydroxides. The solubility of manganese (IV) oxide ( $MnO_2$ ) very low within the pH range 3 to 10.

Primary chemical factors controlling sedimentary manganese cycling are the oxygen content of the overlying water, the penetration of oxygen into the sediments, and benthic organic carbon supply. In soils, manganese solubility is determined by two major variables: pH and redox potential. Mn (II) dominates at lower pH and redox potential, with an increasing proportion of colloidal manganese oxy-hydroxides above pH 5 (Howe *et al.*, 2005). The soluble manganese compounds can be leached out under anaerobic conditions as stated in following reaction.





### 2.2.2 Toxicity and health effects of Manganese

Manganese may become noticeable in underground water at concentrations greater than 0.1 mg/l by imparting a colour, odour, or taste to the water. It reaches an undesirable level due to taste, odour, or colour before it becomes a health hazard. The World Health Organization guidance level for manganese in drinking water is 0.4 mg/l to protect against manganese toxicity (WHO, 2004).

Besides imparting bad taste, colour and smell to the water, exposure to high concentration of manganese over the course of years has been associated with toxicity to the nervous system, producing a syndrome that resembles Parkinsonism mostly in the elderly (DEEOH, 2001). Some of health effects related to manganese poisoning are Bronchitis, hallucinations, forgetfulness, reproductive disorder mainly in men etc (WHO, 2004). Some of the symptoms of manganese can be reduced by medical treatment, but the brain injury is permanent. In men it can cause impotence (SDWF, 2004). Manganese effects occur mainly in the respiratory tract and in the brains. A syndrome that is caused by manganese has symptoms such as schizophrenia, dullness, weak muscles, headaches and insomnia (LENNTECH, 2006).

### 2.2.3 Removal of Manganese

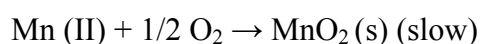
Most drinking water production plants use rapid sand filters for the removal of manganese from ground water (Buamah *et al.*, 2008a). However, there are several processes to remove manganese from groundwater. These are;

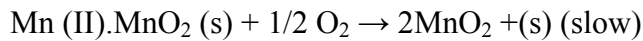
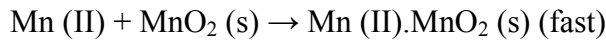
- Oxidation- rapid sand filtration
- Oxidation by potassium permanganate
- Oxidation by chlorination
- Oxidation by ozone
- Manganese green sand filtration
- Manganese removal by lime/soda ash softening
- Biological manganese removal

#### ***Oxidation- rapid sand filtration***

The process involves Aeration –Rapid sand Filtration. In oxidation,  $Mn^{2+}$  gets oxidized to  $Mn_3O_4$  that acts as a catalyst on which new  $Mn^{2+}$  is adsorbed and oxidized to  $Mn_3O_4$  while older  $Mn_3O_4$  gets oxidized to  $MnO_2$ .  $Mn_3O_4$  layer on sand grains is essential for the Mn removal by oxidation and rapid sand filtration process. Therefore backwashing should be done carefully (Petrusevski *et al.*, 2007).

Stumm & Morgan (1981) stated that automatic oxidation proceeds as follows:





Product of Mn (II) oxygenation are non stoichiometric showing various degree of oxidation ranging from  $\text{MnO}_{1.3}$  to  $\text{MnO}_{1.9}$  (30 to 90% oxidation to  $\text{MnO}_2$ ) under varying alkaline conditions.

Manganese Oxidation Kinetics could be described by the equation of Stumm & Morgan (1981)

$$d [\text{Mn (II)}]/dt = -k'_0 [\text{Mn (II)}] + k'_1 [\text{Mn (II)}][\text{MnO}_2]$$

Where,

$$k' = k p\text{O}_2 \cdot [\text{OH}^-]^2$$

$[\text{Mn(II)}]$  = concentration of Mn(II) (mol/l)

$t$  = time (min)

$k'_0$  = reaction rate constant ( $\text{l}^2/\text{mol}^2 \cdot \text{atm} \cdot \text{min}$ )

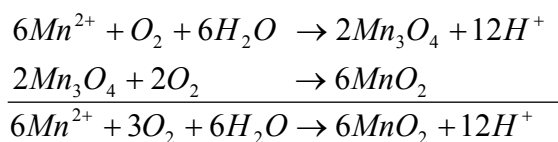
$k'_1$  = reaction rate constant ( $\text{l}^3/\text{mol}^3 \cdot \text{atm} \cdot \text{min}$ )

$p\text{O}_2$  = partial pressure of oxygen (atm)

$[\text{OH}^-]$  = concentration of hydroxyl ion (mol/l)

$[\text{MnO}_2]$  = concentration of  $\text{MnO}_2$  on filter media (mol/l)

The oxidation reaction could be described by the following reaction;



From this equation it can be calculated that 1 mg of Mn requires 0.29 mg of oxygen.

The rate of oxidation of  $\text{Mn}^{2+}$  in rapid sand filters is much lower than that of  $\text{Fe}^{2+}$  and  $\text{MnO}_2$  flocs are finer than Fe-flocs and more difficult to remove.  $\text{Mn}^{2+}$  is adsorbed on filter media and oxidized to  $\text{Mn}_3\text{O}_4$  while older gets oxidized to  $\text{MnO}_2$ . So  $\text{Mn}_3\text{O}_4$  layer on sand grains is essential for Mn removal (Petrusevski *et al.*, 2007).

Manganese oxidation is very low at pH values below 8.6, thus at the usual pH values encountered in most drinking waters (6-8), manganese will not be oxidized. Commonly used oxidizing agents are oxygen, chlorine and potassium permanganate ( $\text{KMnO}_4$ ). Oxidation rates depend on the oxidant used, pH, alkalinity and the presence if organic matter. Generally, potassium permanganate oxidizes the quickest, followed by chlorine and finally oxygen (Samual and Osman, 1983).

***Oxidation by potassium permanganate***

Potassium permanganate oxidizes Mn(II) to Mn(IV) very rapidly and the optimum pH range apparently is 7.2 to 8.3 (Samual and Osman, 1983). Factors that affect removal efficiency include water chemistry, pH temperature and application point, Reaction times are rapid under normal conditions of temperature and pH. In most cases, 5 to 10 minutes of reaction time is sufficient (Carus, 2005).

***Oxidation by chlorination***

Chlorination is widely used for oxidation of divalent iron and manganese. 1 mg/l of soluble manganese requires 1.29 mg/l of chlorine. Chlorine oxidizes Mn(II) to Mn(IV) over a wide range of pH. However, the formation of disinfectant-by – products e.g. tri-halomethanes (THMs) would be a problem.

***Oxidation by ozone***

Ozone may be used for iron and manganese oxidation. 1 mg/l of soluble manganese requires 0.87 mg/l of ozone. If not dosed carefully, ozone and oxidize reduced manganese to permanganate and result in pink water formation as well.

***Manganese green sand filtration***

Iron and manganese can be removed by green sand filtration. The active material in "greensand" is glauconite. Glauconite is a green clay mineral that contains iron and has ion exchange properties. Glauconite often occurs mixed with other material as small pellets, thus the name "greensand." The glauconite is mined, washed, screened, and treated with various chemicals to produce a durable greenish-black product that has properties that allow it to adsorb soluble iron and manganese (Much, 1992).

As water is passed through the filter, soluble iron and manganese are pulled from solution and later react to form insoluble iron and manganese. Insoluble iron and manganese will build up in the greensand filter and must be removed by backwashing. Backwashing should be done regularly twice a week (Much, 1992).

Manganese dioxide has the ability to adsorb iron and manganese in anaerobic condition. Therefore, there is almost no particulate build –up within the filter bed. Manganese dioxide is the coating on manganese greensand.

Manganese green sand exchange capacity is 1.45 g of Mn (or Fe)/L of manganese green sand (Petrusevski *et al.*, 2007).

### ***Manganese removal by lime/soda ash softening***

When water is softened using lime or lime/soda ash softening processes, a beneficial side effect is virtually complete removal of Fe and Mn. Addition of lime or soda ash raises the pH to about 10 if only calcium is to be removed or about pH 11 if the ferrous and manganous ions are to be precipitated as iron and manganese sludge. Usually insignificant levels of Fe and Mn remain, and no additional Fe and Mn removal treatment is needed (WATEREYE, 1998).

### ***Biological manganese removal***

The biological oxidation of Mn(II) is generally mediated by species of several genera such as *Leptothrix*, *Crenothrix*, *Hyphomicrobium*, *siderocapsa* and *Metallogenium*. Generally, the bacteria reduce the Mn through a biocatalytic process, including intercellular oxidation by enzymatic action, adsorption of the dissolved Mn at the surface of the cell membranes and extra cellular oxidation by catalytic action of excreted polymers. Mn is deposited as manganese dioxide,  $\text{MnO}_2(\text{s})$ , a black precipitate that is denser and more easily dewatered than Mn precipitates from a physical chemical process (Ioannis and Anastasios, 2004).

Typical conditions needed within the filter are pH above 7.5, DO greater than 5 mg/L and redox potential  $>300$  mV.

Limitations for biological manganese removal;

- Difficult to control,
- Bacteria responsible for the process might require stringent conditions (Petrusevski *et al.*, 2007)

## **2.3 Iron in ground water**

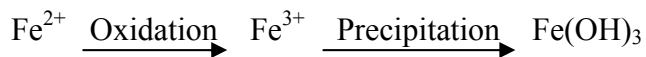
There is no health effect related to iron consumption however, iron in water supplies causes various aesthetic and operational problems including bad taste, discoloration, staining of laundry and plumbing fixtures. Iron deposited in the distribution system may promote the growth of the micro organisms, leading to high turbidity (O'Connor, 1971; Vigneswaran and Visvanathan, 1995). Furthermore, in rural areas, the bad taste and the reddish-brown colour of the ground water due to the presence of iron could discourage the population to consume safe ground water and consequently drive them to contaminated sources. The iron concentration in drinking water should be as low as possible. The guideline value for iron in drinking water for European community as desired value is  $\leq 0.05$  mg/l (Petrusevski *et al.*, 2007) and several water supply companies are aiming at iron levels below 0.03 mg/l in order to minimize the distribution network maintenance costs (Sharma *et al.*, 2001). In Nepal, according to the national drinking water quality standard implementation guidelines -2005, the recommended value for iron in drinking water is  $\leq 0.3$  mg/l (MPPW, 2005).

### 2.3.1 Iron removal process

The iron removal may be either based on physical-chemical or biological process.

#### *Physical-chemical process*

Groundwater is naturally anaerobic, so iron remains in solution. The elimination of ferrous iron is obtained by raising the water redox potential by oxidation. Thus, the ferrous iron is oxidized in ferric iron, which precipitates in iron hydroxide,  $\text{Fe}(\text{OH})_3$ .



Biological process: In anaerobic groundwater, iron remain in soluble forms of  $\text{Fe}^{2+}$ . Naturally occurring bacteria, (Iron bacteria) when placed in the right environment and given the appropriate oxygen rate potential are able to catalyse the oxidation of iron and manganese (Paul, 2002). These bacteria allow the simultaneous oxidation and filtration of these metals at rates two to four times higher than conventional systems. The biological process is catalytic in nature and causes a rapid oxidation of iron by some variation to the physical-chemical reaction (Brian et.al.2001);



The red insoluble precipitates formed are all slightly hydrated iron oxides that are more compact than the precipitates formed by physical chemical processes.

#### *Common treatment processes*

Iron can be effectively removed from water using a number of treatment processes depending on both the form and concentration of the metals and certain water quality factors. Typical factors for iron and manganese removal are (WCHD, 2007);

- The concentration of iron and manganese;
- The pH (acidity) and hardness;
- Silica content and sulphur;
- Dissolved oxygen for some treatment types; and
- The presence of iron and manganese bacteria.

There are five treatment methods for the removal of iron and from home water systems (Herman, 1996)

#### *Water softener (Ion exchange)*

A water softener can remove small amounts of ferrous iron and manganese. The principle is the same as that used to remove the hardness minerals, calcium and magnesium. Iron and manganese in untreated water are flushed from the softener medium (ion exchange) by backwashing, i.e. forcing sodium-rich water back through the device. Iron and manganese in

the untreated water are exchanged with sodium on the ion exchange medium. This process adds sodium to the resin medium, and the iron is carried away in the wastewater. The amount of iron and manganese a softener can remove depends on the water properties, the types of regeneration and backwash controls, and the ion exchange resin or zeolite used. Removal efficiencies by softeners will vary depending on the iron concentrations, water hardness, and pH. Softeners are generally only recommended when the water pH is greater than 6.7, the water hardness is between 3 and 20 grains per gallon (50-350 mg/l) and the dissolved iron concentration is less than 5 mg/l.

### ***Aeration followed by filtration***

High levels of dissolved iron at combined concentrations up to 25 mg/l can be oxidized to a solid form by aeration (mixing with air). For domestic water processing, the 'pressure-type aerator' is often used. In this system, air is sucked in and mixed with the passing stream of water. This air-saturated water then enters the precipitator/aerator vessel, where air separates from the water. From this point, the water flows through a filter where various filter media are used to screen out oxidized particles of iron, manganese and some carbonate or sulphate (WU, 2007). This method adds no chemicals to the water and is most effective in warm climates. The filter must be backwashed frequently to properly maintain the system. To protect the water from contamination by bacteria in the air, the system should be totally enclosed and only biologically safe water should be used (Herman, 1996). Manganese oxidation is slower than that of iron and requires greater quantities of oxygen. Aeration is not recommended for water containing organic complexes of iron/manganese or iron/manganese bacteria that will clog the aspirator and filter.

### ***Oxidizing (catalyst) filter***

When the total combined iron and manganese concentration is less than 15 mg/l, an oxidizing filter is recommended. The filter material is usually natural manganese greensand or manufactured silica gel zeolite coated with manganese dioxide, plastic resin beads, or pumicite, which adsorbs dissolved iron and manganese (Herman, 1996). Some filters are coated with a manganese oxide and are regenerated by using a potassium permanganate solution. An oxidizing filter supplies oxygen to convert ferrous iron into a solid form, which can be filtered out of the water. Frequent backwashing and stirring of a manganese greensand bed helps prevent an iron-fouled bed. Synthetic filters, such as zeolite, require less backwash water and soften the water as it removes the iron and manganese.

### ***Chemical oxidation followed by filtration***

When combined levels of iron and manganese exceed 10 mg/l, the most effective treatment involves oxidation followed by filtration. In this process, a chemical is added to convert any dissolved iron and manganese into the solid, oxidized forms that can then be easily filtered from the water. Chlorine is most commonly used as the oxidant, although potassium

permanganate and hydrogen peroxide can also be used (Bryan et al., 2004). This treatment is particularly valuable when iron is combined with organic matter or when iron bacteria are present (Varner et al., 2007). A small chemical feed pump is used to feed the chlorine solution (usually sodium hypochlorite) into the water upstream from a mixing tank or coil of plastic pipe. A retention time of at least 20 minutes is required to allow oxidation to take place. The resulting solid particles must then be filtered. When large concentrations of iron are present, a flushing sand filter may be needed for the filtering process. When chlorine is used as the oxidizing agent, excess chlorine remains in treated water. If the particle filter is made of calcite, sand, anthracite or aluminium silicate, a minimum quantity of chlorine should be used to avoid the unpleasant taste that results from excess chlorine. The ideal pH range for chlorine bleach to oxidize iron is 6.5 to 7.5. The optimum rate of oxidation of iron and manganese by chlorination is at a pH of about 8.0 and 8.5, respectively (Bruce et al., 1992). Soda ash injected with the chlorine will increase the pH to optimum level. Chlorination is not the method of choice for high manganese levels since a pH greater than 9.5 is required for complete oxidation. Potassium permanganate will effectively oxidize manganese at pH values above 7.5 and is more effective than chlorine oxidation of organic iron if that is a problem. Potassium permanganate is poisonous and a skin irritant. There must be no excess potassium permanganate in treated water and the concentrated chemical must be stored in its original container away from children and animals. Careful calibration, maintenance and monitoring are required when  $\text{KMnO}_4$  is used as an oxidizing agent. Any material used in filtration process requires frequent and regular backwashing or replacement to eliminate the solid iron/manganese particles. Some units have an automatic backwash cycle to handle this task.

### ***Other treatment***

A phosphate compound treatment can be used to control dissolved iron and manganese with combined concentration of up to 3 mg/l. Phosphate compounds work by surrounding the minerals and keeping them suspended in the solution. The phosphate compounds must be introduced into the water at a point where the iron is still dissolved in order to maintain water clarity and prevent possible iron staining. If organic-complex or colloidal iron/manganese is present in untreated water, a longer contact time and higher concentrations of chemicals are necessary for oxidation reaction to take place. Adding aluminium sulphate (alum) improves filtration by causing larger iron/manganese particles to form.

A multistage treatment operation may be necessary, if the water contains high levels of iron and manganese and they are in both, the dissolved and solid forms. The water could first be aerated, then chlorinated to oxidize residual iron and kill bacteria, and then filtered through a mechanical device to remove particles. This can be followed by activated carbon filtration to remove excess chlorine and a water softener for hardness control as well as removal of any residual dissolved iron and manganese (Herman, 1996).



## 2.4 Ammonia in ground water

Ammonia in groundwater originates from domestic wastewater, fertilizers, peat, industrial wastewater etc. Natural level of ammonia in groundwater is usually less than 0.2 mg/l. However, anaerobic groundwater may contain more than 5 mg/l of ammonia. Presence of ammonia in groundwater is an indicator of possible bacteriological (sewage) pollution. Presence of Ammonia ( $\text{NH}_3 + \text{NH}_4^+$ ) in groundwater can negatively effect of manganese removal in the filters. It can cause growth of bacteria in the filter and cause nitrite formation due to lack of sufficient oxygen to complete oxidation of  $\text{NH}_4^+$  to  $\text{NO}_3^-$ . Ammonia affects the effectiveness of disinfection with chlorine and cause taste and odour problems.

### 2.4.1 Ammonia removal processes

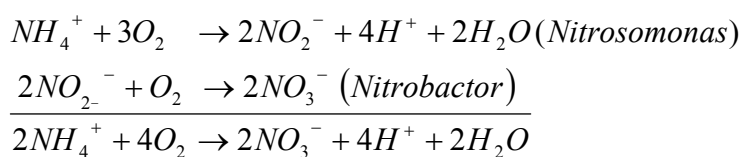
Ammonia can be removed in the following processes:

- Break point chlorination
- Bio-oxidation in slow sand filters, rapid sand filters, dry filters and lakes and rivers
- Air stripping and
- Ion exchange

#### *Ammonia removal in filters*

Concentration of ammonia that can be removed in SSF and RSF is limited by available oxygen and presence of biodegradable organic and inorganic matter that can consume oxygen, Approximately 1.5 mg of ammonia per litre can be typically removed in rapid sand filter (Petrusevski *et al.*, 2007).

Bio-oxidation of ammonia can be illustrated by the following equations;



From above equations it can be calculated that 1 mg of  $\text{NH}_4^+$  requires 3.6 mg of oxygen.

### 2.4.2 Nitrites and Nitrates

Nitrates and nitrites are nitrogen-oxygen chemical units, which combines with various organic and inorganic compounds. Once taken into the body, nitrates are converted into nitrites. The greatest use of nitrates is as a fertilizer. WHO has sated the guideline value for nitrite and nitrate are 50 mg/l and 0.2 mg/l respectively.



### 2.4.3 Health effects of Nitrites and Nitrates

Both short-term and long-term health effects are associated with human exposure to nitrite and nitrates.

**Short-term:** Excessive levels of nitrate in drinking water have caused serious illness and sometimes death. The serious illness in infants is due to the conversion of nitrate to nitrite by the body, which can interfere with the oxygen-carrying capacity of the child's blood. This can be an acute condition in which health deteriorates rapidly over a period of days. Symptoms include shortness of breath and blueness of the skin.

**Long-term:** Nitrates and nitrites have the potential to cause the following effects from a lifetime exposure at levels above the MCL: diuresis, increased starchy deposits, and haemorrhaging of the spleen.

## 2.5 Quality of ground water in Nepal

Nepal has abundant renewable water resources. The annual rainfall varies from 500 mm in some western areas to more than 4,000 mm on the southern slopes of the Himalayan range, with 70-80% occurring in summer (monsoon) and generating runoff to more than 6,000 watercourses. Groundwater of good quality is available at shallow depth and it maintains the base flow of most rivers and is used intensively in the absence of surface water. The most important groundwater basins are located in the Terai Plains and in some of the mid-hill valleys, such as Kathmandu and the Dang.

Deep ground waters present in the Terai are vulnerable to increased concentrations of arsenic, iron, manganese and ammonium (Maharjan, 2007). Other potential groundwater quality problems are associated with high concentrations of dissolved methane and ammonia. The actual scenario of the ground water contamination in Nepal is not clear, probably worse since all the tube wells are not yet tested.

### 2.5.1 Country background

Nepal is a mountainous country with 47% of its population (around 11 million people) living on the flat land in the south Terai region (CBS, 2002). According to the population census data 2001, the total population of Nepal is 23.4 million. Out of this about 10.4 million people (45% of total) live in 20 Terai-districts of Nepal. A large proportion of population in the Terai region being affected by the poor quality of the ground water with adverse health impact.

### 2.5.2 Arsenic in Nepal

Safe drinking water is still an important issue in Nepal. Until 1970s, most rural people of Terai region of Nepal obtained and consumed water from dug-wells, rivers, canals or ponds. These contaminated waters were consumed directly without any treatment. Epidemics of cholera, diarrhoea, typhoid and other water-borne diseases were very common in this region. Thousands of people particularly the infants died only because of drinking these unsafe waters. From 1980s, an idea of tapping ground water came as the most popular program for controlling many waterborne diseases by providing clean and pathogen free drinking water. Agencies and individuals installed a considerable number of shallow tube wells. Although emerging number of tube wells succeeded in reducing the number of death from waterborne diseases but unfortunately it is now established that many of tube wells water contain arsenic at concentration higher than the safe limit for drinking purpose (Panthi *et al.*, 2006).

An unexpected issue came to be known as arsenic contamination in groundwater of Bengal Delta Plain (BDP) in neighbouring Indian State of West Bengal and Bangladesh. The Department of Water Supply and Sewerage (DWSS), with assistance from WHO, Nepal, conducted for the first time a systematic research study on possible arsenic contamination in groundwater of Jhapa, Morang and Sunsari districts of Terai region in 1999. These districts are bordering to Indian State of West Bengal. The study provided evidence of arsenic contamination higher than the safe limit (NASC/UNICEF, 2007).

The potential health risk due to arsenic contaminated drinking water is profound as 48.4% (about 13 million) of the total population of the country inhabits the Terai region. It is estimated that arsenic contamination could affect more than 1.4 million populations across 20 Terai districts using estimated one million tube wells (Lawoti, 2006). Realising the need to address this serious health issue, number of governmental and nongovernmental organizations have initiated tube well testing and mitigation programmes since early 2000.

The first major investigation of arsenic in ground water was completed in 2001 by DWSS/UNICEF, testing 4,000 tube wells in all 20 Terai districts. The study found over 3% tested tube wells above 50 µg/l and over 10% exceeded WHO guideline of 10 µg/l. The “State of Arsenic in Nepal-2003” study done by NASC and ENPHO, tested 18,635 tube wells in 20 Terai districts and reported 23.7% tube wells above WHO guideline of 10 µg/l and 7.4% exceeding Nepal Interim Standard guideline of 50 µg/l (NASC and ENPHO, 2004). Since 2004, blanket testing program was started in all the 20 Terai districts by DWSS and NRCS with the assistance of UNICEF. By March 2007, nearly 640,000 tube wells have been tested in 13 Terai districts under the blanket-testing program. The study contained blanket test data of 327,641 tube wells with additional 11,308 tube well data from “State of Arsenic in Nepal-2003.” The study showed 2.8% tube wells exceeded arsenic levels of 50 µg/l and 13% tube wells above WHO guideline of 10 µg/l (NASC/UNICEF, 2007). The study also found Nawalparasi district as the most affected district with 24% tested tube wells above 10 µg/l and 11.7% above 50 µg/l arsenic levels.

Figure 2-1 shows the vulnerability level of arsenic contamination of ground water in Terai region of Nepal. Out of total 20 districts in the region, 3 districts are highly affected by the arsenic contamination and rest are moderately affected.

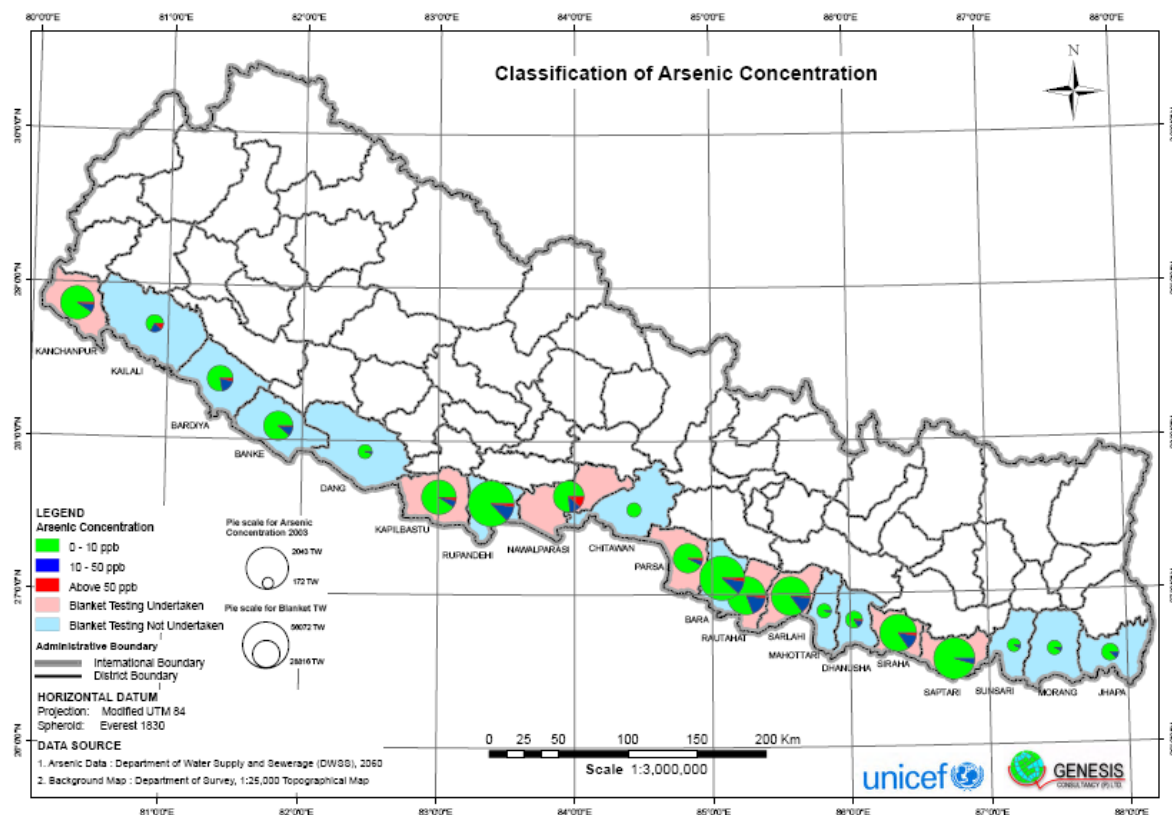


Figure 2-1: Drinking water vulnerability to arsenic in Terai region of Nepal (Source: ENPHO)

### 2.5.3 Arsenic committee in Nepal

In early 2000, the National Arsenic Steering Committee (NASC), which includes major stakeholders from government and non-government sectors, was created as a first step by the government to address the arsenic issue in the country. Some of the key stakeholders involved in testing wells for arsenic concentration in different parts of the country are DWSS/UNICEF, NRCS/ENPHO, RWSSSP, RWSSFDB, NEWAH, PLAN Nepal, DoI, and MoE. The “National Interim Policy on Arsenic” was the first document drafted by NASC to guide stakeholders to work on this issue (NASC, 2001). All agencies involved in the water and sanitation sector then prioritized arsenic testing in their programme areas.

NASC has been developing policies, procedures, and standards to guide agencies and individuals who work in the field of arsenic mitigation in drinking water supplies

Since 2005, it has become mandatory that prior to carrying out any arsenic related research, testing or mitigation, details should be submitted to NASC/DWSS and the programme should be carried out in coordination with other organisations working in the same sector in the programme areas. This is to avoid duplication of programmes and work.

#### 2.5.4 Interim Nepal guidelines and policies for Arsenic in drinking water

The Interim Nepal Guidelines and Policies for Arsenic in Drinking Water were adopted on 1<sup>st</sup> June 2001 by NASC. The policy provides guiding principles for all government and non-government agencies when formulating, designing and implementing arsenic programmes. The policy has established permissible arsenic concentration values of 50 µg/l for drinking water. The policy focuses on immediate attention to be given by stakeholder agencies in identifying the existing “arsenic hot spots” and carrying out more testing on hot spots to better understand the extent and magnitude of arsenic contamination. The policy also highlights health survey and health care issues as well as communication with communities

### 2.6 Arsenic mitigation options for Nepal

#### 2.6.1 Technology options

If unsafe levels of arsenic exist in the drinking water supply, the immediate concern should be finding a safe source of drinking water. There are two main options: finding a new safe source or removing arsenic from the contaminated source. In either case, the drinking water supplied must be free from arsenic, but also from bacteriological contamination, and other chemical contaminants. There may be no single technology that can provide communities with a sustainable, continuous, affordable, safe water supply (Johnson *et al.*, 2001).

The technological options for safe water supply in the arsenic affected areas could be one of the following (Nath and Khalil, 2002);

- i) Tapping ground water from alternate arsenic-free aquifers at a higher depth and proper sealing-off of the arsenic bearing aquifer from the same.
- ii) Large scale piped water supply for the rural communities by drawing water from the rivers and treating them for removal of pathogenic microbes.
- iii) Conservation and protection of traditional surface water sources like ponds, dugwells etc. in the villages. These sources are generally free from arsenic but grossly contaminated with faecal pollution.
- iv) Removing arsenic from the ground water, by using technologies like absorption, co-precipitation or ion- exchange etc. In assessing the best alternative of water supply both, technical and socio-economic criteria should be evaluated.

Technical criteria include water quality & quantity, reliability, robustness, operational safety and environmental soundness. Socio-economic criteria are economic feasibility, institutional capacity and gender considerations, convenience, communication considerations and social acceptability (Begum, 2003).

The Interim Nepal Guidelines and Policies for Arsenic in Drinking Water emphasize on the finding of safe sources of drinking water by source substitution or by removing arsenic from

a contaminated source. Source substitution includes switching to groundwater from safe or new wells, rainwater harvesting and surface water free from harmful levels of arsenic as well as from other chemicals and bacteriological contamination. The main arsenic removal options include methods such as co-precipitation, ion exchange resins, activated alumina absorption, membrane methods and other technologies (NASC/UNICEF, 2007).

The Drinking water supply and sanitation (DWSS) has also prescribed arsenic mitigation guidelines to reduce arsenic levels in drinking water. The guideline prescribes short term and long term safe water alternatives for the most affected areas.

The Arsenic Mitigation Programme in Nepal has promoted a wide range of technology options for arsenic affected areas and also piped water supply wherever feasible (NASC/UNICEF, 2007). These are;

- Improved Dug Wells
- Safe tube wells
- Rainwater Harvesting;
- house hold filters

### ***Improved dug wells (DW)***

Dug well is a traditional technology for withdrawal of ground water. The water of DW is free from dissolved arsenic and iron even in locations where tube wells show arsenic. In arsenic affected areas dug wells have been proven to be safe, acceptable and popular source of alternative water supply (Salehuddin, 2005). However, dug well water may be exposed to microbial contamination. Provision for dug wells with good sanitary protection has been in practice for some time in Nepal (NASC/UNICEF, 2007). Rehabilitation, chlorination and sanitary improvement of the surroundings of dug wells are essential if they are used for drinking purpose.

### ***Rainwater harvesting***

Rainwater harvesting is basically a household-based technology. It has good potential for water supply all over the country. In areas where alternative water sources are not easily available, the potential of rainwater harvesting as alternative source of safe water supply has good prospect. The quality of rainwater is relatively good, but it is not free from all impurities. Cleanliness of roof and storage tank is critical in maintaining good quality of rainwater.

### ***Household filters***

Household filters for arsenic removal were distributed by some agencies as a short term and immediate relief option in areas where alternative water sources are not available. Through research, different filters have been investigated and implemented, which can be used when no arsenic free water is available. However, testing needs to be conducted to verify for how *Optimisation of IHE family filter for manganese removal under laboratory conditions*

long these filters can be used before replacing them or their active element. Examples of these household filters distributed by various implementing agencies are two gagri and three gagri filter systems with chemical powder and arsenic iron removal plant (AIRP). Today however, the improved bio-sand filter, the Kanchan Arsenic Filter, has replaced these short-term mitigation options.

### **2.6.2 Some available Arsenic removal units in Nepal**

A variety of arsenic removal technologies is now available in Nepal. Though some of the available technologies can remove arsenic below WHO guideline value or Nepal standard, not all of them are suitable for rural areas. It is also true that most of the technologies are being continuously refined to make it suitable for rural conditions. For rural people, ease of O & M is the prime criteria for any technology to be successful there. Costs and availability of the materials is also important for its sustainability. Brief descriptions of the commonly used technologies are stated below.

#### ***Two-gagri filter system with chemical powder***

The system consisting two earthen pots (gagri), uses chemical powder (a mixture of  $\text{FeCl}_3$ ,  $\text{NaOCl}$  and charcoal). Ferric chloride is the compound that removes arsenic present in affected water. The candle filter aids in filtration of the coagulants formed in the upper pot. The second pot underneath the first one receives water free from arsenic, iron, bacteria and odour. This system is 90 % efficient in removing arsenic and is below the Nepal interim guideline 50  $\mu\text{g/l}$ .

#### ***Three-gagri filter***

The three gagri filter replicates the three kolshi system of Bangladesh and solves the problem of chemical powder. Oxidation, Adsorption, precipitation and filtration are process for removal of arsenic and iron in this filter. This filter system can remove up to 95% of the arsenic, even when the water is highly contaminated. Retardation of filtration process due to clogging and presence of microbes in the treated water limits the filter's performance. Therefore, techniques for improved of microbiological quality should also be used while providing this option.

#### ***Improved bio-sand filter***

Bio-sand Filters that are being used around the world to remove both physio-chemical and bacteriological contamination is now also being tested for arsenic removal. This filter has been introduced in the Terai region previously for removal of iron and bacteriological contamination. Since this filter system is durable and considering the iron removal efficiency, it is expected that it will also remove arsenic with some modifications. The newly improved



bio-sand filter has a tray above the biological layer where iron nails are kept. This filter uses the process of aeration, absorption and filtration. This system removes iron, arsenic as well as bacterial contamination without using any chemicals. As this system has high flow rate of 30 litres per hour this has been of high demand in the communities not only for arsenic removal but also due to the flow rate that serves the household with ample water per day.

Efficiency tests shows that this filter removes more than 95% arsenic on an average and 99% in most of the cases. So far, the filter has removed arsenic from 580  $\mu\text{g/l}$  to 20  $\mu\text{g/l}$ , which is quite impressive. In some cases, the removal is not that efficient as expected; as the filtration unit was not used properly e.g. iron nails placed in the tray were not spread properly for water to get in contact with the nails. The filter also shows high level of iron removal (up to 99 % with an average of 95%) as well high flow rate (30 litre per hour). If the users are properly oriented on the handling practices then this filter could be used as long-term solution for household level.

Although these filters are efficient for arsenic and iron removal, the study for manganese removal has not been carried out.

### ***Arsenic iron removal plant (AIRP)***

Arsenic Removal Plant is another alternative that is being tested and provided to the affected community. This plant uses principle of slow sand filtration. This plant serves a group of households who are sharing a single tube well. The conventional Arsenic Iron Removal Treatment Plant has been made to remove iron. Since arsenic is removed with the with-drawl of iron in water, this system is used for both purposes. This removal plant has it own limitations like space consumption of 6 sq. ft. From the efficiency study conducted it shows that the plant is efficient if arsenic concentration is more than 50 $\mu\text{g/l}$  but less than or equal to 150 $\mu\text{g/l}$ , since at this level the removal is quit high in the plant. Similarly, iron concentration should be more than or equal to 4 mg/l and less than or equals to 10mg/l for efficient removal. If this range exceeds in water, the removal efficiency of the treatment plant decreases due to various mechanical problems. The efficiency also depends on beneficiaries' willingness to participate and contribute in the operation and maintenance of the plant.

**Some commercially available POU systems for arsenic removal or currently under testing in Bangladesh are;**

- Alcan filter
- Sono 3-Kolshi filter
- Tetra Hedron filter:
- DPHE/DANIDA Bucket Treatment Unit
- STAR filter

### **2.6.3 Manganese in Nepal**

Concentrations of iron and manganese are likely to be mostly low in the shallow ground waters where the aquifers are aerated. However, they are higher in the deep anaerobic aquifers of the Terai region and Kathmandu Valley. (Khadka, 1993). Manganese concentration shallow tube wells is found to be an average 0.4 in Jhapa and 1.3 mg/l in Saptari district in average (CBS, 2006). However, the study has been limited in some districts. The study has not been yet carried out for all the deep tube wells in Terai region. The study on manganese and iron concentration should be carried out in all the arsenic contaminated tube wells.

## **2.7 Previous researches on manganese removal by IHE family filter**

Comparative analysis of some previous MSc. studies on performance of IHE family filter under field condition in Bangladesh is shown in Table 2-1 and the measures taken for the manganese improvement are shown in Table 2-2.



*Table 2-1: Comparative analysis of three MSc studies on performance of IHE Family Filter (Barua, 2006; Khan, 2004a; Salehuddin, 2005)*

	<b>M. S. A. Khan, 2004</b>	<b>A. K. M. Salehuddin, 2005</b>	<b>Raktim Barua, 2006</b>
Type of Filter	1) 3rd generation IHE family filter 2) Filtrix Filter 3) Local prototype I, & II	1) 3rd generation IHE family filter 2) Filtrix Filter 3) Local prototype I&II	1) 3rd generation IHE family filter 2) Local Prototype
Groundwater parameters	As: 180–544 µg/l Fe: 3.95–20.5 mg/l Mn: 0.1–3.13 mg/l PO <sub>4</sub> <sup>3-</sup> : 0.21–2.11 mg/l NH <sub>4</sub> <sup>+</sup> : 0.44–5.49 mg/l.	As: 130–710 µg/l Fe: 3.52–25.31 mg/l Mn: 0.09–3.1 mg/l pH: 6.85–7.26 NH <sub>4</sub> <sup>+</sup> : 0.44–7.45 mg/l	As: 140–746 µg/l Fe: 3.5–20.5 mg/l Mn: 0.09–3.1 mg/l NH <sub>4</sub> <sup>+</sup> : 0.4 – 7.5 mg/l
Arsenic	Effectively removed (at 10 sites out of 12 sites) below 4 µg/l.	Effectively removed (4 µg/l). In most of the sites removal is more effective by IOCS than IOCP	Effective removed below 10 µg/l Arsenic removal efficiency (≥97%)
Iron	Removed consistently below 1 mg/l.	Effectively removed (<0.3 mg/l) satisfactory removal. Removal by IOCS is more effective than IOCP	Efficiency with IOCS was (≥96%)
Manganese	Variable results: - Partially removed - No removal - Increase of Mn Depends on ammonia and possibly methane conc.	Not satisfactorily removed.  Increased even more than in feed water  Removal is more effective by IOCP than IOCS Depends on ammonia and possibly methane conc.	Only 2 out of 11 eleven filters achieved high efficiency of manganese removal (65–95%). rest showed elevated manganese conc. in filtrate 2–19 times higher than in ground water  Depends on ammonia and possibly methane conc.
NH <sub>4</sub> <sup>+</sup>	Varies from no reduction to 85% reduction.	Increased ammonia concentration reduces the manganese in filtration	High conc. of NH <sub>4</sub> <sup>+</sup> in ground water likely control the process within the filter. Mn in the filtrate was high when NH <sub>4</sub> <sup>+</sup> was more than 0.8 mg/l in the ground water

Table 2-2: Extra measures tested for improvement manganese removal (Barua, 2006; Khan, 2004a; Salehuddin, 2005)

	<b>M. S. A. Khan, 2004</b>	<b>A. K. M. Salehuddin, 2005</b>	<b>Raktim Barua, 2006</b>
Polishing filter with locally available materials	Not tested	Both Fe and Mn are removed effectively (66% to 96%)	Removal: Mn: 79%–80%, Fe: 94%–100%, As: 90%–100%, Long-term improvement.
Lime stone layer	Not tested	Fe and Mn in filtrate is reduced significantly immediate after addition but increased gradually	Removal: Mn: 25%- 82 % , Fe : 36-67%, As: 46 - 99% , Short term improvement (1 – 2 weeks)
Chlorination	Not tested	Fe reduction (70–90%). Mn reduction by 30–75% in groundwater containing high iron 90–95% in low iron content water	Removal: Mn : 30%–90% , Fe : 25%–98%, As: no effect , Short term improvement (1–2 weeks) bad taste and odours
Filter media Use of IOCS Use of IOCP Use of IOCS with low Mn	Both IOCS and IOCP demonstrated to be efficient in removal of AS, Fe & Phosphate. With IOCP Mn was not removed at all but with IOCS Mn conc. in filtrate was much higher.	IOCS has much higher As and Fe adsorption capacity but IOCP is better for Mn removal	Mn removal with IOCS media with low Mn content was 22–71 % irrespective of water composition

### **3. MATERIALS AND METHODOLOGY**

To accomplish the research objectives literature review, field study in Nepal, and lab experiments were conducted. The lab experiment included establishing lab set-up, model water preparation, operation of laboratory set-up family filters, samples collection and analysis.

#### **3.1 Literature review**

A literature review on arsenic and manganese contamination in ground water and its effect to human health was carried out. The data on ground water quality such as , arsenic, manganese, ammonia, irons etc. in Terai region of Nepal were collected by extensive literature review. The existing technologies for arsenic and manganese removal from ground water were reviewed in view of learning from the best practices carried out in different countries.

#### **3.2 Field study in Nepal**

Based on the research objectives stated in the introductory chapter, the information on ground water quality of Nepal was collected from the different institutions involved in arsenic mitigation. A number of ground water samples were also collected from remote area of Parsa district in Terai region of Nepal.

##### **3.2.1 Data collection**

Reports on ground water quality in Nepal were collected from government agencies such as Department of Water Supply and Sewerage (DWSS), Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) and non-government organizations (NGOs) such as Environment and Public Health Organization (ENPHO), Filters for Family, Water, Environment and Life (WEL) and Red Cross Society, Parsa, Nepal. The persons contacted during data collection are listed in Annex 1.

##### **3.2.2 Ground water samples collection**

Ground water samples were collected from 9 tube wells from remote area of Parsa district in Terai region of Nepal. All the samples were collected in 150 ml plastic bottles. The bottles were pre-washed with dilute hydrochloric acid properly and later washed three times by distilled water. Finally, the bottles were rinsed with distilled de-ionized water and dried up.

During the ground water samples collection, the bottles were washed with ground water and filled. The tube wells were purged for few minutes before taking the samples from the tube wells intending to collect mid stream of water from the sources. The samples were preserved by acidifying with few drops of concentrated  $\text{HNO}_3$ . Samples were brought to the IHE laboratory for analysis. The name of the owners of sample collected tube wells are listed in Annex 2.

### 3.2.3 Analysis of water samples

The samples collected from Nepal were tested at IHE laboratory. Total iron and manganese were analyzed by using Atomic Absorption Spectrometry Perkin Elmer 3110 with flame (AAS-Flame). Similarly, total arsenic was analyzed by using Atomic Absorption Spectrometer Thermo Elemental Solaar MQZe GF95 with auto sampler (AAS-GF). The samples were neutralized with NaOH in lab for ammonium analysis.  $\text{NH}_4^+$  concentration was analyzed by using Spectrometer (Perkin Elmer lambda 20).

## 3.3 Materials

In this research IHE family filters were used to study the performance in terms of quality parameters. The IHE family filter is a very simple technology. The filters filled with IOCS as the main filter media. Pumice was used as supporting material for IOCS. A layer of  $\text{CaCO}_3$  and Aquamandix were introduced in order to optimize the filters for manganese removal.

### 3.3.1 Filter set up

To set up an IHE family filter, following materials were used;

1. Raw water storage tank (200 litres)
2. Iron and manganese solution storage tank
3. Filtered water storage buckets
4. Adsorbent: IOCS, Aquamandix
5. Calcium carbonate ( $\text{CaCO}_3$ )
6. Supporting filter material: Pumice
7. Polishing sand filter media: Sand (0.8 – 1.2 mm)
8. Polishing filter layer: Sand (0.5 – 1.0 mm)
9. PVC filter columns
10. Plastic tubes, taps, washers, control valves, orifices, nuts, screws etc.

A layer of coarse pumice was provided at the bottom of all filters to support the filter media. Due to its layer size and associated large volume of filter voids, it can retain large amount of

iron flocs coming with the feed water. Besides this, pumice can adsorb iron (II) on its surface. The iron (II) adsorption capacity of pumice is greatly increased with the development of iron oxide coating of the media. (Sharma, 2001)

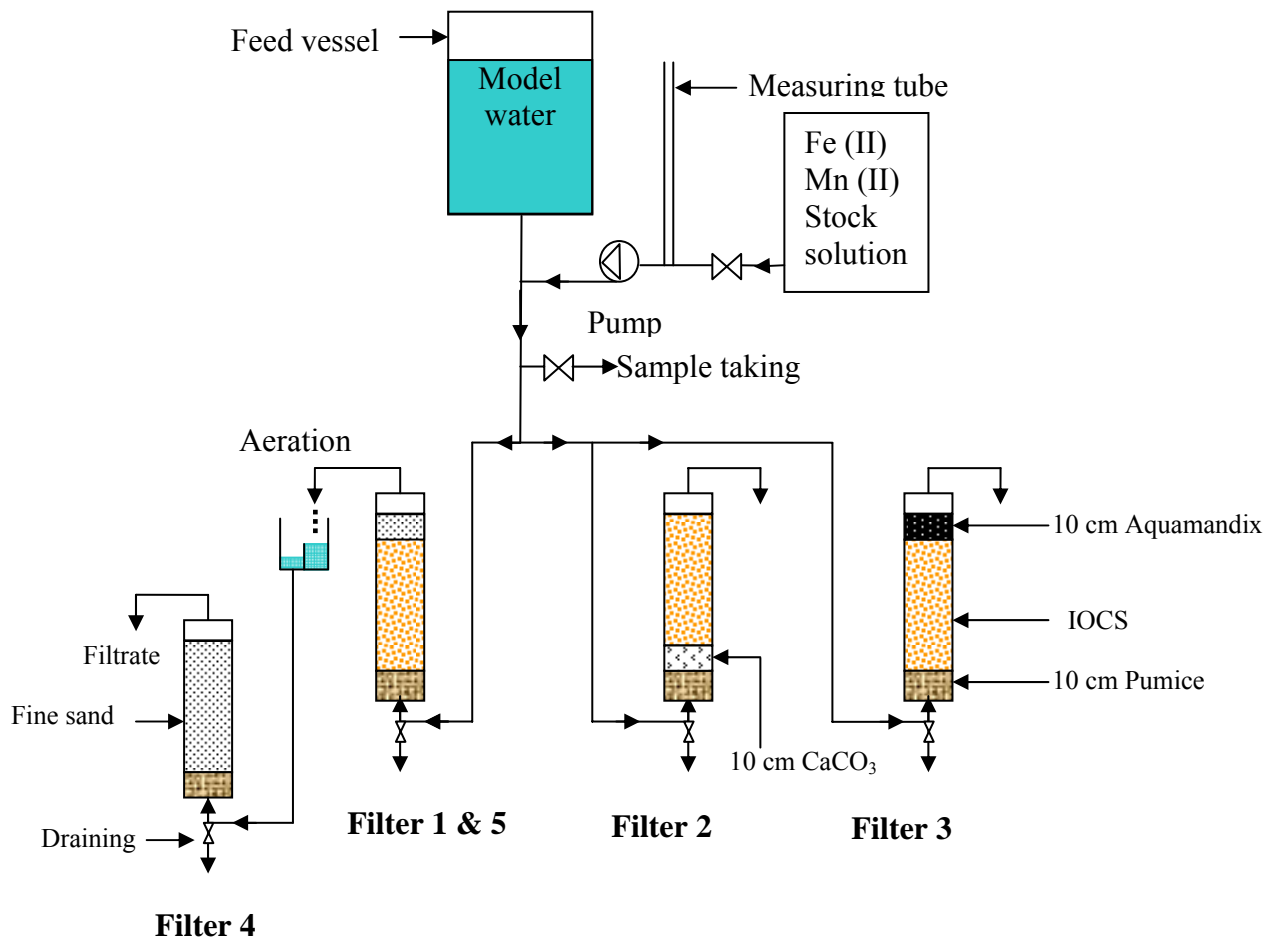


Figure 3-1: Schematic diagram of filter set-up used in laboratory

Initially, three IHE family filters namely Filter 1, Filter 2 and Filter 3, were installed. The dimension of the IHE family filters used for lab experiment was 63 cm in length and 10.2 cm in diameter. All filters were washed with diluted acid and rinsed with clean water. All necessary accessories like valves, fittings, covers etc were thoroughly checked. The 0.6 mm and 2 mm orifices were placed on the outlet and inlet of filters respectively. A fine net was placed on the bottom of filters. Filters were filled with required amount of filter media allowing free board of 5 to 8 cm. Finally, the raw water tank and the vessel with stock solution of iron and manganese were connected to feed line to filters with appropriate tubes. Filters were operated in parallel as shown in Figure 3-1.

After one month of operation of the set-up with the three filters, Filter 4 was installed in series with the Filter 1. This filter was 35 cm in length and 10 cm in diameter. Pumice was used as supporting layer for 20 cm thick sand layer (0.8 – 1.2 mm) allowing 5 cm free board.

After 57 days of filter run, 10 cm of IOCS at top of Filter 1 was taken out and replaced by polishing layer of sand (0.5 – 1.0 mm). A separate IHE family filter (Filter 5) was installed and operated separately using the model water of without ammonium and the similar concentrations other parameters. The Filter 5 was similar to Filter 1 (after introducing the polishing layer of sand).

### 3.3.2 Filter media and Sieve analysis

#### *Filter media*

IOCS (iron oxide coated sand) was used filter media in IHE family filters. IOCS consists of sand grains coated with ferric hydroxide that are used in fixed bed reactors. Total bed depth of all the filter media was 63 cm for all filters (Filters 1, 2 and 3). A commercial product called Aquamandix was used as polishing layer (10 cm thick) on the top of the IOCS layer in Filter 3. In Filter 2, a layer of calcium carbonate (10 cm thick) was placed between the supporting pumice layer and IOCS. Detailed filters set-up is described in section 3.3.1. In order to test effect of the polishing sand filter, an additional filter (Filter 4) with sand (0.8 – 1.2 mm) was placed downstream of Filter 1. The sand (0.5 – 1.0 mm) was also used for polishing layer placed at later stage of lab testing on the top of the IOCS layer in Filter 1. The sieve analysis for all the filter media and supporting material are given in Figure 3-2 to Figure 3-5 and Table 3-3.

**Aquamandix** is a natural, crushed manganese dioxide without additives used for catalytic removal of dissolved iron and manganese in one filtration step even if the pH environment is not ideal.

*Table 3-1: Chemical analysis of Aquamandix*

Parameters	Unit	Average Value
MnO <sub>2</sub>	mass-%	78
Fe <sub>2</sub> O <sub>3</sub>	mass-%	6.2
SiO <sub>2</sub>	mass-%	5.2
Al <sub>2</sub> O <sub>3</sub>	mass-%	3.1
Moisture	mass-%	< 1



Table 3-2: Physical characteristics of Aquamandix

Parameters	Value
Density	3.5 g/cm <sup>3</sup>
Bulk density	2000 kg/m <sup>3</sup>
Shape	irregular
Colour	dark brown to black
Size available	0.5-1.0 mm

[Source: (Aqua, 2001)]

### Sieve analysis of filter media

Sieve analysis of pumice, calcium carbonate ( $\text{CaCO}_3$ ), Iron Oxide Coated Sand (IOCS), Aquamandix were carried out to find out effective diameter of the filter media, which is used to calculate head loss through clean filter bed.

Figure 3-2 shows particle size distribution obtained from the sieve analysis for Pumice used as media for the filter used in this experiment. The  $d_{10}$ ,  $d_{30}$  and  $d_{60}$  values of the Pumice were found to be 6.5 mm, 7.9 mm and 9.5 mm respectively.

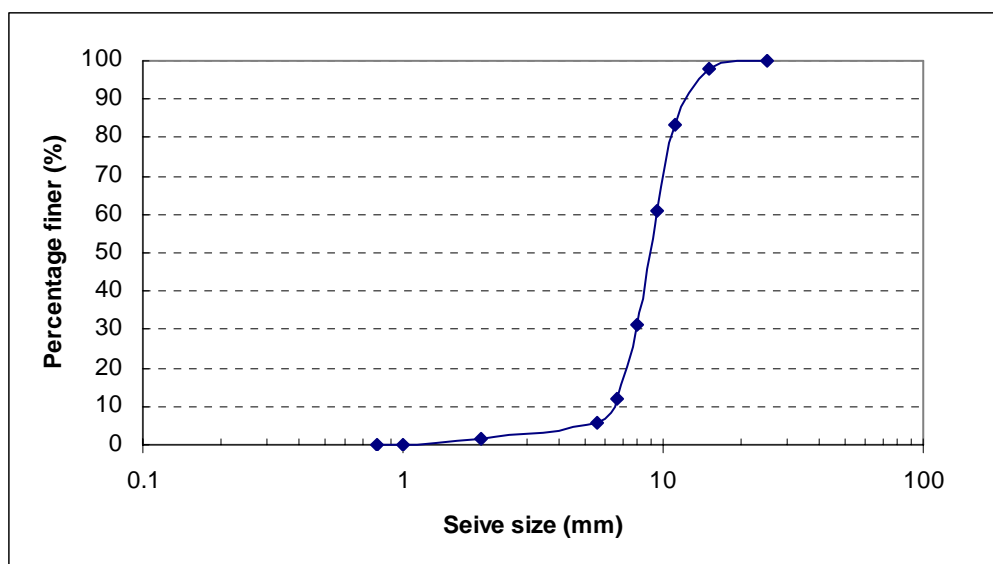


Figure 3-2: Particle size distribution of pumice used as supporting layer of family filters

Figure 3-3 shows particle size distribution obtained from the sieve analysis for Calcium Carbonate ( $\text{CaCO}_3$ ) used as media for the filter used in this experiment. The  $d_{10}$ ,  $d_{30}$  and  $d_{60}$  values of the Calcium Carbonate ( $\text{CaCO}_3$ ) were found to be 2.75 mm, 3.00 mm and 3.47 mm respectively.

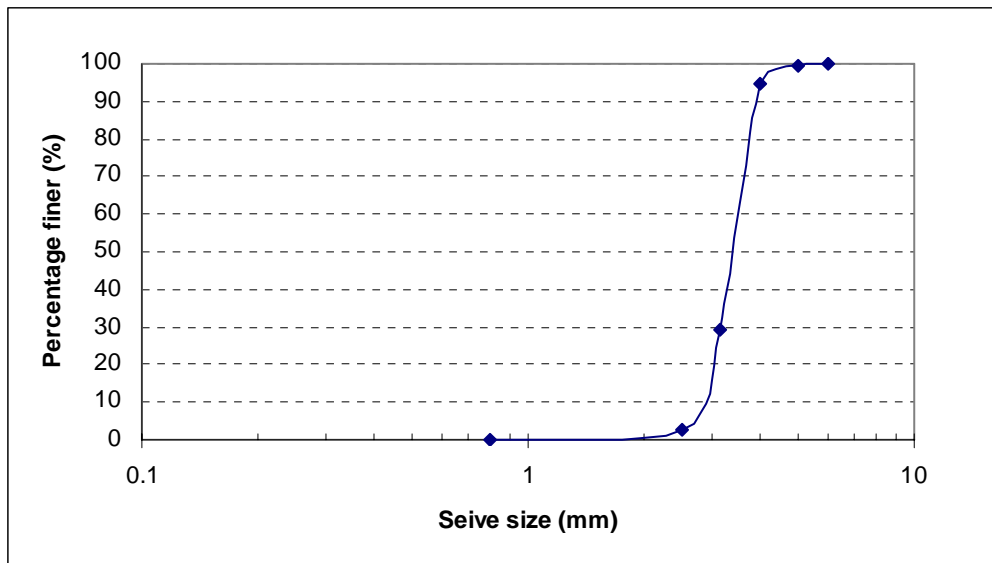


Figure 3-3: Particle size distribution of  $\text{CaCO}_3$  placed above supporting pumice layer in Filter 2

Figure 3-4 shows particle size distribution obtained from the sieve analysis for Iron oxide coated sand (IOCS) used as media for the filter used in this experiment. The  $d_{10}$ ,  $d_{30}$  and  $d_{60}$  values of the Iron oxide coated sand (IOCS) were found to be 2.82 mm, 3.20 mm and 3.50 mm respectively.

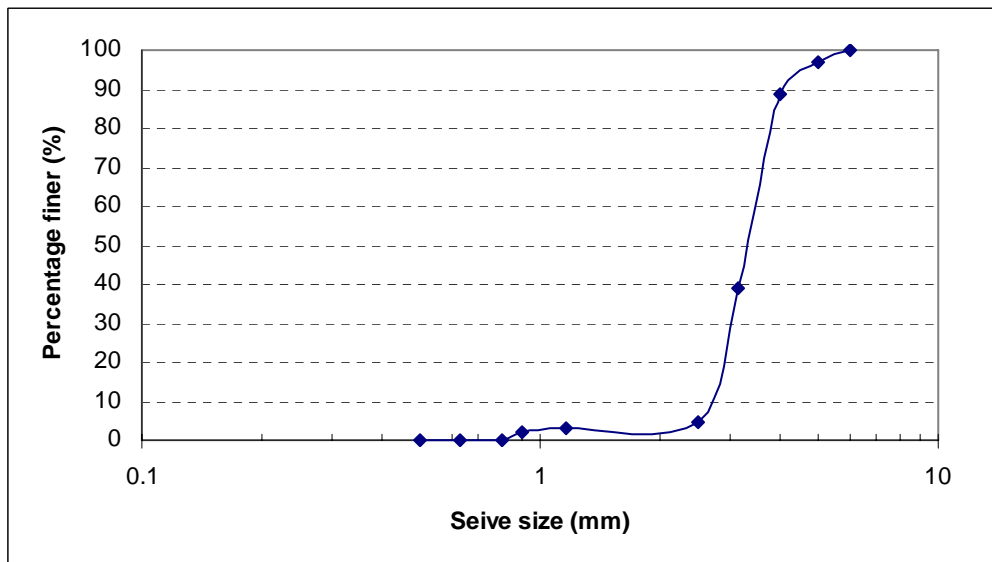


Figure 3-4: Particle size distribution of IOCS used in all filters as arsenic adsorbent

Figure 3-5 shows particle size distribution obtained from the sieve analysis for Aquamandix used as media for the filter used in this experiment. The  $d_{10}$ ,  $d_{30}$  and  $d_{60}$  values of the Aquamandix were found to be 2.82 mm, 3.20 mm and 3.50 mm respectively.



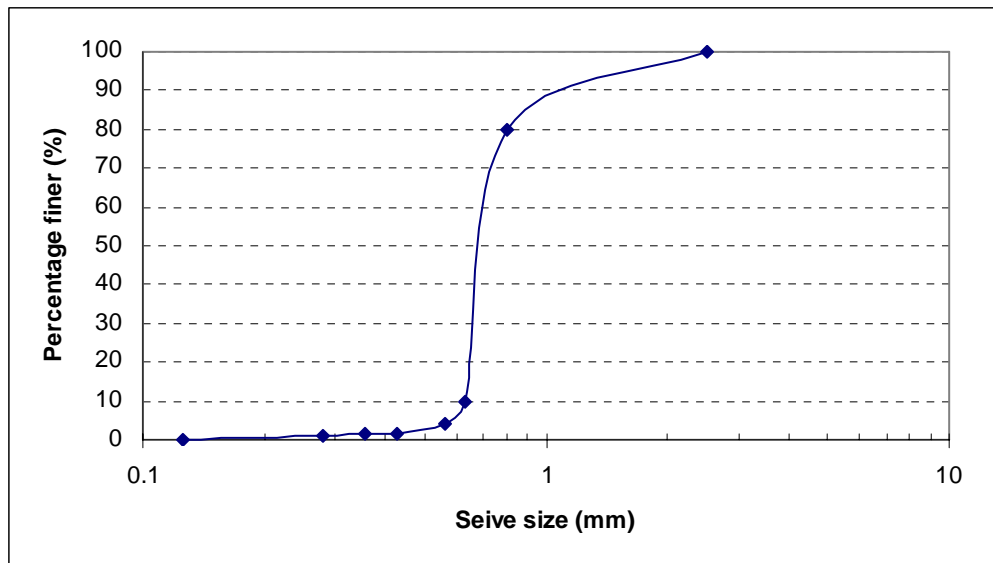


Figure 3-5: Particle size distribution of Aquamandix placed in Filter 3 above IOCS as a polishing layer

The particle size characteristics for Pumice,  $\text{CaCO}_3$ , IOCS and Aquamandix are presented in Table 3-3. The specific diameter ( $d_s$ ) of the media was calculated by using the following relationship (Buiteman and Ives, 2005).

$$\frac{W}{ds} = \sum \frac{W_j}{\sqrt{S_i \cdot S_j}} \quad \text{Where,}$$

- $d_s$  = Specific diameter
- $W$  = Total weight of sand
- $W_j$  = Weight of sand retained on lower sieve
- $S_i$  = Sieve opening of upper sieve
- $S_j$  = Sieve opening of lower sieve

Uniformity co-efficient ( $C_u$ ) of the media is ratio of  $d_{60}$  and  $d_{10}$ .

Table 3-3: Particle size characteristics for filter media

Type	$d_{10}$ (mm)	$d_{60}$ (mm)	$d_s$ (mm)	$C_u$
Pumice	6.50	9.50	7.80	1.46
$\text{CaCO}_3$	2.75	3.47	3.03	1.26
IOCS	2.82	3.50	3.22	1.24
Aquamandix	0.650	0.765	0.741	1.18



Table 3-4: Filter media used in different filters

Filters Name	Filter media	Specific diameter (mm)	Thickness of layer (cm)
Filter 1	IOCS	3.03	45
	Pumice	7.8	10
Filter 2	IOCS	3.03	35
	CaCO <sub>3</sub>	3.22	10
	Pumice	7.8	10
Filter 3	Aquamandix	0.5-1	35
	IOCS	3.03	10
	Pumice	7.8	10
Filter 4	Sand	0.8-1.2	20
	Pumice	7.8	10
Filter 5	Sand	0.5-1	10
	IOCS	3.03	35
	Pumice	7.8	10

### 3.4 Model water Preparation

#### *Preparation of model water*

Model water with similar to average ground water quality of the samples from 9 tube wells of Parsa district of Nepal was used in laboratory experiments. Model water was prepared from Delft tap water by increasing  $\text{HCO}_3^-$  concentration and decreasing pH. Table 3-5 shows the details of the composition of IHE tap water and model water used for Filters 1, 2 and 3. In Filter 5, similar model water but without ammonium was used.

#### *Preparation of iron and manganese solution*

To prepare iron and manganese stock solution, the proper amount of  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  and  $\text{MnSO}_4 \cdot \text{H}_2\text{O}$  was weighed and mixed with demineralised water. pH of the solution was adjusted to be lower than 2 by adding HCl. Iron and manganese stock solution was dosed at constant rate to feed water in order to achieve iron and manganese concentration of 5.0 mg/l and 1.0 mg/l respectively in the model water.

Table 3-5: Water composition of tap water and model water

Parameter	Symbol	Unit	IHE tap water	Model water
pH			8.1	6.8
Bi-carbonate	$\text{HCO}_3$	mg/l	129	275
Iron	$\text{Fe}_2^+$ and $3^+$	mg/l	0.03	5
Manganese	$\text{Mn}_2^+$	mg/l	0.005	1
Ammonium	$\text{NH}_4^+$	mg/l		4
Arsenic	$\text{As}_5^+$ and $3^+$	$\mu\text{g/l}$	0	200
Temperature	T	0C	16	16
Oxygen	$\text{O}_2$	mg/l	10.5	10.5
Calcium	$\text{Ca}^+$	mg/l	53	53
Silicate	$\text{SiO}_3$	mg/l	1.5	1.5
Sulphate	$\text{SO}_4$	mg/l	81	81
Phosphate	$\text{PO}_4$	mg/l	0.03	0.03
Chloride	Cl	mg/l	61	61
Sodium	Na	mg/l	40	40
TOC		mg/l	1.2	1.2

### Chemical and reagents used

Chemical used for preparation of model water is given in Table 3-6.

Table 3-6: Chemical and their purpose in model water preparation

Type of chemical	Purpose
Iron sulphate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ )	For iron (II) concentration in model water
Manganese sulphate ( $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ )	For manganese (II) concentration in model water
Sodium hydrogen carbonate ( $\text{NaHCO}_3$ )	To increase bicarbonate concentration in the model water
Arsenic (III) and (V) solutions	For arsenic concentration in model water
Ammonium Chloride ( $\text{NH}_4\text{Cl}$ )	For ammonium concentration in model water
Hydrochloric acid (HCL)	Acidifying iron and manganese stock solution and pH correction of model water



### 3.5 Operation & maintenance of the IHE family filters

During operation of IHE family filters, the maintenance comprised occasional filter draining and cleaning of model water tanks, tubes, taps etc. Filters were drained out twice a week to maintain hydraulic capacity of unit by removing iron depositions from the filter media. Filter draining also facilitates oxidation of iron and manganese adsorbed on the filter media. In order to drain a filter the inflow valve was closed and the water in the filter column was emptied at high discharge rate. Filter 3 had to be drained daily due to the rapid decrease of capacity.

#### 3.5.1 Effect of water level in feed vessel on model water quality

During 1<sup>st</sup> 15 days of filter run, filters were operated at variable effective head ranging from 22 cm to 73 cm. Iron and Manganese were dosed at constant rate upstream model water inlet to filters. This solution was acidified when mixed with the feed water. As consequence, iron, manganese and pH in feed water were found to be different at different water level in the feed tank.

#### *pH*

Targeted pH of model water was around 6.8. Figure 3-6 shows the effect of available head on pH of feed water. The pH of feed water was found decrease with decreased available head of feed water. Variation of pH at different available head was a consequence of; constant dosing rate of acidified iron and manganese stock solution, and variable capacity of filters.

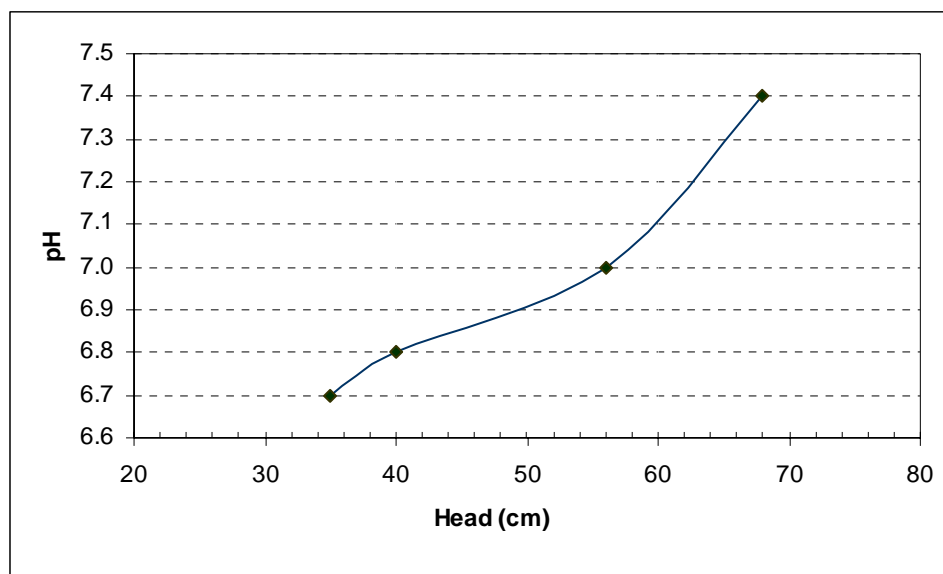


Figure 3-6: pH in feed water entering filter at different available head (water level in model water tank)

#### *Iron concentration in feed water*



Figure 3-7 shows the concentration of iron in feed water entering filters at different available head (water level in model water storage tank). The concentration of iron in feed water was found increase with decrease of the available head.

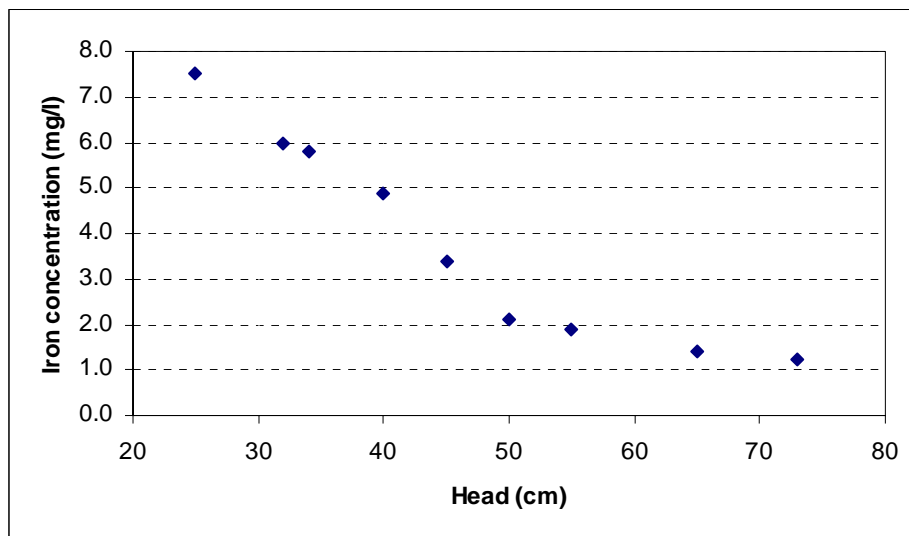


Figure 3-7: Iron concentration in feed water entering filter at different available head (water level in model water tank)

### ***Manganese concentration in feed water***

Figure 3-8 shows the concentration of manganese in feed water entering filters at different available head (water level in model water storage tank). The concentration of manganese in feed water was found increase with decreased in the available head.

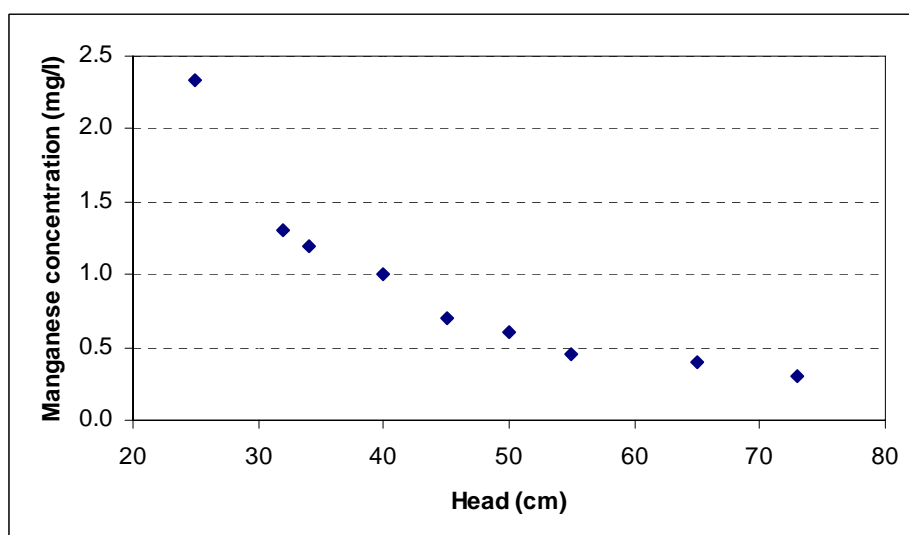


Figure 3-8: Manganese concentration in feed water entering filter at different available head (water level in model water tank)

In order to avoid variation pH and concentrations of iron and manganese of feed water, constant head of 40 cm was maintained in the feed water tank from 15 days of filter run. This

was achieved with a help of pump that feeds model water at constant flow rate of 2.1 l/s. Operation of IHE family filters in laboratory is given in Figure 3-9



Figure 3-9: Operation of filters (Filter 1: with IOCS only, Filter 2: with  $\text{CaCO}_3$  on bottom of IOCS, Filter 3: with Aquamandix on top of IOCS and Filter 4: a polishing sand filter) in the laboratory

### 3.5.2 Sample collection in the lab

For determining water quality, samples were collected daily from the inlet and outlet of all filters. All samples were collected in 75 ml plastic bottles. To study the ripening period of filters, samples were also collected immediately after restart of filter run after draining and subsequently every 20 to 30 minutes during first hours of filter run. All samples were preserved by adding a few drops of  $\text{HNO}_3$  in the sample bottle and analyzed later in IHE laboratory.



### 3.6 Analysis of samples

In order to analyze quality parameters of the feed and filtrates of all the filters, various chemicals and reagents were used. The detailed chemicals used and their purposes are tabulated in Table 3-7.

Table 3-7: Chemical and their purpose in sample analysis

Type of chemical	Purpose
Iron sulphate ( $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ )	Standard solution for iron analysis
Manganese sulphate ( $\text{MnSO}_4 \cdot \text{H}_2\text{O}$ )	Standard solution for manganese analysis
Standard Arsenic(III) and (V) solutions	Calibration for Atomic Absorption Spectrometer with Graphite Furnace (AAS-GF)
Nitric acid ( $\text{HNO}_3$ )	For sample preservation and AAS-GF sample preparation
Nickel Nitrate $\text{Ni}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$	For AS Matrix modifier
Hydrochloric acid (HCL)	Acidifying iron and manganese stock solution and pH correction of model water
De-mineralized water	For dilution and preparation of chemical solutions
Ammonium Chloride ( $\text{NH}_4\text{Cl}$ )	and standard for ammonium calibration for spectrophotometer
Sodiumsalicylate ( $\text{NaC}_7\text{H}_5\text{O}_3$ )	For Salicylate reagent used for ammonium analysis
Sodiumcitratedihydrate ( $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$ )	
Disodiumpentacyano nitrosylferrate (III) ( $\text{Na}_2\text{Fe}(\text{CN})_5\text{NO} \cdot 2\text{H}_2\text{O}$ )	
NaOH	For Dichloroisocyanurate reagent for ammonium analysis
Sodiumdichloroisocyanurate ( $\text{NaC}_3\text{N}_3\text{O}_3\text{Cl}_2$ )	
$\text{H}_3\text{PO}_4$	Colour reagent for $\text{NO}_2\text{-N}$ test
Sulfanilamide	
N-(1-naphthyl)-ethylenediamine dihydrochloride	
$\text{NaNO}_2$	For stock $\text{NO}_2^-$

Arsenic concentration was analyzed in feed water and filtrates by Atomic Absorption Spectrometer Thermo Elemental Solaar MQZe GF95 with auto sampler (AAS-GF). The detection limit of AAS-GF is 2 – 50  $\mu\text{g/l}$ . The accuracy of this instrument is  $\pm 3\%$ .

Iron and manganese were analyzed by Atomic Adsorption Spectrometer Perkin Elmer 3110 with Flame (AAS-F) and ICP Perkin Elmer Optima 3000. AAS-F can measures iron



concentration in the range of 0.05 – 6 mg/l and manganese concentration in the range of 0.02 – 2 mg/l. Fe and Mn concentration were also analyzed with the help of Hach colorimeter (DR/890 colorimeter). The detection range of the Hach colorimeter is from 0 – 3.3 mg/l and 0.2 – 20 mg/l for iron and manganese respectively. Iron was measured according to Ferro Vermethod (Powder Pillows) for iron total. Manganese was measured by using citrate and sodium (Powder Pillows).

$\text{NH}_4^+$  and  $\text{NO}_2\text{-N}$  in feed water and filtrate were determined with the help of the Spectrophotometer (Perkin Elmer lambda 20).

For measuring flow, samples were collected in a 500 ml cylinder flask both, before and after draining. pH and DO are the very important parameters influencing the removal capacity of the filters. These parameters in feed water and filtrates were also tested frequently in the lab. The pH of water was measured by a WTW pH 323 portable pH-meter. The DO was measured by using oxygen meter. Table 3-7 shows the equipments used for analysis of different parameters in feed water and filtrates.

Table 3-8: Equipment and their purpose in sample analysis




Equipment	Purpose
1) Atomic Absorption Spectrometry Perkin Elmer 3110 with flame ( AAS-Flame) 2) ICP Perkin Elmer Optima 3000	To analyze total Iron and manganese
Atomic Absorption Spectrometer Thermo Elemental Solaar MQZe GF95 with autosampler (AAS-GF)	To analyze arsenic (III) and (V)
Spectrometer (Perkin Elmer lambda 20 )	To analyze $\text{NH}_4^+$ and $\text{NO}_2\text{-N}$
323 portable pH and oxygen meter	To measure pH and DO

Some of the equipments used in sample analysis are shown below.

		
Spectrometer	Oxygen meter	pH meter





		
HACH colorimeter	AAS – flame	AAS – GF

### ***Membrane filter (MF)***

In order to test presence of iron and manganese flocs, the feed water and filtrate of all filters (Filter 1, 2, 3 and 4) were filtered through 0.45  $\mu\text{m}$  membrane filter with the help of syringe. A new filter was used for each sample. Filtrate was acidified and stored in a polyethylene bottle and later analyzed for arsenic, iron and manganese.



## 4. RESULTS AND DISCUSSION

### 4.1 Introduction

This chapter presents sample water taken from Nepal, characteristics of filters, analysis of lab data and discussion on results obtained together with the data analysis.

### 4.2 Analysis of sample water taken from Nepal

Nine samples were collected from remote area of Parsa district in Nepal. These samples were tested at IHE laboratory. The samples were neutralized in lab for ammonium analysis as those were acidified during collection in the field. Table 4-1 gives results on the As, Fe, Mn and  $\text{NH}_4^+$  contents of the sample water taken from Nepal. The national drinking water standard for the parameters along with the WHO standard is also presented in the table. These parameters of the samples water were used to prepare the model water for further laboratory experiments.

Table 4-1: Water composition of sample water from Nepal

Parameter	Sample no.									Standard	
	N1	N2	N3	N4	N5	N6	N7	N8	N9	Nepal	WHO
Arsenic ( $\mu\text{g/l}$ )	185	155	235	120	6	55	75	2	115	50	10
Iron ( $\text{mg/l}$ )	0.30	1.76	1.22	4.56	0.28	0.44	2.26	0.74	4.16	0.3	0.3
Manganese ( $\text{mg/l}$ )	0.99	0.34	0.72	0.43	0.37	0.46	0.43	0.18	0.40	0.2	0.4
Ammonium ( $\text{mg/l}$ )	3.78	0.01	0.02	0.08	0.13	0.11	0.30	0.21	2.01	1.5	1.5

Arsenic concentrations in the samples water were observed in the range of 2 – 235  $\mu\text{g/l}$ . 7 samples out of total 9 samples has the concentration higher than the national and WHO standard of 50  $\mu\text{g/l}$  and 10  $\mu\text{g/l}$  respectively. The remaining two samples have found the concentration far below the standards.

Similarly, iron concentration in the samples was observed in the range of 0.28 – 4.56  $\text{mg/l}$ . Only one sample out of total 9 samples has concentration less than Nepal standard of 0.3  $\text{mg/l}$ .

Furthermore, manganese concentration in the samples analyzed were observed to be in the range of 0.18 – 0.99  $\text{mg/l}$ . 8 samples out of total 9 samples has the concentration higher than

the national standard of 0.2 mg/l. Similarly, 5 samples out of the total 9 samples have the concentration higher than the WHO standard of 0.4 mg/l.

In addition, ammonium concentration in the samples was also analyzed and observed in the range of 0.01 – 3.78 mg/l. Only 2 samples out of total 9 samples have the concentration higher than the national and WHO standards of 1.5 mg/l.

The average value of arsenic concentration in ground water in tube-wells of Bangladesh is 180 µg/l (Khan, 2004a). Ammonium concentration in Bangladeshi shallow ground water was found to be in general higher as compared to shallow ground water in the Terai region of Nepal. However, at some ground water well in Nepal, high ammonia levels, comparable to levels in Bangladesh were found. The ammonium concentration in ground water of Bangladesh at 12 different sites, where the IHE family filters were installed ranging from 0.44 mg/l to 5.49 mg/l (Khan, 2004a). Therefore, in order to simulate very unfavourable conditions, very high concentration of ammonium of 4 mg/l was spiked in feed water.

The results obtained from lab test for the total number of the sample water, can be summarised with respect to the WHO guideline values as follows;

- 22 % of samples had As below 10 µg/l,
- 22 % of samples had Fe below 0.3 mg/l,
- 44 % of samples had Mn below 0.4 mg/l, and
- 78 % of samples had  $\text{NH}_4^+$  below 1.5 mg/l.

Based on the range of concentrations of the samples water, the model water used in the filter experiments was prepared using the composition;

- As → 200 µg/l,
- Fe → 5 mg/l,
- Mn → 1 mg/l, and
- $\text{NH}_4^+$  → 4 mg/l.

## 4.3 Hydraulic characteristics of filters

### 4.3.1 Filter capacity without filter media

#### *Using 0.8 mm orifice size at out let of the filter*

Flow rates at different head by using orifice size of 0.8 mm for Filters 1, 2 and 3 are shown in Figure 4-1. The required flow rate of 2.1 l/h was determined, based on the standard filtration rate of 0.25 m/h established and used in previous researches with IHE family filter. The corresponding head for 0.8 mm orifice size to the flow rate of 2.1 l/h was found to be about 15 cm.

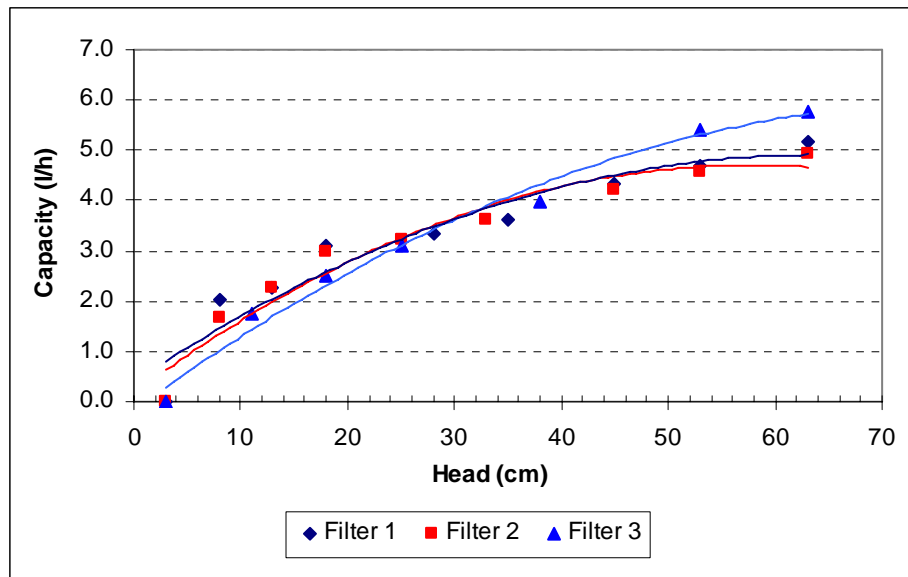


Figure 4-1: Capacity of three family filter units without filter media as a function of available head for an orifice of 0.8 mm

#### Using 0.6 mm orifice size at out let of the filter

Flow rates at different head by using orifice size of 0.6 mm for Filters 1, 2 and 3 are shown in Figure 4-2. The required flow rate of 2.1 l/h was determined, based on the standard filtration rate of 0.25 m/h established and used in previous researches with IHE family filter. The corresponding head for 0.6 mm orifice size to the flow rate of 2.1 l/h was found to be about 35 cm.

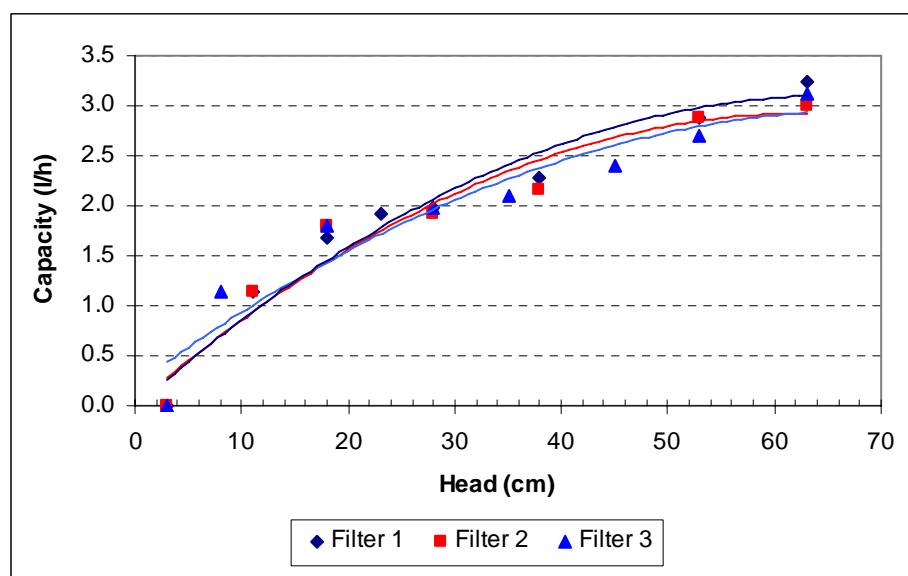


Figure 4-2: Capacity of three family filter units without filter media as a function of available head for an orifice of 0.6 mm

Based on the experiments, 0.6 mm orifice was selected for the outlet of the filters. From the lab experiment, it was determined the head for corresponding to flow rate of 2.1 l/h should be about 40 cm for 0.6 mm orifice size.

#### 4.3.2 Head loss in filter bed and effect on filter capacity

The **Kozeny–Carman equation** is a relation used in the field of fluid dynamics to calculate the pressure drop of a fluid flowing through a packed bed of solids. The equation is only valid for laminar flow. Assuming the grains of filter media used as spherical in shape, Head loss through the bed of supporting layer of pumice and other filter media used in this experiment, namely; IOCS,  $\text{CaCO}_3$  and Aquamandix were calculated using Kozeny – Carman equation (Graham, 2007).

$$H_0 = 180 \frac{\nu}{g} \cdot \frac{(1 - P_0)^2}{P_0^3} \cdot \frac{V_f}{d_s^2} \cdot L$$

Where,

- $H_0$  = Head loss through bed of sand (m)
- $\nu$  = Kinematics viscosity ( $\text{m}^2/\text{s}$ )
- $g$  = Specific gravity =  $9.81 \text{ m/s}^2$
- $P_0$  = Porosity
- $V_f$  = Filtration rate (m/s)
- $d_s$  = Specific diameter of filter media (m)
- $L$  = Length of filter bed (m)

The Kinematics viscosity depends upon the temperature and can be calculated by using following expression.

$$\nu = \frac{497 \times 10^{-6}}{(T + 42.5)^{1.5}}$$

Table 4-2 shows the detailed calculation of head-losses through different filter media for bed thickness of 10 cm. The model water was prepared at temperature of  $16^\circ\text{C}$  in the laboratory. Therefore, the corresponding viscosity is  $1.11 \times 10^{-6} \text{ m}^2/\text{s}$  for the temperature at  $16^\circ\text{C}$ . From the experience of previous researches, the porosity of the filter media IOCS (iron oxide coated sand) and IOCP (iron oxide coated pumice) was 45 % (Khan, 2004a). As the thickness of calcium carbonate and Aquamandix layers are very small porosity for these material were also considered as 45%. The filtration rate of 0.25 m/h was taken for the all media. The specific diameter of the filter media used in this calculation was obtained from the sieve analysis (Table 3-3).

The head losses through the bed of all filter media for the thickness of 10 cm were ranging from  $7.7 \times 10^{-6} \text{ m}$  to  $8.4 \times 10^{-4} \text{ m}$ . The highest head loss of  $8.4 \times 10^{-4} \text{ m}$  was found in the media

of Aquamandix. The Filter 1, Filter 2 and Filter 3 had same total length of filter bed (total 63 cms). Based on the head loss through the filter media, the maximum head loss of 1.06 mm was found in Filter 3 having filter media of; 10 cm thick pumice, 43 cm thick IOCS and 10 cm thick Aquamandix. The result shows that head loss in the total filter bed is negligible and consequently, effect of this head loss on the filter capacity could be neglected.

*Table 4-2: Head-loss calculation for different filter media*

Parameters	Pumice	IOCS	CaCO <sub>3</sub>	Aquamandix
Kinematics viscosity at temperature 16°C (v) (m <sup>2</sup> /s)	$1.11 \times 10^{-6}$	$1.11 \times 10^{-6}$	$1.11 \times 10^{-6}$	$1.11 \times 10^{-6}$
Porosity (P <sub>0</sub> )	0.45	0.45	0.45	0.45
Filtration rate (Vf) (m/h)	0.25	0.25	0.25	0.25
Specific diameter of filter media (ds) (mm)	7.80	3.03	3.09	0.75
Length of filter bed (L) (m)	0.10	0.10	0.10	0.10
Head loss through bed of sand (H <sub>0</sub> ) (m)	$7.7 \times 10^{-6}$	$5.1 \times 10^{-5}$	$4.9 \times 10^{-5}$	$8.4 \times 10^{-4}$

#### 4.3.3 Capacity of filter after long-term run and effect of filter draining

The constant head of about 40 cm with 0.6 mm orifice in outlet line was used to analyse the capacity of the filters. The initial capacity of all filters was approximately 2.1 l/h. Capacity of filters was measured regularly at constant head of about 40 cm throughout the testing period.

It was observed that the capacity of Filter 1 reduced by approximately 35% after one week run. The filter capacity further reduced rapidly after two weeks run. The capacity was reduced by nearly 30% after 3 days run of cleaning period. The reduction of capacity recovery of the Filter 1 was observed to be 0.94 l/h in 100 days (about 0.48% daily reduction of initial capacity of 2.1 l/h).

Initially, the Filter 1 was drained once per week during the 1<sup>st</sup> two weeks and then the filter was drained two times per week for the remaining period. The minimum capacity of the filter before draining was gradually decreased. This was clearly indicated by a linear line introduced for the minimum capacity of the filter before the draining as shown in Figure 4-3. Similarly, the restoring capacity after cleaning also decreased gradually over the experimental period. After each draining of the filter, the filter capacity was restored considerably.

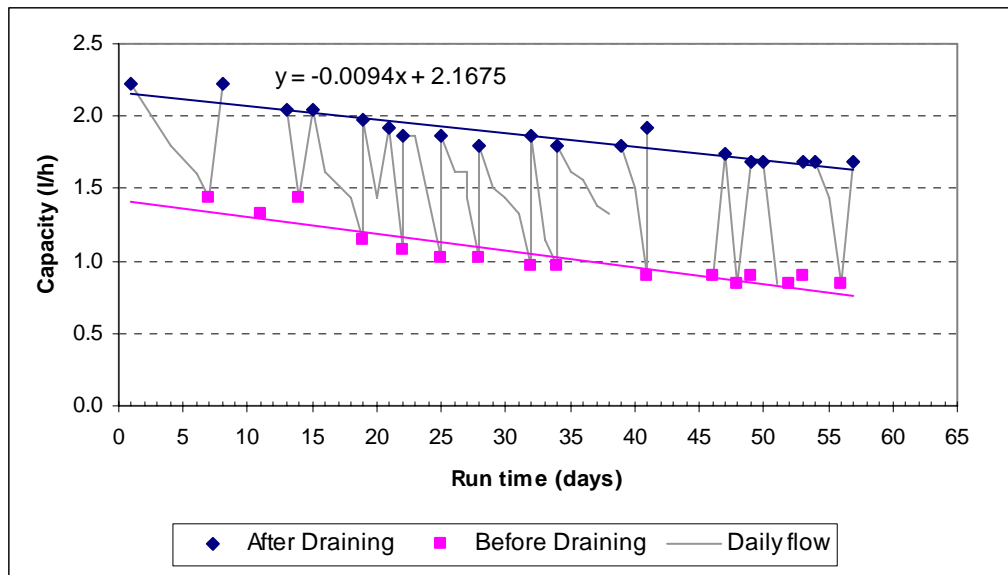


Figure 4-3: Capacity of Filter 1 with IOCS as a function of run time and filter draining (Average  $V_f = 0.25$  m/h; Model water: As (III) =  $100 \mu\text{g/l}$ ; As (V) =  $100 \mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^- = 275$  mg/l;  $\text{NH}_4^+ = 4$  mg/l; pH = 6.8)

The capacity of the Filter 2 as a function of the filter run time is shown in Figure 4-4. It was observed that the capacity of Filter 2 reduced by approximately 30% after one week run. The filter capacity reduced rapidly after two weeks run. The capacity of the filter was reduced by nearly 30% after 3 days run after cleaning of the filter. The reduction of capacity recovery of the Filter 2 was observed to be 0.65 l/h in 100 days (about 0.31% daily reduction of initial capacity of 2.1 l/h).

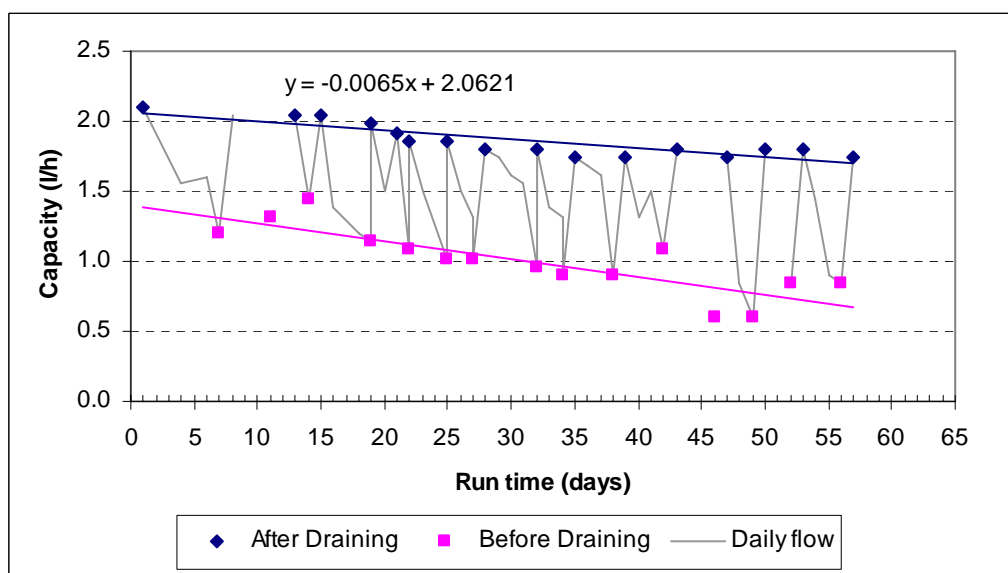


Figure 4-4: Capacity of Filter 2 with IOCS and  $\text{CaCO}_3$  as a function of run time and filter draining (Average  $V_f = 0.25$  m/h; Model water: As (III) =  $100 \mu\text{g/l}$ ; As (V) =  $100 \mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^- = 275$  mg/l;  $\text{NH}_4^+ = 4$  mg/l; pH = 6.8)

The Filter 2 was drained once per week during 1<sup>st</sup> two weeks and was drained twice per week for remaining period. As indicated by the trend lines introduced for the minimum and maximum capacity of the filter before and after the draining, the capacity of the filter gradually decreased (Figure 4-4). After each draining of the filter, the filter capacity was restored considerably.

On Figure 4-5, it was observed that the capacity of the Filter 3 reduced by approximately 60% after one week run. The filter capacity reduced rapidly after three weeks of filter run. The filter was drained once per week during 1<sup>st</sup> two weeks. Unlike the Filter 1 and Filter 2, the capacity of Filter 3 reduced by almost 100% within 1 or 2 days run after each draining. This filter clogged much faster than other filters. Consequently, this filter needed draining either on daily or on every alternative day. Iron particles clogged the filter rapidly due to the layer of fine Aquamandix on the top of IOCS.

Unlike to the trends of gradually decreasing restoring capacity after the cleaning of the Filter 1 and Filter 2, the desired capacity of 2.1 l/h was restored by the Filter 3 after the draining. It was observed that after 57 days of continuous filter operation, the filter capacity still maintained capacity a little below the initial value of about 2.1 l/h (Figure 4-5). The reduction of capacity recovery of the Filter 3 was observed to be 0.28 l/h in 100 days (about 0.13% daily reduction of initial capacity of 2.1 l/h).

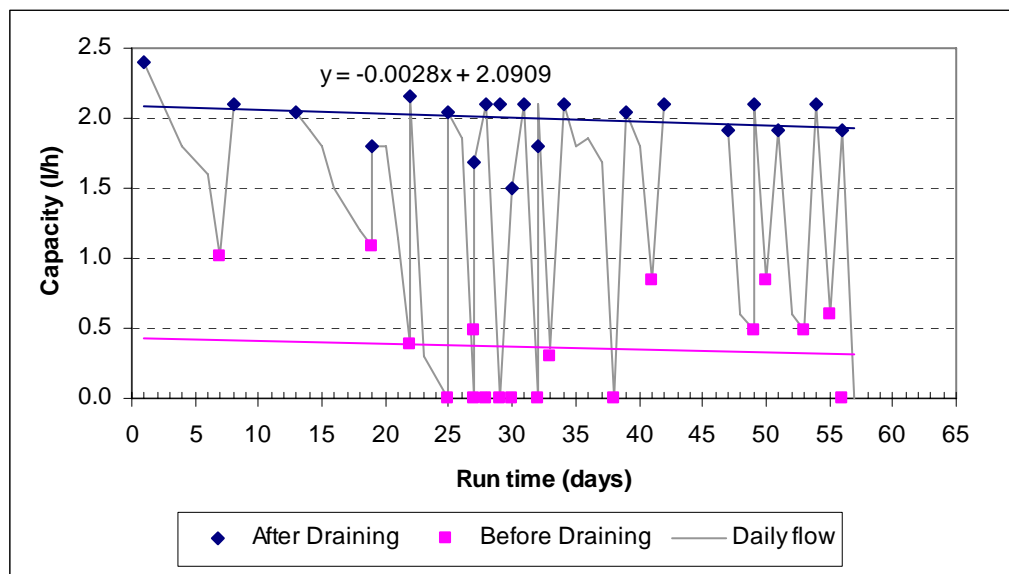


Figure 4-5: Capacity of Filter 3 with Aquamandix and IOCS as a function of run time and filter draining (Average  $V_f = 0.25$  m/h; Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^- = 275$  mg/l;  $\text{NH}_4^+ = 4$  mg/l; pH = 6.8)

The reduction of filter capacity was mainly due to the oxidation of iron and subsequent removal of flocs in the filters. Another reason might be due to the presence of high concentration of ammonia resulting growth of biomass. Both iron flocs and biomass growth reduced the porosity of filters. The presence of high concentration of nitrite about 2.15 mg/l (Figure 4-24) in filtrates also proved formation of large amount of biomass in the filters. The



number of draining throughout the operational period might lead to accumulation of finer grains of media at the bottom of the filters, which can develop significant head loss in the filtration process.

Both the Filter 1 and Filter 2 did not restore the original capacity by the draining of the filters. The reduction rates of the filter capacity of both these filters were higher than that of the Filter 3. These filters need other measures such as thorough washing or replacement of the filter media more frequently than that for the Filter 3 in order to achieve original capacity of the filters.

## 4.4 Performance of filters

### 4.4.1 Dissolved oxygen (DO) and pH

The range of dissolved oxygen (DO) and pH during the experiment period for both feed water and filtrates of all filters are presented in Table 4-3. The DO in feed water was found to be in the range of 7.21 ~ 10.4 mg/l.

Table 4-3: Range of O<sub>2</sub> and pH on feed water and filtrates

Filter	O <sub>2</sub> (mg/l)		pH	
	Feed water	Filtrate	Feed water	Filtrate
Filter 1	7.21-10.4	0.15-1.0	6.5-7.2	6.7-7.2
Filter 2	7.21-10.4	0.11-2.1	6.5-7.2	6.8-7.4
Filter 3	7.21-10.4	0.1-2.0	6.5-7.2	6.9-7.4
Filter 4	4.9-8.3	3.0-6.3	7.1-7.9	6.9-7.1

### 4.4.2 Arsenic removal

Total arsenic concentration in the feed water was observed from 158 µg/l to 230 µg/l during the experiment period. The filters were stopped on 7<sup>th</sup> day and 43<sup>rd</sup> day of operation for one week and 4 days respectively.

During the first week of operation of Filter 1, the arsenic removal efficiency was observed as 95% ~ 99%. This removal efficiency decreased gradually to 75% ~ 95% later on. The arsenic concentration in the filtrate of this filter was observed to be usually below Nepal standard of 50 µg/l but above WHO standard of 10 µg/l (Figure 4-6). It was also observed that the arsenic concentration in the filtrate always increased immediately after the filter stop.

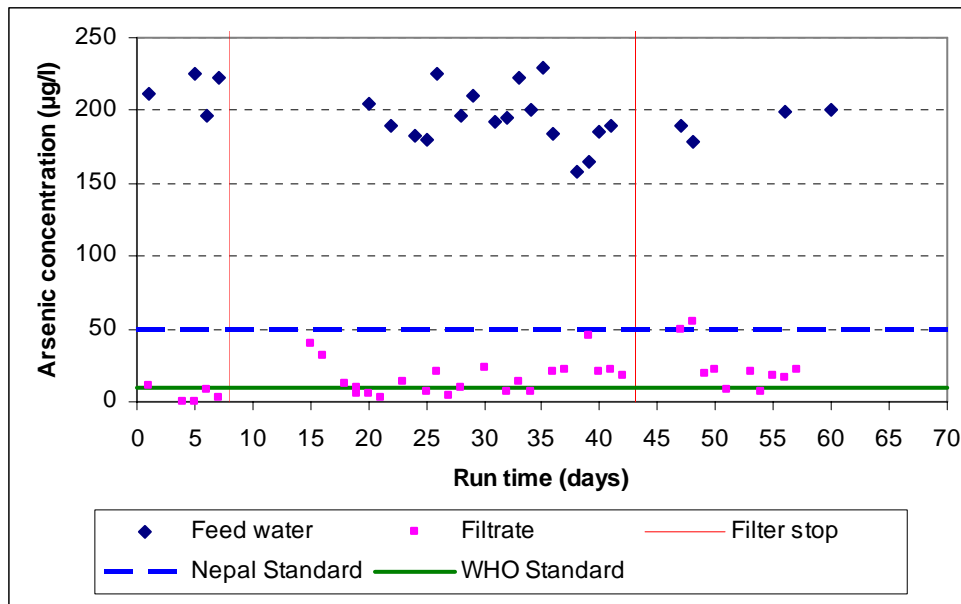


Figure 4-6: Arsenic concentration in feed and filtrate in Filter 1 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

Similar to Filter 1, the arsenic removal efficiency of Filter 2 was observed as 95% ~ 99% during 1<sup>st</sup> week of operation and approximately 75% ~ 95% afterwards (Figure 4-7). The arsenic concentration in filtrate of this filter also observed to be below Nepal standard of 50 µg/l but above WHO standard of 10 µg/l in most of the cases. It was also observed that the arsenic concentration in the filtrate was much higher immediate after the filter stop.

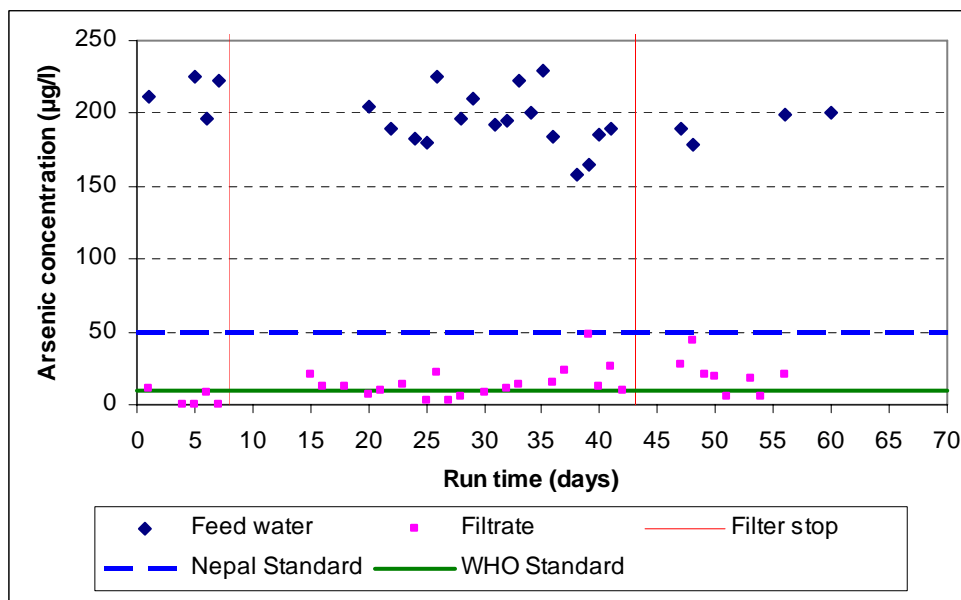


Figure 4-7: Arsenic concentration in feed and filtrate in Filter 2 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

The removal efficiency of Filter 3 was observed as 94% ~ 99% throughout the experiment period (Figure 4-8). The filter removed arsenic below the Nepal standard (50 µg/l) as well as



the WHO standard of 10  $\mu\text{g/l}$  throughout the experimental period. However, the arsenic concentration was found to be slightly higher immediate after the draining of the filter.

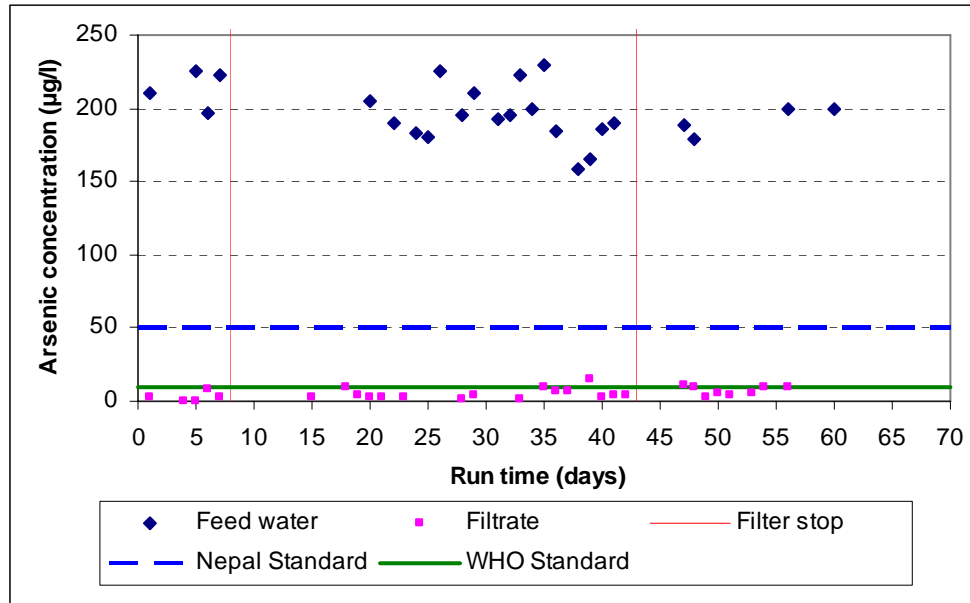


Figure 4-8: Arsenic concentration in feed and filtrate in Filter 3 (Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

Performance of this filter in terms of arsenic removal was the best among the three filters tested in this study. The reason for the better removal efficiency of this filter compared with Filters 1 and 2 is likely due to the adsorption and to a large extent straining action of very small iron flocs with As adsorbed with the help of the Aquamandix layer placed on top of IOCS.

To confirm the suspicion, the filtrate contained particulate Fe material from the filters they were filtered through a 0.45  $\mu\text{m}$  membrane filter. The arsenic concentration after filtration through the membrane was found to be significantly lower in both feed and filtrates of all the filters (Figure 4-9). It implies that Fe (II) present in feed water was already partially oxidized to Fe (III) before it passed through the filters and so some portion of arsenic was attached on to the flocs of the oxidized iron. These particulates escaped from the filters.

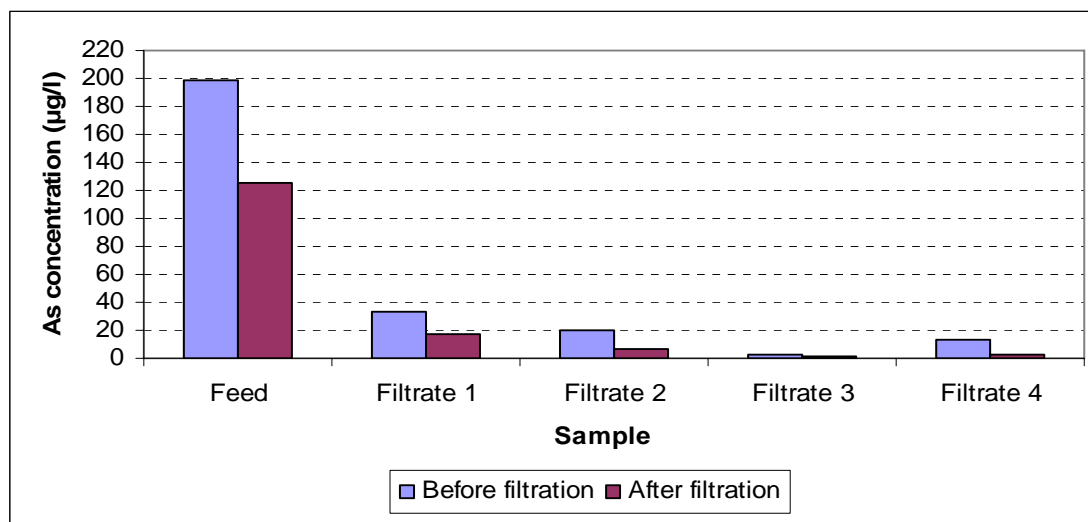


Figure 4-9: Arsenic concentration in feed and filtrates before and after filtration through 0.45 µm filter (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

### Effect of draining on arsenic removal performance

In Filter 1 and Filter 2 arsenic concentration was raised up to the level higher than the 10 µg/l, but lower than 50 µg/l immediately after the draining of the filters. The concentration gradually decreased to the levels of 4 µg/l and 3 µg/l within 24 hours for Filter 1 and Filter 2 respectively. In Filter 3, the maximum concentration immediately after draining was found to be 25 µg/l. and it reduced to below the detection limit of 2 µg/l within 24 hours (Figure 4-10).

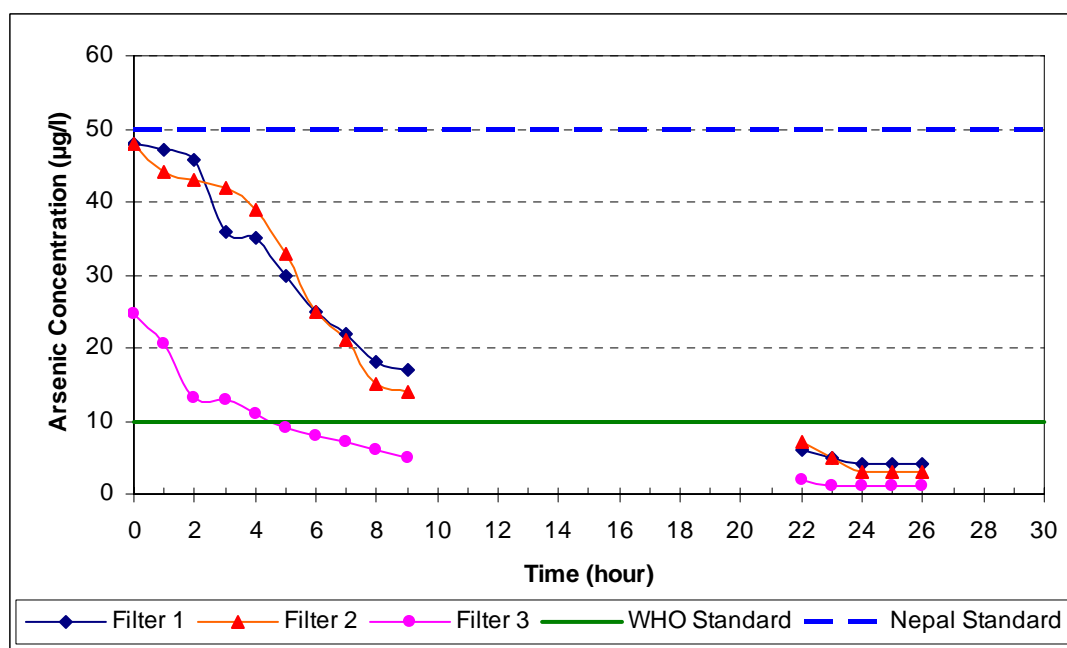


Figure 4-10: Arsenic concentration in filtrate at different filters after draining (average  $V_f = 0.25$  m/h; Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

To improve upon the quality of the filtrate from the filter, a polishing sand filter was installed at downstream of Filter 1 in series on 35<sup>th</sup> day of operation (Filter 4). The filtrate of Filter 1 was aerated before being fed into the polishing sand filter. This polishing filter removed effectively arsenic to the level below WHO standard of 10 µg/l (Figure 4-11).

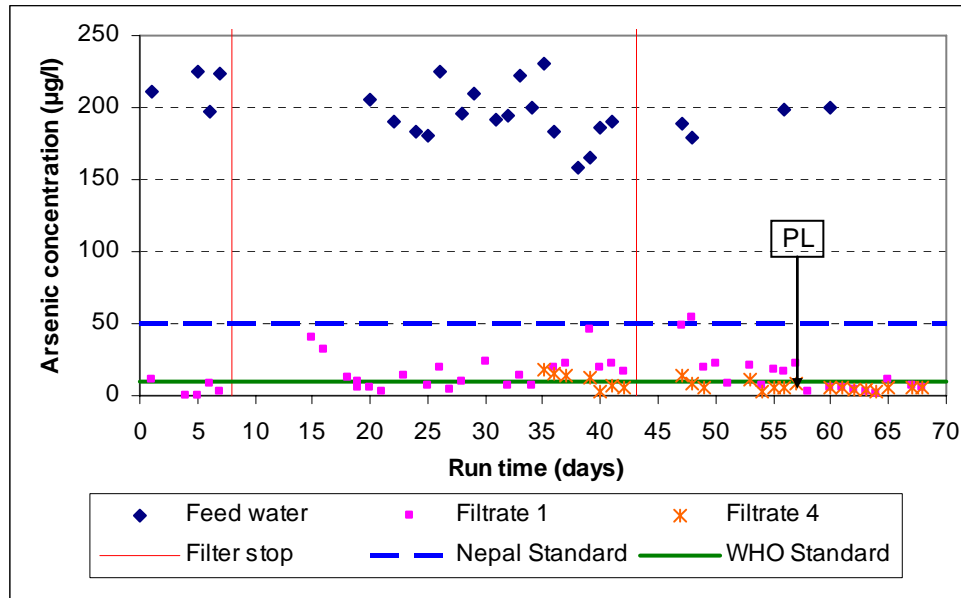


Figure 4-11: Arsenic concentration in feed and filtrate in Filter 1 and Filter 4 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8; PL= polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

The increased removal efficiency of the Filter 4 was due likely to following reasons;

- Adsorption of As onto to the fine particles of oxidised iron in filtrate 1. Straining action of fine sand removed iron particles including attached arsenic,
- The aeration might have enhanced the oxidation of As (III) to As (V), and
- The little remaining dissolved iron (II) oxidised to iron (III) due to the aeration of the filtrate resulting in fine iron flocs formation. Arsenic in filtrate was adsorbed to the iron particles. Fine sand in filter 4 removed iron flocs with attached arsenic.

As performance of the Filter 4 was very efficient on arsenic removal, it was decided to place a polishing layer of fine sand layer on top of IOCS in Filter 1. After 57 days of operation, a polishing layer with 10 cm thick fine sand of size fraction 0.5 mm to 1.0 mm was applied to the top of the IOCS in Filter 1. After addition of this layer the arsenic removal efficiency increased significantly up to 97.5%. The arsenic concentration of the filtrate was observed below WHO standard of 10 µg/l. The filter with the polishing layer removed oxidised iron flocs through predominantly straining action. The same concentration of arsenic in filtrates of both Filter 1 and Filter 4 strongly proved the straining action of fine sand (Figure 4-11).

#### 4.4.3 Iron removal

A study on analysis of 1260 samples for iron by NRCS/ENPHO, RWSSFDB and DWSS/UNICEF showed that 33 % of total samples contained very high iron level (more than 5 mg/L) different areas in Nepal (Shrestha, 2002). For this research, a number of samples were collected from Parsa district Nepal and analyzed in IHE. Iron in these samples was found to range from 1.24 mg/l to 4.16 mg/l (Table 4-1).

The iron removal efficiency of Filter 1 was about 90 % for 1<sup>st</sup> week of filter operation and then it reduced to value between 70% and 90% throughout the experimental period. The iron concentration in filtrate of the Filter 1 filled with IOCS started to increase after one week of operation. The iron concentration in filtrates increased to the level above the Nepal standard of 0.3 mg/l for most of the filter run time after two weeks of filter run time (Figure 4-12). This is likely due to the oxidation of iron (II) prior to the adsorption of IOCS inside the filter. It was observed that about 30% of iron (II) was already oxidised resulting in formation of fine iron flocs, which partially passed through the filters. The difference in iron concentration in filtrate of the Filter 1 before and after the membrane filtration through the 0.45 µm membrane confirms the escape of iron particle in the filtrate (Figure 4-15).

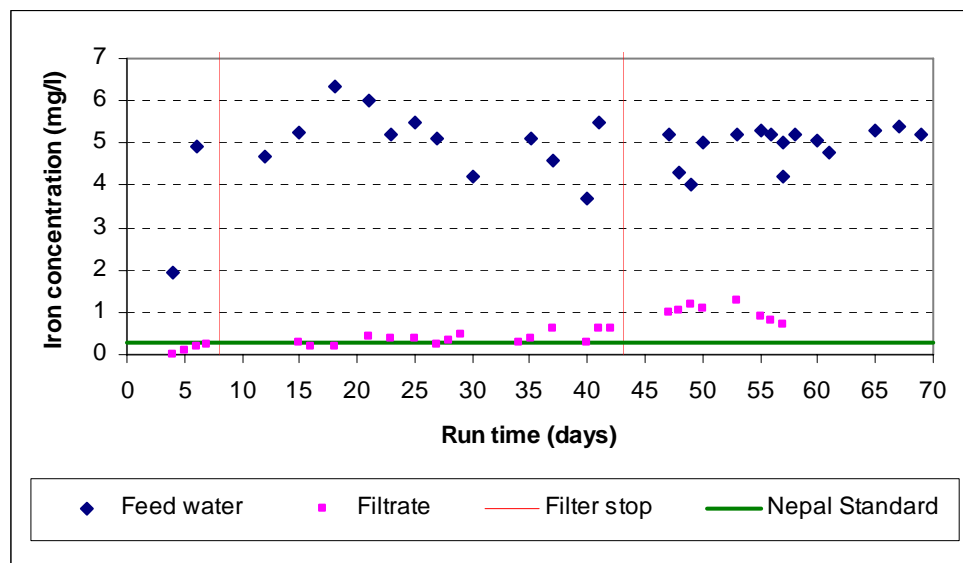


Figure 4-12: Iron concentration in feed and filtrate in Filter 1 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

Iron removal capacity of Filter 2 was almost similar to that of Filter 1. However, the performance of this filter in term of iron removal efficiency was better than that of Filter 1 some times due to the presence of CaCO<sub>3</sub> layer (Figure 4-13).

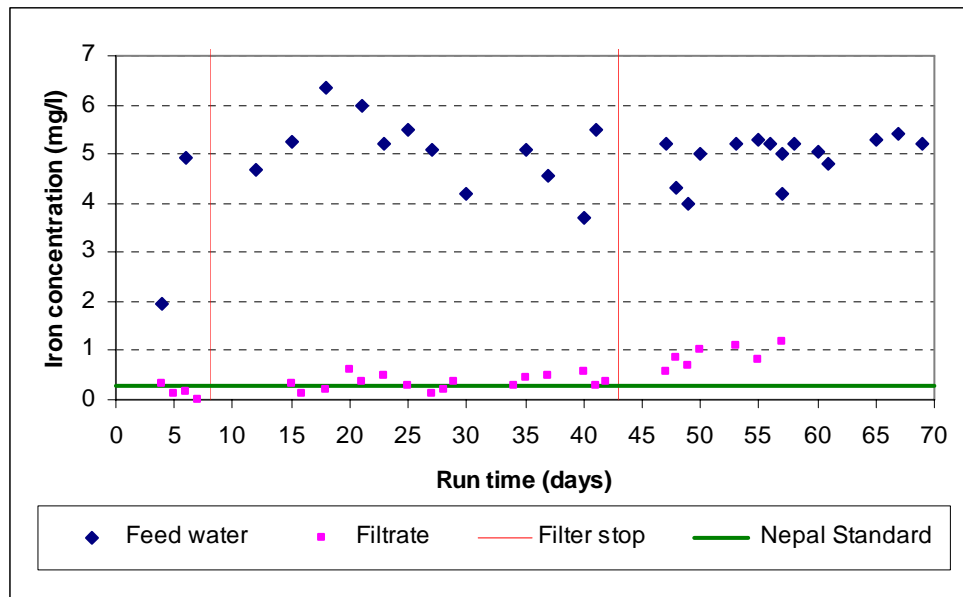


Figure 4-13: Iron concentration in feed and filtrate in Filter 2 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

The removal efficiency of Filter 3 was observed as best compared to the Filters 1 and 2 throughout the experiment period. The filter removed iron below Nepal standard of 0.3 mg/l for most part of the experiment period (Figure 4-14).

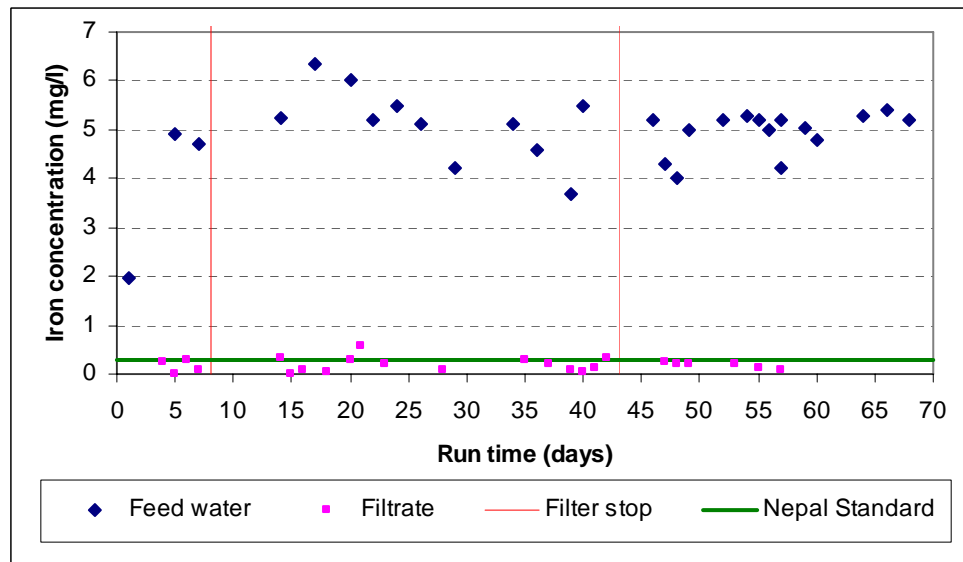


Figure 4-14: Iron concentration in feed and filtrate in Filter 3 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

To confirm the suspicion, the filtrate contained particulate Fe material from the filters they were filtered through a 0.45 µm membrane filter. The feed water and filtrates of all filters were filtered immediately through a 45 µm membrane. This filtration was done very fast intending to avoid oxidation of the iron (II). Iron concentration in water filtered through the membrane was much lower than it was in filtrate of all filters as shown in Figure 4-15. It



implies that Fe (II) present in feed water was already partially oxidized to Fe (III) before it passed through the filters. These particulates escaped from the filters.

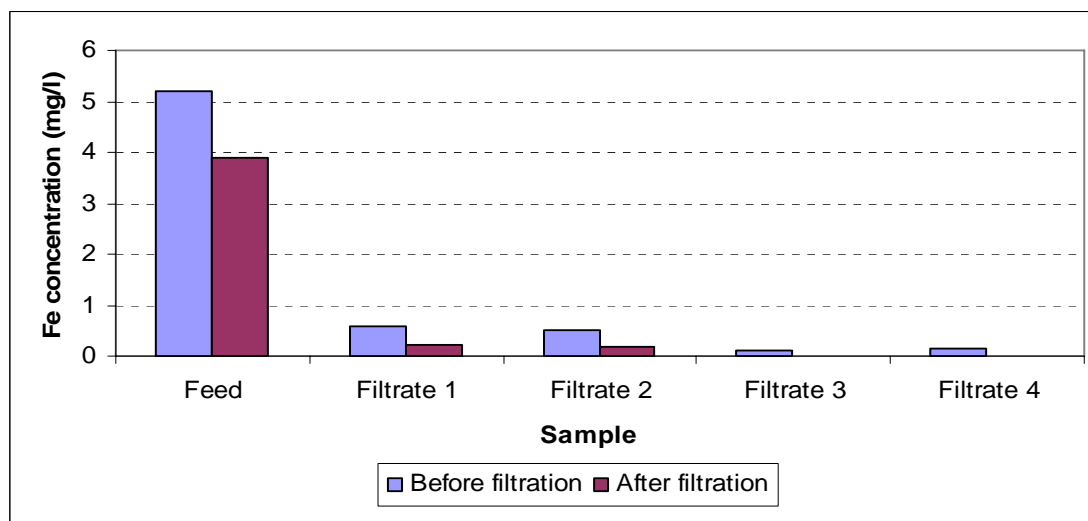


Figure 4-15: Iron concentration in feed and filtrate before and after filtration through 0.45  $\mu\text{m}$  filter (Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

### Effect of draining on iron removal performance

Iron concentration was very high immediately after the draining in all filters. The concentration gradually decreased to the levels of 0.2 mg/l and 0.15 mg/l within 24 hours for Filters 1 and 2 respectively. In Filter 3, the maximum concentration immediately after draining was 0.25 mg/l and it reduced to level of 0.06 mg/l within 24 hours (Figure 4-16).

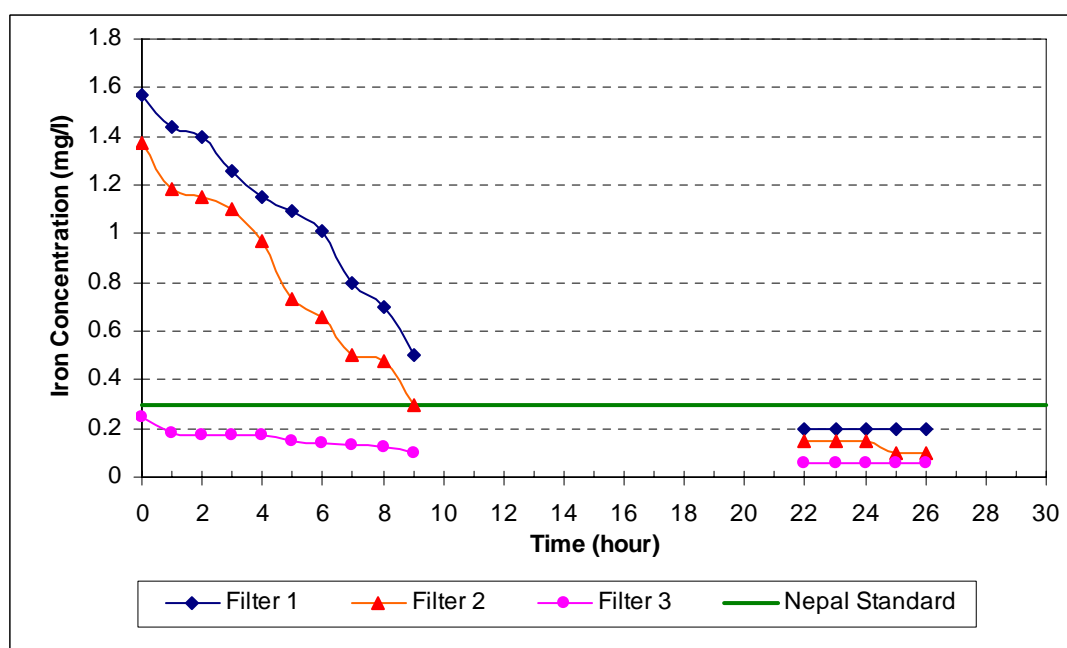


Figure 4-16: Iron concentration in filtrate at different filters after draining (average  $V_f$  = 0.25 m/h; Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)



After introducing Filter 4 filled with fine sand in series with Filter 1, the iron removal efficiency was increased to higher than 95% (Figure 4-17).

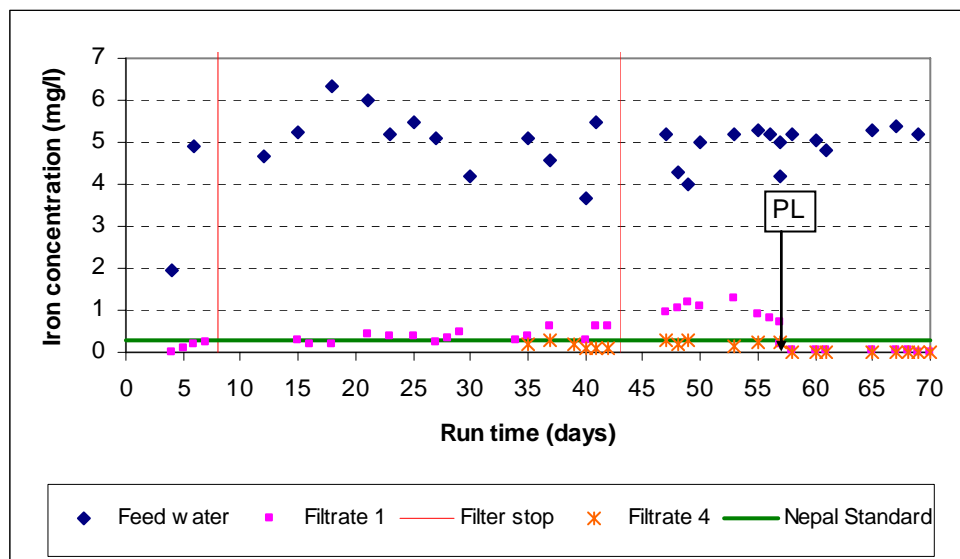


Figure 4-17: Iron concentration in feed and filtrate in Filter 1 and Filter 4 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8; PL= polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

It was observed that Filter 4 removed iron to the level below WHO and Nepal standard of 0.3 mg/l. This is mainly due to straining action of fine sand, which removed most of the iron flocs escaped from Filter 1. In addition, the aeration of the filtrate of Filter 1 also accelerates the oxidation of any remaining iron (II) and the flocs thus formed, was removed from the straining action.

#### 4.4.4 Manganese removal

Manganese removal was not pleasing by the Filter 1 (Figure 4-18). This filter removed manganese satisfactory below the level of WHO standard 0.4 mg/l only during the 1<sup>st</sup> week of operation. The manganese concentration in the filtrate gradually increased afterwards. After one month of operation, the manganese concentration was found to be above the concentration of feed water. It indicates that Mn was leaching out from the IOCS filter media.

The filter was drained and allowed to stay dry for some hours but it did not improve the efficiency of the manganese removal of the filter.

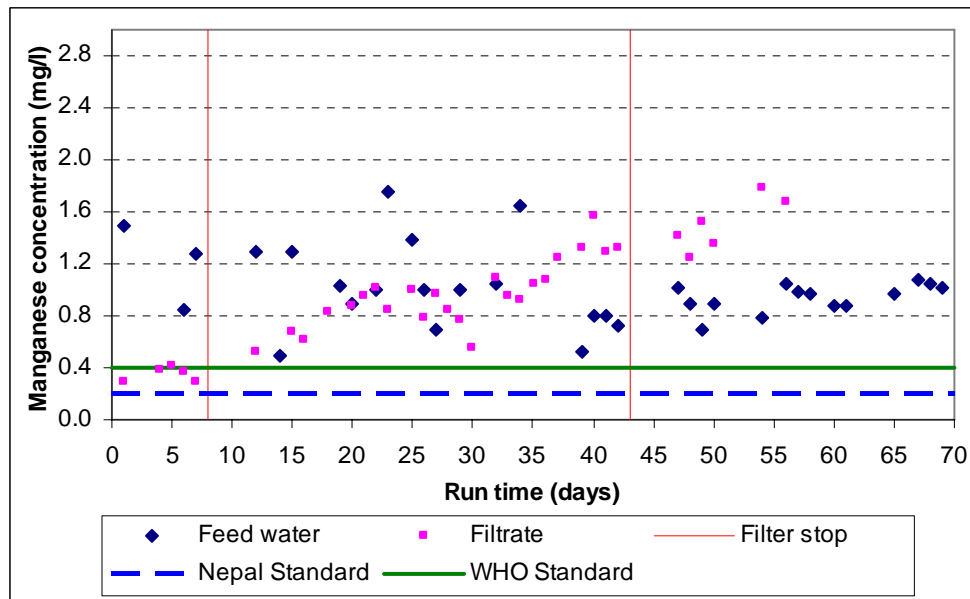


Figure 4-18: Manganese concentration in feed and filtrate in Filter 1 (Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

The trend of manganese removal achieved with Filter 2 was similar to the removal of manganese with the Filter 1. Manganese concentration in filtrate of the Filter 2 started to increase above the level in feed water approximately after 30 days of filter run (Figure 4-19).

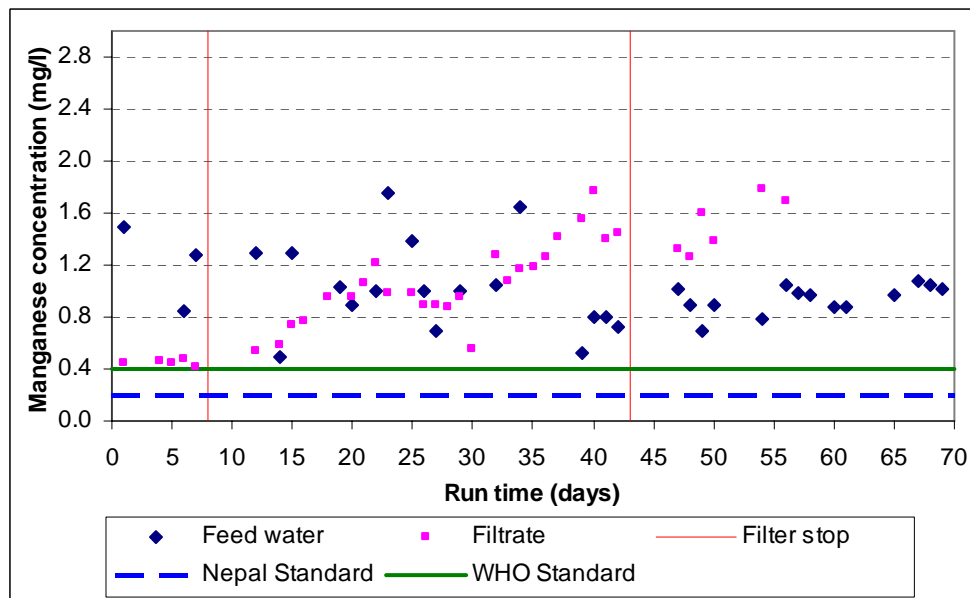


Figure 4-19: Manganese concentration in feed and filtrate in Filter 2 (Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

As manganese removal is better at higher pH, a layer of calcium carbonate was introduced at the bottom of the IOCS in the Filter 2. This intervention resulted in only moderate pH to 7.2. Table 4-3 shows the oxygen concentration and pH in feed water and filtrates of different

filters. Using Langelier index, the saturation pH (pH<sub>s</sub>) was calculated for the model water. The pH<sub>s</sub> was found to be 7.5. So the model water was not very aggressive to the CaCO<sub>3</sub>. The average pH of feed water was observed as 6.8 and the saturation index was -0.7. Ammonia present in model water resulted in complete consumption of available oxygen in the feed water.

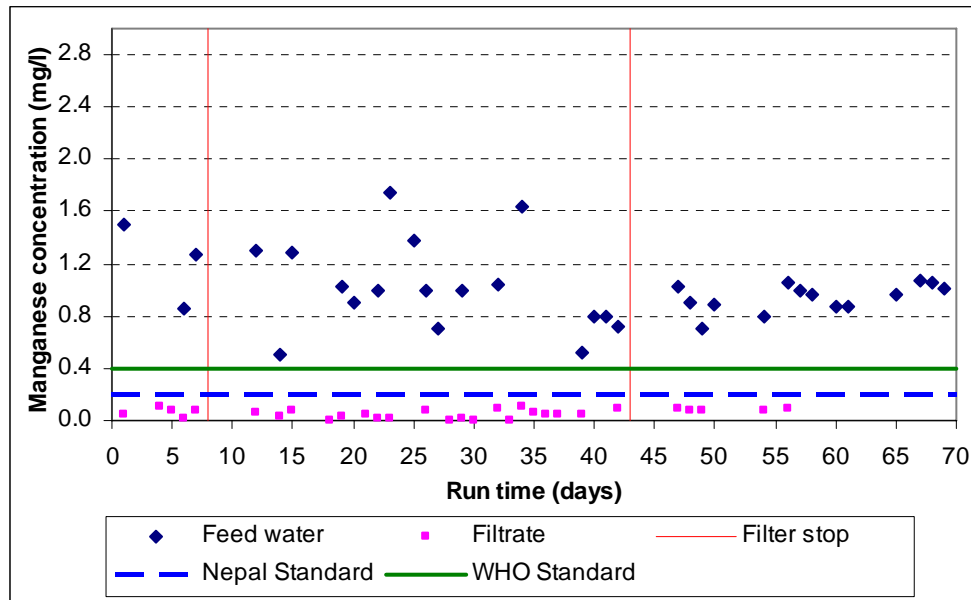


Figure 4-20: Manganese concentration in feed and filtrate in Filter 3 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; NH<sub>4</sub><sup>+</sup> = 4 mg/l; pH = 6.8)

In Filter 3, manganese was consistently removed below the WHO standard 0.4 mg/l and the Nepal standard of 0.2 mg/l throughout the experiment period. The manganese concentration in the filtrate was ranging from 0 mg/l to 0.1 mg/l with the removal efficiency ranging from 90% to 100% (Figure 4-20). Aquamandix layer introduced in this filter showed the best performance for the manganese removal efficiency.

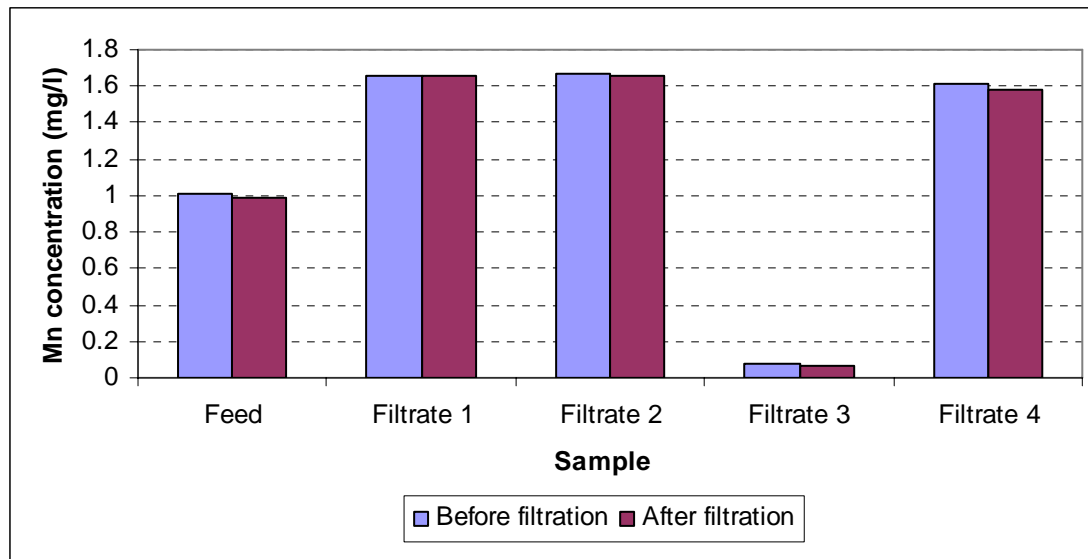


Figure 4-21: Manganese concentration in feed and filtrate before and after filtration through 0.45 µm filter (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8)

Feed water and filtrate from all filters were filtered through the 0.45 µm membrane. In contrast to results of similar experiment for arsenic and iron, the concentration of manganese in feed and filtrate before and after filtration through 0.45 µm filter were very similar (Figure 2-1). The rate of manganese oxidation was very low at average pH of 6.8 for the feed water.

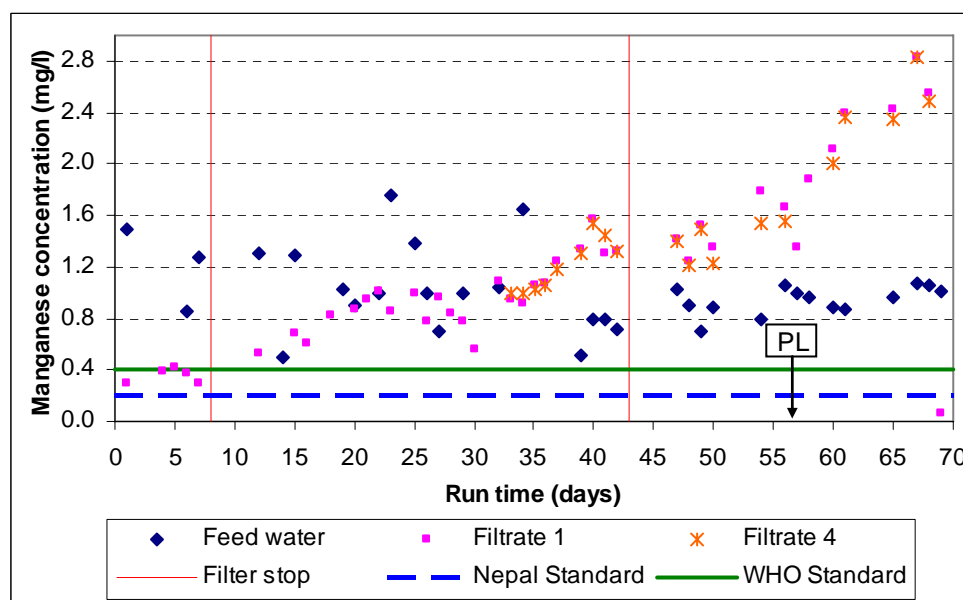


Figure 4-22: Manganese concentration in feed and filtrate in Filter 1 and Filter 4 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; pH = 6.8; PL= polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

The polishing filter was installed in the series after aeration of filtrate of Filter 1 on 35 days of the filter run hoping that the available air after aeration will increase the rate of oxidation

of manganese (Figure 4-22). This measure could not improve the manganese removal efficiency of the Filter 1 for 35 days of experiment period for the Filter 4.

After 57 days of filter run, the manganese concentration in filtrate increased to 2 mg/l (Figure 4-22) which was 2 times higher than the concentration of manganese in feed water. A layer of fine sand was placed in the Filter 1, but increasing trend of manganese concentration in the filtrate was observed to be the same as before introducing the layer.

#### 4.4.5 Ammonia removal

Figure 4-23 shows ammonia removal achieved with different filters in the period from 30 to 42 days of filters run. The ammonia removal with the Filter 3 was better compared to the others Filter 1 and Filter 2. Filter 3 removed the ammonium concentration to the value less than 1.0 mg/l, which is less than WHO and Nepal standards of 1.5 mg/l. The concentration of ammonia in filtrate of the Filter 1 was observed to be up to 2.92 mg/l on 30th day of the filter run. The polishing filter (Filter 4) removed almost all ammonia found in filtrate of the Filter 1. The reason for the removal of ammonium in filtrate of Filter 4 is likely due to the available oxygen in water after aeration.

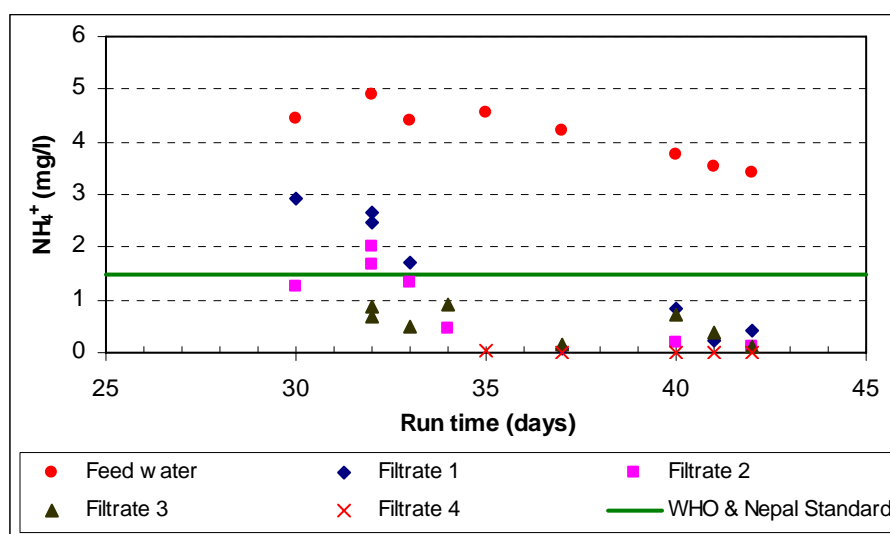


Figure 4-23: Concentration of ammonia ( $\text{NH}_4^+$ ) in feed water and filtrates of different filters (Model water: As (III) = 100  $\mu\text{g/l}$ ; As (V) = 100  $\mu\text{g/l}$ ; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  =  $4 \pm 1.0$  mg/l; pH = 6.8)

#### 4.4.6 Concentration of Nitrite and Nitrate in the filtrate

Ammonium concentration in feed water was in the range 3.43 mg/l to 4.9 mg/l. Nitrosomonas bacteria converted ammonium into nitrite ( $\text{NO}_2^-$ ) in the presence of oxygen. Figure 4-24 shows the result of the nitrite analysis in filtrate of the different filters. Average nitrite in filtrate of the Filter 1 was 0.4 mg/l.

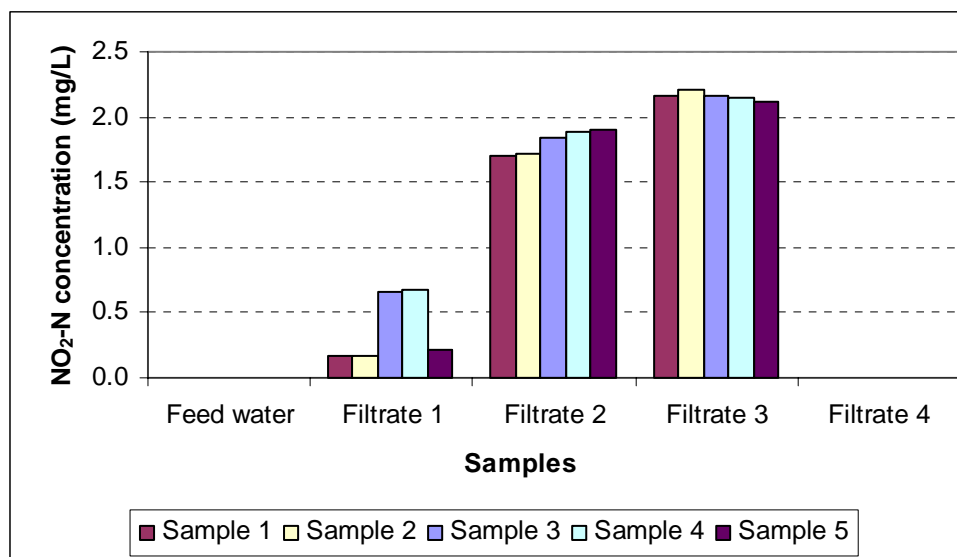


Figure 4-24: Concentration of Nitrite ( $\text{NO}_2\text{-N}$ ) in feed water and filtrates of different filters (Model water:  $\text{As (III)} = 100 \mu\text{g/l}$ ;  $\text{As (V)} = 100 \mu\text{g/l}$ ;  $\text{Fe} = 5 \pm 0.5 \text{ mg/l}$ ;  $\text{Mn} = 1 \pm 0.5 \text{ mg/l}$ ;  $\text{HCO}_3^- = 275 \text{ mg/l}$ ;  $\text{NH}_4^+ = 4 \pm 1.0 \text{ mg/l}$ ;  $\text{pH} = 6.8$ )

The average nitrite in filtrate of Filters 2 and 3 were  $1.75 \text{ mg/l}$  and  $2.15 \text{ mg/l}$  respectively. Nitrite was not removed below WHO standard ( $0.2 \text{ mg/l}$ ). Main reason for this is probably the unavailability of sufficient oxygen for survival of nitrobactor (annex Table 7-1).

The average DO available in the feed water was  $9.5 \text{ mg/l}$ . As there is high amount of ammonium, maximum amount of oxygen was consumed for ammonium reduction. The nitrosomonas bacteria consumed most of oxygen to convert ammonium into nitrite. Nitrosomonas and nitrobactor are aerobic bacteria. In addition, Nitrobactor converts nitrite to nitrate (section 2.4.2). Dissolved oxygen in feed water was  $9.5 \text{ mg/l}$ . On the 40<sup>th</sup> day, the DO consumed for ammonium reduction to nitrite was  $7.83 \text{ mg/l}$ ,  $9.46 \text{ mg/l}$ ,  $8.06 \text{ mg/l}$ ,  $2.18 \text{ mg/l}$  in Filter 1, Filter 2, Filter 3 and Filter 4 respectively. Therefore, there was negligible or no oxygen available in filtrates for reduction of nitrite to nitrate after ammonium reduction. According to the analysis of DO in filtrates (section 4.4.1), it can be also concluded that there is anoxic condition in the filters. In consequence, high concentration of nitrite was found in all the filters. The table 4.4.6 shows the oxygen available in filters after reduction of ammonium and nitrite.

Table 4.4.6 : Calculation of  $O_2$  available and used for biological ammonium oxidation to  $NO_2^-$  and  $NO_3^-$

Oxygen	Filter 1	Filter 2	Filter 3	Filter 4
$O_2$ in feed water (mg/l)	9.5	9.5	9.5	6.6
$O_2$ (mg/l) required for $NH_4^+ \rightarrow NO_2^-$	7.83	9.46	8.06	2.18
$O_2$ mg/l consumed for $NO_2^- \rightarrow NO_3^-$	2.49	2.56	1.95	0.73
$O_2$ mg/l available for $NO_2^- \rightarrow NO_3^-$	$\approx 0$	$\approx 0$	$\approx 0$	3.69

## 4.5 Performance of reference filter for model water without Ammonium

In order to test the performance of the IHE family filter with IOCS for ground water without ammonium, a separate filter (Filter 5) was installed after 69 days of experiment period. The size and configuration of the Filter 5 was similar to that of the Filter 1 with 10 cm thick polishing sand layer on top of IOCS. In this experiment same polishing filter (Filter 4) after aeration was used in the series with Filter 5. Model water without ammonium concentration was prepared for a reference experiment. Same concentrations of arsenic, iron, manganese,  $HCO_3^-$ , pH etc. were there in this model water.

### 4.5.1 Manganese removal

Manganese removal efficiency of the IHE family filter for the model water prepared without ammonium is shown in Figure 4-25. The manganese concentration in the filtrate of Filter 5 was low as about 0.06 mg/l at beginning and gradually increased to 0.52 mg/l on 30<sup>th</sup> day of the filter run. The manganese concentration was always below the WHO standard of 0.4 mg/l for 1<sup>st</sup> 28 days of filter run and it was found to be above after 29 days of the filter run. The concentration of filtrate of the Filter 5 was below the Nepal standard of 0.2 mg/l for up to 15 days of filter run time and then it increased above the standard value.

The manganese removal efficiency of the filter was better for the model water without ammonium than that for the model water with high ammonium content (Figure 4-18). The efficiency of the polishing filter (i.e. Filter 4) was observed as negligible in term of manganese removal. The manganese concentration in filtrate of the Filter 4 was nearly same or reduced by small amount when compared with filtrate of the Filter 5.

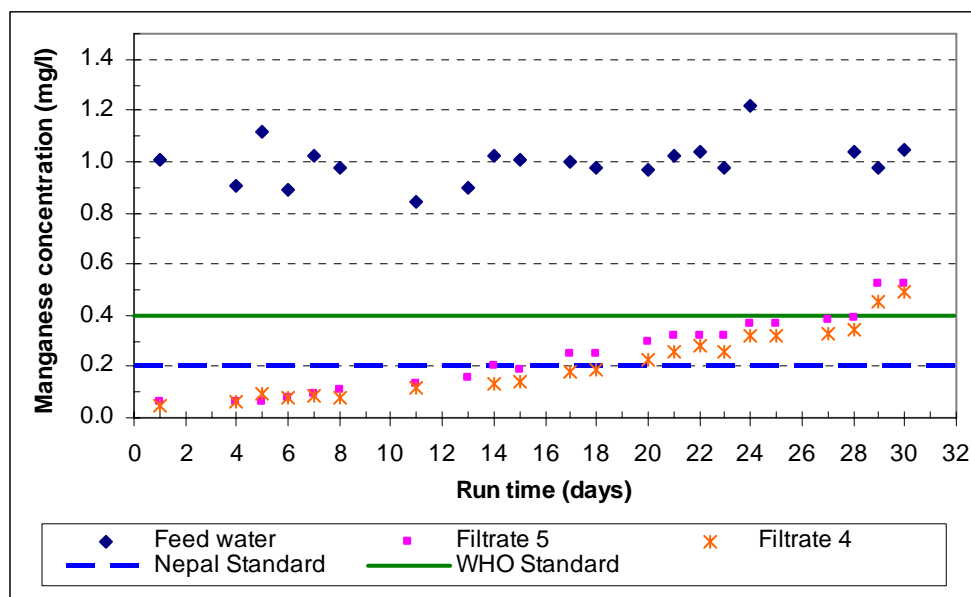


Figure 4-25: Manganese concentration in feed and filtrate in Filter 5 and Filter 4 for feed water without ammonium (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; pH = 6.8; polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

The manganese removal efficiency of the IHE family filter with IOCS was better for the feed water without ammonium content. Therefore, the existing IHE family filter can be used for manganese removal if the feed water is treated to remove ammonium prior to the filtration.

Figure 4-26 shows a comparison between the removal of manganese in model water with and without ammonia. The high concentration of ammonia influenced the manganese removal efficiency. Filter 5 with sand layer on top of IOCS showed higher removal efficiency for manganese when treating model water without NH<sub>4</sub><sup>+</sup>. After 4 weeks of filter run time manganese concentration of the filtrate of filter 5 was about 0.4 mg/l. In the case of Filter 1, when treating model water with NH<sub>4</sub><sup>+</sup> manganese concentration in the filtrate was 0.8 mg/l after 4 weeks. The presence ammonium probably enhances manganese release.



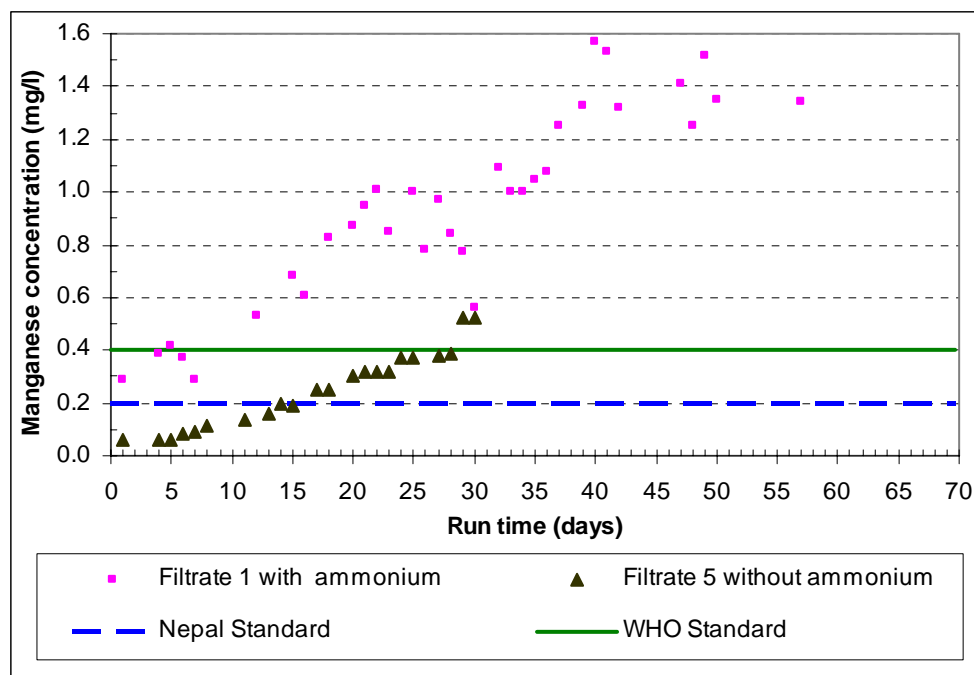


Figure 4-26: Manganese concentration in feed and filtrate in Filter 1, Filter 5 and Filter 4 with and without ammonium (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; pH = 6.8; polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

#### 4.5.2 Arsenic removal

The removal efficiency of Filter 5 was nearly 99% after 1 week of the filter operation. This filter removed the arsenic very effectively below the WHO standard 10 µg/l (Figure 4-27). In the absence of ammonia, sufficient oxygen was available in the filter for oxidation of iron (II) into iron (III) and As (III) into As (V).

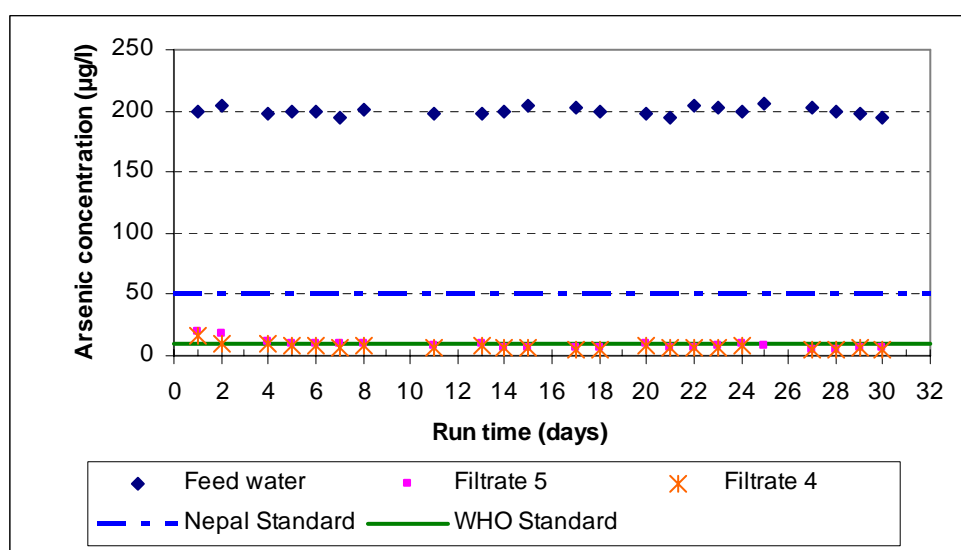


Figure 4-27: Arsenic concentration in feed and filtrate in Filter 5 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; pH = 6.8; polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

### 4.5.3 Iron removal

The Iron removal efficiency of the Filter 5 for model water without ammonium was observed to be nearly 100% from the beginning of the filter run. The iron concentration in the filtrate was found to be below the detection limit of the measuring instrument (ICP Perkin Elmer Optima 3000). It removed iron below the concentration of 0.1 mg/l consistently throughout the experimental period (Figure 4-28).

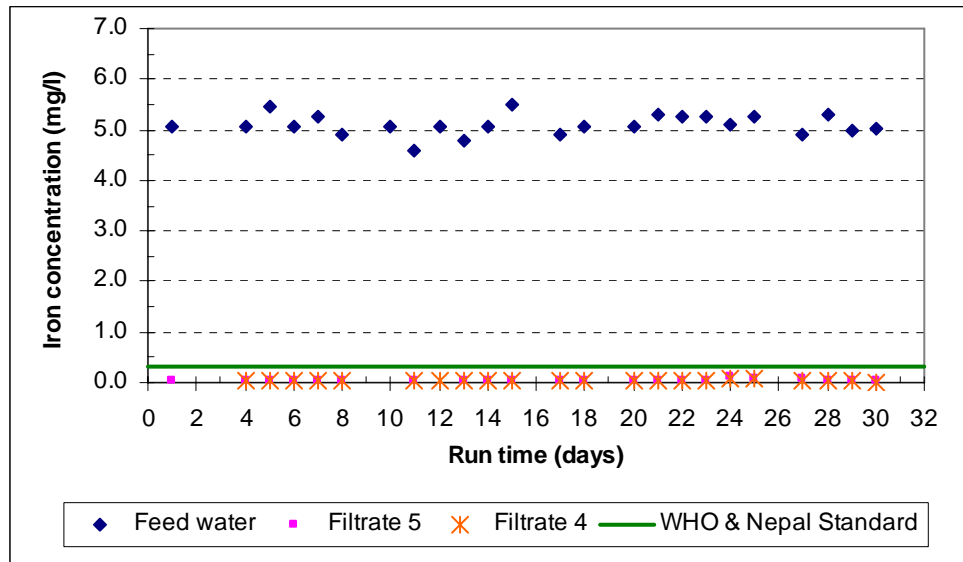


Figure 4-28: Iron concentration in feed and filtrate in Filter 5 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe = 5 ± 0.5 mg/l; Mn = 1 ± 0.5 mg/l; HCO<sub>3</sub><sup>-</sup> = 275 mg/l; pH = 6.8; polishing sand layer of bed depth 10 cm and size fraction 0.5 mm to 1.0 mm)

## 4.6 Cost analysis of IHE family filters with Aquamandix

The unit cost of IHE family filter was approximately € 50 if at least 10 units are manufactured at a time excluding the transportation cost of filter media (Khan, 2004a).

In this research, 10 cm thick Aquamandix layer was added on top of IOCS in the IHE family filter. The corresponding volume used was  $8.17 \times 10^{-4} \text{ m}^3$  in the Filter 3 (internal diameter of 10.2 cm). The cost increment due to application of Aquamandix excluding transportation was analysed as follows;

$$\text{Cost of Aquamandix} = \text{€ } 35 / 25 \text{ kg} = 35/25 = \text{€ } 1.40/\text{Kg}$$

$$\text{Density of Aquamandix (Kg/m}^3\text{)} = 2000 \text{ kg/m}^3$$

$$\text{Volume of Aquamandix used (m}^3\text{)} = 8.17 \times 10^{-4}$$

$$\text{Wt. of Aquamandix used} = 1.634 \text{ kg}$$

$$\text{Cost of Aquamandix used in Filter 3} = 1.4 \times 1.634 = \text{€ } 2.30$$

Therefore, initial cost of IHE family filter will be increased by approximately € 2.50 per filter with addition of polishing layer of Aquamandix.

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

1. Highest concentration among the samples collected from ground water of Parsa, Nepal was observed to be in the range of 2  $\mu\text{g/l}$  – 235  $\mu\text{g/l}$ . Similarly, iron and manganese concentrations were found to be in the range of 0.28 mg /l – 4.56 mg/l and 0.2 mg/l – 0.99 mg/l respectively. Highest concentration of ammonium in the ground water samples was 3.78 mg/l.
2. After one-week run of the filters, the capacity in the filter with IOCS only (Filter 1) reduced by 35%; filter with a layer of  $\text{CaCO}_3$  (Filter 2) reduced by 30%; and filter with a polishing layer of Aquamandix (Filter 3) reduced by 60%.
3. Simple draining of filters helped largely to recover the filter capacity. Nevertheless, prolonged filter operation resulted in capacity reduction. Extrapolation of the results obtained in study showed the capacity of Filter 1 would reduce by 0.94 l/h in 100 days. Similarly, the capacity would reduce by 0.65 l/h and 0.28 l/h in 100 days in Filter 2 and Filter 3 respectively.
4. The arsenic removal efficiency was affected by the presence of  $\text{NH}_4^+$  in the model water. For model water with high  $\text{NH}_4^+$ , the As concentration in filtrates of Filters 1 and 2 were found to be between 0–50  $\mu\text{g/l}$ . Filter 3 removed arsenic consistently below the WHO standard (10  $\mu\text{g/l}$ ) throughout the experimental period. The Aquamandix is responsible for the improved arsenic removal. This removal is likely due to the straining of the iron micro-flocs and / or adsorption of arsenic. When the polishing layer of sand was added in Filter 1, the arsenic concentration in the filtrate was observed to have dropped consistently below the WHO standard (10  $\mu\text{g/l}$ ).
5. The average iron removal efficiencies of Filters 1 and 2 for 57 days of filter run were found to be 88% and 89% respectively. The average removal efficiency in the filter 3 was found to be 96%. Filter 3 removed iron consistently below the Nepal standard (0.3 mg/l) throughout the experimental period. The reason was likely due to the adsorption and straining of the fine particles of the Aquamandix.
6. In the previous study with the IHE family filter in Bangladesh, removal of iron and arsenic with IOCS was observed to be satisfactory (i.e. below WHO standard) in most of the sites. This could be attributed to prolonged available contact time for aeration of the feed water under the field conditions.
7. A serial connection of a polishing sand filter after simple aeration to the IOCS filter or addition of a polishing layer of sand (0.5 – 1.0 mm) on top of the IOCS could be a solution for the efficient removal of arsenic and iron micro-flocs.
8. Manganese removal was not satisfactory with both Filter 1 and Filter 2 when treating water with high  $\text{NH}_4^+$ . These filters removed manganese below WHO standard (0.4 mg/l) only during the first 2 weeks of operation. After this period, manganese

- concentration in filtrate started to increase. In addition, manganese level was found beyond the concentration in feed water (1 mg/l) after 4 weeks.
9. The layer of  $\text{CaCO}_3$  on the bottom of IOCS (Filter 2) could not increase pH significantly. Consequently, the efficiency of manganese removal was similar to the Filter 1.
  10. Filter 3 equipped with a polishing layer of Aquamandix on the top of IOCS consistently removed manganese below WHO standard (0.4mg/l) throughout the experimental period.
  11. Post sand filtration after aeration did not remove manganese within the experimental period (65 days). This is likely due to the low pH of the feedwater (i.e. about 7.5) which therefore could not facilitate the oxidation of  $\text{Mn}^{2+}$ . Moreover, the shorter period of filter run could also be a limitation.
  12. High concentration of ammonia (4 mg/l) present in the feed water gave rise to  $\text{NO}_2$  in the filtrates of the filters. The  $\text{NO}_2$  concentrations in the filtrate of the filters with Aquamandix and  $\text{CaCO}_3$  were 4 – 5 times higher than that of the filter with only IOCS. A polishing sand filter installed after aeration resulted in  $\text{NO}_2$  removal.
  13. Reference filter (i.e. Filter 5) with sand layer on top of IOCS showed higher removal efficiency for manganese when treating model water without  $\text{NH}_4^+$ . After 4 weeks of filter run time manganese concentration of the filtrate of filter 5 was about 0.4 mg/l. In the case of Filter 1, when treating model water with  $\text{NH}_4^+$  manganese concentration in the filtrate was 0.8 mg/l after 4 weeks. The presence of ammonium probably enhances manganese release.
  14. The IHE family filter with addition of Aquamandix layer on the top of IOCS showed best results by way of arsenic, iron, and manganese removal when treating groundwater with high  $\text{NH}_4^+$ . A polishing filter might be required to avoid formation of  $\text{NO}_2$ .
  15. Addition of polishing layer of Aquamandix on top of the IOCS will increase the cost of IHE family filter not more than 2.5 Euro.

The table 5.1 shows the performance IHE family filter, with IOCS as the only filter media, as monitored during this study. The Table 5.2 presents effect of different measures introduced and tested in this research in order to improve manganese removal efficiency.

*Table 5.1. Performance of IHE Family filter with IOCS as filter media*

Quality parameters	Summary of results and observations
Model water composition	As (III): 100 µg/l As (V): 100 µg/l Fe (II): 5 mg/l Mn(II): 1 mg/l NH <sub>4</sub> <sup>+</sup> : 4mg/l.
Arsenic	Effectively removed below Nepal Standard but values frequently above WHO standard
Iron	Effectively removed below Nepal Standard but inconsistent
Manganese	Not satisfactorily removal
NH <sub>4</sub> <sup>+</sup>	All filter removed ammonium below 1.5 mg/l after about 1 month of ripening
NO <sub>2</sub>	Much higher than WHO guideline value in all filters

*Table 5.2. Effect of extra measures applied to enhance manganese removal*

Extra measures for manganese removal	Result obtained from this research
Type of Filter	2nd generation of IHE family filter
Aeration followed by polishing sand filter	Both Fe and As are removed very effectively (≥96%), Mn removal not improved (very poor ) Removed NH <sub>4</sub> <sup>+</sup> efficiently below 1.5 mg/l Removed NO <sub>2</sub> efficiently below WHO standard
Lime stone layer	Mn. removal was not significantly improved (poor Mn removal) No effect on NO <sub>2</sub> formation/removal
Polishing layer of fine sand on top of IOCS	Removed arsenic and iron particulates efficiently below WHO standard No effect on manganese removal
Polishing layer of Aquamandix at the top of IOCS	Removed arsenic, iron and manganese efficiently below WHO standard. No positive effect on NO <sub>2</sub> formation/removal

## 5.2 Recommendations

The following recommendations can be considered for further improvement of the IHE family filters.

1. Long-term monitoring of the performance of the IHE family filter with polishing layer of Aquamandix in field condition is required to determine the breakthrough.
2. The design and long-term performance of the post sand filter should be established and tested in field condition.
3. Additional research is required for better understanding NO<sub>2</sub> formation in filters.

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## 7. APPENDICES

### Annex 1: Name and address of the persons contacted during field visit in Nepal

1. Nepal water supply Corporation
2. Dr. Makhan Maharjan- ENPHO, Baneshwor, Kathmandu Nepal
3. Madhav Pahari- UNICEF, Jawalakhel, Lalitpur, Nepal
4. Abadh Kishore Mishra- Department of water supply and sewerage (DWSS), Panipokhari, Kathmandu, Nepal
5. Ganesh Thapa, DWSS, Panipokhari, Kathmandu, Nepal
6. Red cross society, Birgunj, Parsa Nepal
7. Ms Linda Smith, Filters for Families, Bakhundol , Lisper, Nepal
8. Kamal Jaisi, DOLIDAR, Jawalakhel, Nepal
9. Samples collected and visited site - Parsa, Nepal

### Annex 2: Name of the owners of sample collected tube wells

Name of the owners	Sample Name
Raghubir Bhandari	1
Kameshwor Prasad Kurmi	2
Dhruba Prashad Kurmi	3
Ramji Prajapati	4
Raj Kishor Raut	5
Rameshwor Shah	6
Puspa Raj Prashad Kurmi	7
Brijit Raut Kurmi	8
Binu Raut Kurmi	9





### Annex 3: Selected photographs of field visit



Figure 7-1: Typical tube wells in Parsa, Nepal



Figure 7-2: Use of tube –well water for domestic purpose in rural area of Parsa, Nepal





Figure 7-3: A man drinking water directly from tube-well in Parsa, Nepal



Figure 7-4: Sample collection from tube-well in Parsa, Nepal



Figure 7-5: One of the typical bio-sand filters for arsenic removal used in Nepal



Figure 7-6: Sono-filter going to be used for arsenic removal in Nepal (Source: Filter for family)





*Figure 7-7: Draining of filter in the lab*



*Figure 7-8: IOCS used as adsorbent in IHE family filter*



Figure 7-9:  $\text{CaCO}_3$  used in IHE family filter to increase pH of feed water



Figure 7-10: IHE family filter (IOCS) followed by polishing sand filter after aeration step



Figure 7-11: Feeding of model water with Fe and Mn stock solution



Figure 7-12: Aquamandix used as polishing layer in IHE family filter





*Figure 7-13: Samples prepared for NO<sub>2</sub>-N test*



*Figure 7-14: IHE family filters in operation*



Figure 7-15: Pumice used as supporting material in IHE family filter



Figure 7-16: Samples prepared for  $\text{NH}_4^+$  test

**Annex 4: Calculation of  $\text{NH}_4^+$  and Nitrite removal in filtrate**
*Table 7-1: Calculation of  $\text{NH}_4^+$  and Nitrite removal in filtrate*

	<b>Filter 1</b>	<b>Filter 2</b>	<b>Filter 3</b>	<b>Filter 4</b>
$\text{NH}_4^+$ in (mg/l)	3.75	3.75	3.75	0.82
$\text{NH}_4^+$ out (mg/l)	0.82	0.21	0.73	0.00
$\text{NH}_4^+$ removed (mg/l)	2.93	3.54	3.02	0.82
$\text{O}_2$ in feed water (mg/l)	9.5	9.5	9.5	6.6
$\text{O}_2$ (mg/l) $\text{NH}_4^+$ (per mg) $\rightarrow \text{NO}_2^-$	2.67	2.67	2.67	2.67
$\text{O}_2$ (mg/l) required for $\text{NH}_4^+ \rightarrow \text{NO}_2^-$	7.83	9.46	8.06	2.18
$\text{NO}_2^-$ (mg) $\text{NH}_4^+$ (per mg) $\rightarrow \text{NO}_2^-$	2.56	2.56	2.56	2.56
$\text{NO}_2^-$ calculated (mg/l)	7.51	9.07	7.73	2.09
$\text{NO}_2^-$ in experiment (mg/l)	0.4	1.75	2.15	0
$\text{NO}_2^-$ removed (mg/l)	7.11	7.32	5.58	2.09
$\text{O}_2$ (mg/l) $\text{NO}_2^-$ (per mg) $\rightarrow \text{NO}_3^-$	0.35	0.35	0.35	0.35
$\text{O}_2$ mg/l consumed for $\text{NO}_2^- \rightarrow \text{NO}_3^-$	2.49	2.56	1.95	0.73
$\text{NO}_2 - \text{NO}_3$ per mg	1.35	1.35	1.35	1.35
$\text{NO}_3$ calculated	9.59	9.89	7.53	2.83
$\text{O}_2$ mg/l available for $\text{NO}_2^- \rightarrow \text{NO}_3^-$	0	0	0	3.69



## Annex 5: DO and pH in feed and filtrate

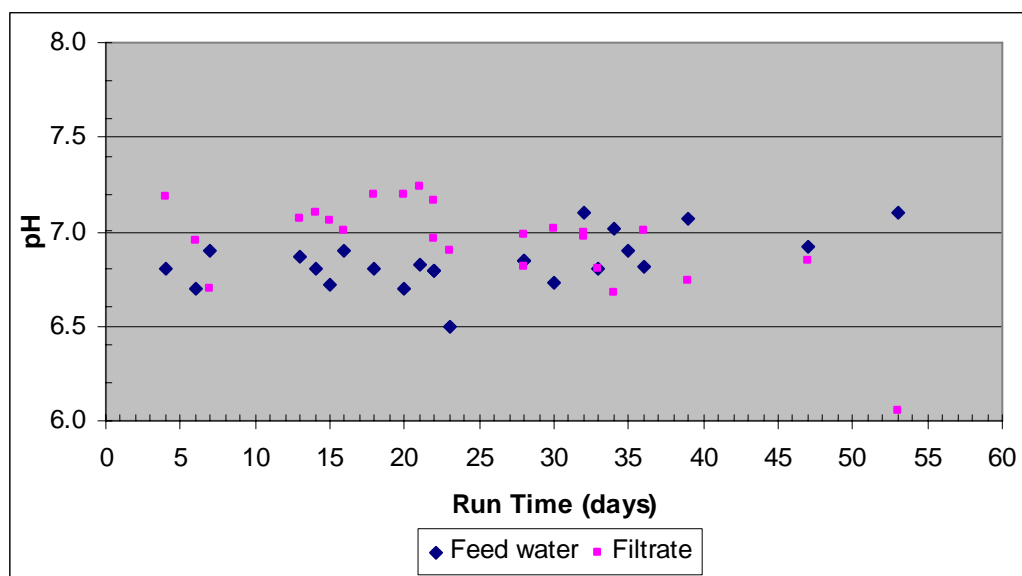


Figure 7-17: pH in feed and filtrate in Filter 1 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS)

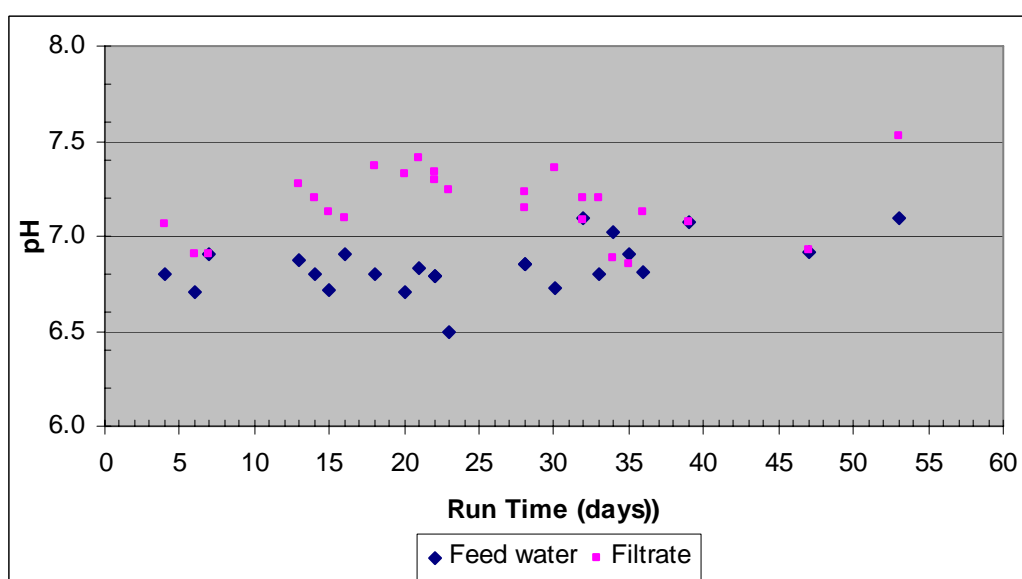


Figure 7-18: pH in feed and filtrate in Filter 2 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer  $\text{CaCO}_3$  on bottom)

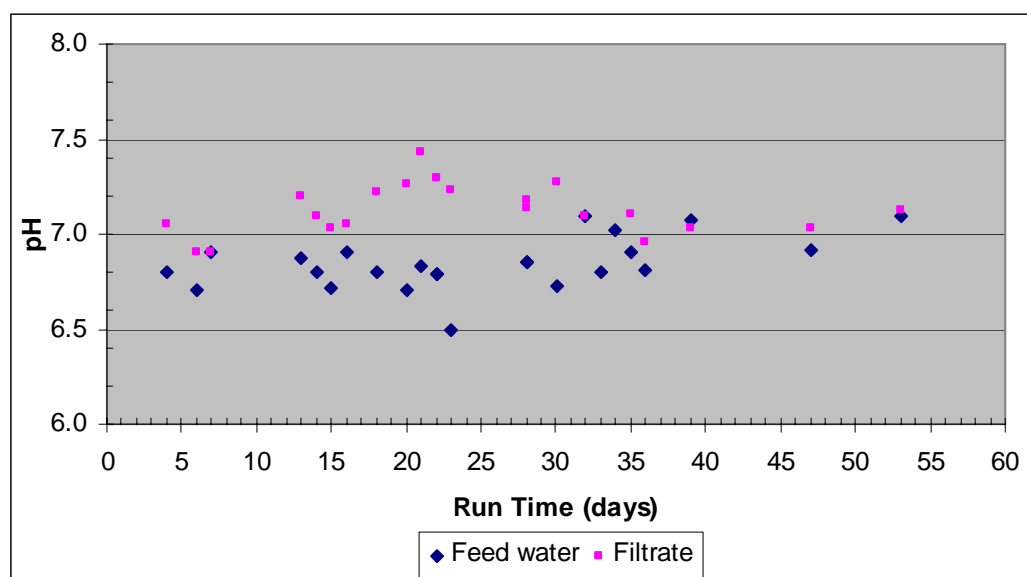


Figure 7-19: pH in feed and filtrate in Filter 3 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)

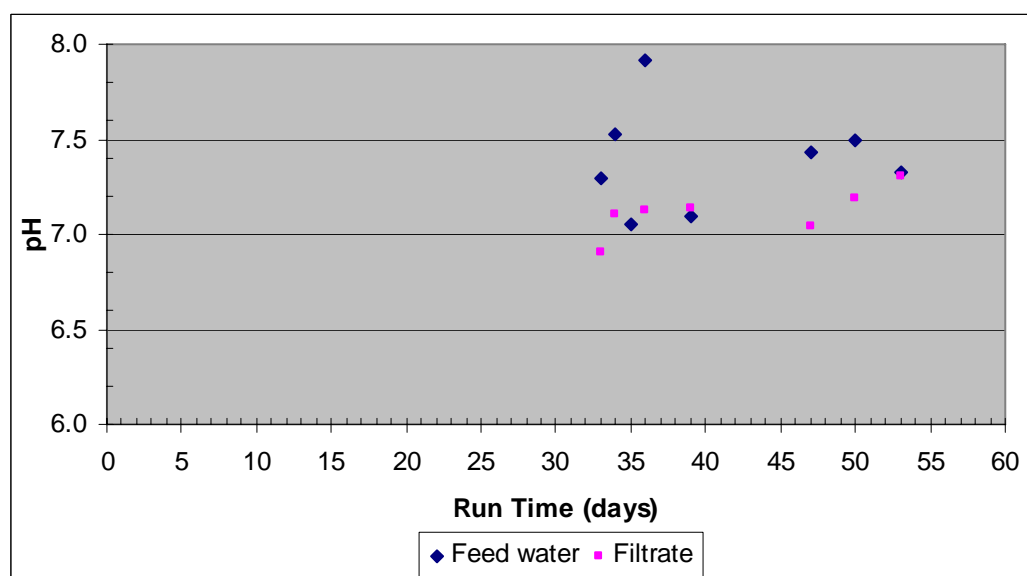


Figure 7-20: pH in feed and filtrate in Filter 4 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)



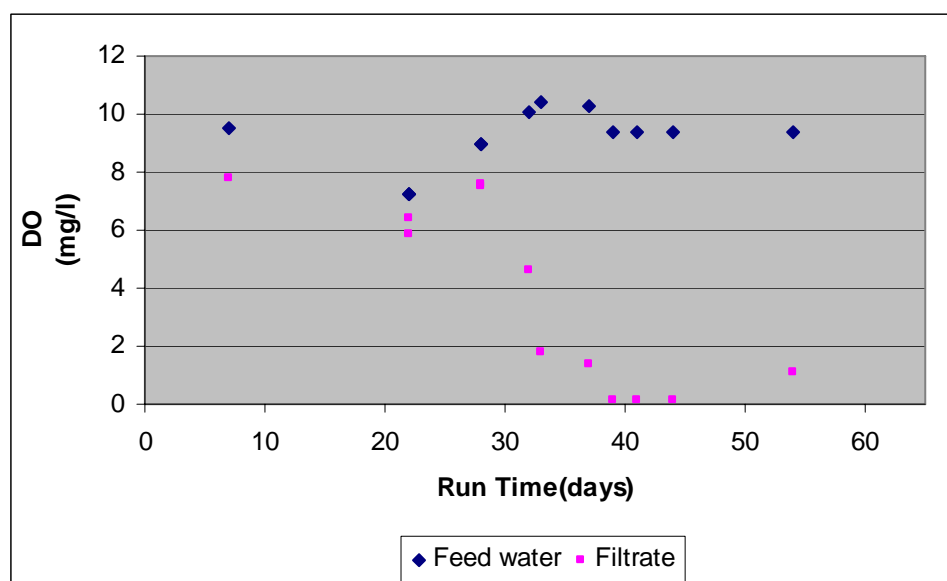


Figure 7-21: DO in feed and filtrate in Filter 1 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)

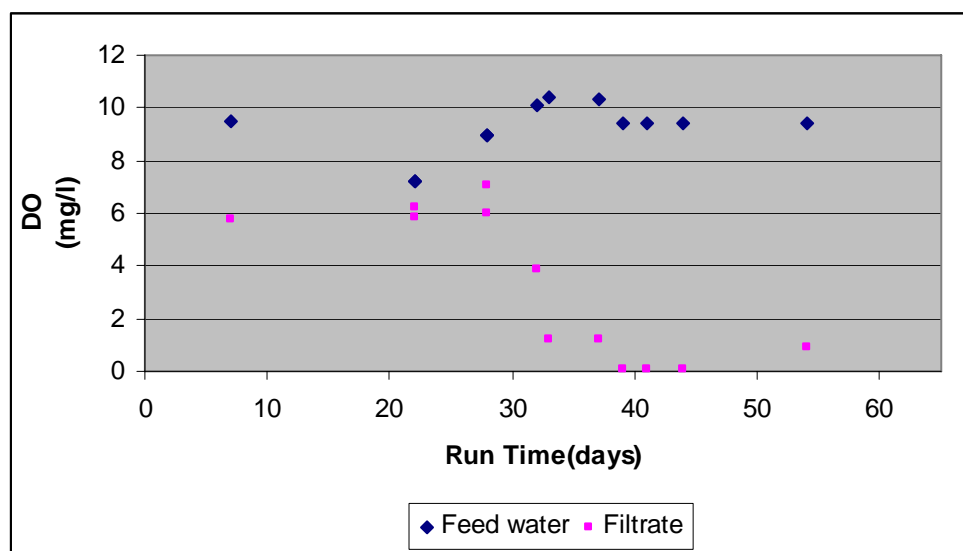


Figure 7-22: DO in feed and filtrate in Filter 2 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)

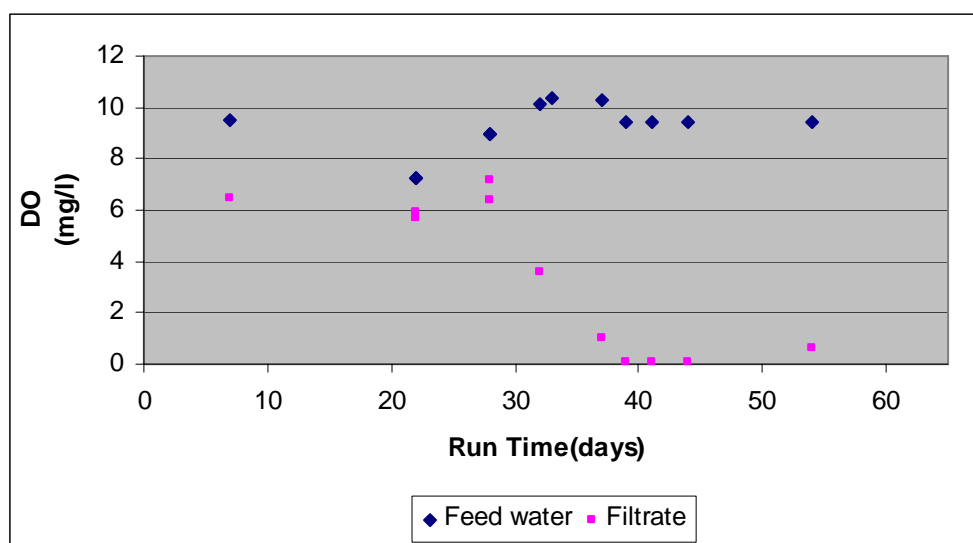


Figure 7-23: DO in feed and filtrate in Filter 3 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)

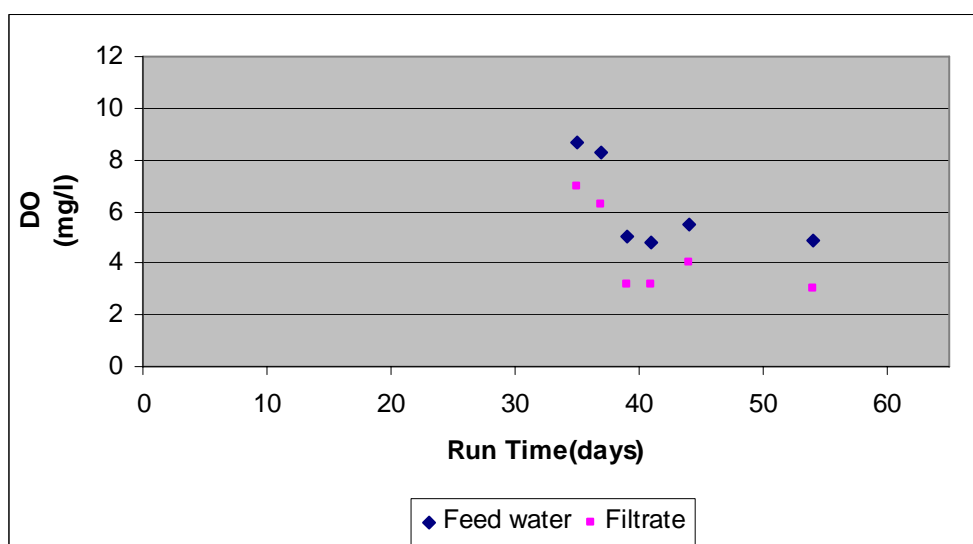


Figure 7-24: DO in feed and filtrate in Filter 4 (Model water: As (III) = 100 µg/l; As (V) = 100 µg/l; Fe =  $5 \pm 0.5$  mg/l; Mn =  $1 \pm 0.5$  mg/l;  $\text{HCO}_3^-$  = 275 mg/l;  $\text{NH}_4^+$  = 4 mg/l; Filter Media IOCS with 10 cm layer Aquamandix on top)