The Arsenic Biosand Filter (ABF) Project:

Design of an Appropriate Household Drinking Water Filter for Rural Nepal

Final Report
July 2003

Prepared for
Rural Water Supply and Sanitation Support Programme
Butwal, Nepal

and
Environment and Public Health Organization
Kathmandu, Nepal

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ACKNOWLEDGEMENTS

Tommy Ngai would like to thank the Lemelson Foundation, and MIT IDEAS Competition for funding my project; RWSSSP and FINNIDA for their field support, comfortable accommodation, transportation, and friendship; ENPHO for their research assistance; and IBS for their hospitality.

Tommy Ngai would like to thank his supervisor and friend, Susan Murcott, for her inspiration and guidance to motivate him to pursuit this project. Her meticulous review of this report is greatly appreciated.

Sincere thanks are given to the MIT Department of Civil and Environmental Engineering, and all members of the MIT Nepal Water Project. The development of the Arsenic Biosand Filter would not be possible without the years of research contribution and bright ideas by these members.

Finally, Tommy Ngai would like to thank Ms. The Best Employee Ever for her good company and her dedication to the project. Tremendous level of synergy and excitement was experienced as a result of highly effective teamwork.

Sophie Walewijk would like to thank Mr. Super Nice Boss for his good friendship and for the opportunity he gave her to continue working on an arsenic removal solution appropriate for developing countries.

Sophie Walewijk would also like to thank Professor Leckie for his support on the project, and her Ph.D. Principal Investigator, Dr. Reinhard, for allowing her to devote a good chunk of her time on this project.

THE ARSENIC BIOSAND FILTER (ABF) PROJECT: DESIGN OF AN APPROPRIATE HOUSEHOLD DRINKING WATER FILTER FOR RURAL NEPAL

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ABSTRACT

A household-level drinking water filter (Arsenic Biosand Filter, ABF), appropriate for rural Nepal, was developed at Massachusetts Institute of Technology to simultaneously remove arsenic and pathogens from tubewell water. The ABF can be entirely constructed by trained local labor using locally available materials. A laboratory study and a three-months pilot study were conducted in Nepal from September 2002 to January 2003 to evaluate the performance of the filter under various setups, to investigate long-term removal efficiencies, to improve the filter design, and to implement the filter in arsenic-affected villages.

The Arsenic Biosand Filter was found to be effective in removing arsenic (range = 87 to 96%, mean = 93%), total coliform (range = 0 to >99%, mean = 58%), *E. Coli* (range = 0 to >99%, mean = 64%), and iron (range = >90 to >97%, mean = >93%). The users liked the high flowrate (range = 4 to 23 L/hr, mean = 14 L/hr), simple operation, minimal maintenance, as well as the clean-looking and good-tasting water coming out of the filters. They think the filter is a durable, permanent solution to their drinking water problems. On-going research at MIT and Stanford will seek to further enhance filter performance, and user-friendliness.

Implementation schemes and cost recovery issues were discussed with local partners, including the Rural Water Supply and Sanitation Support Programme (RWSSSP) and Environment and Public Health Organization (ENPHO). These agencies will proceed with implementation plans.

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1. PROJECT BACKGROUND

The Massachusetts Institute of Technology (MIT) Nepal Water Project is a program intended to increase awareness of water quality problems in Nepal, and to provide assistance in solving these problems. Since 1999, about 30 Master of Engineering students at the MIT Civil and Environmental Engineering Department have traveled to Nepal to study various water quality and household/community level water treatment issues. Tommy Ngai was a member of the 2001-2002 research team. He investigated arsenic speciation in tubewell water, and evaluated the performance of an activated alumina based arsenic treatment technology in the Rupandehi and Nawalparasi Districts. Details of his research can be found in his 2001 Master of Engineering thesis[1].

After observing and learning about the socio-economic conditions at numerous arsenic-affected villages, Tommy Ngai was determined to develop a better household level water treatment technology, appropriate for rural Nepal. Based on previous work by MIT lecturer Susan Murcott, and other members of the MIT Nepal Water Project, Tommy Ngai invented the Arsenic Biosand Filter (ABF). The ABF effectively and simultaneously remove arsenic and pathogens.

Tommy Ngai entered the MIT IDEAS Competition, a campus-wide competition intended to promote students' innovation in solving real work problems. His invention was awarded the Lemelson International Technology Prize. As a result, the IDEAS committee and the Lemelson Foundation funded Tommy Ngai's team to further develop and implement his design.

Tommy Ngai initiated the Arsenic Biosand Filter (ABF) Project in May 2002. Since that time, Tommy Ngai traveled twice to Nepal: September-October 2002 and December 2002-January 2003. While in Nepal, he worked closely with local agencies including Rural Water Supply and Sanitation Support Programme (RWSSSP) in Butwal, the Environment and Public Health Organization (ENPHO in Kathmandu and Panchanagar, and the International Buddhist Society (IBS) in Lumbini. (Refer to Appendix A for more information about these organizations.) Two team members, Debu Sen (inactive member, now dismissed) and Sophie Walewijk (active member) also accompanied Tommy Ngai to Nepal to complete the ABF project.

2. PROJECT MOTIVATION AND GOALS

Nepal is a developing country in south central Asia landlocked between China to the north and India to the south. The land area is 140 000 km^2 and the year 2000 population is 23 millions, of which 20 millions is rural[2]. Nepal is one of the world's poorest and least developed countries. The average annual income per capita is $210 US[3]. About 42% of the people live below the national poverty line[4]. Due to the poor economic conditions and ineffective government institutional programs, proper water and sanitation services are often lacking, resulting in serious health concerns. The severity of water problems is even more prominent in remote rural villages. The infant mortality rate is very high at 74/1000 live births, compared with 5/1000 in the U.S. The under-five mortality is even higher at 105/1000 births[5]. 54% of the children suffer from moderate to severe stunting on account of water-borne diseases[6]. Diarrheal diseases kill 44000 children annually. The average life expectancy is only 58, compared with 77 in the U.S.[7]. These serious health concerns are the main motivation for this project.

Arsenic and pathogens are two of the most significant drinking water contaminants in Nepal. However, much of the current research effort by the scientific community focuses on independent treatments for arsenic or pathogens. In addition, many of these treatment systems are inappropriate in a number of ways. As a result, people have no choice but to continue to drink contaminated water, leading to horrible health consequences.

As an extension to the MIT Nepal Water Project, the goals of the ABF project are:

- To research and develop a simple arsenic & pathogen removal technology that is appropriate for rural Nepal.
- To conduct laboratory and field experiments to assess the filter performance under various alternative filter setups.
- To initiate and monitor a pilot study on the filter performance.
- To collaborate with local non-government organizations (NGOs) and water supply agencies to implement the filter.

3. DRINKING WATER SITUATION IN NEPAL

3.1 Arsenic Contamination

The Nepal Terai is the flat plain in the southern part of the country, and it is a part of the Gangetic watershed. A handful groups became concerned about arsenic as a potential problem in Nepali drinking water due to Nepal's proximity to Bangladesh and West Bengal. In 1999, the Department of Water Supply and Sewerage (DWSS) received financial support from the World Health Organization (WHO) and UNICEF to initiate various arsenic monitoring programmes[8]. Monitoring was conducted on the groundwater of southern Nepal by a number of national and international organizations. The 1999 study by DWSS in the districts of Jhapa, Morang, and Sunsari in eastern Nepal found that 9% of the 268 tubewell water samples contained arsenic above the WHO guideline of 10 μg/L. The highest concentration was found to be 75 μg/L[9]. In January 2000, a study by Halsey of the MIT Nepal Water Project 1999-2000 showed that 18% of 172 tested tube wells of the Terai region were contaminated with arsenic at concentrations above the WHO guideline, with the highest detected at 111 μg/L[10]. In 2001, the NRCS conducted a study in eight other districts of the Terai region including Rautahat, Bara, Parsa, Nawalparasi, Rupandehi, Kapilvastu, Banke, and Bardiya. It was found that 22% of the investigated tubewells had arsenic level exceeding the WHO guideline, and the maximum level of contamination was found to be 165 μg/L[11]. Also in 2001, the Rural Water Supply and Sanitation Support Program (RWSSSP) found that 9.8% of 1508 samples in the districts of Rupandehi, Nawalparasi, and Palpa had over 10 μg/L of arsenic [12]. The highest concentrations were measured in the village development community (VDC) of Devdaha of Rupandehi district where two wells had over 2000 μg/L of arsenic[13]. From these studies, it is clear that arsenic is a problem in the groundwater of the Nepal Terai region. It can potentially escalate into a serious health issue if the problem is not addressed properly.

Health Effects

Arsenic has long been long known as a poison. Exposure to arsenic via drinking water initially causes skin diseases such as pigmentation (dark and light spots on the skin) and arsenicosis (hardening of skin on hands and feet). Later, cancer of the skin, lungs, bladder, and kidney may occur[14]. Both the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) have classified arsenic as carcinogenic. Unfortunately, there is no cure for these diseases. In many parts of Bangladesh, West Bengal, as well as isolated pockets in Nepal, the arsenic level in the groundwater can be over 100 times higher than the WHO and EPA guidelines[15] of 10 μg/L. For more details on arsenic origins and health effects, refer to Ngai's thesis[16].

3.2 Pathogens Contamination

Pathogens, such as bacteria, viruses, protozoa and helminthes, are the most common water-related problem in developing countries, including Nepal. A study in the Lumbini Zone of Nepal (including Nawalparasi and Rupandehi Districts, which are part of the present study area) by Gao in 2002 showed that about 50% of 45 tubewell samples were contaminated[17].

Health Effects

These pathogens can cause diarrhea, trachoma, schistosomiasis, cholera, amebiasis, giardiasis, stunting and other diseases[18]. At any given time, about half of the population in Nepal is suffering from these diseases. Modern medication and health services are usually too costly to be widely available in the rural areas.

4. ARSENIC BIOSAND FILTER (ABF) THEORY

The Arsenic Biosand Filter (ABF, Figure 1) is a version of the BioSand Filter (BSF) modified to include arsenic removal capability. The original BioSand Filter (BSF, Figure 2) is a household-scale sand filter developed by Dr. David Manz of the University of Calgary, Canada. The BSF has been tested by several governments, research and health institutions, and NGOs in Canada, Vietnam, Brazil, Nicaragua, Bangladesh[19] and other countries. Section 4.1 shows the design of the ABF; Sections 4.2 and 4.3 explain how the ABF removes arsenic and pathogens from drinking water; and finally, Sections 4.4, 4.5 and 4.6 describe the manufacture and installation procedures, the operation procedure and the cleaning procedure.

Figure 1 - Concrete Arsenic Biosand Filter

Figure 2 - Plastic BioSand Filter

4.1 ABF Design

The design of the Arsenic Biosand Filter has evolved throughout the course of the ABF project to reflect design improvements. The latest design of the ABF is shown in Figure 3. The ABF is an integration of two removal units: the arsenic removal unit, and the pathogen removal unit. The arsenic removal unit consists of the metal diffuser box, iron nails, and a polyester cloth. The pathogen removal unit consists of sand and gravel layers. The Nepali version of the cross-sectional diagram, distributed in Sarawal during the education workshop on January 5, 2003 (will be described in Section 7.1.5 and 7.2.5) can be found in Appendix D.

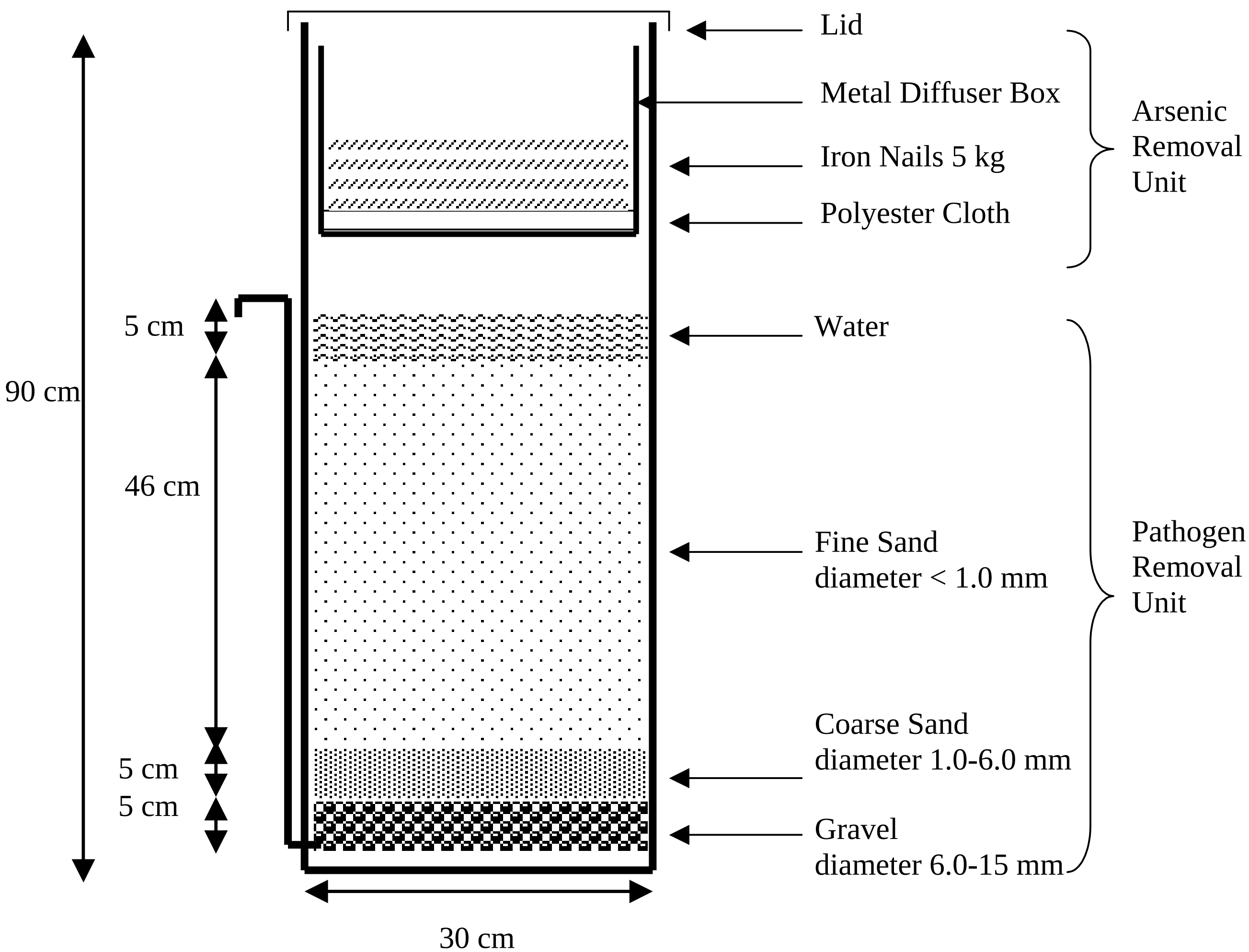

Figure 3 - Cross-Section of the Arsenic Biosand Filter Design (Jan 2003)

4.2 Arsenic Removal

Numerous studies have shown that ferric hydroxide (iron rust) is an excellent adsorbent for arsenic[20,21,22,23,24,25,26,27]. A surface complexation reaction occurs when aqueous arsenic species come into contact with ferric hydroxide. Both species of arsenic found in water (arsenite and arsenate) are effectively and tightly bound to the ferric hydroxide[28,29]. A simplified explanation of these processes is discussed below, as applied to an ABF.

In the ABF, iron nails are exposed to air and water, and rust very quickly, producing ferric hydroxide particles. When arsenic-contaminated water is poured into the ABF, the arsenic is rapidly adsorbed onto the surface of the ferric hydroxide particles. Some of these arsenic-loaded ferric hydroxide particles are trapped by the polyester cloth, but most of the particles are flushed past the polyester cloth, onto the underlying fine sand layer. Because of the very small pore space of the fine sand layer, almost all ferric hydroxide particles and ferric-hydroxide-arsenic-particles will settle on top of the fine sand layer (Figure 4). Since most of the arsenic in the water is already adsorbed onto the ferric hydroxide, and almost all ferric hydroxide is trapped on top of the fine sand layer, as a result, arsenic is effectively removed from the water.

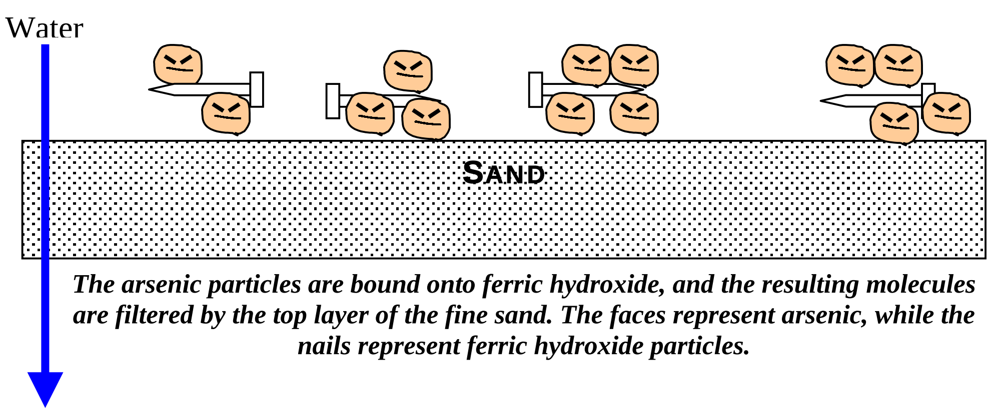

Figure 4 - A Simplified Illustration of the Arsenic Removal Mechanisms

4.3 Pathogen Removal

The processes of pathogens removal in microbially contaminated source water are not yet well understood. It is currently believed that pathogens in an ABF can be removed primarily by two mechanisms: physical-chemical, and biological[30, 31, 32]. A simplified explanation of these processes is discussed below, as applied to an ABF. Details on the pathogen removal mechanisms are beyond the scope of this study. Readers are referred to research by Lukacs[33], Lee[34], and Buzunis[35]. See Figure 5 for a simplified illustration of the physical-chemical and biological removal mechanisms.

Physical-Chemical Mechanisms

Of the many physical-chemical processes associated with filtration, surface straining and inter-particle attraction (or attachment) are probably the most important processes responsible for pathogen removal in an ABF. Surface straining refers to the trapping of foreign particles on top of the filter bed because the particles are too large to pass through the bed. A tightly packed bed of sand grains can capture particles about 5% of the grain diameter. For example, sand with a diameter of 0.1 mm will strain out particles that are 5 μm or larger[36]. This is substantially larger than many particles to be removed from surface water such as cysts (1-20 μm) and bacteria (0.1 to 10 μm)[37]. Viruses are much less than 1μm and must, therefore, be removed by other means[38], such as biological mechanisms.

Interparticle attraction refers to the process with which the foreign particles are adsorbed to the filter medium (i.e. sand). This process is affected by a variety of chemical interactions between microbial cells and porous media including hydrophobicity (i.e. polarity) and surface charge[39,40].

Biological Mechanisms

Following the installation of an ABF, foreign particles such as dust, dirt, organic substances, and iron particles will begin to settle on top of the fine sand layer as a filter cake. As water is poured into the ABF, dissolved organic carbon, dissolved oxygen, and nutrients present in the influent water will support elevated biological populations within the filter cake and in the top few centimeters of the fine sand[41]. This diverse biological population is known as the biofilm. It is consists of algae, bacteria, protozoa, and small invertebrates[42].

The ABF is designed in such a way that there is always about 5 cm of standing water above the fine sand layer. The 5 cm height was reportedly to be the optimum height for pathogen removal. If the water level is too shallow, the biofilm layer can be easily disturbed and subsequently damaged by the force of the incoming water. On the other hand, if the water level is too deep, an insufficient amount of oxygen diffuses to the biofilm, resulting in suffocation of the microorganisms in the biofilm layer[43]. In addition to the 5 cm protective water layer, the diffuser box above the fine sand layer serves an important purpose to reduce the force of input water from disturbing the top layer of sand[44].

When microbially contaminated water is poured into the ABF, predator organisms that reside in the biofilm layer will consume the incoming pathogens[45]. Recent studies and experiments conclude that this process can be a significant cause of bacterial removal in slow sand filters[46].

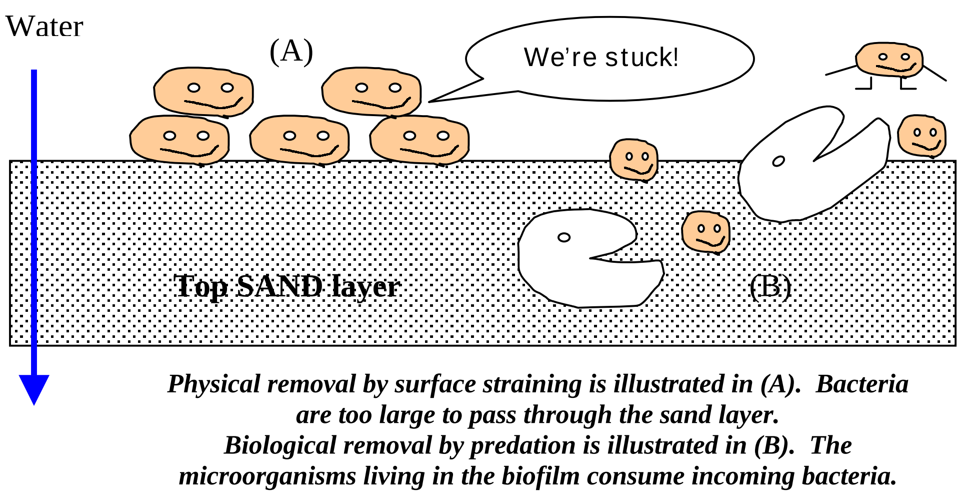

Figure 5 - A Simplified Illustration of the Pathogen Removal Mechanisms

Biofilm Ripening

When an ABF is newly installed, or when the biofilm layer is damaged (e.g. during the filter cleaning), time is needed for the biofilm to grow to maturity. This is called the ripening period. The ripening period can be as short as a day and can go up to several weeks, depending on the water temperature and chemistry[47,48]. For example, high concentration of organic substances in the influent water may encourage biofilm growth[49]. During the ripening period, the filter does not remove bacteria effectively because only physical-chemical mechanisms are at work to remove bacteria. A study by Bellamy et al. concluded that a new sand bed could remove 85% of the coliform bacteria in the influent. As the sand bed matures biologically, the percent removal improves to more than 99% for coliform bacteria[50]. Current research is underway at MIT by Pincus to determine the ripening time and *E. Coli* removal efficiency for newly installed biosand filters[51].

4.4 ABF Manufacturing and Installation Procedure

4.4.1 Manufacturing

The ABF can be entirely constructed with locally available materials, and with local labor. Concrete ABF were made by the International Buddhist Society (IBS), which contracted out the actual construction work to a local mason, Durga Ale. (Refer to Appendix E for a thorough explanation on filter construction[52].) Figure 6 shows newly made ABFs at the IBS. The metal diffuser boxes were manufactured in a metal shop in Kathmandu (Figure 7 and Figure 8).

Figure 6 - Newly made ABFs at IBS

Figure 7 - A Metal Workshop in Kathmandu

Figure 8 - A newly made Metal Diffuser Box from the Metal Workshop

4.4.2 Installation Procedure

. The materials needed for installation are:

- A concrete bio-sand arsenic filter (including a metal box and a lid)
- 2 bottles of Piyush*

* Piyush is a locally manufactured calcium hypochlorite solution

- 2.5 L gravel (above 6.0 - 15 mm grain size)
- 2.5 L coarse sand (1.0 - 6.0 mm grain size)
- About 30 L of fine sand (less than 1.0 mm grain size)
- 1 piece of polyester cloth (30 X 30 cm)
- 5 kg of iron nails

Once constructed, each ABF is flushed with water to get rid of dirt, sand, mud, and dried leaves (Figure 9). Then for each filter, two bottles of 60 mL Piyush solution (Figure 10) are mixed with 20 L of water in a bucket. The entire 20 L mixture is poured into the ABF filter to disinfect it. All sands and gravel are carefully washed before filling the filter to get rid of very fine particles and clay, in an effort to minimize clogging. Then 2.5 L of gravel that can be collected in a local river (diameter 6-15mm) is slowly added to the filter. The gravel layer is flattened before 2.5 L of coarse sand (diameter 1-6mm) are slowly added on top of the gravel layer. The coarse sand can be purchased from a local sand-crushing operation (Figure 11 and Figure 12) and sieved with a mosquito net. The coarse sand layer is flattened as well. Then, the filter is slowly filled up with fine sand that can be collected from a local river (diameter <1 mm) up to 5 cm below the water outlet level (see Figure 3). Any air bubble trapped in the filter will clog the system. Therefore, during the filling operation, it is important to make sure that there is always a higher level of water than of sand. Additional water may be added if necessary. In other words, each layer is added to water. Once the sand was put in place, a square piece of polyester cloth is cut and placed inside the metal diffuser box. Five kg of shoe tack iron nails of size 19 mm are added to the metal box. The metal box is inserted into the ABF, which is then closed with the filter lid.

The filter is left undisturbed for 24 hours, during which time the Piyush solution disinfected the sand layers. After 24 hours, tubewell water is added to the filter to flush the Piyush solution. Water is added until there was no more chlorine odor in the filtered water. The filter is then considered ready for use.

Figure 9 - Washing ABFs at RWSSSP Laboratory

Figure 10 - Piyush Disinfecting Solution

Figure 11 - A Local Sand Crushing Operation by a Riverside near Butwal

Figure 12 - Filling up Bags of Crushed Sand

4.5 ABF Operation Procedure

The operation procedure is simple. First, ensure iron nail surface is always flat (no holes or spaces in the iron nail layer) before use. If the surface is not flat, then the box is taken out and shaken to evenly distribute the iron nails. The metal box must be returned to the filter. Then, slowly pour water into the metal box, and collect the filtered water from the outlet. The filter lid should be closed at all time, except when pouring water into the filter. When the water flow is too low, the filter needs to be cleaned.

4.6 ABF Cleaning Procedure

Cleaning the ABF is simple, and should be done when the water flow rate becomes too low. First, the filter lid and the metal box containing the iron nails are removed. Then the top 2 cm of the sand are gently scraped by hand. As a result of this scraping, the water that sits above the sand will become very turbid. The next step is to remove that turbid water using a small container. Arsenic-free water is then slowly added to replace the water that was just removed. The scraping and water removal procedure is repeated five times. Then the metal box containing the iron nails is shaken vigorously to make sure that iron nails cover the whole surface of the box. Finally, the metal box is put back into the filter, and the lid is put back on. The filter is clean, and can be used immediately.

The disposal of a small volume of arsenic-containing water (produced from the cleaning procedure) to nearby ditches is not believed to pose significant health threat to human. According to risk assessment analysis, of the three major arsenic exposure pathways (namely, ingestion, adsorption, and inhalation), ingestion of arsenic (mainly through drinking arsenic-contaminated water) is the only significant route of entry. Arsenic intake into human body by skin adsorption is generally minimal[53]. Inhalation of arsenic is also minimal because arsenic is not volatile. In addition, a study by the Australian National University and the University of Queensland found that food irrigated with arsenic contaminated water is unlikely to add significantly risk to total arsenic exposure among Bangladeshis[54].

(Refer to Appendix D for a copy of the pictorial cleaning instructions given to villagers during the educational workshop in Sarawal.)

4.7 ENPHO's Arsenic Biosand Filter Setup

In addition to Tommy Ngai's ABF design, which is described above, ENPHO also installed at least 6 ABF on their own. Their filter setup is identical to the final design by Tommy Ngai's team, as shown in Section 4.1 Figure 3. Refer to Appendix F for a description of their filter design and pilot study.

4.8 RWSSSP's 3-Kolshi Filters Setup

About fifteen 3-Kolshi Filters were installed at two arsenic-affected villages (Dubiya VDC and Barkalpur VDC) by RWSSSP in the summer of 2002. Refer to Appendix G for a description of their filter design and pilot study.

5. ANALYTICAL METHODS

This section describes the analytical methods used to measure all relevant water quality parameters in this study. The parameters include:

- Total inorganic arsenic
- Total iron
- Bacteria (Total coliform & *E. Coli*, and H_2S bacteria)
- Flow rate

It is worth noting that Tommy Ngai and Sophie Walewijk used different field test kits for filter monitoring than RWSSSP or ENPHO because they have different options available. Table 1 summaries the various analytical methods used by these three groups to measure the water quality parameters listed above. Details on each of these analytical methods will be discussed in the following sections.

Table 1 - Analytical Methods used by Tommy Ngai's Team, RWSSSP, and ENPHO

	Tommy & Sophie	**RWSSSP**	**ENPHO**
Arsenic	• Industrial Test Systems field test kit • MIT lab	• ENPHO new arsenic field test kit • ENPHO lab	• ENPHO lab
Iron	• HACH field test kit	• N/A	• N/A
Bacteria	• M-Coliblue24 membrane filtration	• ENPHO P/A H_2S bacteria test vial	• N/A
Flow rate	• Graduated cylinder	• N/A	• N/A

Note:
N/A = Not Applicable. This particular water quality parameter was not measured in their regular monitoring.

Before collecting a water sample from a tubewell, the well is purged for approximately 30 seconds (about 5-10 L). Water used to fill filters was also collected after the initial purging. This procedure attempts to mimic the usual water collection and filter usage practices by villagers.

5.1 Arsenic

Four analytical methods for total inorganic arsenic are described below. Tommy Ngai's team used the Industrial Test System Inc. (ITS) Arsenic Check™ Field Test Kit for all their analysis in this study. The accuracy of this field test kit was investigated in a separate study by Tommy Ngai, where he compared split-sample results analyzed by this test kit with the more accurate and precise MIT Parsons Laboratory's Perkin-Elmer Graphite Furnace Atomic Absorption Spectrometer (GFAAS). Refer to Appendix H for the comparison results. RWSSSP used the New Arsenic Test Kit developed by ENPHO for their arsenic monitoring activities. RWSSSP also sent some of their water sample to the ENPHO Laboratory to verify their test kit results. ENPHO used their laboratory's SOLAAR 969 Hydride Generation Atomic Absorption (HGAAS) for their monitoring activities. The accuracy of this HGAAS was investigated in a separate study by Tommy Ngai, where he compared split-sample results analyzed by the HGAAS with the MIT's GFAAS; and the two results are found to be very similar. Comparison results can be found in Appendix H.

5.1.1 Industrial Test Systems Inc. Arsenic Check™ Field Test Kit

This U.S.-made arsenic field test kit, shown in Figure 13, provides a safe and easy method to test for aqueous inorganic arsenic. This method requires no electricity and no refrigeration. The detection range is from 0 to 800 μg/L, with the most reliable range between 5 to 100 μg/L. The upper detection limit can be extended to 4000 μg/L with a simple 1 to 5 dilution. Components supplied in this kit include a detailed description of the test method, a color chart, three chemical reagents with material safety data sheets, three measuring spoons for the reagents, test strips, two reaction bottles, four bottle caps, a thermometer, and a zip-loc test strips disposal bag.

The chemistry of the reaction is based on the conversion of inorganic arsenic compounds in water to arsine gas (AsH_3) by the reaction with zinc dust and tartaric acid[55]. The test results are determined by colorimetry. The color chart is standardized at 25°C, starting at pure white for 0 μg/L arsenic, a tint of yellow for 5 μg/L arsenic, to slightly more yellow at 10 μg/L, and increasing yellow intensity at 20, 50, 100, 200, and 500 μg/L. At 500 μg/L arsenic, the color is dark brown. It is recommended that the water sample temperature be between 20°C and 30°C for accurate reading off the color chart. This test tolerates up to 2 μg/L hydrogen sulfide and 0.5 mg/L antimony without test result interference. No interference from iron or sulfate was found. There are 100 tests per kit, selling at $120 per kit.

A test was performed as part of the thesis study by Tommy Ngai in 2002 to determine the accuracy of this field test kit[56]. Results on 23 split-samples showed the test kit results agreed with the MIT GFAAS results 78% of the time, which is fairly good. It is therefore assumed that the ITS test kit results are dependable and accurate. Refer to Appendix H for more details.

Procedure as performed by Tommy Ngai and Sophie Walewijk:

1. Plastic sampling bottles shown in Figure 14, were used to collect water samples. Prior to sampling, the bottles were washed with arsenic-free and iron-free water. During sample collection, the bottles were rinsed with the actual sample water. Then the bottles were filled up with the sample water.
2. A clean reaction bottle was filled with the sample to the 100 mL mark.
3. Three leveled pink spoons of reagent 1 (tartaric acid) were added to the bottle. The bottle was capped and shaken vigorously for 15 seconds, time after which the tartaric acid would be dissolved. The contents were allowed to sit for another 15 seconds.
4. Three leveled red spoons of reagent 2, which contains a mixture of ferrous salts, were introduced to the reaction bottle. Again, the bottle was capped and shaken vigorously for 15 seconds, time after which the metal salts are dissolved. The content was allowed to sit for 2 additional minutes.
5. Then three leveled white spoons of reagent 3 (zinc dust), were added to the bottle and shaken vigorously for 15 seconds. Immediately after the 15 seconds, the yellow bottle cap was replaced with a white cap that allows a test strip containing mercuric bromide to be inserted into the bottle.

6. A test strip was inserted into the bottle cap opening, with the red mark of the strip facing the center of the cap. The cap opening was quickly closed to secure the strip and to prevent gas from escaping the reaction bottle.
7. The bottle was capped for the next 30 minutes. Both hydrogen gas and arsine gas bubbled out of the solution. The produced arsine gas then reacted with the mercuric bromide on the test strip to form mixed mercury halogens (such as AsH_2HgBr) that appeared with a color change from white to yellow or brown.

Figure 13 - Industrial Test Systems Arsenic Check^{TM} Field Test Kit

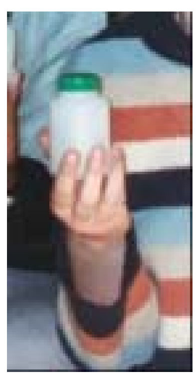

Figure 14 - Bottle Used to Collect Arsenic and Iron Samples

8. At the end of 30 minutes, the test strip was taken out of the bottle and compared to the color chart to determine the arsenic concentration. The comparison was performed within the following five minutes because the color begin to fade away

after five minutes. In addition, because hydrogen may cause an explosion, and arsine gas is toxic, it is highly recommended that the test be conducted in a well-ventilated* area away from fire and other sources of ignition[57].

5.1.2 Perkin-Elmer Graphite Furnace Atomic Absorption Spectrometry (GFAAS)[58]

The GFAAS instrument from the MIT Parsons Laboratory was used as a check for the accuracy of the ITS Test Kit and of the ENPHO lab HGAAS results.

GFAAS is one of the methods for measuring arsenic in drinking water that is approved by the United States Environmental Protection Agency (USEPA). Atomic absorption is based on the principle that atoms will absorb light at some characteristic wavelength. These wavelengths are related to the atomic structure of an element and the energy required for the promotion of its electrons from one quantum level to another. Therefore each element has its own characteristic wavelength. A wavelength of 193.7 nm is recommended for arsenic. The amount of light absorbed by an element at a certain wavelength can be correlated to the concentration of the element within the linear calibration range. The reliable calibration range is as low as 1-5 μg/L As, and as high as 200 μg/L As. Dilution of samples with higher arsenic concentrations may be required. Chemical interferences may occur, but they can be ameliorated by the use of matrix modifiers. This instrument is not suitable for field use because of its large size and the sensitivity of some of its delicate components to transportation. The GFAAS requires electricity, but no refrigeration.

Procedure as performed by Tommy Ngai and Sophie Walewijk:

1. Water samples from Nepal were first preserved by adding a drop of 6 M hydrochloric acid (HCl) per 10 mL of sample at the time of collection. This

* A study by Hussam et al showed that in the immediate vicinity of some arsenic test kits, the arsine gas concentration can reach over 35 times the threshold limiting value (TLV) of 50 ppbv of arsenic from a single experiment with 100 μg/L of total arsenic in solution.

acidification prevents the precipitation of aqueous iron that would otherwise adsorb arsenic.

2. At the MIT laboratory, 1 mL of the water sample was carefully pipetted into a plastic vial specially made for GFAAS analysis. The vial was placed on the sampling dish. A set of standard arsenic solutions and matrix modifiers was also placed on the sampling dish. The dish has a capacity of 75 samples.
3. A pre-programmed arsenic testing procedure was loaded on the GFAAS computer control. Information on the test samples was entered into the computer.
4. The test procedure was started by clicking the START button on the computer screen. The instrument then automatically took a small amount of the sample and volatilized the arsenic atoms by intense heating. Once the atoms were excited, a monochrome lamp at 193.7 nm sent an optical beam through the headspace above the sample. The instrument measured the absorption and reported it as a peak focused around the 193.7 nm wavelength. The area under the peak was numerically integrated. The integrated results were displayed on the computer screen and on a printer printout.
5. By comparing the area under the peak of the sample water with standard arsenic solutions, the concentration of the sample was determined. Because of the variances associated with the instrument, a standard calibration curve was developed for every six to eight samples analyzed to maintain accurate measurements.

5.1.3 ENPHO New Arsenic Field Test Kit[59]

ENPHO developed this new test kit in the summer of 2002 as an improvement over their previous arsenic field test kit. The detection range is 10 μg/L to 250 μg/L. Each test kit consists of a glass arsine generator flask, a 25 mL measuring cylinder, mercuric bromide paper, mercuric bromide paper holder, cotton, a forceps, acid tablets, lead acetate, and sodium borohydride. Detailed instructions and a color chart are also included with each test kit. The principle for this kit is that arsenic in water reacts with sodium borohydride in the presence of an acidic medium to form arsine gas, which produces a yellow to brown stain on the mercuric bromide paper. This principle is very similar to the ITS

Arsenic Test Kit used by Tommy Ngai described in 5.1.1. The cost for each ENPHO New Arsenic Field Test Kit, including chemicals for 50 tests is 6200 Nepali Rupees (~US$81). The replacement cost for the chemicals is 2500 Nepali Rupees (~US$32) per 50 tests, which is about US$0.65 per test.

Procedure as recommended by ENPHO:

1. Plastic sampling bottles shown in Figure 14, are used to collect water samples. Prior to sampling, the bottles are washed with arsenic-free and iron-free water. During sample collection, the bottles are rinsed with the actual sample water. Then the bottles are filled up with the sample water.
2. 25 mL of the water sample is transferred to the arsenic generator flask using the measuring cylinder.
3. Mercuric bromide paper is inserted into the paper holder.
4. One acid tablet is added to the sample in the generator flask. Swirl the flask gently to dissolve and mix the acid table.
5. Sodium borohydride is added to the flask. The mercuric bromide paper holder is immediately inserted into the flask to close the flask. The sample is left undisturbed for 10 minutes.
6. Then, using the forceps, the mercuric bromide paper is taken out of the flask, and compared to the color chart to determine arsenic concentration. If the arsenic concentration is greater than the reliable detection limit of 250 μg/L, the sample should be diluted and retested.

5.1.4 SOLAAR 969 Hydride Generation Atomic Absorption Spectrometer (HGAAS)[60]

ENPHO has a British made HGAAS in their laboratory for accurate measurement of arsenic. The HGAAS technique is based on the atomic absorption measurement of arsenic generated by thermal decomposition of arsenic (III) hydride. Arsenic (III) is reduced to gaseous arsenic (III) hydride by reaction with sodium tetrahydroborate in a hydrochloric acid medium. As (III) and As(V) have different sensitivities using this technique so pentavalent arsenic must be reduced to trivalent arsenic prior to measurement. This reduction is carried out using hydrochloric acid, potassium iodide and ascorbic acid.

A test was performed on this instrument against the MIT GFAAS to determine the accuracy of the HGAAS results. Results on 22 split-samples showed the average absolute difference between the two AAS instruments is 31%, which is very good. It is considered that the HGAAS results are usually dependable and accurate. Refer to Appendix H for more details.

5.2 Total Iron

Neither RWSSSP nor ENPHO tested for iron in their regular monitoring activities. Tommy Ngai's team used the HACH Portable Iron Test Kit Model IR-18 to test for total iron.

5.2.1 HACH Portable Iron Test Kit Model IR-18

The HACH iron field test kit Cat. No. 1464-00, shown in Figure 15, is a simple method to test for iron. It requires no electricity and no refrigeration. The detection range is from 0.1 to 5 mg/L. The upper detection limit can be extended to 10 mg/L with a 1 to 2 dilution. All components are supplied in the kit, including a detailed description of the test method, a color disc and comparator, two test tubes, and individually wrapped FerroVer Iron Reagent Powder Pillow with material safety data sheets.

Figure 15 - HACH Portable Iron Test Kit Model IR-18

The test results are determined by colorimetry. Accuracy is not affected by undissolved powder. The color chart is graduated, starting at pure transparent for <0.1 mg/L iron, a tint of orange for 0.3 mg/L iron, to slightly more orange at 1 mg/L, and increasing orange intensity to 5 mg/L. The chemistry of the reaction is based on the complexation of aqueous iron with sulfite ligand to form an orange color complex. There are 100 tests per kit, selling at $40 per kit.

Procedure as performed by Tommy Ngai and Sophie Walewijk:

1. A small quantity of the water sample collected for arsenic analysis was used for iron analysis. Prior to sampling, the plastic collection bottles (Figure 14) were washed with arsenic-free and iron-free water. During sample collection, the bottles were rinsed with the actual sample water. Then the bottles were filled up with the sample water.
2. Both test tubes were filled with the water sample to the 5 mL mark.
3. One packet of reagent was added to one of the two tubes. Both tubes were capped and shaken for 30 seconds.
4. The blank test tube was inserted into the top left opening in the disc comparator. The tube with reagent addition was inserted into the top right opening in the disc compartment.
5. The comparator was held up to a light source such as the sky or a lamp. The disc was rotated until the color matches in the two windows. Iron concentration was shown in the scale window.

5.3 Bacteria

In practice, monitoring of indicator organisms frequently replaces the direct monitoring of pathogens for assessing the microbial quality of drinking water. Indicator organisms do not themselves cause the illnesses, but they can be found in association with pathogenic species, and their concentration can be related to that of pathogens. Indicator tests are cheaper, easier to perform and yield faster results, compared to direct pathogen monitoring[61,62]. Commonly used indicators are total coliforms, *E. Coli*, and H_2S bacteria, which are all fecal indicators. Tommy Ngai's team tested for total coliforms and *E. Coli* using Millipore M-Coliblue24 Broth, Membrane Filtration and Incubation. RWSSSP tested for H_2S bacteria using ENPHO Presence/Absence H_2S Bacteria Test Vials. Refer to research by Low for more information on the appropriate microbial indicator tests for drinking water in developing countries[63].

5.3.1 Millipore M-Coliblue24 Broth, Membrane Filtration and Incubation[64]

Millipore M-Coliblue24 broth is a culture medium that selects for total coliforms and *E. Coli*. The broth was developed specifically for culturing microorganisms on membrane filters, and the broth is available in convenient single-use 2 mL plastic ampoules. The broth combines the speed of presence-absence coliform test with the enumeration of membrane filtration. In this test, *E. Coli* turn blue, and other coliforms red. Total coliforms is the sum of the two.

The main pieces of equipment needed were: Petri Dishes with pads, filter paper with grid, Millipore m-ColiBlue24 broth ($170 for 100 tests), forceps, methanol, Millipore portable membrane filtration assembly unit, and an Amy Smith Phase Change Incubator[*]. This incubator maintains a constant 35°C temperature without using electricity. Before use, the incubator is immersed in boiling water until the waxy substance inside is completely melted. Over the next 24 hours, the wax solidifies and releases heat to maintain a 35°C temperature.

Procedure as performed by Tommy Ngai and Sophie Walewijk:

1. Disposable Whirlpack Bags were used for sample collection, as shown in Figure 16. Each new bag was sterile and sealed. During sampling, a bag was unsealed, filled up with about 150 mL sample water, and closed. The bag was then placed in a portable cooler until analysis. Analysis was performed on the same day as sample collection.

[*] The Amy Smith Phase Change Incubator was created by Amy Smith of MIT's Edgerton Center

2. Distilled water was boiled and let cooled to room temperature for several hours. The working surface was sterilized by burning methanol on it. The top part of the membrane filter unit was sterilized by placing it in boiling water for 5 minutes. This part was then allowed to cool to below 35°C for about 15 minutes. While cooling down, the part was covered with sterile aluminum paper. Figure 17 is a picture of the filter assembly unit.
3. The top filter part was sterilized between each sample.
4. Steps five to seven outline the procedure to obtain one Petri dish. There was one Petri dish per filter sample, and two Petri dishes per tubewell sample (a 1:10 and a 1:1 dilutions, with the 1:10 dilution filtered first).
5. The lid from a Petri dish containing an absorbent pad was removed. An m-ColiBlue24 broth ampoule was inverted 2 or 3 times to mix the broth. The cap of the ampoule was twisted open, and its contents evenly poured over the absorbent pad. The lid was placed back on the Petri dish.
6. The membrane filter assembly was set up. A filter, grid side up, was placed into the assembly using sterile forceps. 100 mL of sample or diluted sample were filtered by creating a vacuum below the filter, using the pump-syringe attached to the assembly.
7. The filter, grid side up, was then transferred on the absorbent pad in the previously prepared Petri dish using sterile forceps. A slight rolling motion was applied during the transfer to avoid air to be trapped in between the pad and the filter. The Petri dish was replaced.
8. The Petri dishes were inverted and incubated in the Amy Smith Incubator at 35°C for 24 hours. Before use, the incubator was heated with boiling water until the inside waxy substance became liquid. The incubator was placed into its foam insulation, and the resulting package was rolled in towels and placed into an insulated place such as an oven. The oven should be off.
9. The Petri dishes were removed from the incubator and colonies were counted, using the grid of the filter to avoid double-counting or missing some colonies (Figure 18). A magnifying glass and a desk lamp were used to facilitate the process.

Figure 16 - Whirlpack Bag Used to Collect Bacterial Samples

Figure 17 - Membrane Filter Unit

Figure 18 - Example of a Plate

Coliform density was reported as number of colony forming units (CFU) per 100 mL of sample. Preferably, each plate should have between 20 and 80 colonies for easy and accurate counting. Samples that produced more than 250 colonies were reported as "too numerous to count" (TNTC). Some colonies may overlap thus creating counting errors. One in ten dilutions of tubewell water samples were made to avoid this. Figure 19 shows a microbial test performed at the makeshift laboratory at RWSSSP guesthouse.

5.3.2 ENPHO Presence/Absence H_2S Bacteria Test Vials[65]

RWSSSP purchased ENPHO P/A H_2S Bacteria Test Vials from ENPHO to monitor the presence or absence of H_2S bacteria in their water sample. Unlike the membrane filtration method used by Tommy Ngai and Sophie Walewijk to quantify water contamination, the P/A test is a qualitative test that produces a yes or no result. It is a very simple test based on the reaction of H_2S gas produced by the metabolism of bacteria like Salmonella, Proteus, Citrobacter, Klebsiella, etc. with iron to form a black precipitate of iron sulfide. All necessary chemicals are included in the vial when purchased. Each test vial costs 50 Nepali Rupees (~US$0.65) including a 10 Nepal Rupees (~US$0.13) deposit on the vial, which is refundable upon return. Figure 20 shows an example of a P/A H_2S bacteria test. The vial on the left contains no H_2S bacteria while the vial on the right is contaminated.

Procedure as recommended by ENPHO:

1. A P/A test bottle is carefully filled to the top with the water sample.
2. The bottle is placed undisturbed for 48 hours in a room having temperature between 22-44^{0}C.

After 48 hours, if the color of the liquid inside the bottle changes into black color, then it indicates that the sample is contaminated.

Figure 19 - Microbial Test Performed at a Makeshift Laboratory at the RWSSSP Guesthouse

Figure 20 - P/A H_2S Bacteria Test Showing Uncontaminated Sample (left) and Contaminated Sample (right)

5.4 Flow Rate

Flow rate of the ABF was measured by Tommy Ngai's team with a 100 mL plastic graduated cylinder and a stopwatch. RWSSSP and ENPHO did not measure filter flow rate in their regular monitoring.

Procedure as performed by Tommy Ngai and Sophie Walewijk:

1. Water was poured into the diffuser box to approximately half full.
2. Once a steady stream of water was flowing out of the filter outlet (typically 10-15 seconds), water was collected using a graduated cylinder.
3. The time needed to fill the cylinder to the 100 mL mark was measured in seconds. The measurement was scaled up from seconds per 100 mL to liters per hour.

6. Laboratory Experiments at RWSSSP

Tommy Ngai traveled to Nepal between September 14 and October 4, 2002, and between December 26, 2002 and January 14, 2003 as part of the project work. Debu Sen, a former team member, accompanied Tommy during the September/October trip. Sophie Walewijk, a current active member, assisted Tommy during the December/January trip. For both trips, Tommy and his teammates stayed at and worked with Rural Water Supply and Sanitation Support Programme (RWSSSP) in the city of Butwal, Rupandehi District.

Two major parts of the fieldwork conducted in Nepal are:

- Laboratory experiments at RWSSSP office – September 2002 (Chapter 6)
- Pilot study in Sarawal and Devdaha Village Development Committees (VDCs) – September 2002 to January 2003 (Chapter 7)

6.1 Laboratory Experiments Overview

The laboratory experiments conducted at the RWSSSP office in September 2002 consisted of two parts: the main experiment, and three additional experiments. The purpose of all these experiments was to investigate the arsenic performance of five different ABF arrangements under actual local conditions, prior to a pilot study involving the distribution of selected ABF designs to arsenic-affected households. Section 6.1.1 describes the five filter arrangements for the experiments. Section 6.1.2 and 6.1.3 describes the main experiment and the three additional experiments in detail. Section 6.2 shows the results of these experiments.

6.1.1 Filter Arrangements

The five filters were installed at the garage of the RWSSSP office (Figure 21). A detailed description of each filter arrangement follows.

Figure 21 - RWSSSP Laboratory Showing Five ABFs

Arrangement #1 – Control

This arrangement was essentially a Biosand Filter (BSF). The only difference was that the diffuser plate in a regular BSF was replaced with a metal diffuser box (Figure 22). A piece of polyester cloth was placed inside the box, with no iron nails added. The pathogen removal unit was the same, with the usual amount of sand and gravel. Raw water was poured directly into the diffuser box as usual. A few brick chips (20-30 mm diameter) were placed inside the metal box to stabilize the polyester cloth.

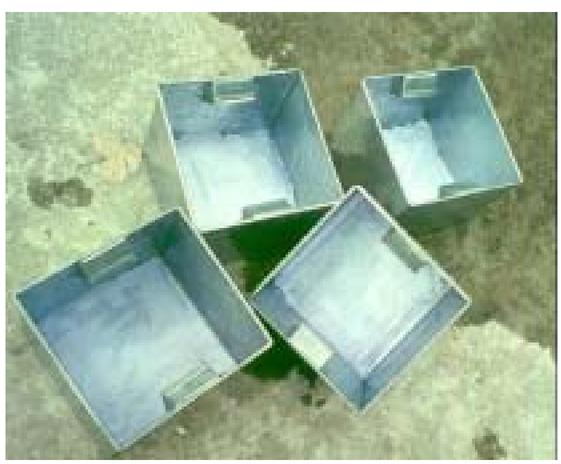

Figure 22 - Metal Diffusers Boxes with Polyester Cloth

Arrangement #2 – Coagulation/Flocculation

This arrangement was tested because of favorable results from Hwang's study[66], and by recommendation of Dr. Manz, the inventor of the BioSand Filter[67]. The setup of this filter was similar to arrangement #1. There was a piece of polyester cloth, but no iron nails in the metal diffuser box. A few brick chips (20-30 mm diameter) were placed inside the metal box to stabilize the polyester cloth. The pathogen unit was unchanged. The only difference between this arrangement and the previous arrangement was that the raw water was pre-treated in a 20 L plastic bucket before it was poured into the diffuser box. For every 20 L bucket of raw water, one packet of ENPHO's black coagulation powder was added (Figure 23). ENPHO's powder contained ferric chloride as coagulant, charcoal as flocculent (weighting agent), and sodium hypochlorite as oxidant and disinfectant. Details about this coagulation process can be found in Hwang's thesis[68]. According to Hwang's study, the powder should be added to the raw water and mixed vigorously with a stick or stirrer for 1 minute. Then the water should be left undisturbed for 30 minutes. Finally, the supernatant (water on the top that is free of settled materials) should be carefully poured into the ABF.

Arrangement #3 – High Quality Iron Nails

In this filter, 2.5 kg of high quality shoe tack iron nails were added to the metal diffuser box of an ABF (Figure 24). These nails are of high quality because they are very strong (i.e. do not bend easily). The nails cost 80 Nepali rupees (NRs) per kg. Brick chips (20-30 mm diameter) were added on top of the nails to prevent iron nails from scattering with the force of the incoming raw water. The pathogen unit was left unchanged.

Arrangement #4 – Medium quality Iron Nails

In this filter, 2.5 kg of medium quality iron nails (NRs.40/kg) were added to the metal diffuser box. These nails are medium quality because they can be easily bent with bare hands. Brick chips (20-30mm diameter) were added on top of the nails to prevent iron nails from scattering with the force of the incoming raw water. The pathogen unit was unchanged.

Figure 23 - ENPHO's Black Coagulation Powder Added to 20 L of Water

Figure 24 - A Diffuser Box Full of High Quality Shoe Tack Iron Nails

Arrangement #5 – High Quality Iron Nails & Sand Layer

In this setup, the metal box was replaced by two 10 L plastic diffuser buckets stacked on top of each other (Figure 25 and Figure 26). Holes were drilled at the bottom of both buckets. The lower diffuser bucket had a polyester cloth covering the holes, on top of which there was a 25mm layer of fine sand (diameter <1mm). The second diffuser bucket was filled with 2.5 kg of high quality shoe tack iron nails, which were covered with a few brick chips.

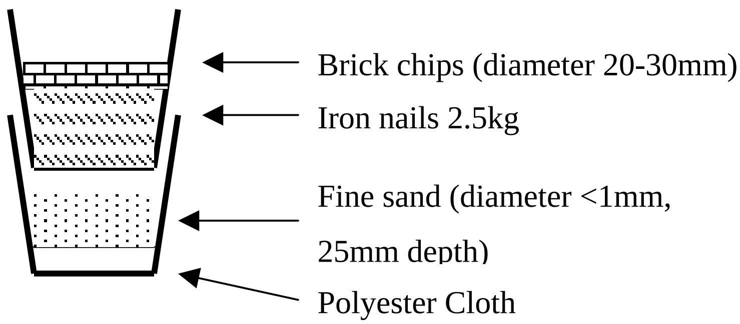

Figure 25 - Diagram of the Two Diffuser Buckets

Figure 26 - Diffuser Bucket Replacing the Metal Box in the ABF

6.1.2 Main Experiment

200 L of arsenic contaminated tubewell water from Nir B. Gurung's well* in Devdaha VDC were collected each morning for experimental use (Figure 27). 40 L of water were poured into each of the five filters when Tommy Ngai returned to RWSSSP in the afternoon (Figure 28). Arsenic and iron concentrations of the raw well water were measured at the RWSSSP laboratory, just before passing the water through the filters. Filtered water samples were collected when approximately 40 L of water had passed through each of the five filters. The filtered water samples were analyzed for arsenic and iron. The temperatures of both the raw water and the treated water were usually about 25°C. Flow rate measurements were taken when the filter was full (i.e. water level was at the highest, at about 25 cm above the outlet). Each filter arrangement held approximately 20 L of water, except arrangement #1 (regular Biosand Filter). The reservoir of this regular biosand filter was damaged such that the capacity was reduced to about 12 L (water level of about 15 cm above the outlet).

* According to RWSSSP, this well is known to contain one of the highest arsenic concentrations of all wells in Nepal.

Figure 27 - Collecting Water from Devdaha

Figure 28 - Laboratory Experiments in Progress

6.1.3 Additional Experiments

Three simple additional experiments were carried out to measure arsenic and iron concentrations at intermediate points in the set-up. The purpose of these additional experiments was to gain a better understanding of the actual arsenic removal mechanism in the different filter arrangements. These experiments are described below:

Additional Experiment 1

This experiment seeks to determine the proportion of arsenic that can be removed by the coagulation/flocculation process in arrangement #2. To achieve this objective, a supernatant water sample was taken and analyzed for arsenic and iron. The results were compared to the raw water composition.

Additional Experiment 2

In arrangement #3, a sample of the water exiting the metal diffuser box (after it passed through the high quality shoe tack iron nails bed but before it reached the fine sand layer) was collected and analyzed to investigate how much of the total influent arsenic was bound to the iron nails that remains in the diffuser box. Arsenic and iron results for the post-diffuser sample were compared to the raw water that was poured into the metal diffuser box.

Additional Experiment 3

In arrangement #5, an experiment was conducted to investigate how much of the total arsenic could be removed by the diffuser buckets. Arsenic and iron results from samples taken between the lower diffuser and the sand were compared to the raw water (Figure 29).

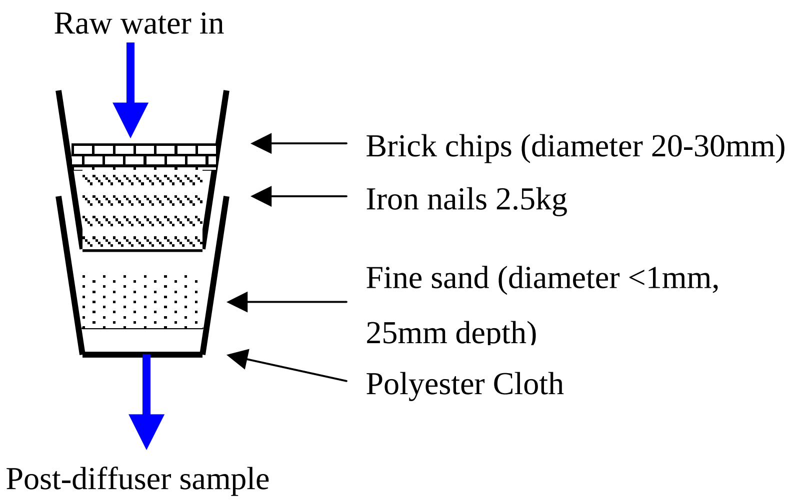

Figure 29 - Location of Post-diffuser Sample Collection

6.2 Results and Discussions

6.2.1 Main Experiment

Arsenic Results

Table 2 shows a summary of the different filter arrangements. Table 3 and Table 4 show the arsenic test results of the five filters.

Table 2 - Summary Description of RWSSSP Lab Experiments Filter Arrangements

	Description
Arrangement #1	No iron nails. Same as regular BioSand Filter
Arrangement #2	Coagulation/Flocculation using ENPHO powder
Arrangement #3	2.5 kg of high quality shoe tack iron nails*
Arrangement #4	2.5 kg of medium quality iron nails*
Arrangement #5	2.5 kg of high quality iron nails and sand layer

Table 3 - Arsenic Test Results in mg/L for Lab Experiments at RWSSSP

Volume of raw water treated (L)	**Raw water (μg/L)**	**Arr. #1 filtered (μg/L)**	**Arr. #2 filtered (μg/L)**	**Arr. #3 filtered (μg/L)**	**Arr. #4 filtered (μg/L)**	**Arr. #5 filtered (μg/L)**
40	800	ND	ND	ND	ND	ND
80	750	5	ND	5	5	ND
120	900	8	ND	5	5	ND

ND = Non-Detect = < 5 μg/L total arsenic

Table 4 - Arsenic Test Results in % Arsenic Removal for Lab Experiments at RWSSSP

Volume of raw water treated (L)	**Raw water (μg/L)**	**Arr. #1 % As removal**	**Arr. #2 % As removal**	**Arr. #3 % As removal**	**Arr. #4 % As removal**	**Arr. #5 % As removal**
40	800	>99	>99	>99	>99	>99
80	750	99	>99	99	99	>99
120	900	99	>99	99	99	>99

* The nails are considered “high quality” because they are very strong (i.e. not easy to bend)

* The nails are considered “medium quality” because they can be easily bend with bard hands.

Discussion of Results

One important observation is that even a newly installed BioSand Filter (i.e. arrangement #1), which was our control, does remove some arsenic. One explanation is that the sand has some initial arsenic removal capacity. Detectable arsenic concentration was first measured after 80 L of water was filtered, as shown in Table 3, column 3.

Comparison between the five filter arrangements shows that the best performing filters are arrangements #2 and #5. Both filters produced water that contained less than 5 μg/L of arsenic after treating 120 L of arsenic-contaminated water. However, the arsenic concentrations in the other filtered samples are also very low, at 5 μg/L. Strictly speaking, the difference in performance between filter arrangements #2, #3, #4, and #5 is too small to provide sufficient evidence to suggest which filter works the best. The difference between each filtrate could well be attributed to errors associated with the field test kit's accuracy[69]. A previous study by Ngai showed that the field test kit results agree 78% of the time with Graphite Furnace Atomic Absorption Spectrometry (GFAAS), a more sophisticated and accurate laboratory equipment[70].

It was also observed that when a bucket full of water was poured into the metal diffuser box, the force of water could easily disperse the iron nails in arrangements #3 and #4. This can lead to short-circuiting (i.e. arsenic contaminated water bypassing the iron nails). In such cases, all arsenic would not be removed. In an effort to protect the nails layer, a layer of brick chips of about 20-30 mm diameters was added on top of the nails.

The conclusion for the laboratory study arsenic results is that arsenic removal is very good. However, the study is inconclusive in determining the relative arsenic removal efficiency of each filter arrangement. A longer-term study (e.g. pilot study) is necessary.

Iron Results

Iron tests were performed on the same water samples as the arsenic tests. Results are shown in Table 5 and Table 6.

Table 5 - Iron Test Results in mg/L for Lab Experiments at RWSSSP

Volume of raw water treated (L)	Raw water (mg/L)	Arr. #1 filtered (mg/L)	Arr. #2 filtered (mg/L)	Arr. #3 filtered (mg/L)	Arr. #4 filtered (mg/L)	Arr. #5 filtered (mg/L)
40	1.2	ND	ND	ND	ND	ND
80	1.3	ND	ND	ND	ND	ND
120	1.2	ND	ND	ND	ND	ND

ND = Non-Detect = <0.1 mg/L total iron

Table 6 - Iron Test Results in % Iron Removal for Lab Experiment at RWSSSP

Volume of raw water treated (L)	Raw water (mg/L)	Arr. #1 % Fe removal	Arr. #2 % Fe removal	Arr. #3 % Fe removal	Arr. #4 % Fe removal	Arr. #5 % Fe removal
40	1.2	>92	>92	>92	>92	>92
80	1.3	>92	>92	>92	>92	>92
120	1.2	>92	>92	>92	>92	>92

Discussion of Results

Iron removal is very high. All filtered samples contained non-detectable levels of iron (i.e. <0.1 mg/L). This result is very encouraging for two reasons. First, because arsenic is tightly bound to iron surface, if iron is found in the filtered water, then it is very likely that arsenic will also be found. Therefore, complete iron removal is desirable. Second, iron gives color and odor to water. The USEPA and WHO drinking water guidelines for iron are both 0.3 mg/L[71]. Although higher iron content does not lead to adverse health effect in absence of arsenic, water with >0.3 mg/L iron may be aesthetically objectionable to the consumer.

Flow Rate Results

Five flow rate measurements were taken for each sampling time. The average of the five measurements are shown in Table 7, Table 8 and Figure 30.

Table 7 - Flow Rate Results for the Lab Experiments at RWSSSP

Volume of raw water treated (L)*	Arr. #1 flow rate (L/hr)	Arr. #2 flow rate (L/hr)	Arr. #3 flow rate (L/hr)	Arr. #4 flow rate (L/hr)	Arr. #5 flow rate (L/hr)
15	54	63	75	71	69
60	51	52	68	75	36
100	52	42	60	66	18
140	50	31	56	64	10

* Volume of raw water treated: refers to the actual volume of water that was filtered and that exited the outlet. It does not include water that was still inside the filter or in the diffuser box.

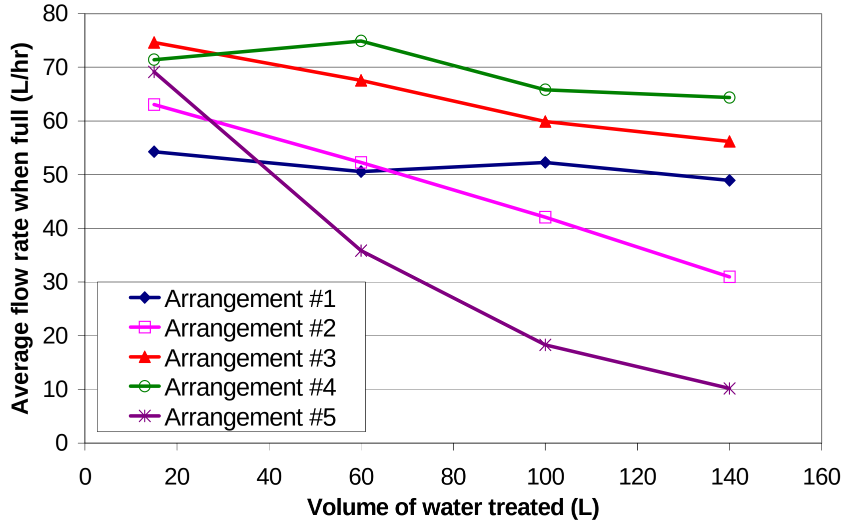

Figure 30 - Flow Rate as a Function of Volume of Water Treated

Table 8 - % Change in Flow Rate over the Duration of the Experiments

	Arr. #1	Arr. #2	Arr. #3	Arr. #4	Arr. #5
% Decrease in flow rate *	7	51	25	10	86

* Calculated by comparing the flow rate at 15 L volume of raw water treated and that at 140 L volume of raw water treated.

Discussion of Results

In general, each filter arrangement had a very high initial flow rate, ranging from 54 to 75 L/hr. One of the reasons for these high initially flow rates is that the sand layers in newly installed filters were loose, and therefore had high porosity (i.e. void space). Over time, sand compaction occurred, which reduced the porosity and decreased the flow rate. Another explanation for the high flow rates, especially when compared to a similar plastic laboratory models (flow rate about 20 L/hr), is that the fine sand used in the concrete filter is not as fine as the sand used in the plastic model of the filter. High flow rate is beneficial to the users; because that means that they do not need to wait a long time to obtain water. On the other hand, high flow rate may reduce the contact time between the raw water and the iron nails. Arsenic removal efficiency may be reduced.

Important insight into filter performance can be gained by comparing the flow rate results for the different filter arrangements. For arrangement #1 (control), the flow rate decreased very slightly over the experimental period, from 54 L/hr to 50 L/hr (7%). This decrease could be attributed to sand compaction, as well as to clogging of the filter from the sand, dust, and iron particles in the raw water. There was no addition of iron nails, so iron particules did not contribute to clogging. For all other filter arrangements, the decrease in flow rate exceeds 7%, and is assumed to be the direct result of the arsenic removal unit (i.e. the iron nails).

For arrangement #2 (coagulation/flocculation), the flow rate decreased by 51%. Of this 51%, 44% is considered to be due to the coagulation/flocculation pre-treatment process. It was observed that only about half of the flocs settled to the bottom of the bucket, even after the recommended 30-minutes wait. The other half of the flocs were suspended or floated on the water surface. When the supernatant was poured into the ABF, some of the unsettled flocs entered the ABF. Over the course of the experiment, these flocs accumulated on top of the fine sand layer in the ABF, leading to filter clogging.

For filter arrangement #3 (high quality iron nails), the drop in flow rate was moderate, at 25%. Of the 25%, 18% could be attributed to the arsenic removal unit (i.e. high quality iron nails). It was observed that these iron nails rusted rapidly. Upon contact with water, the nails started to oxidize almost instantaneously. It was also observed that the polyester cloth could trap only large sand, iron, and dust particles in the raw water. The cloth was much less effective to trap smaller-sized iron particles. As a result, most iron particles were deposited on top of the fine sand layer. After the experiments, a thin layer of orange iron rust particles could be seen on top of the sand (Figure 31).

Figure 31 - Iron Rust Deposit on Top of the Fine Sand Layer

For filter arrangement #4 (medium quality iron nails), the drop in flow rate was minimal, at 10%. Of the 10%, only 3% could be attributed to the arsenic removal unit (i.e. medium quality iron nails). As for the high quality iron nails, it was observed that these medium nails rusted very rapidly. Upon contact with water, the nails were oxidized almost instantaneously. It was also observed that the polyester cloth could only trap large sand, iron, and dust particles in the raw water. The cloth was much less effective to trap smaller-sized iron rust. As a result, most iron particles were deposited on top of the fine sand layer. After the course of the experiments, a thin layer of orange iron rust particles could also be easily seen.

For filter arrangement #5 (double bucket setup), the flow rate were the worst, with an 86% drop over the course of the experiment. Of the 86% drop in flow rate, 79% could be attributed to the arsenic removal unit setup. It was observed that the fine sand layer in the lower diffuser bucket was quickly clogged up with iron particles. A thorough wash of the sand in the lower diffuser bucket could clean up the clog, but this procedure was not easy. Part of the sand was usually lost during each wash. In addition, this procedure would have to be performed quite frequently. Therefore, this filter arrangement was not recommended for further study.

6.2.2 Additional Experiments

Additional Experiment 1 – Arsenic and Iron Results

Arsenic and iron concentrations of the supernatant are compared to that of the raw water as shown in Table 9.

Table 9 - Additional Experiment 1 Results

	Raw water	**Supernatant**	**Change**
Total arsenic (μg/L)	900	500	44% decrease
Total iron (mg/L)	1.2	3.4	180% increase

Discussion of Results

This experiment shows that the coagulation/flocculation process removed less than half of the total arsenic in the raw water. One explanation for the poor arsenic removal is incomplete precipitation, probably due to poor mixing and settling regime. A mixing and settling time of 30 minutes may be insufficient. However, Hwang's work on the optimal mixing and settling regime for ENPHO's powder shows that the incremental improvement in arsenic removal by lengthening the mixing-settling time is insignificant, therefore not worth the effort. Moreover, even a 30-minutes mixing-settling time may be too inconvenient for villagers to use.

A second explanation for the poor arsenic removal is insufficient arsenic oxidation. Of the two major oxidation states of inorganic arsenic, namely As(III) and As(V), As(V) occur as negatively charged $H_2AsO_4^-$ or $HAsO_4^{2-}$ species at normal groundwater pH of 6-8, while As(III) occur as neutral H_3AsO_3 species at pH below 9.2[72]. Many studies have indicated that the coagulation/flocculation process, in which arsenic binds or adsorbs on coagulant flocs, depends on the charge on the arsenic species. Generally, negatively charged species, such as As(V), are removed more readily than neutral species, such as As(III). For this reason, oxidation of As(III) to As(V) may be necessary in order to effectively remove arsenic from water sources that contain high concentrations of

As(III)[73,74,75,76]. An arsenic speciation study by Tommy Ngai in January 2002, in which he surveyed over 40 tubewells in the Nawalparasi and Rupandehi Districts of Nepal, found that on average 79% of all inorganic arsenic was in the As(III) oxidation state. Only 21% was in the As(V) oxidation state. Unless the majority of the As(III) is effectively oxidized by the calcium hypochlorite contained in the ENPHO powder during the 30 minutes mixing/settling, these As(III) may be unlikely to be removed by the coagulation/flocculation process. Therefore, high arsenic concentration remained in the supernatant.

Additional Experiment 2 – Arsenic and Iron Results

Arsenic and iron concentrations for the post-diffuser sample are compared to that of the raw water as shown in Table 10.

Table 10 - Additional Experiment 2 Results

	Raw water	**After diffuser**	**Change**
Total arsenic (mg/L)	900	800	11% decrease
Total iron (mg/L)	1.2	3.6	200% increase

Discussion of Results

The experiment shows that only a small percentage of the total arsenic in the influent is adsorbed onto the iron nails in the metal diffuser box. The majority of arsenic apparently bypasses the iron nails and enters the fine sand layer below the diffuser. A hypothesis is established to explain this phenomenon.

First, the iron nails' surface is oxidized upon exposure to water and air. As a result, ferric hydroxide is formed on the iron nails' surface. Second, when arsenic contaminated water passes through the iron nails bed, arsenic is quickly adsorbed to the ferric hydroxide surface. Thus in theory, very low concentrations of arsenic should be found in the effluent. However, iron hydroxide particles are constantly exfoliated ("peeled-off") from the iron nails, i.e. they break off into smaller particles. This exfoliation is probably due to the weak structural strength of rusted iron, and/or the scouring action of the passing water, and/or other mechanisms. These exfoliated iron hydroxide particles are loaded with arsenic. The mesh size of the polyester cloth is too large to block these small iron-arsenic particles from escaping the diffuser box and entering the fine sand layer below. As a result, high arsenic level was detected in the post-diffuser sample.

One implication of this hypothesis is that the constant exfoliation of iron nails would expose the inner, unoxidized parts of the iron nails. This is highly desirable because the more ferric hydroxide formed, the higher the arsenic adsorption capacity of these iron nails. Arsenic breakthrough would occur when the surface of all iron nails would be saturated with arsenic, and the exfoliation process would not keep generating sufficient amounts of ferric hydroxide to adsorb arsenic. More research is required to test the validity of this hypothesis.

Additional Experiment 3 – Arsenic and Iron Results

Raw water and a post-diffuser sample of filter arrangement #5 (double bucket setup) were collected and tested. Results are shown in Table 11.

Table 11 - Additional Experiment 3 Results

	Raw water	**After diffuser**	**Change**
Total arsenic (μg/L)	900	150	83% decrease
Total iron (mg/L)	1.2	0.2	83% decrease

Discussion of Results

Unlike the previous two experiments, the arsenic removal unit in this arrangement actually removes a significant amount of arsenic. The above-mentioned hypothesis still pertains; however, the reason why significant amount of arsenic was removed in this arrangement but not in the previous (83% compared to 11%) is that there is an additional sand layer in this arrangement. Arsenic-loaded iron particles are trapped by the sand layer in the bottom bucket. Nevertheless, it seems that the 25 mm sand layer in the lower bucket was insufficiently deep to effectively trap all iron particles. A small amount of iron particles was able to pass through the sand layer and exit the diffuser. This may explain the presence of arsenic in the post-diffuser water.

6.2.5 Summary of the Laboratory Experiments at RWSSSP Results

A summary table of the laboratory results is shown in Table 12.

Table 12 - Summary of the Lab Experiments at RWSSSP

	Arr. #1	**Arr. #2**	**Arr. #3**	**Arr. #4**	**Arr. #5**
Arsenic removal	excellent	excellent	excellent	excellent	excellent
Iron removal	excellent	excellent	excellent	excellent	excellent
Flow rate decrease	minimal	high	moderate	low	very high
Recommended for continued study	yes	no	yes	yes	no

The conclusion of the laboratory experiments portion of the study is that filter arrangements #1 (control), #3 (high quality iron nails), and #4 (medium quality iron nails) should be studied further. These arrangements have excellent arsenic and iron removal efficiency, as well as minimal to moderate decrease in flow rate over time. Serious flaws were found in arrangements #2 and #5, which were thus rejected for further study. For example, for arrangement #2, the 30-minutes wait can be cumbersome for some users, and the coagulation powder may not be readily available in many rural villages. Arrangement #5 has an unacceptably slow flow rate.

Arrangement #1 and #3 were chosen to be used in the pilot study at Sarawal and Devdaha VDC. The reason why Arrangement #3 was chosen over Arrangement #4 in the pilot study is that ENPHO highly recommended the high quality iron nails over the medium quality iron nails based on their studies[77]. Nevertheless, the choice of iron nails should be further investigated in another study.

7. PILOT STUDY IN SARAWAL AND DEVDAHA VILLAGE DEVELOPMENT COMMITTEES (VDCS) – SEPTEMBER 2002 TO JANUARY 2003

7.1 Pilot Study Overview

A pilot study was set up by Tommy Ngai in September-October 2002, in collaboration with RWSSSP. The filters were monitored by RWSSSP starting October 2002, until Tommy Ngai's team returned in December 2002. Table 13 shows the five stages of the pilot study. There are two main purposes to the pilot study program. The first purpose is to determine the long-term technical performance of the ABF, such as arsenic removal efficiency, pathogen removal efficiency, iron removal efficiency, and flow rate, and to modify design to improve performance. The second purpose is to investigate the social acceptability of ABF, and to modify design according to users' feedback. Results of the pilot study are discussed in Section 7.2.

Table 13 - Five Stages of the ABF Pilot Study

Stages	**Time**	**Description**
1. Installation	Sep-Oct 2002	Installed 10 ABFs in two villages
2. Monitoring by RWSSSP	Oct-Dec 2002	Tested arsenic and H_2S P/A bi-weekly
3. Monitoring by Tommy Ngai and Sophie Walewijk	Dec-Jan 2002	Measured arsenic, iron, total coliform, *E. Coli*, flowrate
4. ABF Modifications and New Design	Jan 2002	Develop new design, upgraded/re-installed all ABFs
5. Education Workshop	Jan 2002	Demonstrated installation, operation, and maintenance procedures

7.1.1 Installation

Tommy Ngai and RWSSSP traveled to two arsenic-affected villages (Goini in Sarawal VDC and Mandangram in Devdaha VDC) in late September to inspect the local drinking water situation. Ten households were selected on the basis of high arsenic level in their drinking water. Each household was asked if they would like to participate in a pilot study to evaluate the performance of a new water filter. They were informed that the ABF are experimental and are not guaranteed to remove arsenic, iron and bacteria. All ten households agreed to participate, partly because they currently do not have any satisfactory alternative to their poor quality drinking water. Even if the filters were to perform poorly, they would still be better off with the filters than with their existing conditions. They also understood that their ABF is not free of charge. At the end of the pilot study, they would need to pay a nominal fee if they wish to keep their ABF. Refer to Appendix I for more details regarding the use of human subjects in scientific study.

A total of 10 ABFs were installed on September 30, 2002 and October 3, 2002 (Figure 32, Figure 33, Figure 34, Figure 35) following the installation procedure described earlier in Section 4.4. Seven ABFs were installed in the village of Goini, and three ABFs were installed in the village of Mandangram. Tommy Ngai demonstrated the installation, operation and maintenance procedure to both the men and women of each household. A simple pamphlet in Nepali was handed out to remind each household about the ABF operation and maintenance procedures. Four members of the RWSSSP staff, namely Bhim Parajuli, Umesh Sharma, Devi Wagle, and Tula Bhattrai, were trained on filter installation, operation and maintenance.

Sarawal

In Sarawal, there were three different setups among the seven installed filters. The first setup contained no iron nails. The second setup contained 1.25 kg of high quality shoe tack nails. The third setup contained 2.5 kg of high quality shoe tack nails. The quantity of iron nails in each filter was determined from arsenic (using ITS Field Kit) and iron test (using HACH Test Kit) results of the raw well water, analyzed before the filter installation. These results are discussed in Section 7.2 (Table 20). In general, households with high iron and low arsenic in their water were given the filter arrangement #1 (i.e. no iron nails). Households with moderate iron and moderate arsenic in their water were given the second setup (i.e. 1.25 kg iron nails). Households with very high arsenic concentration in their water were given 2.5 kg of iron nails*. Table 14 shows the selected households in Sarawal and their respective ABF setup.

Figure 32 - Unloading New ABFs in Sarawal

Figure 33 - Filter Maintenance Demonstration at Harinarayan Chaudhary's House

Figure 34 - Gathering Material to Install an ABF

Figure 35 - Shivsagar Yadav's Tubewell, ABF, and House

* It should be noted that all ENPHO's ABF (except one) were given 5 kg of iron nails regardless of arsenic or iron concentration of the well water. The only exception was that one ABF contains no iron nails because total iron concentration in the well water was very high.

The quantity of sand and gravel in each of the filters followed the description stated in Section 4.1, Figure 3. The only exception is that the size coarse sand used in four of the filters (Nirahi Psd. Chaudhary, Harinarayan Chaudhary, Chintamani Chaudhary, and Ramashankar Yadav), was too large. Tommy Ngai and RWSSSP staff forgot to bring coarse sand on the day of filter installation. The coarse sand was obtained from the village as a replacement. The other three filters (Harilal Yadav, Ramashankar Yadav, Shivsager Yadav) were installed on the next day, and had the correct-sized coarse sand.

Appendix B shows the full details of each households' filter, including location, installation/re-installation dates, etc.

Table 14 - Sarawal: Selected Households and Their ABF Setup

Contact Person	Iron nails given (kg)	Installation date
Nirahi Psd. Chaudhary	1.25	Sep 30, 2002
Harinarayan Chaudhary	1.25	Sep 30, 2002
Chintamani Chaudhary	0	Sep 30, 2002
Ramashankar Yadav*	2.5	Sep 30, 2002
Harilal Yadav	0	Oct 1, 2002
Ramashankar Yadav*	1.25	Oct 1, 2002
Shivsager Yadav	2.5	Oct 1, 2002

*Ramashankar Yadav has two houses, and collects water from two different wells

Devdaha

Three households were selected in the village of Mandangram, Devdaha VDC, Rupandehi District. Each household collected their water from the same source, the Nar B. Gurung's tubewell. According to RWSSSP, this well is known to contain one of the highest arsenic concentrations of all wells in Nepal (2600 μg/L), based on RWSSSP's data. This is also the tubewell that was used in the Laboratory Experiments at RWSSSP (Section 6). The well water was tested for arsenic (using ITS Kit) and iron (using HACH Test Kit) concentration before installing the filters. Although the arsenic concentration is high, only 1.25 kg, rather than 2.5 kg of high quality shoe tack iron nails was included in each filter. It was done to minimize the concern about filter clogging, as observed in the laboratory experiments. It was believed that the problem of clogging could be reduced if less iron nails were given. The three filters were installed identically.

Because of the lower amount of iron nails in these ABFs, it was suspected that arsenic breakthrough might occur. The RWSSSP staff was told to carefully monitor these three ABFs. In case of arsenic breakthrough, RWSSSP staff was instructed to immediately remove the old iron nails, and to replace with 2.5 kg of new iron nails. Table 15 shows the selected household filters in Devdaha, and their ABF setup.

The quantity of sand and gravel in each of the filters followed the description stated in Section 4.1, Figure 3. Correct sand sizes were used.

Appendix B shows the full details of each of these households, including location, installation/re-installation dates, etc.

Table 15 - Devdaha: Selected Households and Their ABF Setup

Contact Person	Iron nails given (kg)	Installation date
Nar B. Gurung	1.25	Oct 2, 2002
Durga Kumari	1.25	Oct 2, 2002
Tek B. Hamal	1.25	Oct 2, 2002

7.1.2 Monitoring by RWSSSP

Upon completion of the filters installation, Tommy Ngai asked RWSSSP to monitor the filter performance until his team returned in December 2002. Six of the seven ABFs at Sarawal were monitored bi-monthly by RWSSSP from October 2002 to December 2002. The seventh ABF, Shivsager Yadav's ABF, was not monitored because his well was not constructed by RWSSSP, and was therefore outside of RWSSSP's responsibility. In Devdaha, all three ABFs were monitored bi-weekly. Arsenic in the raw water and filtered water was measured with a field test kit distributed by ENPHO, and sometimes a split sample was taken to be analyzed at ENPHO's laboratory with their British made

SOLAAR 969 AA spectrometer. H_2S Bacteria Presence/Absence Tests supplied by ENPHO were used to test for pathogens.

Three of the seven ABFs in Sarawal were decommissioned by RWSSSP in mid-December 2002 because their monitoring results showed arsenic in the filtered water were above the Nepali guideline of 50 μg/L.

7.1.3 Monitoring by Tommy Ngai and Sophie Walewijk

Tommy Ngai and Sophie Walewijk traveled to Nepal to from December 2002 to January 2003 to follow-up on the monitoring of the 10 filters installed (Figure 36, Figure 37, Figure 38) and to make necessary changes to the design. They also visited six additional ABFs installed by ENPHO staff between September 2002 and October 2002, which were constructed following the same design concept of Tommy Ngai. Refer to Appendix F for a description of the ENPHO ABF design and pilot study. Table 16 lists the 16 households visited, and the sampling dates. Because three of the filters were decommissioned, pre and post-filtration water samples were collected and tested from the remaining 13 locations. The water quality parameters tested were:

- Total arsenic
- Total iron
- Total coliform
- *E. Coli*

Flow rate was measured for each filter as well (Figure 37). The users were also asked how often they cleaned the filter (if ever), and whether clogging was a serious issue. Table 16 shows the 16 total locations.

Figure 36 - Tommy Ngai and Sophie Walewijk Collecting a Tubewell Water Sample at Phagu N. Chaudhary’s Tubewell in Tilakpur VDC.

Figure 37 - Sophie Walewijk Measuring Flow Rate at Tek Bahadur Hamal’s ABF in Devdaha VDC.

Figure 38 - Analyzing Samples at the RWSSSP Guesthouse at Night

Table 16 - ABF Households Visited by Tommy Ngai and Sophie Walewijk

Contact person	Sampling date	As + Fe	Bacteria	Flow rate
Nirahi Psd. Chaudhary	Dec 31, 2002	Y	Y	Y
Harinarayan Chaudhary	decommissioned	Y	Y (well only)	N
Chintamani Chaudhary	decommissioned	Y	N	N
Ramashankar Yadav	decommissioned	Y	Y (well only)	N
Harilal Yadav	Dec 31, 2002 & Jan 5, 2003	Y	Y	Y
Ramashankar Yadav	Dec 31, 2002	Y	Y	Y
Shivsager Yadav	Dec 31, 2002	Y	Y	Y
Nir B. Gurung	Dec 29, 2002	Y	N	Y
Durga Kumari	Dec 29, 2002	Y	N	Y
Tek B. Hamal	Dec 29, 2002	Y	N	Y
Nim Chaudhary	Jan 3, 2003	Y	Y	Y
Min Chaudhary	Jan 3, 2003	Y	Y	Y
Phakir Kami	Jan 3, 2003	Y	Y	Y
Phagu N. Chaudhary	Jan 3, 2003	Y	Y	Y
Lila B. Pun	Jan 3, 2003	Y	Y	Y
Bhanu Primary School	Jan 3, 2003	Y	Y	Y

In addition, Tommy Ngai and Sophie Walewijk visited five 3-Kolshi filters installed by RWSSSP in the village of Rangai in Dubiya VDC, Kapilvastu district in the summer of 2002. Two filters were damaged at the time of visit. Arsenic, iron, and flow rate for the remaining three filters were analyzed. Table 17 shows the 3 locations. Refer to Appendix G for a description of the RWSSSP 3-Kolshi Filter design and pilot study.

Table 17 - 3-Kolshi Filters Visited by Tommy Ngai and Sophie Walewijk

Contact person	Sampling date	As + Fe	Bacteria	Flow rate
Aitwari Chaudhary	Jan 1, 2003	Y	N	Y
Sukhal Chaudhary	Jan 1, 2003	Y	N	Y
Jhinku Chaudhary	Jan 1, 2003	Y	N	Y

7.1.4 ABF Modifications and New Design

Based on the lessons learned from the pilot study monitoring, as well as feedback from ENPHO, RWSSSP staffs and users, the design for ABF was slightly modified by Tommy Ngai and Sophie Walewijk on January 3, 2003. The new design contains 5 kg of the high quality shoe tack iron nails, instead of 0, 1.25 or 2.5 kg of nails in the old design. The brick chips in the old design were found unnecessary as well (Secton 7.2.3). This new design is expected to be more robust and user-friendly, and to achieve higher arsenic removal efficiency. This is the design shown in Section 4.1 Figure 3.

All ABFs were immediately upgraded to the new setup by Tommy Ngai's team with the help of RWSSSP staff on January 4, 2003. The upgrade consisted of two parts – first, to remove the brick chips and to increase the amount of iron nails in the existing filters to 5 kg; and second, to reinstall the three decommissioned filters. The procedures are described below.

Add Iron Nails

The procedure to add nails was simple. First, the brick chips in the diffuser box were removed and discarded. Second, new nails were washed to rid of dust. Then the new nails were added to the diffuser box. The amount of iron nails added was determined based on the difference between the existing amount of iron nails and 5 kg.

Re-installation

After RWSSSP emptied the three non-performing filters, all filter components were left at the users' home. When Tommy Ngai's team and RWSSSP returned to re-install the filters, some of the previous components were reused. The reused material included the concrete filter casing, metal diffuser box, polyester cloth, iron nails, filter lid, gravel, and fine sand. New coarse sand, Piyush solutions, and additional iron nails were brought to the villages for re-installation. The empty filters were first flushed with water to get rid of dirt and dust. Gravel, coarse sand, fine sand, and iron nails were also washed. A total of 5 kg of iron nails was used. Then, the filters were filled-in with the filter media, layer by layer, following the filter installation instructions described in Section 4.4.2.

Due to insufficient time, arsenic was tested for only two of the filters that only received additional iron nails (Table 18), and for the three re-installed filters (Table 19). Samples were collected after one day of use. Appendix B shows the full details of each of these households, including location, installation/re-installation dates, monitoring results, etc.

Table 18 - Two ABFs Selected for Arsenic Analysis after Having Added More Nails

Contact person	**Sampling date**	**As**	**Bacteria**	**Flow rate**
Nirahi Psd. Chaudhary	Jan 5, 2003	Y	N	N
Ramashankar Yadav	Jan 5, 2003	Y	N	N

Table 19 - Arsenic Analysis for the three Re-installed ABFs.

Contact person	**Sampling date**	**As**	**Bacteria**	**Flow rate**
Harinarayan Chaudhary	Jan 5, 2003	Y	N	Y
Ramashankar Yadav	Jan 5, 2003	Y	N	Y
Ramashankar Yadav	Jan 5, 2003	Y	N	Y

7.1.5 Education Workshop

On January 5, 2003, Tommy Ngai and Sophie Walewijk, Umesh Sharma and Bhim Parajuli from RWSSSP and a staff member from ENPHO organized a village-wide education workshop at the village of Goini in Sarawal VDC, Nawalparasi District (Figure 39 and Figure 40). Health issues related to arsenic contamination were presented by RWSSSP and ENPHO staff. The ABF filter setup, operation, and maintenance were also demonstrated by Tommy Ngai and Sophie Walewijk. Posters on how to detect skin diseases resulting from arsenic exposure were posted on the walls of the village, and handouts on how to clean the filters were distributed to each household present at the workshop (see Appendix D).

Figure 39 - Tommy Ngai Explaining How to Operate the ABF

Figure 40 - Umesh Sharma Translating Sophie Walewijk's Explanations on How to Clean the ABF

7.2 Results and Discussion

7.2.1 Installation

Sarawal

Water from each of the seven selected tubewells in Sarawal was tested for arsenic and iron by Tommy Ngai before installing the filters. Results are shown in Table 20.

Table 20 - Sarawal Tubewell Test Results, and Quantity of Iron Nails

Contact Person	As (μg/L)	Fe (mg/L)	Nails quantity (kg)
Nirahi Psd. Chaudhary	350	1.4	1.25
Harinarayan Chaudhary	400	1.3	1.25
Chintamani Chaudhary	350	1.6	0
Ramashankar Yadav	500	1.5	2.5
Harilal Yadav	250	2.3	0
Ramashankar Yadav	400	1.4	1.25
Shivsager Yadav	900	1.4	2.5

Devdaha

Water from Nar Bir Gurung's tubewell in Devdaha, which serves three households, was tested for arsenic and iron by Tommy Ngai before installing the filters. Results are shown in Table 21.

Table 21 - Devdaha Tubewell Test Results, and Quantity of Iron Nails

Contact Person	As (μg/L)	Fe (mg/L)	Nails quantity (kg)
Nar Bir Gurung	860	1.3	1.25
Durga Kumari	860	1.3	1.25
Tek B. Hamal	860	1.3	1.25

7.2.2 Monitoring Results by RWSSSP

Arsenic and H_2S Bacteria Results

Summary results for the nine households are shown in Table 22 to Table 31. Detailed results are in Appendix B.

Table 22 - Monitoring Results for Nirahi Chaudhary, Iron Nails = 1.25 kg

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	A	P	20	ND	>75	186	ND	>97
Oct 20, 2002	N/A	N/A	200	ND	>98	N/A	N/A	N/A
Nov 14, 2002	A	P	N/A	ND	N/A	363	5	99
Nov 29, 2002	N/A	P	10	ND	>50	N/A	N/A	N/A
Dec 16, 2002	A	A	300	ND	>98	213	30	86
				Average=	80		*Average=*	94

ND = Non-Detected =< 5 µg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 23 - Monitoring Results for Harinarayan Chaudhary, Iron Nails = 1.25 kg.

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	A	P	60	ND	>92	237	7	97
Oct 20, 2002	N/A	N/A	250	100	60	N/A	N/A	N/A
Nov 14, 2002	N/A	A	N/A	300	N/A	401	140	65
Nov 29, 2002	N/A	A	320	80	75	N/A	N/A	N/A
Dec 16, 2002	A	A	350	200	43	372	137	63
				Average=	67		*Average=*	75

ND = Non-Detected =< 5 µg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 24 - Monitoring Results for Chintamani Chaudhary, Iron Nails = 0 kg

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	P	P	90	ND	>94	156	24	85
Oct 20, 2002	N/A	N/A	250	150	40	N/A	N/A	N/A
Nov 14, 2002	N/A	P	150	ND	>97	456	227	50
Nov 29, 2002	N/A	P	350	70	80	N/A	N/A	N/A
Dec 16, 2002	A	P	400	400	0	288	207	28
				Average=	62		*Average=*	54

ND = Non-Detected =< 5 µg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 25 - Monitoring Results for Ramashankar Yadav, Iron Nails = 2.5 kg

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	P	P	70	ND	>93	298	ND	>98
Oct 20, 2002	N/A	N/A	350	150	57	N/A	N/A	N/A
Nov 14, 2002	A	A	50	450	0.0*	616	160	74
Nov 29, 2002	N/A	P	180	60	67	N/A	N/A	N/A
Dec 16, 2002	P	P	450	350	22	N/A	N/A	N/A
				Average=	48		*Average=*	86

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence
* Note: For Nov 14, 2002 arsenic test kit results, the filtered water contained 450 μg/L As, which is higher than the raw water 50 μg/L As. This may be due to incorrect analytical procedure, or errors associated with the test kit accuracy.

Table 26 - Monitoring Results for Harilal Yadav, Iron Nails = 0 kg

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	P	P	60	ND	>92	67	ND	>93
Oct 20, 2002	N/A	N/A	200	ND	>98	N/A	N/A	N/A
Nov 14, 2002	N/A	A	N/A	ND	N/A	272	9	97
Nov 29, 2002	N/A	P	320	10	>97	N/A	N/A	N/A
				Average=	95		*Average=*	95

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence
* Note: During the Dec 16, 2002 monitoring round, no water sample was taken because Harilal Yadav has stopped using the filter. He claimed that the filter did not remove arsenic.

Table 27 - Monitoring Results for Ramashankar Yadav, Iron Nails = 1.25 kg

Sampling date	**H2S P/A**		**Arsenic by ENPHO test kit**			**Arsenic by ENPHO lab**		
	raw	*filtered*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*	*raw ($\mu g/L$)*	*filtered ($\mu g/L$)*	*% removal*
Oct 3, 2002	A	P	20	ND	>75	163	ND	>97
Oct 20, 2002	N/A	N/A	200	ND	>98	N/A	N/A	N/A
Nov 14, 2002	A	P	N/A	ND	N/A	451	ND	99
Nov 29, 2002	N/A	P	10	ND	>50	N/A	N/A	N/A
Dec 16, 2002	A	A	300	ND	>98	377	24	94
				Average=	80		*Average=*	97

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 28 - Monitoring Results for Nir Bir Gurung, Iron Nails = 1.25 kg

Sampling date	H2S P/A		Arsenic by ENPHO test kit			Arsenic by ENPHO lab		
	raw	*filtered*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*
Oct 3, 2002	P	A	150	ND	>97	N/A	N/A	N/A
Oct 20, 2002	N/A	N/A	250	ND	>98	N/A	N/A	N/A
Nov 14, 2002	N/A	N/A	N/A	ND	N/A	848	9	99
Nov 29, 2002	N/A	P	>500	ND	>99	N/A	N/A	N/A
Dec 16, 2002	P	A	>500	ND	>99	936	12	99
				Average=	>98		*Average=*	99

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 29 - Monitoring Results for Durga Kumari, Iron Nails = 1.25 kg

Sampling date	H2S P/A		Arsenic by ENPHO test kit			Arsenic by ENPHO lab		
	raw	*filtered*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*
Oct 3, 2002	P	P	150	ND	>97	N/A	N/A	N/A
Oct 20, 2002	N/A	N/A	250	ND	>98	N/A	N/A	N/A
Nov 14, 2002	N/A	A	N/A	ND	N/A	848	ND	>99
Nov 29, 2002	N/A	P	>500	ND	>99	N/A	N/A	N/A
Dec 16, 2002	P	A	>500	ND	>99	N/A	N/A	N/A
				Average=	>98		*Average=*	>99

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 30 - Monitoring Results for Tek B. Hamal, Iron Nails = 1.25 kg

Sampling date	H2S P/A		Arsenic by ENPHO test kit			Arsenic by ENPHO lab		
	raw	*filtered*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*	*raw (μg/L)*	*filtered (μg/L)*	*% removal*
Oct 3, 2002	P	P	150	ND	>97	N/A	N/A	N/A
Oct 20, 2002	N/A	N/A	250	ND	>98	N/A	N/A	N/A
Nov 14, 2002	N/A	A	N/A	ND	N/A	848	ND	>99
Nov 29, 2002	N/A	P	>500	ND	>99	N/A	N/A	N/A
Dec 16, 2002	P	A	>500	ND	>99	N/A	N/A	N/A
				Average=	>98		*Average=*	>99

ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested
A = Absence, P = Presence

Table 31 - Summary of RWSSSP Monitoring Results for Arsenic

Contact person	Iron nails (kg)	Average % As removal (ENPHO test kit)	Average % As removal (ENPHO lab)
Nirahi Psd. Chaudhary	1.25	80	94
Harinarayan Chaudhary	1.25	67	75
Chintamani Chaudhary	0	62	54
Ramashankar Yadav	2.5	48	86
Harilal Yadav	0	95	95
Ramashankar Yadav	1.25	80	97
Nar Bir Gurung	1.25	>98	>99
Durga Kumari	1.25	>98	>99
Tek B. Hamal	1.25	>98	>99
	Average=	81	89

Note:
ND = Non-Detected =< 5 μg/L arsenic
N/A = Not tested

Discussion of Results - Arsenic

The arsenic removal efficiency of the nine arsenic biosand filters was excellent. The average removal is 81% according to the field test kit results, and 89% according to the more accurate laboratory analytical results. Refer to Appendix H for a discussion comparing the accuracy of various arsenic test methods.

At the time of the first monitoring round on October 3, 2002, all ABFs were able to produce filtered water that met the Nepali arsenic drinking water guideline (50 μg/L As). The filtered water contained between non-detectable level of arsenic (<5 μg/L) and 24 μg/L. These results in the regular biosand filters without the arsenic unit (Chintamani Chaudhary and Harilal Yadav) confirmed with the laboratory experimental observation that the regular biosand filter had some arsenic removal capacity. At the time of the second monitoring round on October 20, 2002, three ABFs were not reducing arsenic concentrations to an acceptable level. The ENPHO test kit results showed that the filtered water of Harinarayan Chaudhary had 100 μg/L As, Chintamani Chaudhary had 150 μg/L As, and Ramashankar Yadav had 150 μg/L As. The same three ABFs were also non-performing at the time of the third monitoring round on Nov 14, 2002. The

ENPHO test kit and laboratory results showed that the filtered water of Harinarayan Chaudhary had 300 μg/L As (field test kit) and 140 μg/L As (lab), Chintamani Chaudhary had < 5 μg/L As (field test kit) and 227 μg/L As (lab), while Ramashankar Yadav had 450 μg/L (field test kit) and 160 μg/L As (lab). These three ABFs continued to show unacceptable levels of arsenic in the filtered water for all other monitoring rounds as well. These three ABFs were decommissioned by RWSSSP just prior to the arrival of Tommy Ngai and Sophie Walewijk in late December 2002. These three ABFs were emptied of their content. On the other hand, all other ABFs worked well, with arsenic concentrations in the filtered water never exceeding the Nepali guideline of 50 μg/L.

Inappropriate installation procedure is believed to be a major cause for the poor arsenic removal in the three decommissioned filters. These three filters, plus Nirahi Chaudhary's filter, were installed on September 30, 2002. During that day, Tommy Ngai and the RWSSSP staff forgot to bring coarse sand. Sand was obtained from the village as a replacement. However, the sand size was not correct. The size of the coarse sand was too large.

One important observation from the above data is that high iron concentration in the influent water may enhance arsenic removal. For example, Chintamani Chaudhary's filter had no iron nails. The presence of arsenic in the filtered water at the time of the second monitoring round shows that arsenic breakthrough had occurred. The natural arsenic removal capacity of the regular biosand filter (BSF) had been exhausted. This suggested that iron nails may be necessary in his filter. In contrast, Harilal Yadav's filter, which is another ABF without iron nails, had excellent arsenic removal for all monitoring rounds. Apparently the natural arsenic removal capacity of Harilal Yadav's ABF was not yet exhausted. One explanation is that his tubewell water contained more iron (2.3 mg/L) compared to Chintamani's water (1.6 mg/L). The higher iron content in the raw water could have adsorbed and subsequently removed more arsenic from the raw water. If the raw water contains sufficiently high iron, then iron nails may not be necessary to remove arsenic.

Wide fluctuations in the raw water arsenic concentrations for a same tubewell were observed. For example, laboratory analysis showed that Chintamani Chaudhary's tubewell contained 156 μg/L, 456 μg/L, and 288 μg/L of arsenic from the Oct 3, Nov 14, and Dec 16 sampling rounds. While the fluctuation could be due to seasonal changes in the groundwater chemistry, this is unlikely because of the shallowness of the well (55 feet). All RWSSSP tubewells were drilled to the second aquifer, which is a confined aquifer. The groundwater chemistry in a confined aquifer is usually minimally affected by the surface weather conditions. Therefore the change in climate may play only a minor role with respect to the wide fluctuation in arsenic concentrations.

A more likely cause for such a wide fluctuation is inappropriate sampling techniques. For example, the time elapsed between sample collection and laboratory analysis was sometimes as long as a month. If the sample was not properly preserved, then the arsenic in the sample could have settled to the bottom of the container. This would yield false results.

In addition, inaccurate analytical technique appeared to be a problem. The ENPHO test kit and laboratory results were frequently in disagreement. For example, in Ramashankar Yadav's raw tubewell water. The test kit showed 70 μg/L and 50 μg/L As on Oct 3 and Nov 14, while the laboratory showed 298 μg/L and 616 μg/L As. The differences between the two analytical techniques were very significant. In such cases, the ENPHO laboratory results are taken to be more accurate. A split-sample test comparing the arsenic test results between the ENPHO Laboratory's SOLAAR 969 Hydride Generation Atomic Absorption Spectrometer and the MIT Parsons Laboratory's Perkins-Elmer Graphic Furnace Atomic Absorption Spectrometry by Tommy Ngai in June 2002 showed that the average difference between the two analytical methods is 31%. This is very good. The high level of agreement between the two instrument suggested that the ENPHO Laboratory' arsenic results are usually dependable and accurate. Refer to Appendix H for details on the above lab analysis comparisons.

Discussion of Results – Pathogen

Table 32 summaries the results for RWSSSP pathogen monitoring using ENPHO's P/A H_2S bacteria test vials.

Table 32 - Summary of RWSSSP Monitoring Results for P/A H_2S bacteria

Influent	**Effluent**	**Bacteria removal?**	**# of ABFs**	**% of total**
A	A	N/A	3	N/A
A	P	No	1	20
P	P	No	1	20
P	A	Yes	3	60
		Total	8	100

Note:
A = Absence of H_2S bacteria using ENPHO P/A H_2S bacteria test vials
P = Presence of H_2S bacteria using ENPHO P/A H_2S bacteria test vials

N/A = Not applicable. Since both influent and effluent don't have H_2S bacteria, it is not possible to determine if the ABF removed bacteria. These three filters are not included in the % calculation

The P/A H_2S bacteria tests results from RWSSSP monitoring showed that three of the eight filters have indeterminate bacteria removal results because both the influent and effluent are absence of H_2S bacteria. For the remaining five filters, three (60%) were able to remove bacteria.

The above bacteria results are not very reliable due to incorrect incubation temperatures. The P/A test vials were incubated at ambient temperature in the RWSSSP office. The room temperature in the summer (April to October) can be as high as 30-35°C, but drop to as low as 10-15°C in the winter (November to March). The incubation temperature is an important parameter affecting the accuracy of the test results. According to ENPHO, the test vials should be maintained at temperature between 22 and 44°C for 48 hours. Outside of this temperature range, the proper biochemical processes may not occur to provide accurate analytical results (e.g. bacteria may be stressed thus unable to reproduce).

RWSSSP was advised that one way to improve the test reliability is to incubate the vials at a constant temperature, such as using an Amy Smith incubator (see Page 25).

In addition, it should be noted that the P/A H_2S bacteria test result may not correlate well with the more accurate membrane filter technique used by Tommy Ngai's team[78,79]. Nevertheless, P/A H_2S bacteria test has its merits, including low cost and simplicity of use.

7.2.3 Monitoring Results by Tommy Ngai and Sophie Walewijk

Tommy Ngai and Sophie Walewijk visited a total of 16 households (the original 10 filters in the pilot study plus six filters setup by ENPHO) and monitored 13 ABFs (seven of the original 10 filters plus six by ENPHO). Three of the original 10 filters were decommissioned by RWSSSP thus not tested. The test results and discussion for total arsenic, total iron, total coliform, *E. Coli*, and flow rate are presented in the next few sections.

Arsenic

Arsenic results are presented in Table 33. These results were obtained using the ITS Arsenic Field Test Kit. Detailed results are in Appendix B.

Table 33 - Arsenic Results from Tommy Ngai and Sophie Walewijk Monitoring

Contact person	Iron nails quantity (kg)	Arsenic by ITS Test Kit		% removal
		Raw (μg/L)	*Filtered (μg/L)*	
Nirahi Psd. Chaudhary	1.25	350	80	77
Harinarayan Chaudhary	1.25	Decommissioned		25[1]
Chintamani Chaudhary	0	Decommissioned		25
Ramashankar Yadav	2.5	Decommissioned		25
Harilal Yadav	0	250	30	88
Ramashankar Yadav	1.25	400	30	93
Shivsager Yadav	2.5	900	ND	>99
Nar Bir Gurung	1.25	700	300	57
Durga Kumari	1.25	700	30	96
Tek B. Hamal	1.25	700	ND	>99
Nim Chaudhary	0	20	ND	>75[2]
Min Chaudhary	5	160	15	91
Phakir Kami	5	80	60	25[3]
Phagu N. Chaudhary	5	120	ND	96
Lila B. Pun	5	60	8	87
Bhanu Primary School	5	120	ND	96
			Average =	75

Note:
ND = Non-Detect =< 5 μg/L As
N/A = Not tested

1. For decommissioned filters, the % arsenic removal efficiency is assumed to be 25%. This is to avoid a high bias on the average % removal if these decommissioned filters are ignored in the calculation.

2. The % arsenic removal is likely to be higher than 75%, but this can only be confirmed using an arsenic test with a lower detection limit.

3. The 25% removal efficiency is obtained by Tommy Ngai using ITS Field Kit. According to the ENPHO monitoring results shown in Appendix F, the raw water and filtered water contained 241 μg/L and 6 μg/L of arsenic respectively. Therefore, the arsenic removal efficiency would be 98%, instead of 25%. Due to the inconsistency between ITS Field Kit and ENPHO Lab, this result was not included in the average % arsenic removal calculation.

Discussion of Results

Arsenic results are good. The average arsenic removal efficiency of the entire set of 16 ABFs is 75%. However, it should be noted that this value is derived from filters with different quantity of iron nails. It is necessary to divide the 16 filters into four different groups, according to iron nails given, in order to better understand the arsenic performance of the different filter setup. Table 34 and Figure 41 compare the arsenic removal efficiencies of the four groups of ABFs.

Table 34 - Arsenic Removal Efficiencies for Different ABF Setups

Iron nails quantity (kg)	# of ABFs	% As removal for each ABF	Average % As removal
0	3	Decommissioned[1], 88, >75	63
1.25	6	77, decommissioned, 93, 57, 96, >99	75
2.5	2	decommissioned, >99	62
5	5	91, 25[2], 96, 87, 96	93

Note:
The average % arsenic removal for each group was calculated assuming the decommissioned ABFs have 25% arsenic removal efficiency.

1. For decommissioned filters, the % arsenic removal efficiency is assumed to be 25%. This is to avoid a high bias on average % removal if these decommissioned filters are ignored in the calculation.

2. The 25% removal efficiency is obtained by Tommy Ngai using ITS Field Kit. According to the ENPHO monitoring results (Appendix F), the raw water and filtered water contained 241 μg/L and 6 μg/L of arsenic respectively. Therefore, the arsenic removal efficiency would be 98%, instead of 25%. Due to the inconsistency between ITS Field Kit and ENPHO Lab, this result was not included in the average % arsenic removal calculation.

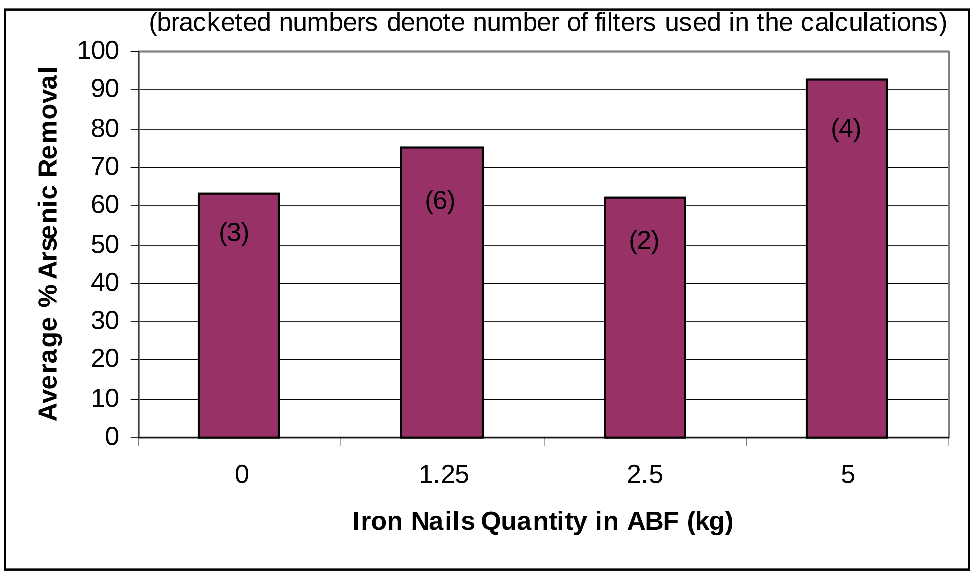

Figure 41 - Arsenic Removal Efficiencies for Different ABF Setups

It is found that the group of ABFs with 5 kg iron nails has the highest average arsenic removal efficiency, at 93%, which agrees with the ENPHO monitoring results of 95% (Appendix F). In addition, the % arsenic removal for the individual filters within 5 kg iron nails group is more consistent, with smaller fluctuations. This is in contrast with the ABFs in other groups, of which some of the ABFs had to be decommissioned due to unacceptable performance. One reason that the 5 kg group has the best performance is because of the thickest iron nails bed depth. The thick bed depth allows the longest contact time between the arsenic contaminated water and the iron nails, which leads to the highest arsenic adsorption. Another reason is that the pouring of water can easily disperses the iron nails to the sides, especially when the iron nail bed depth is thin (Figure 42). This condition leads to short-circuiting because the "hole" in the iron bed allowed raw water to pass through the arsenic removal unit without ever contacting any iron nails. This condition was observed on several occasions for ABFs with small quantities of iron nails, but to a lesser degree in the 5 kg iron nails group.

Figure 42 - Dispersed Iron Nails

The brick chips did not accomplish their function of protecting the underlying iron nails from dispersion by the inlet water. On the contrary, the brick chips hindered the user to easily redistribute (re-flatten) the dispersed iron nails. When the metal diffuser box contains only iron nails with no brick chips, the user can easily redistribute (re-flatten) the iron nails by removing the box and vigorously shaking the box. Another way of protecting the underlying iron nails is to place another diffuser above the nails. Further investigation is recommended to determine which of the above two methods (vigorous shaking periodically vs. additional diffuser) is more socially acceptable and technically superior.

The third reason why the 5 kg iron nails ABFs have the highest arsenic removal efficiency is that the arsenic concentration for raw water corresponding to these filters are in general lower than for the other ABFs. The five 5 kg iron nails ABFs received raw water with arsenic concentration between 60 to 160 μg/L (according to ITS field kit), where as all other ABFs received raw water with higher arsenic concentration, between 250 to 900 μg/L* (according to ITS field kit). The higher raw water arsenic concentration can exhaust the arsenic adsorption capacity of the iron nails more quickly, leading to breakthrough of arsenic. Nevertheless, excellent arsenic removal efficiency was observed for some of the high arsenic water (e.g. Shivsager Yadav's 900 μg/L As water was treated to non-detected; and Tek B. Hamal's 700 μg/L As water was treated to non-detected). This shows that the ABF can achieve a high degree of arsenic removal.

It should be noted that the ABF installed at Bhanu Primary School by ENPHO is the first ABF in Nepal. It was installed on September 5, 2002 by ENPHO, who followed the installation instruction given by Tommy Ngai in July 2002. The ABF at the school is currently serving about 200 students, as opposed to other filters that are serving one family. Because of the earliest installation date and the highest number of users, this ABF has probably treated more water than any other ABFs in Nepal. The fact that this filter can still remove a high percentage of arsenic suggests that the iron nails may have a very high arsenic adsorption capacity.

In conclusion, it was found that the average arsenic removal efficiency for the four filters with 5 kg of iron nails was 93%, which is consistent with ENPHO's results of 95% (Appendix F). It is therefore recommended that each new filter should contain about 5 kg of iron nails. Less nails may result in poorer arsenic removal performance, more nails may make the box too heavy to handle. It was also found that brick chips do not protect the iron nails from dispersion when water is forcefully poured into the diffuser. One solution is to add a diffuser plate on top of the iron nails.

* These five ABF were installed by ENPHO. 5 kg of iron nails were in each of these filters regardless of influent arsenic concentration

Iron

Iron test results using HACH filed test kit are shown in Table 35. Detailed results are in Appendix B.

Table 35 - Iron Results from Tommy Ngai and Sophie Walewijk Monitoring

Contact person	**Iron nails quantity (kg)**	**Iron by HACH Test Kit**		**% removal**
		Raw ($\mu g/L$)	*Filtered ($\mu g/L$)*	
Nirahi Psd. Chaudhary	1.25	1.4	ND	>93
Harinarayan Chaudhary	1.25	Decommissioned		N/A
Chintamani Chaudhary	0	Decommissioned		N/A
Ramashankar Yadav	2.5	Decommissioned		N/A
Harilal Yadav	0	2.3	ND	>96
Ramashankar Yadav	1.25	1.4	ND	>93
Shivsager Yadav	2.5	1.4	ND	>93
Nar Bir Gurung	1.25	1.3	ND	>92
Durga Kumari	1.25	1.3	ND	>92
Tek B. Hamal	1.25	1.3	ND	>92
Nim Chaudhary	0	3.8	ND	>97
Min Chaudhary	5	1.1	ND	>91
Phakir Kami	5	2.3	ND	>96
Phagu N. Chaudhary	5	1.4	ND	>93
Lila B. Pun	5	1.2	ND	>92
Bhanu Primary School	5	1.1	ND	>90
			Average =	>93*

Note:
ND = Non-Detect =<0.1 mg/L
N/A = Not tested

Discussion of Results

Iron removal for all ABFs is excellent, at >93%*. All filtered water contain non-detect level of iron (<0.1 mg/L). This is desirable because effective iron removal is a key pre-requisite for effective arsenic removal. As discussed previously, the surface of iron particles is usually loaded with arsenic, because of the chemical interactions between arsenic and ferric hydroxide. Therefore, if iron is found in the filtered water, then arsenic is very likely to be found as well.

* The % iron removal is likely to be higher than 93%, but this can only be confirmed using an iron test with a lower detection limit.

The converse may not be true. If no iron is found in the filtered water, this does not mean that arsenic is not found: it may or may not be found. For example, if all the iron particles are saturated with arsenic, any excess arsenic will pass through the filter into the drinking water. There is not enough iron to adsorb all arsenic. As a result, the filtered water may not contain iron, but arsenic would still be found in the filtered water. One implication of this observation is that the use of iron test as a replacement for arsenic test may not be appropriate. It is true that if iron is detected in the filtered water, arsenic will likely be found in the sample. But, if no iron is detected in the filtered samples, this does not mean that there is no arsenic. In this case, no information about arsenic content in the filtered water can be deducted.

An important observation was made at the household of Nim Chaudhary in Tilakpur VDC. Iron concentration was found to be very high in the well water, at 3.8 mg/L (according to HACH test kit). Because of the high iron content, ENPHO staff decided not to add any iron nails in the diffuser box. Yet, after three months the filtered water still did not contain any detectable level of arsenic. This observation confirms the earlier suggestion that high iron in the raw water is beneficial for arsenic removal.

During a site visit, Phagu N. Chaudhary of Tilakpur VDC indicated that the main reason for his household to continue to use the ABF is its excellent iron removal. According to him, high iron in his water used to taint his cooked rice with a brown color. Because the ABF water contains no iron, his family now enjoys white rice very much. One important implication is that effective iron removal can produce clean-looking and good-tasting water, which in turns encourage the users to continue to use the filter.

Similar findings were observed in a survey study in Nepal by Paynter in 2001[80]. In his study,

> the 89% who reported "liking" the biosand filter (BSF) addressed more immediate, direct improvements in their water. Particularly they noted that the water tasted better, there was plenty of water, the BSF always removed the seasonal cloudiness and that the filtered water was cool. It seems likely that it is these "non-essential" parameters - taste, amount, clarity, and temperature - that will

determine the acceptance of the BSF project. Because the health effects of the BSF may take months or years to become apparent - and that's assuming the BSF is being used properly - the non-essential parameters will greatly influence the user's decision to continue using the BSF. Of course, there are other parameters to consider in behavioral change, particularly the additional labor involved. Put another way, if a person has been using the BSF properly for half a year and doesn't feel any healthier, that person will be more likely to continue using the BSF if there are other, more tangible benefits that are not essential to the improvement of his health.

The conclusion for this iron study is that all ABFs were able to produce water with non-detectable amount of iron (i.e. < 0.1 mg/L). This is favorable for the social acceptability of the ABFs because iron-free water is aesthetically pleasing to some users.

E. Coli and Total coliforms

Results of *E. Coli* and total coliform tests, analyzed using Millipore M-Coliblue24 membrane filtration method are shown in Table 36. Detailed results are in Appendix B.

Table 36 - *E. Coli* and Total Coliforms Results from Tommy Ngai and Sophie Walewijk Monitoring

Contact person	**Total Coliform by M-Coliblue24**			***E. Coli* by M-Coliblue24**		
	Raw[1] *(CFU /100mL)*	*Filtered (CFU /100mL)*	*% Removal*	*Raw (CFU /100mL)*	*Filtered (CFU /100mL)*	*% Removal*
Nirahi Chaudhary	3	0	>99	3	0	>99
Harinarayan Chaudhary	0	Decom[2]	N/A	0	Decom	N/A
Ramashankar Yadav	160	Decom	N/A	11	Decom	N/A
Harilal Yadav	340	52	85[3]	30	1	97[3]
Ramashankar Yadav	25	1	96	4	0	>99
Shivsager Yadav	0	0	N/A[4]	0	0	N/A[4]
Nim N. Chaudhary	450	49	89	60	9	85
Min N. Chaudhary	100	163	0[5]	16	0	>99
Phakir Kami	100	15	85	0	5	0
Phagu N. Chaudhary	34	42	0	1	40[6]	0
Lila B. Pun	49	47	4	4	0	>99
Bhanu Primary School	61	22	64	2	18	0
	Average =		58	*Average =*		64

Note:

1. Some of the raw water samples were analyzed at a 1:1 dilution (i.e. no dilution) and a 1:10 dilution. In those cases, the results derived from the dilution factor that gave the more accurate plate count (i.e. counts preferably between 20-80) are reported in this table.

2. Decom = Decommissioned ABF. Because no water sample could be collected for these wells, these filters are not included in the average % removal calculations.

3. Harilal Yadav's water samples were analyzed a first time on December 31, 2002 and yielded more bacteria in the filtered water than in the raw water. The results were judged doubtful, and a second analysis was performed on January 5, 2003. The new results yielded a 84.7 % removal of the total Coliforms and a 97 % removal of *E. Coli*.

4. Because the raw water and filtered water of Shivsager Yadav was free of total coliform and *E Coli*, there is no value for % removal for either indicator. The filter is not included in the average % removal calculations.

5. For those filters with a higher count in the filtered water than raw water, the % removal is assumed to be zero in the average % removal calculations.

6. The blue dots representing *E. Coli* colonies were on the extremity of the plate, making the results doubtful.

Discussion of Results

On average, the total coliform removal and *E. Coli* removal was reasonable, at 58% and 64% respectively. A possible reason for not achieving even better performance could be that the biofilm has not ripened. As a result, biological removal processes were not at work to remove the influent total coliform and *E. Coli*. Unfavorable water chemistry such as insufficient nutrient may affect the normal biofilm growth.

A second reason for the moderate performance is that the sand layer could have been disturbed by the users just before the monitoring by Tommy Ngai and Sophie Walewijk. This would have damaged the biofilm, and would have allowed bacteria to pass through the filter.

Improvements in pathogen removal can also be attained by optimizing the filter installation procedure. In a 2002 study in Lumbini by Stroller and Coan, it was found that sand preparation method for a biosand filter had a significant impact on its subsequent bacterial removal efficiency[81]. On-going research at MIT by Pincus and others seeks to clarify some of these issues[82].

It is interesting to note that the ABFs installed in Sarawal VDC performed superior to the ABFs installed in Tilakpur or Panchanager VDCs (Table 37 and Figure 43).

Table 37 - Comparing Total Coliform and *E. Coli* Average % Removal for ABFs in Different VDCs

VDC	**# of ABFs**	**Average % Total Coliform Removal**	**Average % E. Coli Removal**
Sarawal	3	93	98
Tilakpur	4	44	46
Panchanager	2	34	50

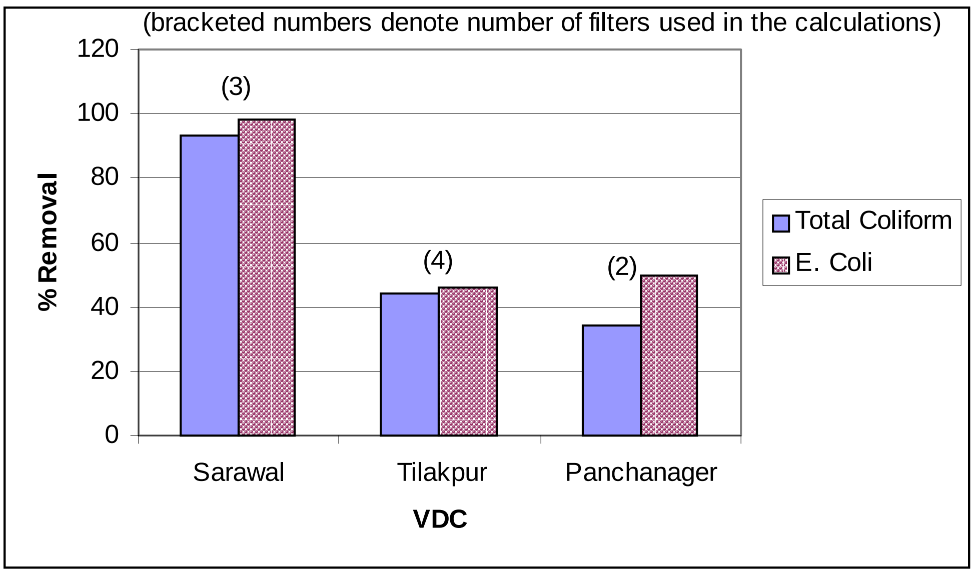

Figure 43 - Comparing Total Coliform and *E. Coli* Average % Removal for ABFs in Different VDCs

The filters in Sarawal removed an average of 93% and 98% total coliforms and *E. Coli* respectively. On the other hand, the average total coliform and *E. Coli* removal was 44% and 46% respectively in Tilakpur, and 34% and 50% respectively in Panchanager. It is speculated that discrepancy in the pathogen removal efficiencies may be attributed to the different ABF setups. The ABFs in Sarawal contained relatively less iron nails than those in Tilakpur and Panchanager. Perhaps the higher quantity of iron nails in the Tilakpur and Panchanager ABFs altered the influent water in a way (e.g. higher iron concentration) that hindered the normal biofilm ripening, or reduces the biofilm's ability to remove influent pathogens. Perhaps the higher quantity of iron nails in those ABFs resulted in more frequent filter clogging such that the users must clean the filter more frequently, leading to disturbance to the otherwise healthy biofilm layer. Table 38 compares the iron nails quantity to total coliform and *E. Coli* removal. It should be noted that the above speculations must be carefully investigated to establish any validity. The authors are unaware of any link between iron concentration in water and biofilm health. This speculative relationship is unlike the clear relationships between the presence of iron in the water and arsenic removal. Therefore it is unreasonable to calculate average total coliform and *E. Coli* removal efficiency of the ABF based only on the filters that contained 5 kg of nails. It is proposed that the calculated average total coliform and *E. Coli* removal efficiency be calculated from all filters.

Table 38 - Comparing Iron Nails Quantity to Total Coliform and *E. Coli* % Removal

Iron nails quantity (kg)	**# of ABFs**	**Total Coliform and *E. Coli* by M-Coliblue24**	
		Average % Total Coliform Removal	***Average % E. Coli Removal***
0	2	87	91
1.25	2	98	99
5	5	31	40

Another explanation for the significantly different pathogen removal efficiency between the filters in Sarawal and those in Tilakpur and Panchanager is because of different water composition. The water chemistry at Sarawal may be more favorable for coliform removal than the water at Tilakpur and Panchanager. For example, microorganism attachment to sand particles is pH dependent[83]. It should be noted that Tilakpur and Panchanager are next to each other, while Sarawal is about 10 km to the south of Panchanager. Due to the proximity between Tilakpur and Panchanager, the groundwater chemistry between these two VDCs may be more similar to each other than the groundwater from Sarawal. This may explain the equally poor performance from Tilakpur and Panchanager. However, without further investigation on the local groundwater characteristics disparity, this above explanation cannot be supported.

It should be noted that pathogen removal results can be easily tampered by inappropriate water handling practices. For example, the filter outlet can be easily contaminated if a kid touches it with his/her dirty hand. In this case, the filtered water sample may show high bacteria counts (i.e. low removal efficiency) even though the filter itself may have excellent pathogen removal efficiency. Therefore, user education on basic health and hygiene is crucial to the proper use of the filter to bring improved health benefits.

The conclusion for the pathogen monitoring by Tommy Ngai and Sophie Walewijk is that the ABFs removed a reasonable percent of total coliform (58%) and *E. Coli* (64%). The three ABFs in Sarawal VDC had far superior removal efficiency than those in Tilakpur and Panchanager VDCs.

Flow rate

Flow rate results are shown in Table 39.

Table 39 - Estimated Maximum Flow Rate for Each Filter

Contact person	**Flow rate (L/hr)**	**Flow rate measured when diffuser was**	**Calculated max flow rate when full (L/hr)**
Nirahi Psd. Chaudhary	14	3/4 full	19
Harinarayan Chaudhary	Decom[1]	N/A	N/A
Chintamani Chaudhary	Decom	N/A	N/A
Ramashankar Yadav	Decom	N/A	N/A
Harilal Yadav	23	3/4 full	31
Ramashankar Yadav	Not measured	N/A	N/A
Shivsager Yadav	24	1/2 full	48
Nar Bir Gurung	13	1/3 full	39
Durga Kumari	28	Completely full	28
Tek B. Hamal	4	1/3 full	12
Nim Chaudhary	11	1/3 full	33
Min Chaudhary	8	1/3 full	24
Phakir Kami	9	1/3 full	27
Phagu N. Chaudhary	7	1/3 full	21
Lila B. Pun	20	1/2 full	40
Bhanu Primary School	9	1/3 full	27
Average=	14		29

Note:
1. Decom = Decommissioned filters. Because no flow rate could be measured, these filters are excluded in the calculations of average flow rate.

2. The diffuser box can hold about 20 L of water.

Discussion of Results

Darcy's Law governs the flow rate of the filter. That is, the filter flow rate is proportional to the water level above the outlet pipe. The higher the water level, the higher the hydraulic head, which leads to higher Darcy flux through the sand, which in turn means higher flow rate[84]. In the ABF design, the hydraulic head above the outlet pipe can be roughly approximated by the water level in the diffuser box. Therefore, under identical conditions, an ABF with a full diffuser box will have a flow rate three times higher than a ABF with a diffuser box 1/3 full. Table 39 shows the estimated maximum flow rate for each ABF from flow rate measurements, and assuming a full diffuser box.

In general, the ABFs have high flow rates. If we assume the flow rate measurements taken during the actual site visit represent the actual conditions under normal use, then the average flow rates experienced by the users would ranged from 4 L/hr to 28 L/hr, with an average of 14 L/hr. However, some users may realize that a higher flow rate could be achieved by filling up the diffuser to the top with water. This would correspond to the calculated maximum flow conditions. The calculated maximum flow rates ranged from 12 L/hr to 48 L/hr, with an average maximum flow rate of 29 L/hr.

High flow rates are desirable for many reasons. First, a filter with a high flow rate provides sufficient water for a large household. According to RWSSSP's household survey data, many of the above households receiving ABFs have up to 15 people per household (See Appendix B). Second, users do not need to wait a long time before obtaining safe drinking water. When the flow rate is excessively low, say less than 1 L/hr, the users have a tendency to skip filtration[85]. Finally, if the flow rate is high enough to support more than one family, then the cost of the filter can be shared among several households.

A 2003 study by the World Health Organization (WHO) concluded that a minimum of 7.5 L of safe water per capita per day is necessary to meet basic consumption and basic hygiene needs[86]. Consider a large household of 15 members sharing one ABF. The minimum daily needs according to WHO is 7.5 X 15 = 112.5 L. To meet this need, a filter must be able to deliver 9.4 L/hr of water for 12 hours daily. Comparing this figure with the values obtained in Table 39. It is found that most of the above ABFs are able to deliver at least 9.4 L/hr under normal use conditions, thus sufficient to supply for the entire family of 15. Moreover, if the users fill up the diffuser box beyond the normal use level (typically between 1/3 to 1/2 full), then even higher flow rates can be obtained. It should be noted at none of the above ABFs has a calculated maximum flow rate less than 9.4 L/hr. Therefore, all of the ABFs should be capable of providing sufficient amount of safe water for a large family, satisfying the minimum WHO recommendations.

During Tommy Ngai and Sophie Walewijk's site visit in December, they talked to the ABF users to learn about the users' perception on the filter clogging issue. Of the 12 ABFs monitored, only a few had been cleaned by the users because of low flow rates. This suggests that most of the ABFs continued to deliver sufficient water quantity after three months of operation. When the users were asked to demonstrate the cleaning/maintenance technique, the users were often able to accurately perform the operations.

From the laboratory experiments results shown in Table 7, the flow rate decreased with respect to volume of raw water treated. When those results are compared to the flow rates shown in Table 39, it is revealed that the rate of flow rate decrease is less severe during the pilot study than during the laboratory experiments. For example, if we linearly extrapolate the decrease in the maximum flow rate for arrangement #3 over the duration of the pilot study, then the maximum flow rate after three months would drop to merely 0.13 L/hr. Fortunately, the lowest measured flow rate was 12 L/hr, not 0.13 L/hr, and the user confirmed that the ABF had never been cleaned since installation. Therefore, this pilot study shows that extrapolation of the flow rate trends from the laboratory experiments might underestimate the actual flow rate. This result is encouraging because it shows that clogging is not as serious a problem as initially predicted.

Based on the flow rates study, it is concluded that most of the ABFs is capable of providing sufficient quantity of water for a household of 15 members, based on the latest WHO research study recommendation of 7.5 L/capita/day. The average flow rate under normal conditions is 14 L/hr. Higher flow rate may possible if the users fill up the diffuser to the top with water. The calculated average maximum flow rate is 29 L/hr. In addition, clogging of the filter is not a serious problem.

3-Kolshi Filters - Arsenic and Flowrate Results

Arsenic and flow rate results of the three operational 3-Kolshi filters are shown in Table 40. The other two 3-Kolshi filters observed were damaged during the visit.

Table 40 - Arsenic, Iron, and Flow Rate Results for 3-Kolshi Filters from Tommy Ngai and Sophie Walewijk Monitoring

Contact person	**Arsenic by ITS Kit**			**Iron by HACH Kit**			**Flow rate (L/hr)**
	Raw (μg/L)	*Filtered (μg/L)*	*% removal*	*Raw (mg/L)*	*Filtered (mg/L)*	*% removal*	
Aitwari Chaudhary	40	ND	>88	1.0	ND	>90	3
Sukhal Chaudhary	40	ND	>88	1.0	ND	>90	0.3
Jhinhu Chaudhary	40	15	65	1.0	ND	>90	3
	Average=		80			>90	2.1

Note: All three households use the same well
ND = Non-Detect =< 5 μg/L As or =<0.1 mg/L Fe

Discussion of Results

The arsenic removal was good, with an average of 80% removal*. Iron removal was also good, with an average of 90% removal. According to RWSSSP, the price is also good, at

* The 80% removal efficiency may seem low. The filter may be able to remove a higher percentage of arsenic. However, we cannot verify this because the inlet arsenic concentration (40 μg/L) is too low, approaching the detection limit of the test kit.

about 400 Nepali Rupees (approx. US$ 5.1). However, before recommending this filter for implementation, other issues such as durability and social acceptability should be considered. For example, RWSSSP installed five 3-Kolshi filters in this remote village approximately six months prior to the visit by Tommy Ngai and Sophie Walewijk. Of the original five filters, two were damaged, thus not in use. One was leaking from a crack, and had not been repaired. The other filter had the inlet water flowing straight through the filter media without any restriction, resulting in water not treated at all. The observations suggest that 3-Kolshi filters are fragile. To ensure that the users in remote villages can continue to drink filtered water when their filters are damaged, either the users should be taught how to repair a broken filter, or new kolshis should be available at nearby markets.

Another major drawback of the 3-Kolshi filters is the low flow rate. Two of the filters treated water at 3 L/hr, and the third filter treated water at only 0.3 L/hr. For example, if the WHO's recommendation of 7.5 L/capita/day is to be met for a family of 15 people, then 7.5 X 15 = 112.5 L/day is required. However, a filter with a flow rate of 3 L/hr can only deliver a maximum of 72 L per day even if operated continuously for 24 hours a day. Therefore the 3-Kolshi filter is unable to meet the basic consumption and hygiene needs to protect health according to WHO[87]. Moreover, the filter at 0.3 L/hr operated at 24 hours a day can only produce 7.2 L/day. This is not even enough for one person. The users indicated that flow rate is indeed a major problem. They wanted to have a second, or even a third filter to cover their water needs. In comparison, the ABF has an average of 14 L/hr flow rate.

7.2.4 ABF Modification and New Design

Based on the lessons learned from the pilot study monitoring, as well as feedback from ENPHO, RWSSSP staffs and users, the new design for ABF was completed by Tommy Ngai and Sophie Walewijk on January 3, 2003. The new design contained 5 kg of the high quality shoe tack iron nails, and no brick chips. Refer to Section 4.1 Figure 3 for a diagram on the new design.

All ABFs were immediately upgraded in Sarawal to the new setup on January 4. Due to insufficient time, total arsenic was tested for only two of the upgraded setups (Table 41), and for the three reinstalled filters (Table 42). All arsenic results were based on analysis by Tommy Ngai performed in Jan 2003.

Table 41 - Arsenic Removal Improvement from Pre-upgraded to Upgraded Design

Contact person	**Arsenic by ITS Kit**					
	Pre-upgraded			**Upgraded**		
	Raw ($\mu g/L$)	*Filtered ($\mu g/L$)*	*% removal*	*Raw ($\mu g/L$)*	*Filtered ($\mu g/L$)*	*% removal*
Nirahi Psd. Chaudhary	350	80	77	75	6	92
Ramashankar Yadav	400	30	93	200	8	96
	Average=		85	*Average=*		94

Table 42 - Arsenic Removal Improvement after Re-installation

Contact person	**Arsenic by ITS Kit**		
	Re-installed		
	Raw ($\mu g/L$)	*Filtered ($\mu g/L$)*	*% removal*
Harinarayan Chaudhary	400	80	80
Chintamani Chaudhary	350	40	89
Ramashnkar Yadav	700	50	93
	Average=		87

Discussion of Results

An arsenic removal comparison between the pre-upgraded filters and the upgraded filters shows that the additional iron nails contributed to immediate additional arsenic removal. For Nirahi Chaudhary, the arsenic removal efficiency increased from 77% to 92%. For Ramashnkar Yadav, the arsenic removal efficiency increased from 93% to 96%. Although no arsenic test was performed on the other ABFs, it is anticipated that all other ABFs would experienced an increase in arsenic removal efficiency as well.

The arsenic removal efficiency of the three re-installed filters seems promising. The three filters shown in Table 42 had been decommissioned by RWSSSP in mid-December due to unacceptable arsenic removal capability. For the three filters, the new design yielded an average arsenic removal efficiency of 87%.

7.2.5 Education Workshop Observations

During the monitoring visits, Tommy Ngai and Sophie Walewijk found that some villagers have misconceptions on drinking water and health. For example, one user indicated that drinking clean-looking filtered water, as opposed to his discolored raw tubewell water (high iron), can turn his skin whiter, which is highly desirable from the Nepali's perspective on beauty. In addition, a social acceptability study of three different arsenic technologies (i.e. ABF, 3-Kolshi, 2-Kolshi) conducted by George Tabbal[88] in Nepal in 2003 indicated that villagers in general know what arsenic is, but do not make the link between arsenic and its effects on their personal health. It is therefore very important to educate people about arsenic, its health effects, and its removal from the water they drink.

Forty-five adult villagers (both men and women) attended the education workshop conducted by RWSSSP, ENPHO, and Tommy Ngai's team on January 3, 2003. The attendees asked very pertinent questions. Lots of children were also present. One of the main questions asked was why RWSSSP only installed seven filters in the village if arsenic is such a health threat.

During the educational workshop and the monitoring visits, Tommy Ngai and Sophie Walewijk observed that the villagers take good care of their filters and generally follow the distributed operating and cleaning instructions. Written instructions in Nepali - prepared by Tommy Ngai, Sophie Walewijk and translated by RWSSSP - were distributed to the villagers during the education workshop. (Refer to Appendix D for a copy of the written instructions)

Most users like the high flow rate, simple operation, minimal maintenance, as well as the clean-looking and good-tasting water coming out of the filters. They think the filter is a durable, permanent solution to their drinking water problems.

7.2.6 Summary of the Pilot Study Results

Important insights into the ABF performance were learned from the pilot study. The most important findings are restated here:

- 5 kg of iron nails is the recommended amount to be used in the metal diffuser box. Less nails may result in poorer arsenic removal performance, more nails may make the box too heavy to handle. The iron nails should be tested to ensure they do not leach out harmful substances to the water.
- Results based on ABFs with 5 kg of iron (Table 34) show an arsenic removal of 93%.
- Average results based on all ABFs show total coliform removal at 58% (Table 36), *E. Coli* removal at 64% (Table 36), iron removal at >93% (Table 35), and flow rate at 14 L/hr (Table 39). A longer study is recommended to confirm these values.
- The main arsenic removal mechanism appears to be arsenic adsorption to ferric hydroxide particles. The arsenic adsorption capacity of the iron nails should be investigated to determine the frequency of iron nails replacement.
- High iron concentration in raw water is beneficial as it may aid arsenic removal.
- Bacteria removal efficiency can be improved by further investigating optimal sand preparation, installation, operation, and cleaning methods.
- The clean-looking and good-tasting filtered water resulting from an effective iron removal is appealing to many users. While health improvements may take months or years to appear, these favorable "observable" water qualities (e.g. clarity, color, taste) may promote quick acceptance of the filter.
- Most users like the high flow rate, simple operation, and minimal maintenance of the filter. They think the filter is a durable, permanent solution to their drinking water problems.
- The clogging problem seems less severe than suggested by the laboratory study. Even after three month without any cleaning, flow rate was still reasonably high (Table 39) to supply sufficient quantity of water for a large family, according to a recent WHO study on minimum water needs to stay healthy.

- Although the 3-Kolshi filters have good arsenic and iron removal (Table 40), it is observed that inadequate flow rate is a serious drawback. The durability and social acceptability of the filter are other issues to consider.

8. CONCLUSIONS

The Arsenic Biosand Filter Project make a positive contribution to the growing body of knowledge on appropriate household scale arsenic removal filters in Nepal. The ABF is one of only three types of household arsenic removal filters tested at a pilot scale in Nepal to date.

Results from the three-month pilot study are encouraging. The average arsenic removal for the ABFs containing 5 kg iron nails is 93%. Total coliform and *E. Coli* removal for all filters are reasonable at 58% and 64% respectively. Iron removal is excellent at >93%. Flow rate is very high at 14 L/hr. These results are tabulated in Table 43.

Table 43 - Summary Technical Performance of ABF Pilot Study

Technical Indicator	**Range**	**Average Results**
Arsenic removal	87 to 96%	93%
Total coliform removal	0 to >99%	58%
E. Coli removal	0 to >99%	64%
Iron removal	>90 to > 99%	>93%
Flow rate	4 to 23 L/hr	14 L/hr

Regarding social acceptability, people like the high flow rate, simple operation, and minimal maintenance of the filter. In addition, the clean-looking and good-tasting filtered water is appealing. While health improvements may take months or years to appear, these favorable “observable” water qualities (e.g. clarity, color, taste) may promote quick acceptance of the filter. Most users think of the ABF as a very durable and appropriate solution to arsenic and pathogens contamination.

9. FUTURE WORK AND RECOMMENDATIONS

The major development stage of the ABF is completed. Several steps are proposed for the future. They are divided into four categories – filter performance, filter cost, implementation, and project effectiveness evaluation.

Filter Performance

It is recommended to:

- Monitor the arsenic removal of the new ABF design for another six months to evaluate the arsenic adsorption capacity of 5 kg iron nails in order to determine the appropriate iron nails replacement frequency.
- Test the arsenic adsorption capacity of different types of iron nails to determine the best irons in terms of cost and performance.
- Test the composition of iron nails to ensure that no harmful substances will leach out from the nails into the water.
- Investigate the effect on arsenic and bacterial removal if the space between the top of the stationary water level within the filter and the bottom of the diffuser box is reduced.*
- Investigate the possibility of adding a diffuser plate above the iron nails to protect the nails from dispersion due to the force of the incoming water.
- Monitor the bacterial removal of the new ABF design, and study the effect of iron nails on bacterial performance.

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* Currently, the volume between the stationary water level within the filter and the bottom of the diffuser box is up to 5 L. Coincidentally, it was observed that most users pour about 5-10 L of water into the filter during each use. The influent water usually passes through the iron nails bed quickly, and accumulates in this 5 L space. It is because the resistance to water flow through the iron nails bed is much less than the resistance to water flow through the fine sand layer below. If the space (volume) between the sand layer and diffuser box is reduced, then a greater portion of the incoming 5-10 L water will remain in the diffuser box, instead of accumulating in the space below. This will increase the contact time between the influent water and the iron nails, and may improve arsenic removal.

Secondly, if the space (distance) between the sand layer and diffuser box is reduced, then the disturbance to the sand layer (and possibly the bio-film) from the falling force of the incoming water may be reduced.

- Study the effect of sand preparation methods on bacterial performance to determine the optimal methods.

Filter Cost Reduction

Modifications of the filter design may reduce the filter construction cost. Possible modifications include:

- Use cheaper iron nails (technical performance should be evaluated)
- Build the filter casing using plastic or fiber-glass, instead of concrete
- Use a plastic bucket to hold the nails, instead of a metal box.
- Teach the users how to build a filter in their homes, using bricks to construct the filter casing.

Implementation

Some aspects to consider are:

- Cost recovery: What is users' ability and willingness to pay? Which agency will be responsible for collection of payment? How to minimize subsidies? What will be the funding sources?
- Manufacturing options: What is the optimal option to produce the ABF, in terms of materials, location and production process?
- Can we reduce implementation cost by setting up filter training workshops at village level to teach the villagers how to construct an ABF using materials available to them? How much flexibility is there in terms of choice of construction materials?
- Under which social and geologic circumstances is providing an ABF necessary. This can be answered by conducting a health-based study modeled after the WHO health-based targets[89].

Project Evaluation

The effectiveness of the project implementation should be measured frequently in order to assess current progress and to guide future directions. Recommendations include:

- Conduct a health survey pre- and post- filter implementation to evaluate the effectiveness of the filters in improving the users' health. Health indicators may include diarrheal prevalence rate, and arsenic concentration in hair and nail samples.
- Investigate the long-term usage rate of the filters. Results may be used to make further design improvements to improve the filter's social acceptability. This investigation may carried similarly to the social acceptability studies conducted by Tabbal[90] and Paynter[91].

Access to adequate safe drinking water is a basic human right[92]. It is not a privilege available only to a selected few. Instead, it should be accessible to every single person on our planet. Safe drinking water not only improves health, but also aids the social and economic development of a society. Every effort should be taken to protect this right.

10. TEAM MEMBERS BIOGRAPHY

Tommy Ngai received a Master of Engineering degree from the Massachusetts Institute of Technology Civil and Environmental Engineering Department. He is currently a lecturer at MIT, assisting students of the MIT Nepal Water Project to conduct research. He traveled to Nepal in January 2002 to study the arsenic contamination situation, and to field test an arsenic removal technology. He returned to Nepal two more times to carry out his ABF project. His interest in searching for a practical solution for the arsenic problem began with his undergraduate project on arsenic removal in Bangladeshi groundwater. He is well informed of various existing arsenic treatment technologies including their strengths/weaknesses.

Sophie Walewijk is currently pursuing a Ph.D. at Stanford University, where she received a Master of Engineering degree in Civil and Environmental Engineering. Her interest in finding a practical solution for the arsenic problem in rural areas of developing countries began with her undergraduate project on arsenic removal from Bangladeshi groundwater. Since then, she attended talks and conferences on arsenic. At the same time, she focused her research on bacteria. Sophie performed preliminary experiments on the BioSand Filter at Stanford, and traveled to Nepal in December 2002 -January 2003 to study the bacterial removal capacity of the ABF.

Appendices

APPENDIX A - DESCRIPTION OF PARTNER ORGANIZATIONS

The following organizations have kindly contributed to the Arsenic Biosand Filter Project.

1. Department of Civil and Environmental Engineering, Massachusetts Institute of Technology (MIT)

Description:

The MIT Nepal Water Project was initiated by the Master of Engineering Program of the Civil and Environmental Engineering Department in 1999. The main objectives of this project are to increase awareness of water quality problems in Nepal, and to provide assistance in solving these problems.

Address:

77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA

Contact Person:

Susan Murcott, Lecturer and Principal Investigator of the MIT Nepal Water Project
Phone number: 617-452-3442 Email: murcott@mit.edu

2. Rural Water Supply and Sanitation Support Programme (RWSSSP)

Description:

RWSSSP is a programme that is run by a consultant, Plancenter Ltd, in cooperation with the government of Nepal and the government of Finland. Since its initiation in 1990, RWSSSP is working in eight districts, including six in Lumbini Zone plus Parbat and Tanahun districts. RWSSSP is currently headquartered in Butwal.

Address:

Rural Water Supply and Sanitation Support Programme Nepal
G.P.O. Box 12, Butwal
Nepal

Contact Person:

Heimo Ojanen, Team Leader
Phone: +977-71-540782, +977-71-540513, +977-71-546572
Email: heimoojanen@wlink.com.np

3. Environment and Public Health Organization (ENPHO)

Description:

ENPHO is an independent research laboratory and research institute established in Kathmandu in 1990. Their main objectives are to conduct research on public health, water, wastewater, soil, air and sound pollution; to disseminate research findings through public media; and to develop and promote appropriate technologies on water and wastewater treatment, solid waste management, and air emission control.

Address:

Environment and Public Health Organization
Thapagaon, New Baneshwor,
Kathmandu, Nepal

Contact Person:

Roshan Shrestha, Executive Chairperson
Phone: +977-1-491052, +977-1-491376, +977-1-493188
Email: rshrestha@mos.com.np, enpho@mail.com.np

4. International Buddhist Society (IBS)

Description:

IBS is a non-governmental organization (NGO) established in Lumbini, Nepal to provide health assistance to 19 surrounding villages. Besides distributing biosand filters to the villagers, IBS also conduct health education workshops for the rural population, as well as operating a free health clinic.

Address:

International Buddhist Society
Buddha Nagar, Lumbini, Nepal

Contact Person:

Bhikkhu Maitri, Founder Chairman
Phone: +977-71-80133
Email: maitribs@mail.com.np, matri_btw@wlink.com.np

APPENDIX B - MASTER DATA SET OF ALL PILOT STUDY ARSENIC BIOSAND FILTERS

This appendix includes data for each of the pilot study ABFs visited by Tommy Ngai's team. There are 16 ABFs in total (10 installed by Tommy Ngai + 6 installed by ENPHO). In addition, data for three 3-Kolshi filters is included at the end.

Arsenic Biosand Filter #1

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Nirahi Psd. Chaudhary 2528 16
Installation date Installed by Iron nails given	Sep 30, 2002 Tommy Ngai and RWSSSP (Umesh Sharma) 1.25 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	350	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	20 186	ND ND	> 75 > 97	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	200	ND	> 98	ENPHO kit
Nov 14, 02	RWSSSP	363	5	99	ENPHO lab
Nov 29, 02	RWSSSP	10	ND	> 50	ENPHO kit
Dec 16, 02	RWSSSP	300 213	ND 30	> 98 86	ENPHO kit ENPHO lab
Dec 31, 02	Tommy	350	80	77	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	75	6	92	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.4	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	1.4	ND	93	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	A	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	A	P	No	ENPHO P/A
Nov 29, 02	RWSSSP	Not tested	P	No	ENPHO P/A
Dec 16, 02	RWSSSP	A	A	N/A	ENPHO P/A
Dec 31, 02	Sophie	3 TC 3 EC	0 TC 0 EC	> 99% > 99%	M-Coliblue24 M-Coliblue24

Notes:

P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	14	3/4 full	19

Notes:

Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

The user indicated that his filter was cleaned once every month, in order to improve the flow rate. The last cleaning was on Dec 21, 02.

Arsenic Biosand Filter #2

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Harinarayan Chaudhary 2529 20
Installation date Installed by Iron nails given	Sep 30, 2002 Tommy Ngai and RWSSSP (Umesh Sharma and Tula Bhattrai) 1.25 kg
Decommission date Decommissioned by	mid Dec 2002 RWSSSP
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	400	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	60 237	ND 7	>92 97	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	250	100	60	ENPHO kit
Nov 14, 02	RWSSSP	401	140	65	ENPHO lab
Nov 29, 02	RWSSSP	320	80	75	ENPHO kit
Dec 16, 02	RWSSSP	350 372	200 137	43 63	ENPHO kit ENPHO lab
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	400	80	80	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.3	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	A	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	A	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	A	A	N/A	ENPHO P/A
Dec 31, 02	Sophie	0 TC 0 EC	Decommissioned Decommissioned	N/A N/A	M-Coliblue24 M-Coliblue24

Notes:

P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	Decommissioned	N/A	N/A

Notes:

Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Arsenic Biosand Filter #3

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Chintamani Chaudhary 2530 20
Installation date Installed by Iron nails given	Sep 30, 2002 Tommy Ngai and RWSSSP (Tula Bhattrai) 0 kg
Decommission date Decommissioned by	mid Dec 2002 RWSSSP
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	350	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	90 156	N/D 24	>94 85	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	250	150	40	ENPHO kit
Nov 14, 02	RWSSSP	456	227	50	ENPHO lab
Nov 29, 02	RWSSSP	350	70	80	ENPHO kit
Dec 16, 02	RWSSSP	400 288	400 207	0 28	ENPHO kit ENPHO lab
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	350	40	89	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.6	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	A	P	No	ENPHO P/A
Dec 31, 02	Sophie	N/A	Decommissioned	N/A	M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	Decommissioned	N/A	N/A

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Arsenic Biosand Filter #4

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Ramashankar Yadav 2531 12
Installation date Installed by Iron nails given	Sep 30, 2002 Tommy Ngai 2.5 kg
Decommission date Decommissioned by	mid Dec 2002 RWSSSP
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	500	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	70 298	ND ND	>93 >98	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	350	150	57	ENPHO kit
Nov 14, 02	RWSSSP	616	160	74	ENPHO lab
Nov 29, 02	RWSSSP	180	60	67	ENPHO kit
Dec 16, 02	RWSSSP	450	350	22	ENPHO kit
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	700	50	93	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.5	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	N/A	Decommissioned	N/A	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	A	A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	P	P	No	ENPHO P/A
Dec 31, 02	Sophie	160 TC (1:10) 286 TC 0 EC (1:10) 11 EC	Decommissioned Decommissioned Decommissioned Decommissioned	N/A N/A N/A N/A	M-Coliblue24 M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
(1:10) = one in ten dilution

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	Decommissioned	N/A	N/A

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Ramashankar Yadav has two houses, and collects water from two different wells.

Arsenic Biosand Filter #5

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Harilal Yadav 2532 15
Installation date Installed by Iron nails given	Oct 1, 2002 RWSSSP (Devi Wagle) 0 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	250	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	60 67	ND ND	>92 >93	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	200	ND	98	ENPHO kit
Nov 14, 02	RWSSSP	272	9	97	ENPHO lab
Nov 29, 02	RWSSSP	320	10	97	ENPHO kit
Dec 16, 02	RWSSSP	Harilal Yadav stopped using the filter because he claimed that the filter did not remove arsenic			ENPHO kit
		N/A	N/A	N/A	ENPHO lab
Dec 31, 02	Tommy	250	300	88	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	N/A	N/A	N/A	N/A

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	2.3	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	2.3	ND	96	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	A	A	N/A	ENPHO P/A
Dec 31, 02	Sophie	340 TC (1:10)* TNTC TC 30 EC	N/A 52 TC* 1 EC	85% 97%	M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:

P	= Presence of H_2S bacteria
A	= Absence of H_2S bacteria
ENPHO P/A	= ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24	= Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC	= Total Coliform
EC	= *E. Coli*
TNTC	= to numerous to count, >250 CFU/100mL
(1:10)	= one in ten dilution
*	= used to calculate % removal

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	23	3/4 full	31

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Harilal Yadav indicated that his filter's flow rate has been very high since installation, therefore there was never a need to clean the filter.

Arsenic Biosand Filter #6

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Ramashankar Yadav 3347 12
Installation date Installed by Iron nails given	Oct 1, 2002 Tommy Ngai 1.25 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	N/A N/A N/A

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	400	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	20 163	ND ND	>75 97	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	200	ND	>98	ENPHO kit
Nov 14, 02	RWSSSP	0.451	ND	99	ENPHO lab
Nov 29, 02	RWSSSP	0.01	ND	>50	ENPHO kit
Dec 16, 02	RWSSSP	300 377	ND 24	>98 94	ENPHO kit ENPHO lab
Dec 31, 02	Tommy	400	30	93	ITS
Jan 4, 03	Tommy	200	8	96	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.4	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	1.4	ND	93	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	A	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	A	P	No	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	A	A	N/A	ENPHO P/A
Dec 31, 02	Sophie	25 TC 4 EC	1 TC 0 EC	>96% >99%	M-Coliblue24 M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
TNTC = to numerous to count, >250 CFU/100mL
(1:10) = one in ten dilution

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	Not measured	N/A	N/A

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Ramashankar Yadav has two houses, and collects water from two different wells.

Arsenic Biosand Filter #7

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Sarawal Goini
Contact person RWSSSP sample number Number of people in this household	Shivsager Yadav N/A No information
Installation date Installed by Iron nails given	Oct 1, 2002 RWSSSP (Umesh Sharma) 2.5 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	Jan 4, 2003 Tommy Ngai and RWSSSP 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 29, 02	Tommy	900	Pre-installation	N/A	ITS
Dec 31, 02	Tommy	900	ND	>99	ITS
Jan 4, 03	Filter upgraded: iron nails increased to 5 kg, brick chips removed				
Jan 4, 03	Tommy	N/A	N/A	N/A	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check^{TM} Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 29, 02	Tommy	1.4	Pre-installation	N/A	HACH
Dec 31, 02	Tommy	1.4	ND	93	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Dec 31, 02	Sophie	0 TC 0 EC	0 TC 0 EC	N/A N/A	M-Coliblue24 M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 31, 02	Tommy + Sophie	24	½ full	48

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Because this family is new to the village, they are not covered under RWSSSP's responsibility. Therefore, neither arsenic nor bacteria monitoring by RWSSSP was performed at this ABF.

Arsenic Biosand Filter #8

Filter Information:

District Village development committee (VDC) Village	Rupandehi Devdaha Mandangram
Contact person RWSSSP sample number Number of people in this household	Nir B. Gurung N/A 10
Installation date Installed by Iron nails given	Oct 2, 2002 RWSSSP (Devi Wagle) 1.25 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	N/A N/A N/A

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 23, 02	Tommy	850	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	150 N/A	ND N/A	>97 N/A	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	250	ND	>98	ENPHO kit
Nov 14, 02	RWSSSP	848	9	99	ENPHO lab
Nov 29, 02	RWSSSP	>500	ND	>99	ENPHO kit
Dec 16, 02	RWSSSP	>500 936	ND 12	>99 99	ENPHO kit ENPHO lab
Dec 30, 02	Tommy	700	300	57	ITS
Jan 03	Tommy	N/A	N/A	N/A	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 23, 02	Tommy	1.3	Pre-installation	N/A	HACH
Dec 30, 02	Tommy	1.3	ND	92	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	A	Yes	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	N/A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	P	A	Yes	ENPHO P/A
Dec 30, 02	Sophie	Not sampled	N/A	N/A	M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 30, 02	Tommy + Sophie	13	1/3 full	39

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Nir B. Gurung's tubewell contains one of the highest arsenic concentration of all wells under RWSSSP's project area.
This tubewell is shared by three families (Nir B. Gurung, Durga Kumari, and Tek B. Hamal).

Arsenic Biosand Filter #9

Filter Information:

District Village development committee (VDC) Village	Rupandehi Devdaha Mandangram
Contact person RWSSSP sample number Number of people in this household	Durga Kumari N/A No information
Installation date Installed by Iron nails given	Oct 2, 2002 RWSSSP (Umesh Sharma) 1.25 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	N/A N/A N/A

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 23, 02	Tommy	860	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	150 N/A	ND N/A	>97 N/A	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	250	ND	>98	ENPHO kit
Nov 14, 02	RWSSSP	848	ND	>99	ENPHO lab
Nov 29, 02	RWSSSP	>500	ND	>99	ENPHO kit
Dec 16, 02	RWSSSP	>500 N/A	ND N/A	>99 N/A	ENPHO kit ENPHO lab
Dec 30, 02	Tommy	700	30	96	ITS
Jan 03	Tommy	N/A	N/A	N/A	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check^{TM} Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 23, 02	Tommy	1.3	Pre-installation	N/A	HACH
Dec 30, 02	Tommy	1.3	ND	92	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	P	A	Yes	ENPHO P/A
Dec 30, 02	Sophie	Not sampled	N/A	N/A	M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 30, 02	Tommy + Sophie	28	Full	28

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

This family collects water from Nir B. Gurung's tubewell.
Nir B. Gurung's tubewell contains one of the highest arsenic concentration of all wells under RWSSSP's project area.

Arsenic Biosand Filter #10

Filter Information:

District Village development committee (VDC) Village	Rupandehi Devdaha Mandangram
Contact person RWSSSP sample number Number of people in this household	Tek B. Hamal N/A No information
Installation date Installed by Iron nails given	Oct 2, 2002 Tommy Ngai 1.25 kg
Decommission date Decommissioned by	N/A N/A
Re-installation/ Upgrade date Re-installed/ Upgrade by Iron nails given	N/A N/A N/A

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Sep 23, 02	Tommy	860	Pre-installation	N/A	ITS
Oct 3, 02	RWSSSP	150 N/A	ND N/A	>97 N/A	ENPHO kit ENPHO lab
Oct 20, 02	RWSSSP	250	ND	>98	ENPHO kit
Nov 14, 02	RWSSSP	848	ND	>99	ENPHO lab
Nov 29, 02	RWSSSP	>500	ND	>99	ENPHO kit
Dec 16, 02	RWSSSP	>500 N/A	ND N/A	>99 N/A	ENPHO kit ENPHO lab
Dec 30, 02	Tommy	700	ND	>99	ITS
Jan 03	Tommy	N/A	N/A	N/A	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO kit = ENPHO New Arsenic Field Test Kit, analyzed by RWSSSP technical staffs
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Sep 23, 02	Tommy	1.3	Pre-installation	N/A	HACH
Dec 30, 02	Tommy	1.3	ND	92	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Oct 3, 02	RWSSSP	P	P	No	ENPHO P/A
Nov 14, 02	RWSSSP	N/A	A	N/A	ENPHO P/A
Nov 29, 02	RWSSSP	N/A	P	N/A	ENPHO P/A
Dec 16, 02	RWSSSP	P	A	Yes	ENPHO P/A
Dec 30, 02	Sophie	Not sampled	N/A	N/A	M-Coliblue24

Notes:
P = Presence of H_2S bacteria
A = Absence of H_2S bacteria
ENPHO P/A = ENPHO H_2S Bacteria Presence Absence Test
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Dec 30, 02	Tommy + Sophie	4	1/3 full	12

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

This family collects water from Nir B. Gurung's tubewell.
Nir B. Gurung's tubewell contains one of the highest arsenic concentration of all wells under RWSSSP's project area.

Arsenic Biosand Filter #11

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Tilakpur Patkhauli
Contact person RWSSSP sample number Number of people in this household	Nim N. Chaudhary N/A No information
Installation date Installed by Iron nails given	Oct 30, 2002 ENPHO 0 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Early Dec 02	ENPHO	78	3	96	ENPHO lab
Jan 3, 03	Tommy	20	ND	>75 *	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable
* = The % arsenic removal is likely to be higher than 75%, but this can only be confirmed using an arsenic test with a lower detection limit.

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	3.8	ND	97	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Jan 3, 03	Sophie	450 TC (1:10)* 135 TC 60 EC (1:10)* 0 EC	N/A 49 TC* N/A 9*	89% 85% 	M-Coliblue24 M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
(1:10) = one in ten dilution
* = used to calculate % removal

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	11	1/3 full	33

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

According to ENPHO, the influent contains high iron concentration (about 7-8 mg/L). ENPHO decided not to give any iron nails to this filter.

Arsenic Biosand Filter #12

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Tilakpur Patkhauli
Contact person RWSSSP sample number Number of people in this household	Min N. Chaudhary N/A No information
Installation date Installed by Iron nails given	Oct 30, 2002 ENPHO 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Early Dec 02	ENPHO	241	6	98	ENPHO lab
Jan 3, 03	Tommy	160	15	91	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	1.1	ND	91	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Jan 3, 03	Sophie	100 TC (1:10)* 38 TC 10 EC (1:10) 16 EC	N/A 163* N/A 0	0% >99%	M-Coliblue24 M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
(1:10) = one in ten dilution
* = used to calculate % removal

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	8	1/3 full	24

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

Min Chaudhary indicated that the ABF was last cleaned on Nov 19, 2002 because of low flow rate.

Arsenic Biosand Filter #13

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Tilakpur Patkhauli
Contact person RWSSSP sample number Number of people in this household	Phakir Kami N/A No information
Installation date Installed by Iron nails given	Oct 30, 2002 ENPHO 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (µg/L)	Filtered water (µg/L)	% Removal	Test Method
Early Dec 02	ENPHO	241	6	98	ENPHO lab
Jan 3, 03	Tommy	80	60	25*	ITS

Notes:
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check^{TM} Field Test Kit , analyzed by Tommy
N/A = Not applicable
* = Reliability of this result is doubtful.

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	2.3	ND	96	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Jan 3, 03	Sophie	100 TC (1:10)* TNTC TC 0 EC	N/A 15 TC* 5 EC	85% 0%	M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
TNTC = to numerous to count, >250 CFU/100mL
(1:10) = one in ten dilution
* = used to calculate % removal

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	9	1/3 full	27

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Arsenic Biosand Filter #14

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Tilakpur Tilakpur
Contact person RWSSSP sample number Number of people in this household	Phagu N. Chaudhary N/A No information
Installation date Installed by Iron nails given	Oct 30, 2002 ENPHO 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Early Dec 02	ENPHO	224	4	98	ENPHO lab
Jan 3, 03	Tommy	120	ND	96	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	1.4	ND	93	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Jan 3, 03	Sophie	34 TC 1 EC	42 TC 40* EC	0% 0%	M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
* blue dots were on the extremity of the plate, doubtful results

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	7	1/3 full	21

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Arsenic Biosand Filter #15

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Panchanagar Bhutaha
Contact person RWSSSP sample number Number of people in this household	Lila B. Pun N/A No information
Installation date Installed by Iron nails given	Oct 30, 2002 ENPHO 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Early Dec 02	ENPHO	157	0.4*	99	ENPHO lab
Jan 3, 03	Tommy	60	8	87	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy
N/A = Not applicable
* = This value of 0.4 mg/L is probably below the reliable detection limit of the instrument, therefore the result is doubtful.

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	1.2	ND	92	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit
N/A = Not applicable

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	Removal	Test Method
Jan 3, 03	Sophie	49 TC 4	47 TC 0	4% >99%	M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	20	½ full	40

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

This well is built by the Nepal Red Cross Society (NRCS). NRCS also monitored arsenic for this well.

Arsenic Biosand Filter #16

Filter Information:

District Village development committee (VDC) Village	Nawalparasi Panchanagar Bhanunagar
Contact person RWSSSP sample number Number of users	Bhanu primary school N/A About 200 student
Installation date Installed by Iron nails given	Sept 5, 2002 ENPHO 5 kg

N/A = Not Applicable

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Early Dec 02	ENPHO	225	38	83	ENPHO lab
Jan 3, 03	Tommy	120	ND	96	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ENPHO lab = ENPHO laboratory atomic adsorption results, analyzed by ENPHO technicians
ITS = Industrial Test Systems Arsenic Check^{TM} Field Test Kit , analyzed by Tommy
N/A = Not applicable

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 3, 03	Tommy	1.1	ND	91	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit

Bacteria Monitoring Results:

Sampling date	Collected by	Well water	Filtered water	% Removal	Test Method
Jan 3, 03	Sophie	40 TC (1:10) 61 TC* 0 EC (1:10) 2EC	N/A 22 TC* N/A 18	64% 0%	M-Coliblue24 M-Coliblue24 M-Coliblue24 M-Coliblue24

Notes:
M-Coliblue24 = Millipore M-Coliblue24 Broth, Membrane Filtration, measured in CFU/100mL
TC = Total Coliform
EC = *E. Coli*
(1:10) = one in ten dilution
* = used to calculate % removal

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)	Flow rate measured when diffuser was	Calculated max flow rate when full (L/hr)
Jan 3, 03	Tommy + Sophie	9	1/3 full	27

Notes:
Maximum flow rate is calculated assuming flow rate is directly proportional to water level in the diffuser box. For example, if the flow rate is 10 L/hr when the diffuser box is 1/3-filled, then the calculated maximum flow is three times 10 L/hr, which is 30 L/hr.

Other Information:

This ABF is the first one installed in Nepal. About 200 students currently drink the filtered water from this filter, which is maintained by the school principal.

3-Kolshi #1

Kolshi Information:

District Village development committee (VDC) Village	Kapilvastu Dubiya Rangai
Contact person RWSSSP sample number Number of people in this household	Aitwari Chaudhary 2528 15
Installation date	August 2002

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (μg/L)	Filtered water (μg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	40	ND	>88	ITS

Notes:
ND = Non-Detect = < 10 μg/L
ITS = Industrial Test Systems Arsenic Check^{TM} Field Test Kit , analyzed by Tommy

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	1	ND	>90	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)
Jan 1, 03	Tommy + Sophie	3

Other Information:

The users indicated that the filter flow rate is too low to produce sufficient for their family of 15. They said three filters are needed.

3-Kolshi #2

Kolshi Information:

District Village development committee (VDC) Village	Kapilvastu Dubiya Rangai
Contact person RWSSSP sample number Number of people in this household	Sukhal Chaudhary 2529 No information
Installation date	August 2002

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (µg/L)	Filtered water (µg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	40	ND	>88	ITS

Notes:
ND = Non-Detect = < 10 µg/L
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy

Iron Monitoring Results:

Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	1	ND	>90	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit

Flow Rate Results:

Sampling date	Collected by	Flow rate (L/hr)
Jan 1, 03	Tommy + Sophie	0.3

Other Information:

The users complained about the very low flow rate of 0.3 L/hr.

3-Kolshi #3

Kolshi Information:

District Village development committee (VDC) Village	Kapilvastu Dubiya Rangai
Contact person RWSSSP sample number Number of people in this household	Jhinku Chaudhary 2530 No information
Installation date	August 2002

Arsenic Monitoring Results:

Sampling date	Collected by	Well water (µg/L)	Filtered water (µg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	40	15	63	ITS

Notes:
ND = Non-Detect = < 10 µg/L
ITS = Industrial Test Systems Arsenic Check™ Field Test Kit , analyzed by Tommy

Iron Monitoring Results:

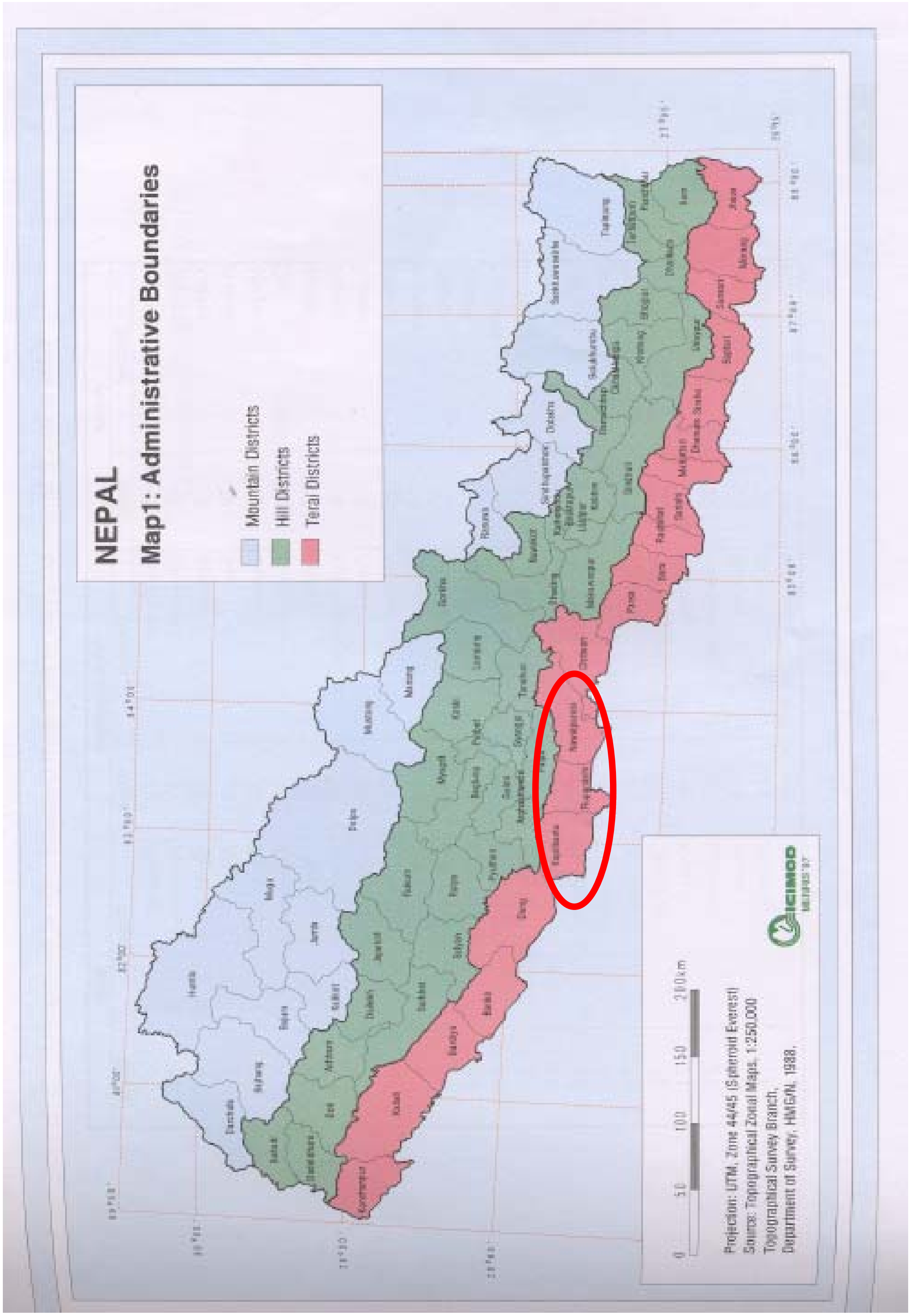
Sampling date	Collected by	Well water (mg/L)	Filtered water (mg/L)	% Removal	Test Method
Jan 1, 03	Tommy + Sophie	1	ND	>90	HACH

Notes:
ND = Non-Detect = < 0.1 mg/L
HACH = HACH Portable Iron Test Kit

Flow Rate Results:

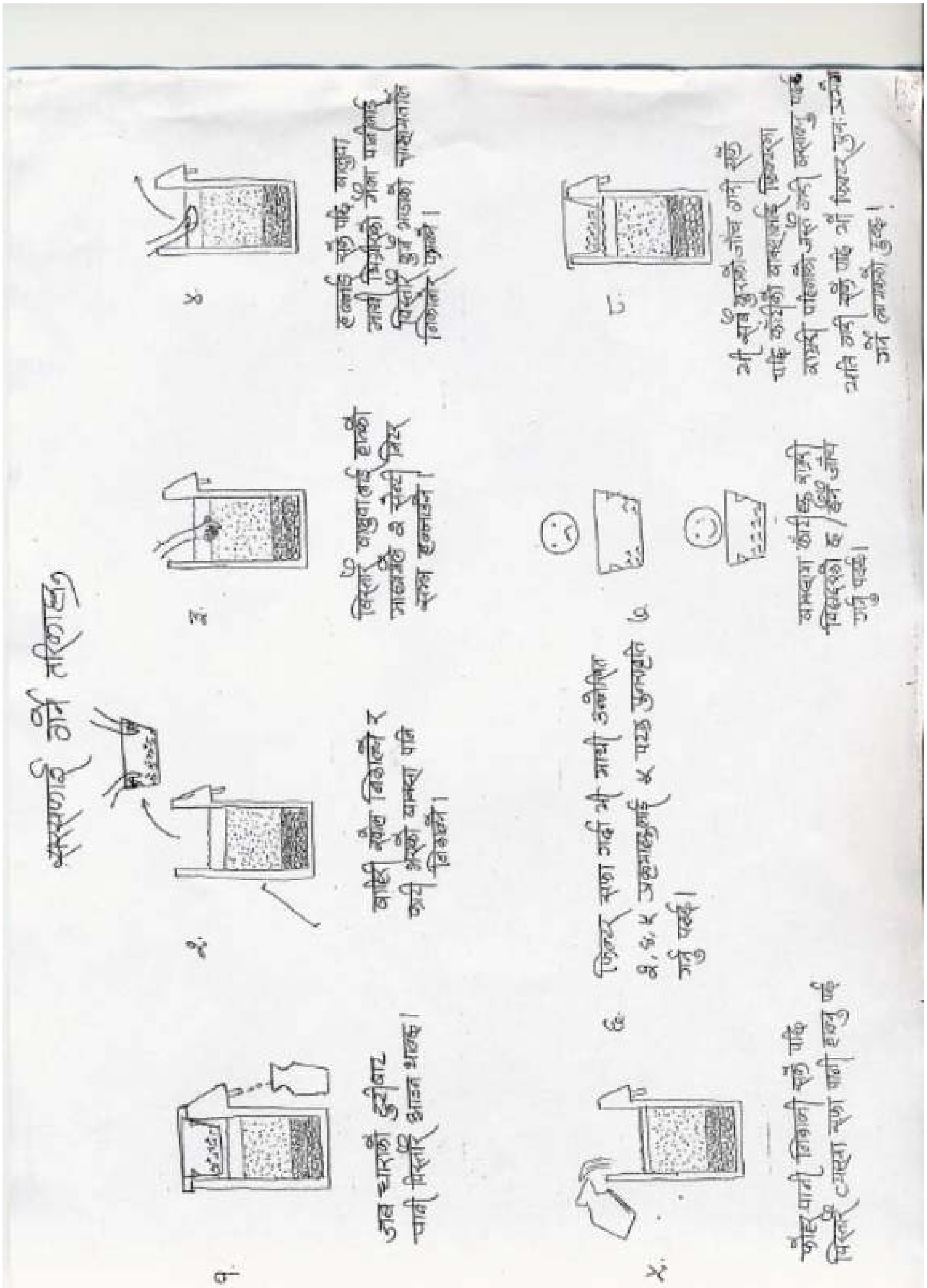
Sampling date	Collected by	Flow rate (L/hr)
Jan 1, 03	Tommy + Sophie	3

APPENDIX C - MAP SHOWING PROJECT DISTRICTS OF NEPAL



APPENDIX D1 - ARSENIC BIOSAND FILTER OPERATING PROCEDURE IN NEPALI

APPENDIX D2 - ARSENIC BIOSAND FILTER CLEANING PROCEDURE IN NEPALI



APPENDIX E - ARSENIC BIOSAND FILTER MANUFACTURING PROCEDURE

The section describes the manufacturing of a Arsenic Biosand filter. The information is an excerpt taken from Lee[93] thesis.

Cross-Section Diagram

Cross-section of a concrete BioSand Filter (BSF) is shown in Figure 44. A BSF has several main components: shell/casing, diffuser plate, fine sand, coarse sand, gravel, and lid. Each of these components will be described in detail in this section. For a ABF, the diffuser plate is replaced by a metal diffuser box filled with iron nails. Table 44 shows the design parameters of a BSF/ABF.

Figure 44 - Cross-Section of a Concrete BioSand Filter

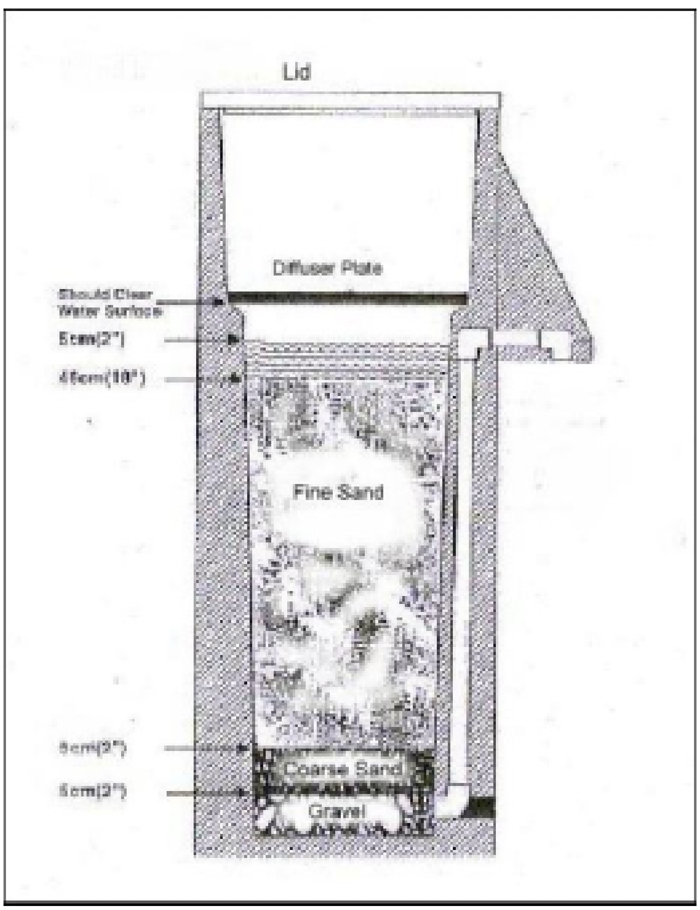


Table 44 - BSF/ABF Design Parameters

Design Parameter	**Value**
Fine Sand Size	<1mm
Coarse Sand Size	1mm – 6mm
Underdrain Gravel Size	6mm – 15mm
Surface Area of Sand	$540m^2$
Initial Flow Rate	1L/min ± 30%
BSF Size	30cm x 30 cm x 90cm

Concrete Shell/Casing

The BSF shell/casing is made of concrete that is casted in a steel mold. Ideally, casting is carried out on site because transportation over long distances with bumpy road conditions to some of the less accessible places in Nepal might cause damages to the BSF shell.

Riser Pipe Assembly

Cut the PVC pipe into four sections and saw off the edges forming a 45° angle as shown in Figure 45.

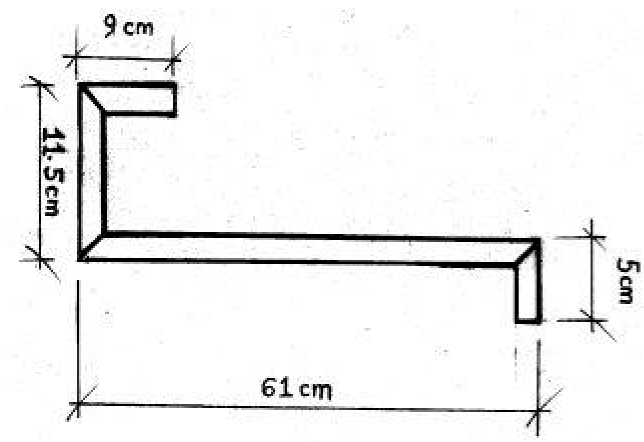


Figure 45 - PVC pipe dimensions (not to scale)

Join the various sections together with glue. Alternatively, heat join using a flat heating plate.

Preparation of Mold

Detailed technical drawings for the steel molds of the concrete version of the BSF are available through Samaritan's Purse or IDRC[94]. Figure 46 shows the cross section of the steel mold. Figure 47 and Figure 48 are pictures of the mold.

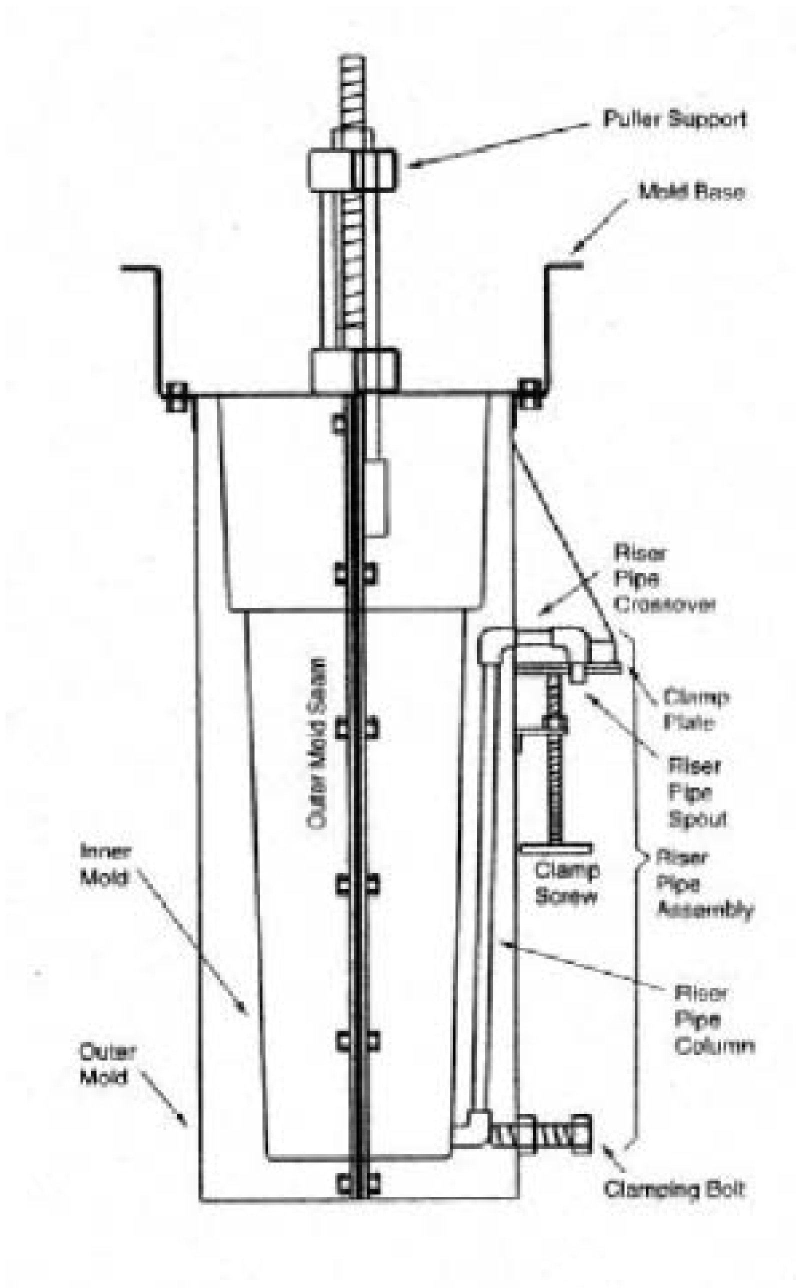


Figure 46 - Cross-Section of Inner and Outer Molds

Figure 47 - Unassembled Steel Mold – Inner Mold (left) and Outer Mold (right).

Figure 48 - Steel Mold for Concrete BSF Shell (assembled)

Stand the fully assembled mold upright, base down. Install the riser pipe that was assembled previously inside the outer mold section. Coat the inside of the molds and the clamping bolt with edible oil or lard. This is to prevent the concrete from sticking to the molds.

Mixing Concrete

Materials required for concrete body include:

- 36 L of cement
- 36 L of sand
- 36 L of gravel
- Water
- Bucket
- Shovel

- Mixing tray/slab or wheel barrow
- Steel or wood rod
- Piece of wood (to use as a trowel)

Concrete is mixed in equal proportion (by volume) in a wheelbarrow or on any clean surface (Figure 49, Figure 50). Water is added a little at a time until concrete reaches the proper consistency. The amount of water needed depends on the initial moisture level of the sand and gravel. As a rough guide, take a handful of the final mixture and squeeze it hard. If the consistency is right, it will just be possible to squeeze a few drops of liquid out of the handful.

Figure 49 - Concrete Mixing I

Figure 50 - Concrete Mixing II

Concrete Pour

The concrete pour should not be carried out in direct sunlight because the concrete must cure in the shade. These are the procedures for pouring:

Pour one third of the concrete into the steel mold. Thrust a steel or wooded rod in and out of the concrete and pound the outside of the mold with a rubber mallet to ensure that the concrete fills all sections of the mold and to release any air bubbles (Figure 51). Repeat this procedure twice more, each time pouring a third of the concrete. Prior to completely filling the mold, oil the top portion of the inner mold as some oil will have worn off in the pouring process.

Figure 51 - Tamping the Concrete Mixture with a Wooden Rod

Level the top of the concrete surface using a short piece of wood. Adjust the clamping bolt which holds the riser pipe against the inner mold so that there is enough pressure to hold the rise pipe in place without causing the outside mold to deflect on that side. This will leave a hole in the filter wall that will have to be patched later. About fifteen minutes after the concrete is poured, release the concrete clamping bolt.

De-molding

Materials required are:

- Mold wrenches
- About 200g of concrete
- Pliers
- Hammer
- Scrap wood

Carefully turn the mold right side up (inner mold legs up). Since the mold, now charged with concrete, has an enhanced capacity to smash fingers, set a piece of wood down to avoid setting the mold flat on the ground. Remove the riser pipe clamping-bolt using a wrench. Clean this bolt and its threading nut with a wire brush after each casting.
Place the puller-support in its slots and screw in the threaded rod. The rod only needs to be threaded the depth of the base nut. Once in place, hand tightens the floating nut against the puller-support crossbar. Remove base bolts. Using a wrench, continue to tighten the floating nut against the crossbar to break the inner mold free. Raise it about 5cm. At this point, the inner mold should be sufficiently loose for two people to lift it out by hand. If the inner mold sticks, tap the outer mold with a rubber mallet while tightening the nut. Set the inner mold aside. Remove the nuts and bolts connecting the two sections of the outer mold. Remove the riser pipe spout using a pair of pliers. Remove the pour spout clamp plate and gasket.

Starting with the rear outer mold section, use both hands to slowly pull back on the mold base and remove this section. Pull gently and evenly, avoiding jerking motion. If the mold does not budge, tap the connection edge (where the halves bolt together) using a piece of wood and a hammer, alternating from one side to another. Be careful not to strike the concrete with the hammer and always use a piece of wood. One person should be pulling on the mold while another is tapping. Remove the front section of the mold.

Using some concrete, patch the hole created by the clamping bolt, any cracks that appear, and any other significant imperfections in the concrete. Scrape the rough edges off the filter. These usually occur at the top of the filter and along the two sides where the seam of the outer mold section was. Scraping should be done while the concrete is still curing.

Keep the filter wet and out of the sun for 2 to 3 days to allow the concrete to cure properly. Water can be poured in to keep the filter body wet. If it cures too quickly due to sun exposure or a warm, dry wind, cracking may occur. Clean the mold and all its parts. If an even, debris-free layer of lard or oil remains on the mold, it may be left for the next casting.

Diffuser Box

The diffuser box is tin metal box with 3 mm perforations spaced 2 cm apart in a square grid at the bottom. The box rests on the inner ledge above the resting water level. The main function of the diffuser box is to distribute the fall of the water over the whole filtering surface to avoid damage to the upper sand layer and the destruction of the biological layer.

A main criterion for the choice of metal is non-corrosiveness. Tin was chosen. A metal box is usually made from three sheets of metal. To increase rigidity, the top edge of the diffuser basin is folded back. Holes are drilled at the base of the diffuser box. The dimensions of a diffuser box are approximately 30 cm x 30 cm x 20 cm. There should be a handle on the box for lifting it out of the filter.

Sand and Gravel

Sand porosity is an important factor relative to the formation of the filter cake and the biologically active zone. Sand porosity depends on the size and shape of the grains. It increases with the size of the grains and with the homogeneity of grain size and shape. High porosity leads to high flow rate and low probabilities of collisions between particles in water and the sand grains. Low porosity will bring about low flow rate and clogging. Therefore, a moderate porosity is required for optimal operation of the BSF. The porosity is small enough to trap particles in the water and large enough to let the water through and allow some room for biological growth.

The following are requirements for the type of sand appropriate for use in a slow sand filter:

- Hard, durable, angular grains free from loam, clay and organic matter. Angular grains decrease porosity and increase resistance to flowing water.
- An effective diameter (d_{10}) range of 0.15-0.35mm.
- A uniformity coefficient (C_u) of less than 3. Uniformity coefficient is a ratio calculated as the size opening that will just pass 60 percent (by weight) of a representative sample of the filter material divided by the size opening that will just pass 10 percent (by weight) of the same sample[95]. This implies a fairly narrow range of grain sizes with an almost even distribution between the smallest 10% and the largest 10% and with most of the grains being a size in the middle. This distribution of sizes decreases the porosity of the sand, increasing the surface area per volume and the likelihood of collisions in the top portions of the sand.

Preparation

There are several steps to the preparation of the sand and gravel.

<u>Step 1: Locating source of gravel and sand</u>

Sand from a crushing operation is usually clean and relatively uniform in size and shape. It requires the least preparation and is often an excellent sand source. In the absence of a manufactured source, it is necessary to locate a natural hillside sand deposit, or use riverbed sand. The fine sand used in the ABFs is river sand. Although river sand could be contaminated from human, animal, and other organic wastes, a study by Stroller and Coan in 2002 showed that biosand filters installed with river sand performed better than biosand filters installed with crushed sand or burnt sand[96]. Research at MIT by Pincus seeks to investigate this apparent paradox[97].

<u>Step 2: Biological quality testing</u>

Each sand source needs to be tested for its biological quality. A sand source that is regularly used should be tested every 6 months. The following is the recommended procedure[98]:

1. Boil about 1 liter of the cleanest and purest water available (not distilled, mineral, or chlorinated water) for about 5 minutes.

2. Let the water cool to room temperature
3. Test a sample of this water for microbial contamination. This is used as a control.
4. Add 5 g of sand to 100 ml of water. Stir to mix, cover and let sit indoor or in the shade for 12 hours.
5. Decant the water into a clean container.
6. Test a sample of this water for microbial contamination.

The boiled water should show negative results. If it does not, there has been a sampling error or the water was not boiled long enough. Positive results in the water with sand sample means the contamination is coming from the sand. Sand from this sand source is not suitable for use in the filter; however it could be used for the construction of the concrete body. More sand sources should be sought out and tested for biological quality as outlined above until a clean source is found[99]. Alternatively, the sand could be disinfected by soaking in a chlorine solution (e.g. Piyush) or spread out in the sun.

Step 3: Sifting

Sifting is required to separate coarse and fine sands from underdrain gravel and larger rocks. A total of three different size screens are needed: 12 mm screen for under-drain gravel, 6 mm screen for the coarse sand, and 1 mm screen for the fine sand.

Step 4: Cleaning and Flow Rate Test

The sand must be free of dirt, clay fines, and organic matter. Slow sand filters are not backwashed so after the sand is placed in the filter beds, it cannot be cleaned quickly or easily. Therefore, sand must be washed and impurities removed before placement in the filter.

Lid

A lid is essential to prevent debris, insects and dirty hands from entering and contaminating the filter. The lid should cover the filter at all times, except when adding water or performing maintenance. The lid may be made out of any material, but it must be clean, must not contain gaps that insects might pass through and should be secure and heavy enough so young children cannot disturb it.

APPENDIX F - ENPHO ARSENIC BIOSAND FILTER SETUP AND PILOT STUDY

Setup

Following the same design concept of Tommy Ngai, ENPHO staff designed and installed six arsenic biosand filters. Their filter setup is identical to the new design by Tommy Ngai's team, as shown in Section 4.1 Figure 3.

Pilot Study

Six ENPHO ABFs were installed between September 5 and October 30, 2002 in the Nawalparasi District (household shown in Table 45). ENPHO staff was responsible for the entire process of the pilot study, including the transportation of the filters to the villages, installation at selected households, education of users, and monitoring of arsenic performance. Arsenic in the raw well water and filtered water was tested every two weeks, using both the ENPHO New Arsenic Field Test Kit, and the ENPHO laboratory.

Table 45 - Summary of the ENPHO ABF Pilot Study

VDC	Village	Contact Person	Installation Date	Iron nails given (kg)
Tilakpur	Patkhauli	Nim Chaudhary	Oct 30, 2002	0
Tilakpur	Patkhauli	Min Chaudhary	Oct 30, 2002	5
Tilakpur	Patkhauli	Phakir Kami	Oct 30, 2002	5
Tilakpur	Tilakpur	Phagu N. Chaudhary	Oct 30, 2002	5
Panchanagar	Bhutaha	Lila B. Pun	Oct 30, 2002	5
Panchanagar	Bhanunagar	Bhanu Primary School	Sep 5, 2002	5

Monitoring Results by ENPHO

The results for the latest monitoring round (early December 2002) by ENPHO are shown in Table 46.

Table 46 - ENPHO Pilot Study Monitoring Results for Arsenic (early December 2002)

Contact Person	**Arsenic by ENPHO Lab**		
	Raw ($\mu g/L$)	*Filtered ($\mu g/L$)*	*% Removal*
Nim Chaudhary	78	3	96
Min Chaudhary	241	6	98
Phakir Kami	175	2	99
Phagu N. Chaudhary	224	4	98
Lila B. Pun	157	0.4*	99
Bhanu Primary School	225	38	83
	Average=		95

Note:
* This value of 0.4 mg/L is probably below the reliable detection limit of the instrument, therefore the result is doubtful. This filter result is not used in the calculation of average arsenic removal.

Discussion of Results

Excellent arsenic removal is observed from all six ABFs installed by ENPHO. The average arsenic removal efficiency is 95%. This value confirm with the 93% removal efficiency obtained by Tommy Ngai's team, testing on the same filters

It should be noted that the ABF installed at Bhanu Primary School is the first ABF in Nepal. It was installed on September 5, 2002 by ENPHO, who followed the installation instruction given by Tommy Ngai in July 2002. The ABF at the school is currently serving about 200 students, as opposed to other filters that are serving one family. Because of the earliest installation date and the highest number of users, this ABF has probably treated more water than any other ABFs in Nepal. The fact that this filter can still remove a high percentage of arsenic suggests that the iron nails may have a very high arsenic adsorption capacity.

APPENDIX G - RWSSSP 3-KOLSHI FILTER SETUP AND PILOT STUDY

Setup

The 3-Kolshi Filter was originally developed at Bangladesh by the following organization in 2000[100]:

- Sono Diagnostic Center Environment Initiative (SDCEI), Kushtia, Bangladesh (Contact: A.H.Khan, et.al , 2000.)
- BRAC, Dhaka Community Hospital, Grameen Bank
- Department of Public Health Engineering (with Ministry of LGD&C, UNICEF)
- NGO Forum (with SDC, DANIDA & CAFOD/EU Partner NGOs)

This technology was transferred to RWSSSP in 2002. A picture of the filter is shown in Figure 52. A cross-section diagram of the filter setup is illustrated in Figure 53.

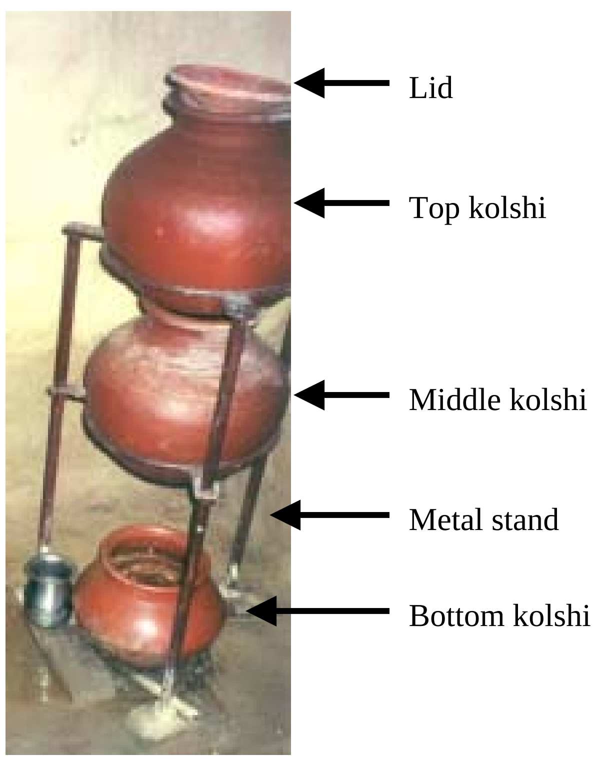


Figure 52 - A 3-Kolshi Filter Installed in a household in Barkalpur VDC of Kapilvastu District

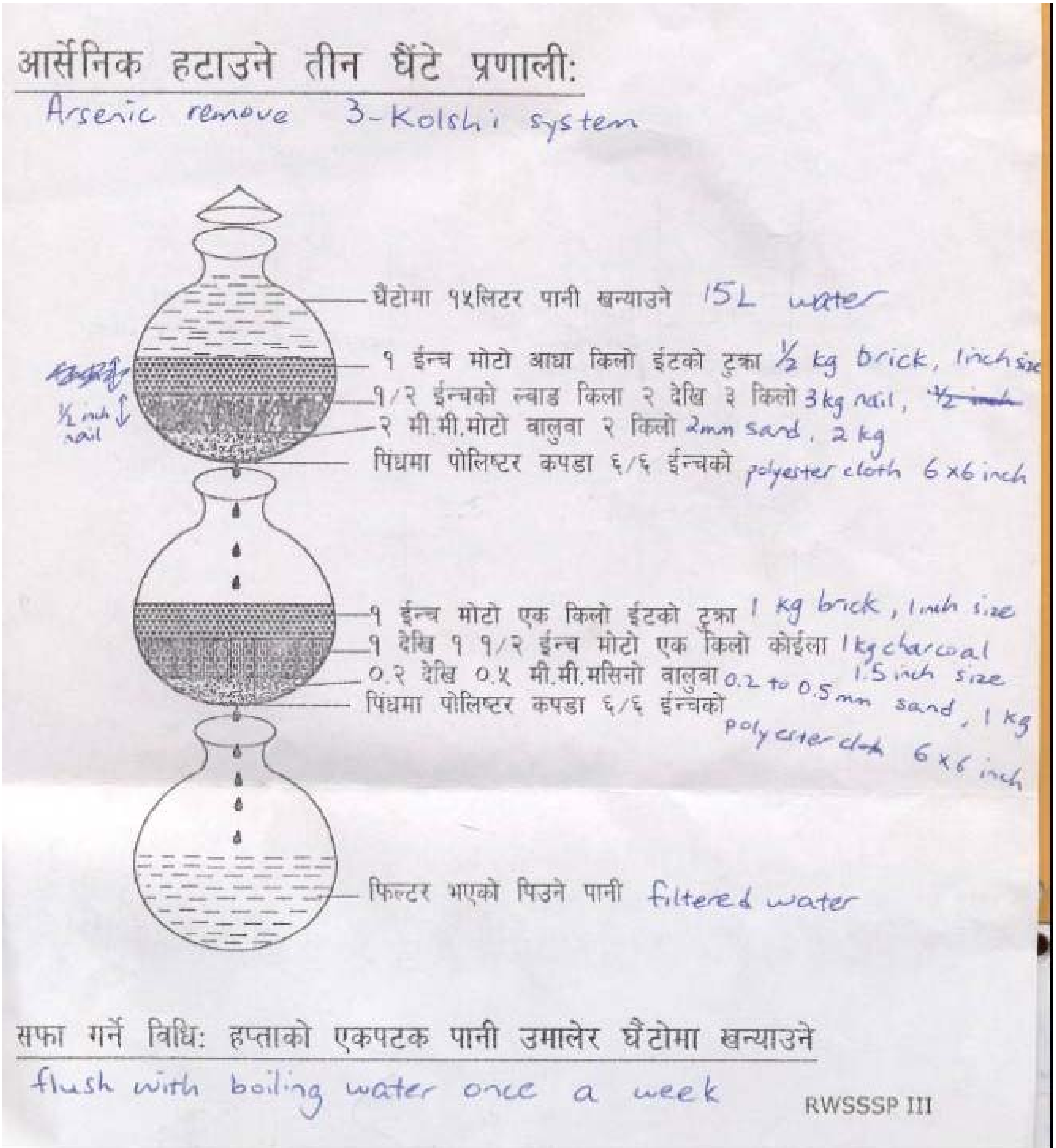


Figure 53 - RWSSSP 3-Kolshi Filter Cross-Section

Pilot Study

About fifteen 3-Kolshi Filters has been installed in two arsenic-affected villages (Dubiya VDC and Barkalpur VDC) by RWSSSP in the summer of 2002. RWSSSP staff was responsible for the entire process of the pilot study, including the transportation of the filters to the villages, installation at selected households, education of users, and monitoring of arsenic performance. Five of the filters have been visited by Tommy Ngai's team to assess the filters' preliminary performances. However, two of the five filters were broken during the visit. Table 47 shows the details of the remaining three filters.

Table 47 - Three RWSSSP 3-Kolshi Filters Visited by Tommy Ngai's Team

District	VDC	Village	Contact Person	Installation Date
Kapilvastu	Dubiya	Rangai	Aitwari Chaudhary (2761)	August 2002
Kapilvastu	Dubiya	Rangai	Sukhal Chaudhary (2761)	August 2002
Kapilvastu	Dubiya	Rangai	Jhinku Chaudhary (2761)	August 2002

Monitoring Results by RWSSSP

The results by RWSSSP are not included here.

APPENDIX H - COMPARISON BETWEEN ANALYTICAL ARSENIC TEST METHODS

This appendix shows the comparison between the arsenic test results from the MIT Parsons Laboratory's Perkin-Elmer Graphite Furnace Atomic Absorption Spectrometer (GFAAS) and ENPHO Laboratory's SOLAAR 969 Hydride Generation Atomic Absorption Spectrometer (HGAAS); followed by the comparison between the MIT's GFAAS and Industrial Test Systems Inc. (ITS) Arsenic Check Field Test Kit. Refer to Chapter 6 for a description of each of the above arsenic test methods.

Comparison between MIT GFAAS and ENPHO HGAAS

In June 2002, 22 arsenic samples collected by ENPHO in Nepal, were analyzed by Tommy Ngai at the MIT Parsons Laboratory's GFAAS for arsenic concentration. After the analysis was completed, the results were sent to ENPHO for comparison. At the same time, a split-sample of these 22 samples were analyzed by ENPHO Laboratory's HGAAS. Table 48 compares the two laboratory results. The average absolute % difference is 31%, which is very good. The high level of agreement shows that the ENPHO laboratory results are usually dependable and accurate.

Table 48 - A Comparison of Arsenic Split-Sample Results Analyzed at MIT Laboratory vs. ENPHO Laboratory

Sample #	**Total Arsenic (μg/L)**		**Absolute % Difference***
	MIT	*ENPHO*	
1	38	67	76
2	380	338	11
3	102	124	22
4	99	134	35
5	59	82	38
6	48	58	21
7	46	89	93
8	334	412	23
9	384	340	12
10	276	281	2
11	222	289	30
12	72	47	35
13	69	31	55
14	66	28	58
15	73	46	37
16	177	123	30
17	138	125	10
18	53	53	0
19	71	95	35
20	41	26	36
21	42	51	21
22	55	51	7
		Average =	31

*Note: The Absolute % Difference is calculated by calculating the absolute value of the difference between MIT and ENPHO values and dividing the difference by the MIT values.

Comparison between MIT GFAAS and ITS Arsenic Field Test Kit

Tommy Ngai compared the arsenic results between the MIT GFAAS and the ITS ArsenicCheck Field Test Kit as part of his Master Thesis work[101]. A total of 23 Nepal water samples were analyzed in Nepal in January 2002 using the ITS Arsenic Field Test Kit. A split-sample of these 23 samples were preserved and brought to MIT for GFAAS analysis. These samples were analyzed by Tommy Ngai between February and March 2002. Table 49 compares the two sets of results. On average, 78% of the results agree with each other, which is quite good. The fairly high level of agreement shows that the ITS Arsenic Field Test Kit results are often dependable and accurate.

Table 49 - A Comparison of Arsenic Split-Sample Results Analyzed at MIT Laboratory vs. Industrial Test Systems Arsenic Check™ Field Test Kit

Sample #	**Total Arsenic (μg/L)**		**Agreement?**
	GFAAS	*ITS kit*	
1	572	500	yes
2	863	800	yes
3	121	100-200	yes
4	328	200	no
5	158	50-100	no
6	149	100-200	yes
7	140	100	yes
8	93	50-100	yes
9	154	100	yes
10	102	100-200	yes
11	103	50-100	yes
12	96	100-200	no
13	95	50	no
14	56	50-100	yes
15	150	100-200	yes
16	91	200	no
17	328	300-500	yes
18	233	200-300	yes
19	242	300	yes
20	45	20-50	yes
21	70	100	yes
22	147	200	yes
23	16	10	yes
		Average =	78 %

APPENDIX I - ETHICS OF EXPERIMENTAL WORK WITH HUMAN SUBJECTS

In the US, public attention was drawn to the ethical issues related to experimental work with human subjects by reported abuses of human subjects in concentration camps during World War II. As a result, in 1978, the National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research (established by Public Law 93-348 in 1974) submitted "The Belmont Report: Ethical Principles and Guidelines for the Protection of Human Subjects of Research."[102], which describes the basic ethical principles underlying the acceptable conduct of research involving human subjects. These principles are respect for persons, beneficence**,** and justice.

In practice, respect for persons involves obtaining the informed consent of subjects, i.e. people should be given clear information about the experiment that they will be subjected to, they should fully understand the terms and conditions and they should be allowed to freely decide whether or not to be part of the experiment. In addition subjects must know that they can withdraw from the research at any time. If a person cannot make an autonomous decision (due to age or mental incapacity), that person should be protected. Tommy Ngai and RWSSSP applied these guidelines by telling villagers that the filters were experimental and not guaranteed to remove arsenic, iron and bacteria. The villagers were asked if they wanted to participate in the experiment, and they all agreed. Most of the villagers currently have no satisfactory alternative to their poor quality drinking water. They believe that even if the filters have mediocre performance, they are still better off with the experimental filters than with their existing conditions.

Beneficence involves protecting subjects from harm by maximizing anticipated benefits and minimizing possible risks of harm. In this case, the filters did have the great potential to remove arsenic, iron and bacteria, while at the same did not represent a health treat. The filters are made of concrete, sand, gravel, and iron nails; and do not contain any known toxic substances. Thus anticipated benefits were maximized and risks were minimized, by the very nature of the ABFs.

Finally, justice requires that the benefits and burdens of research be distributed fairly. This means that if there are burdens placed on the subjects or type of subjects, they should also receive the benefits of the project. For example, it is inappropriate to use poor people in experiments that would only benefit rich people. Tommy Ngai and RWSSSP applied this principle by selecting subjects based on levels of arsenic in wells, and not by any other criteria such as cast, tribe, gender, income, etc. Moreover, the filters directly impact the subjects in a positive way if they work and neutral if they don't work.

In conclusion, the use of human subjects (i.e. villagers) in the ABF pilot study is justified on the above basis.

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