STUDY OF FILTRATION FOR POINT-OF-USE DRINKING WATER TREATMENT IN NEPAL

BY

JUNKO SAGARA

BACHELOR OF ENGINEERING
CIVIL ENGINEERING AND APPLIED MECHANICS
MCGILL UNIVERSITY, JUNE 1999

[redacted]

SUBMITTED TO THE DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF ENGINEERING IN CIVIL AND ENVIRONMENTAL ENGINEERING

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2000

Signature of the Author ______________________________
Department of Civil and Environmental Engineering
May 5, 2000

Certified by ______________________________
Susan Murcott
Lecturer
Department of Civil and Environmental Engineering
Thesis Supervisor

Accepted by ______________________________
Daniele Veneziano
Professor of Civil and Environmental Engineering
Chairman, Departmental Committee on Graduate Studies

STUDY OF FILTRATION FOR POINT-OF-USE DRINKING WATER TREATMENT IN NEPAL

By

Junko Sagara

Submitted to the Department of Civil and Environmental Engineering on
May 5, 2000 in Partial Fulfillment of the Requirements for the Degree of
Master of Engineering in Civil and Environmental Engineering

ABSTRACT

Point-of-use drinking water filtration was studied as a possible drinking water treatment alternative in Nepal. Three filter/purifier systems, Nepalese ceramic candle filter, Indian ceramic candle filter and IPI purifier, were tested for turbidity and microbial removal efficiencies.

The test results indicated that the filter systems had very high turbidity removal efficiencies. All systems reduced the turbidity level of water to less than 1 NTU. However, the filtration processes themselves were observed to be not adequate in terms of removing microbial contaminants. IPI purifier when used together with chlorine disinfection eliminated all microbial contamination, however, in all other cases the treated water was still microbiologically contaminated.

In order to improve the microbial removal efficiency of Nepalese ceramic candle filter, colloidal silver coating was applied onto the ceramic filter candle. The experiments were conducted for filter candles with several concentrations of silver. It was observed that the filters with more than 10mg of silver removed all hydrogen sulfide producing bacteria. However, complete removal of total coliform was not achieved. Moreover, it was not tested whether the effectiveness of the silver remains after long term use of the filter, and thus a further study is recommended.

Out of all three filter systems tested, the Nepalese ceramic candle filter remained to be the most affordable system of all. It is recommended for the Nepalese households to use Nepalese ceramic candle filters combined with a disinfection process.

Thesis supervisor:	Susan Murcott Department of Civil and Environmental Engineering Lecturer

ACKNOWLEDGEMENT

I would like to thank all the following people for their support in completing this thesis.

First of all, I would like to thank the **Massachusetts Institute of Technology** and the **John R. Freeman Fund** for making this project and our wonderful trip to Nepal possible.

Ms. Susan Murcott, my thesis supervisor, for her support and guidance throughout the year.

Dr. Eric E. Adams, my academic advisor, for his guidance and advice.

Mr. Lee Hersh, for his amazing Internet search skills and for providing me with useful information whenever I needed them. I knew that if I asked you I would end up with an answer! Without your research effort this thesis wouldn't have existed.

Mr. Phil Warwick, the director of Industry for the Poor, Inc., and all his staffs for providing me with their filters and lots of information. Thank you so much for being such an amazing host while in Haiti.

Mr. Ron Rivera of Potters for Peace for providing me with information and instructions for making colloidal silver coated filters.

Ms. Mangala Karanjit for her wonderful hospitality while in Nepal and for organizing our field study in Nepal as well as our accommodation and the laboratory space.

Mr. Hans Spruijt, UNICEF-Nepal, for organizing various workshops while we were in Nepal, which allowed us to interact with Nepalese water engineers, technicians and women motivators.

Mr. Dilli Bajracharya, the deputy director of the Central Laboratory of Nepal Water Supply Corporation and his laboratory staffs for providing us with a laboratory space.

Mr. Hari Govinda Parajapati, the president of Nepal Ceramic Co-operative Society, for providing valuable information and for showing us around the potters village in Thimi.

Mr. Pren Shrestra of the DWSS Nepal for his valuable advise and information.

Mr. Maheswor Kafle for his friendship and for exposing us to the amazing culture of his country.

Mr. Jan Nelson for his proofreading effort and for all his support.

Last, but not least, my project team members, **Andrea Wolfe**, **Tricia Halsey**, **Andy Bittner**, **Kim Luu**, **Amer Khayyat** and **Benoit Maag** for being such great teammates and for being amazing friends. The 25 days we spent together in Nepal was something that I will never be able to forget. Thank you guys!!

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Nepal Adhirajya, Kingdom of Nepal, is a landlocked country in south Asia, bordered to the north by Tibet and the Himalayas and to the south, east and west by India. This Himalayan country is rich in freshwater, however, due to the uneven distribution of such freshwater resources and the lack of a developed water infrastructure, only 34% of the population has access to clean, safe drinking water (NepalNet, http://www.panasia.org.sg/nepalnet/water/ water_contamination.htm). Furthermore, only 3% of the population has access to adequate sanitary facilities (Nepal Net).

Waterborne disease is a serious health problem in Nepal. Intestinal parasites, diarrhea and gastrointestinal disorders are common chronic Nepalese health problems (The Library of Congress, 1999) and are often caused by drinking contaminated water. These diseases can lead to disorders related to nutritional deficiencies, which are also chronic problems for Nepalese people. Disorders related to malnutrition, such as goiter, mental retardation, deaf-muteness, and beriberi are especially common in rural areas (Nepal Net).

In 1998/9 Ministry of Health of Nepal estimated that 80,000 children under 5 die annually from preventable diseases (Spruijt, 2000). Diarrheal illnesses are the leading cause of childhood death in Nepal, being the cause for 25% of the total childhood death (UNDP 1998). Of those children who survive, approximately half of them experience stunted growth, suffering from sub-normal weight for height (UNDP 1998). The infant mortality rate in Nepal has been decreasing approximately 8% annually over the last two decades. Nonetheless it has been reported to be one out of ten births in 1998. Furthermore, infants in rural areas are exposed to 1.6 times the risk of death compared to those in the urban areas (UNDP 1998).

Nepal is the seventh poorest nation in the world and approximately half of the Nepalese population lives below the absolute poverty line (CIA Country Factbook, http://rs6.loc.gov/frd/cs/nptoc.html). The per capita income is only US$210 (UNDP 1998). Although cash poor, developing nations such as Nepal often attempt to build centralized water treatment facilities typical of developed urban societies. Such projects are prohibitively expensive, and even if these treatment systems are built, lack of maintenance and skilled labor mean that adequate water treatment cannot be attained for the long-term.

As Nepal lacks the capital resources to undertake large-scale water infrastructure projects, Nepalese people must first rely upon themselves to secure safe water. It could be possible for the people of Nepal to treat their drinking water simply and effectively through the introduction of a water filter treatment system at the household level. In this project, filtration for point-of-use water treatment was studied as an alternative method of water treatment for Nepal. Filtration is one of the most effective yet simplest water treatment processes. Several point-of-use filtration systems were selected as possible system to be used in Nepal. Filtration systems were studied for their performance levels as well as for the economic feasibility and social acceptability. Their performance levels were determined by the removal efficiencies in terms of turbidity and microbiological parameters.

2. DRINKING WATER IN NEPAL

2.1 Water Supply and Treatment in Nepal

Nepalese populations obtain their drinking water mainly from three sources; surface water, groundwater and the municipally supplied piped water supply. In the capital city of Kathmandu, approximately fifty percent of the population has access to municipally treated piped drinking water (Rijal, Fujioka and Ziel, 1996). However, this figure encapsulates only about seven percent of the total Nepalese population. While those living in the city may have access or limited access to public water, populations in other regions do not have access to such water supply. Moreover, many of those who have access to the public water supply must still collect water from communal taps. And, since public water is supplied intermittently, usually for only three to four hours a day, many of those who have access to the public water supply must often rely on other sources of drinking water, such as private wells (Rijal, Fujioka and Ziel, 1996). Therefore, only a very small portion of the Nepalese population actually relies upon the piped water supply.

In rural areas of central and northern parts of Nepal, the main water source is surface water, which includes springs and streams. The quality of such water source fluctuates greatly depending on the season. Although water may have low turbidity during the winter months, at other times of the year water can be very turbid, especially during the monsoon season. Water sources in rural areas are also susceptible to human and animal fecal contamination. Even with low turbidity, water may still be contaminated by pathogenic organisms. In the Kathmandu Valley, surface water is severely polluted by industrial effluent, waste dumping and by the discharge of untreated sewage from residential areas. Thus, surface water in the Greater Kathmandu region is rarely used as drinking water without being treated.

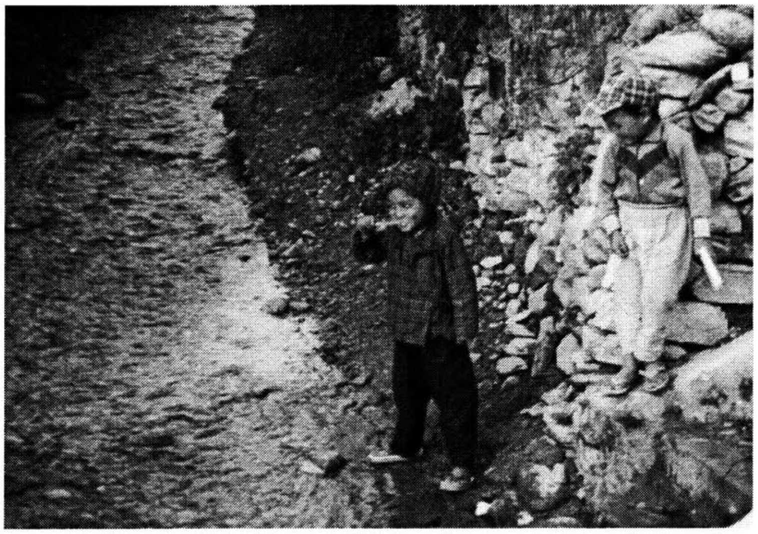

Figure 2.1: Stream Water Source in Rural Nepal

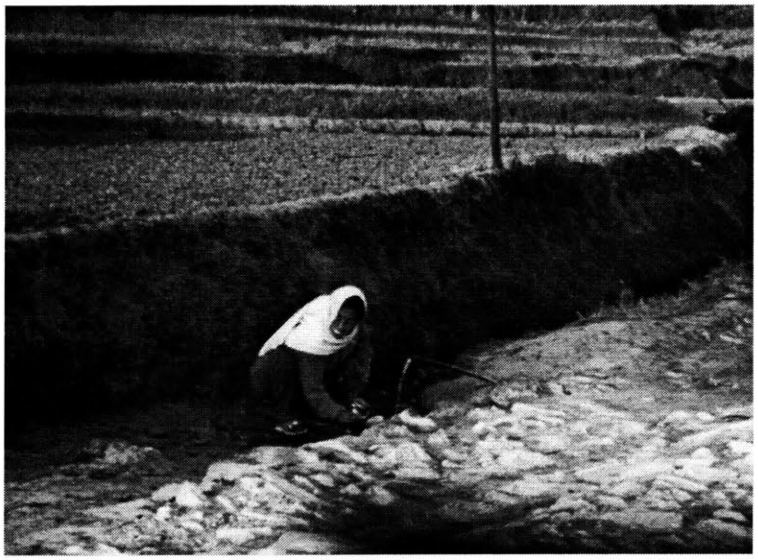

Figure 2.2: Water Source in Rural Nepal (piped from a spring)

Groundwater is an important water source for Nepalese people, especially in the Terai region and to some extent in the middle hills. There are many traditional water sources dependent on groundwater. Several of international development organizations have constructed wells throughout Nepal because well waters are less susceptible to contamination. Furthermore, groundwater quality is less variable compared to the surface water. As an example, Japanese Red Cross of Nepal has constructed more than 10,000 wells in the last decade (Yamada, 2000).

Although water quality is generally less variable in groundwater, in most urban areas groundwater is contaminated due to seepage from septic tanks. Virtually all Kathmandu homeowners build private septic tanks on their property. Unfortunately, most private property consists of tiny plots of land - often covering just sixty square meters – and therefore these plots of land do not have sufficient room for soak pits (Nepal Net). The semi-treated effluent, still contaminated while stored in the tanks, does not have adequate area for dissipation, and therefore becomes concentrated in residential yards. This effluent subsequently seeps into the water table, contaminating the groundwater.

Usage by a large population and inadequate maintenance contribute to the contamination of many traditional water taps. Traditional water taps are especially susceptible to contamination, as they are often located in densely populated areas. However, because such taps often have religious significance and have long since been valued by the local people, many people prefer to use traditional taps in lieu of newly constructed public tap stands, even though the newer ones may provide cleaner water.

Piped drinking water in Kathmandu is also polluted (Wolfe, 2000). One factor contributing to this pollution is inadequate treatment at the municipal water treatment plant. Water treatment plants in Nepal are often as sophisticated as those found in more developed countries, however, due to lack of adequate operation and maintenance, they are less effective in treating the water. The water treatment plants often experience technical problems, and cannot treat water to acceptable quality standards. Another factor contributing to the pollution of piped water hinges on the quality of pipes in the water distribution system. Since the urban water supply is only in use intermittently, changes in water pressure in the pipes create suction within the system. This suction pulls contaminants from the ground, such as leakage from the sewage pipes running along side of the water supply line, and in turn these contaminants enter into the system and consequently contaminate the water.

2.2 Point-of-Use Treatment as an Appropriate Technology in Nepal

Empirical studies of drinking water throughout Nepal found that fecal coliform contamination in the water consistently exceed World Health Organization (WHO) guidelines for water for human consumption (Nepal Net). Although this type of water contamination is often the source of diseases in areas without an adequate water supply, this problem could potentially be overcome through the application of appropriate technology.

In the Kathmandu Valley, water distribution pipes currently in place are in poor condition, and allow contaminants to leak into the treated water supply, as discussed above. In the case of well water, the extraction methods can affect the quality of the water available to the well's users. Buckets and ropes used for extraction are often left on the ground, contaminating the extracted water and also polluting the water in the well. Dirty hands handling the buckets and ropes can also transmit diseases. Furthermore, animals that are allowed near the water source are a source of contamination. Thus, even if the water supply at the source is clean and free from contamination, by the time water reaches the household and is consumed, it has come in contact with various forms of contamination.

Point-of-use treatment systems are meant to create a simple and effective method of providing a clean source of drinking water for domestic use. If the point-of-use treatment unit is able to treat water to an acceptable quality level for drinking water, then the various factors leading to the contamination of water discussed above need not be of concern. Also, when fewer people use one water source, such as individual households, there is a reduction in the transmission of waterborne diseases due to reduced population exposure to the pathogenic organisms residing in the water supply.

Point-of-use treatment systems are also much simpler to use, maintain and supply than large-scale treatment systems. Often in developing countries sophisticated treatment systems are introduced, however, maintenance of such technologically advanced systems is often not adequately performed due to lack in funding, training or skilled labor. Conversely, the effective use of point-of-use treatment systems requires little training, systems are easily maintained by the individual users, and the replacement costs are low. Thus, point-of-use systems not only provide a positive barrier against pathogenic contagion in the home but also can be more cost effective than large-scale projects.

2.3 Current Household Water Treatment in Nepal

In Nepal, the most commonly available point-of-use water treatment unit is the Indian ceramic candle filter. This filter is available in markets all over Kathmandu Valley and is used mainly among middle to upper class strata of the population. The Department of Water Supply and Sewerage of the Nepalese government recommends that the general population treat their drinking water first by boiling and then by filtering the water through commercially available filters.

However, this treatment option is very expensive and economically out of reach for the majority of the population in Nepal. Boiling water requires burning fuel, which is a valuable and limited resource in Nepal. Although this treatment option is highly effective, it cannot be promoted among the lower middle to lower class strata of the population. Furthermore, those living in rural areas do not have access to commercially available water filters due to the limited transportation infrastructure in Nepal.

Because filters available in the city are not available in rural areas, people must find alternative methods of treating water. The water supply in rural areas is normally supplied directly from streams or springs. The use of surface water means that water is exposed to natural forces, and thus the water can be very turbid during the monsoon season. During such times of the year, Nepalese filter their water through a cloth in order to strain some of the visible impurities from the water (Shrestra, 2000). This white cotton cloth, commonly used for bedding covers, is called malmal (Kafle, 2000), and is manufactured and available anywhere in Nepal. This filtration method has traditionally been used in rural areas where the level of drinking water turbidity fluctuates greatly depending on the season. Unfortunately, this method of water filtration is highly ineffective at removing anything but visible contamination from drinking water, and consequently does not prevent the spread of waterborne diseases.

3. FILTRATION

3.1 Filtration for Water Treatment

Filtration is a commonly used, physical, chemical, and in some instances, biological process of water treatment. The filtration process involves separation of suspended solids and impurities from water by passing it through porous media. Removal in a filter is accomplished through a number of mechanisms. Most common mechanisms for filtration are listed below.

- Mechanical Straining

When particles in the water are larger than the pore size of the filter media particles are trapped at the surface of or inside the media, removing the particles from the water.

- Sedimentation

Particles trapped inside the pores of the filter media settle within the pores and are separated from water by a sedimentation process.

- Flocculation

Straining process described earlier results in reduction in the pore size of the filter. This leads to an increase in the velocity of water through the remaining voids, shearing off pieces of captured floc and carrying impurities deeper into the filter bed. Turbulence and the resulting increased particle contact within the pores promote flocculation, resulting in trapping of the larger floc particles (Viessman and Hammer, 1993).

- Adsorption

When an adsorbent, such as activated carbon, is used as a filter media, impurities that exist in the water can be removed by chemical adsorption process. Molecules of the impurities are taken up by the external or internal surface of the adsorbent due to the chemical adsorption process occurring at the solid-liquid interface.

- Biological Metabolism

When a biologically active layer is formed on the top of the filter medium, organic substances are converted into less toxic compounds due to biochemical action. This results in removal of harmful impurities from the water. A biological layer also removes microbiological contaminants that may be present in the water.

In filtration systems, the most commonly used filter medium is sand, however media such as anthracite, crushed magnetite, garnet, coconut husks and other natural and inert synthetic materials are also used. Medium type, size, porosity, pore size and available surface area of the medium are factors determining the effectiveness of the filtration removal process.

3.2 Filtration for Point-of-Use Water Treatment System

The filtration process is a simple and an effective method of treating drinking water, and thus it is a suitable process to be used in point-of-use treatment systems. The filtration process itself does not require any addition of chemicals and can be operated without a power supply. It is also easily adaptable to household-scale systems.

A point-of-use treatment system is any form of water treatment that may be installed or used by a householder within his premises (Jackson, 1992). These devices treat relatively small volumes of water typically only treat drinking and cooking water.

There are numerous of point-of-use water treatment systems available for various purposes and efficacy. Filtration is the most commonly used treatment process for such systems. There are systems for removing hardness, and others to remove dissolved organics by adsorption filters. Furthermore, many point-of-use units remove turbidity, cysts and asbestos fibers by means on particulate filtration. Highly sophisticated filtration systems using processes such as membrane filtration are available in the market, however, for the purpose of this study only the low-cost, appropriate point-of-use filtration devices were considered.

Some point-of-use systems also combine filtration with other treatment processes. When filtration is combined with disinfection, the device is commonly referred to as a "purifier".

The basic designs of the commonly used filtration processes for point-of-use treatment units are discussed below.

- Granular Bed

Granular bed filter consists of granular filtration medium. The medium can be either inert materials such as sand or materials with adsorption capabilities such as activated carbon. Granular bed filters can remove impurities in the form of particulate or dissolved chemicals depending on the type of the filter medium used. Water is passed through the granular medium and the impurities are either strained or adsorbed.

- Spool Filters

Spool filters are made of fiber strings around a core material. Rolled paper cartridges also falls into this category of filter system. Their primary function is to remove particulate by straining mechanisms. The filters can be impregnated with activated carbon, which acts as an adsorbent.

- Pleated Filters

Pleated filters are made of non-woven fabric, pleated paper or membranes with controlled pore size. Membranes may have pore sizes as small as 0.2 micrometer (Regunathan, 1985).

- Pre-coat Filters

Finely powdered diatomaceous earth or other filtering materials are applied to the influent side of the barrier portion of the filter. The pore size can be very small and high particulate removal efficiency can be expected. They are capable of removing particulates that are smaller than 1 micrometer (Regunathan, 1985).

- Candle Filters

Candle filters are typically made of ceramics. Water is passed through the pores of the ceramic filter candle and the particulate contaminants get trapped on or inside the ceramic filter. The pore size of the filter can be as small as 1 micrometer.

- Reverse Osmosis

Water is forced through a membrane with Angstrom-sized pores. It is capable of removing most dissolved substances except volatile organics. Reverse osmosis systems are too expensive to be considered for this study.

The various point-of-use filtration processes discussed above can be used in several types of point-of-use treatment devices. There are four major categories of household point-of-use water treatment devices that are commonly in use.

- Faucet Add-on

Faucet add-on systems are used most commonly for activated carbon filters. Due to the high head above the filter medium, they often do not provide significant reduction of particulate contaminants.

- Under-the-Sink System

Under-the-sink systems are used to treat the water before it arrives at the faucet. Thus, it treats all the water supplied through the existing faucet.

- Whole Household System

Whole household systems treat all the water that is supplied for a household. It is directly connected to the water source of the household. They are relatively large sized due to the large volume of water treated by such system.

- Pour-Through System

Pour-through systems are usually granular bed, spool, or candle filters. Water is poured into the units and goes through the filtering medium by gravity. Sometimes a pump is used to increase the filtration rate.

As discussed above, the majority of the Nepalese population do not have access to municipally supplied tap water, and even if they do, they do not have the water supplied directly to their homes. Thus, the first three point-of-use systems are not applicable for this study. Only the pour-through systems were considered for the purpose of this study.

4. POSSIBLE POINT-OF-USE WATER FILTRATION SYSTEMS

When researching possible technologies to be applied in the developing world, factors aside from science and technology must be also considered. Economic factors, differences in cultural norms, and the limited availability of a given technology also affect the type of point-of-use system chosen. The appropriate point-of-use water treatment system for Nepal must meet the following criteria:

- Adequate treatment performance to meet drinking water quality standards

Since Nepal does not have defined drinking water quality standards for the domestic water supply, the WHO standard for drinking water was used as a reference.

- Low cost

The average annual income of a Nepalese family is approximately US$200; therefore the cost of system is as important as its overall performance. If a high performance system is expensive then it cannot be promoted in Nepal. The current point-of-use systems currently available in Nepal are generally too expensive for the majority of population to afford. This is especially true for those in the rural areas who need the technology the most.

- Wide availability

The recommended point-of-use treatment system must be widely available in order to ensure easy accessibility to the whole population. In terms of system repair or replacement, the availability of parts and new systems is crucial. This wide availability of the system helps people to use the system for the long-term.

- Easy to use and maintain

Point-of-use treatment systems are designed for use in the home, and thus technical knowledge about water treatment should not be necessary to use such systems. In order to ensure that people can use the system correctly for the long-term, the system must be simple to operate and must be easy to repair or replace.

Considering the above criteria, four point-of-use treatment devices were selected and studied as possible point-of-use water filtration systems appropriate for Nepal. The filters studied are:

- Indian Ceramic Candle Filter
- Nepalese Ceramic Candle Filter
- Industry for the Poor Inc. (IPI) Purifier
- BioSand Water Filter

4.1 Indian Ceramic Candle Filter

Ceramic candle filters are one of the most commonly used point-of-use treatment options in many developing countries. The filter element is cylindrically shaped and is made from white clay. When contaminated water passes through the filter, contaminants are strained or trapped by the filter element, treating the water. The typical pore size of the candle filters is 1 micron (Warwick, 1999).

Indian Ceramic Candle Filters are available in Nepal, especially in the city of Kathmandu. They come in a variety of sizes, since they are used not only in private households but also at public and private institutions, including offices, hotels and restaurants. There are many Indian companies that manufacture ceramic candle filters, such as Puro, Bajaj, Himal, Kamal and Swagat. These companies all claim that their products produce absolutely safe, hygienic and crystal clear drinking water.

The design of the Indian ceramic candle filter system is simple. These units normally consist of two stainless steel containers, one placed on top of the other. The top container contains one to four (commonly two) ceramic filter candles. The bottom container collects treated water that seeps down through the ceramic filter candle. Individual users assemble the units by fitting the candle into the top container and a spigot on to the bottom container. The ceramic filter candle must be boiled for 15 to 20 minutes prior to the assembly for sterilization and also to remove any fine clay particles from the ceramic candle. The individual users must keep the ceramic filter candles clean by regularly brushing the surface gently under clean flowing water. When the rate of filtration slows, the filter must once again be sterilized by boiling it. The filter should be replaced after 8 to 12 months of continuous use, depending on the amount of use and the turbidity of the feed water.

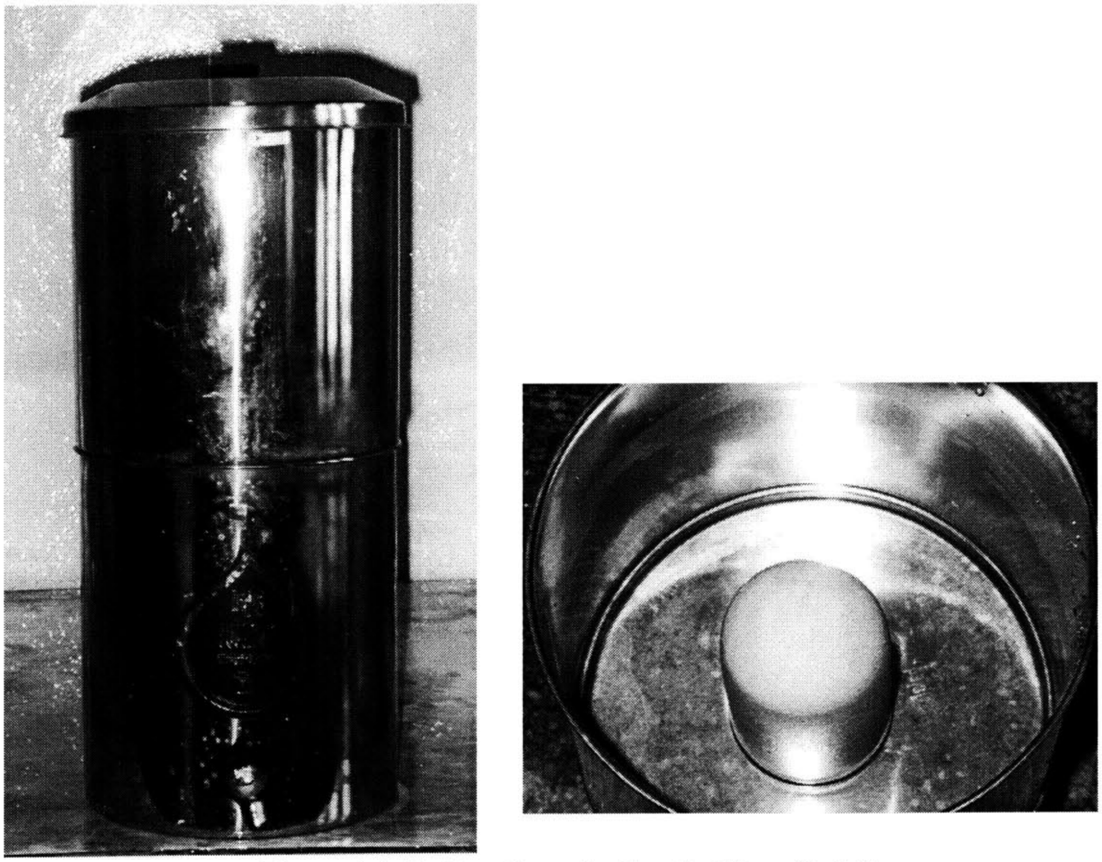

Figure 4.1: Indian Ceramic Candle Filter (Bajaj)

4.2 Nepalese Ceramic Candle Filter

The Nepalese ceramic candle filter is manufactured in Thimi, a small town located to the east of Kathmandu city. The filters are hand-made by Hari Govinda Prajapati, the president of Nepal Ceramics Co-operative Society Ltd., and have been co-developed with cooperation from the Small Business Promotion Project/German Technical (Nepal Ceramics Co-operative Society Ltd., brochure). This type of filter is currently used in the Greater Kathmandu region and in Pokhara (Parajapati, 2000), however, it is not widely used or known of among the Nepalese population generally.

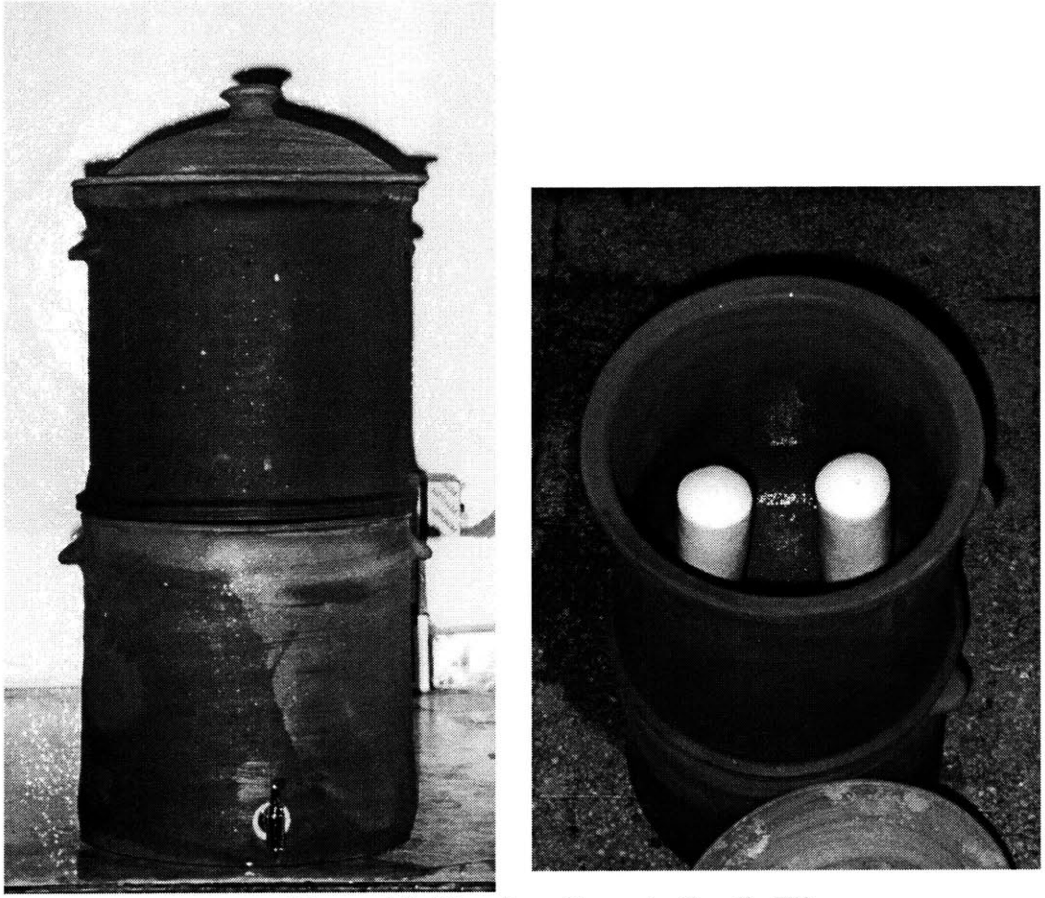

Figure 4.2: Nepalese Ceramic Candle Filter

A Nepalese ceramic candle filter consists of two ceramic containers, one placed on top of the other. The top container holds the two ceramic filter candles while the bottom container is used to receive the filtered water. The bottom container has a spigot at its base. There is a ceramic lid that fits on top of the top container. The containers and the lid are made of red clay, which is readily available in Nepal and is traditionally used by Nepalese potters. An advantage of using clay containers is that clay keeps water cool during the hotter part of the year. The slight natural porosity of the clay allows some water seepage to occur from the canister, which acts as a cooling system on the water stored (Earp, 1992).

As only red clay is available in Nepal, the ceramic filter candles are made with white clay imported from India (Prajapati, 2000). The red clay is much coarser than white clay, and thus is not suited for the ceramic filter candle material. The clay is mixed with charcoal powder so that during firing (at 1050 °C), the charcoal powder vaporizes and only the white clay is left over. The vaporization of the charcoal powder leaves the filter with enough porosity for the water to flow through it. The Nepalese ceramic filter candle appears to be identical to the Indian ceramic filter candles, yet, because they are handmade, the shape and the quality of the ceramic candles vary (some filter candles were observed to have cracks). Thus, quality control is an issue to be considered.

The method of using the Nepalese ceramic filter is the same as that of the Indian filters. The ceramic filter candles must be kept clean by regularly brushing or scraping the surface with a straight edge. The ceramic filter candles must also be replaced at least once a year (Parajapati, 2000).

4.3 Industry for the Poor, Inc. (IPI) Purifier

The IPI Purifier was developed by Industry for the Poor, Inc. (IPI), a non-governmental organization based in Satellite Beach, Florida. IPI has been working on water supply projects in Haiti and the Dominican Republic, and promotes their purifiers for use in rural communities in both of the countries.

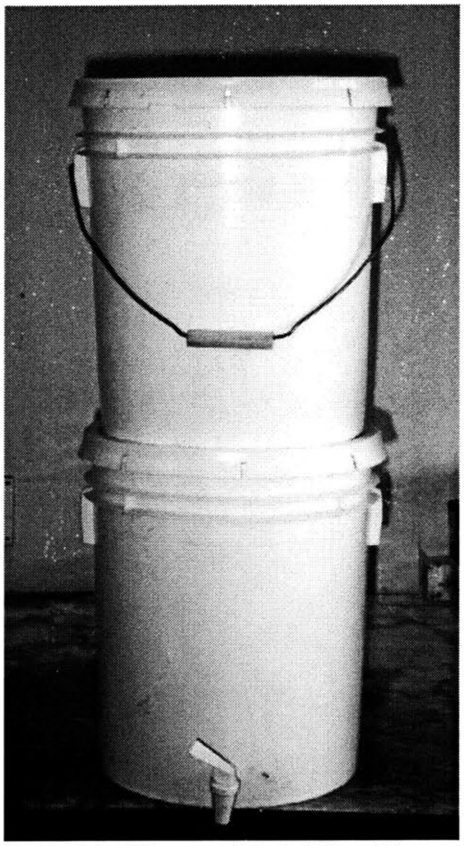

Figure 4.3: IPI Purifier

Like the Indian and Nepalese water filter systems, the IPI Purifier consists of two containers, one placed on top of the other. Both containers are made of white plastic buckets and each bucket has a capacity of twenty liters. Unlike their Indian and Nepalese counterparts that use ceramic candle filters, this purifier uses a sediment and an activated carbon filter to remove particulate impurities in the water. Furthermore, the appropriate technology purifier requires disinfection of water by chlorination before filtration of the water.

Sediment Filter

The top bucket contains a sediment filter made of a porous core with cotton string wound around the outside of it. The sediment filter is shown in the Figure4.4. The sediment filter removes particulate and microorganisms through a straining mechanism. The porosity, which determines the efficiency of impurity removal, is dependent on the tension and fitness of the string wrapped around the core. The sediment filters Tests have shown that the sediment filters remove 85% of particles with particle size of 1 micron, and the overall particle removal is expected to be 99% (Warwick, 1999). The string must be replaced periodically by removing the used string and then winding the spindle with a new string, or an entirely new string filter must be used.

Figure 4.4: IPI Purifier - Sediment Filter

The top container has a handle for easy carrying so that it can be used to collect water at the water source. There is a check valve at the bottom of the top container, and thus the water does not flow out of the container unless it is placed on top of the bottom container. The bottom container does not have a handle in order to prevent people using the container as a collection bucket. The bottom container must not be used to collect polluted source water so as to keep it free from contamination.

The top container also serves as a disinfection basin for the water. It is essential to use chlorine as a disinfectant before filtering the water with the IPI purifier. Since activated carbon can act as a media for bacterial growth the water must be free of microorganisms when passing through the activated carbon filter.

Disinfection

As mentioned above, chlorine is used as a disinfectant in this point-of-use treatment system. Chlorine bleach solution with chlorine concentration of 5.0 to 5.2% is used. When water is added to the sediment filter bucket, 9 to 14 ppm of free chlorine is added into the water to kill all microorganisms present in the water. Prior to filtration, the water is allowed to sit for half an hour after the chlorine addition for adequate disinfection. After the water filters through the sediment and activated carbon filters, chlorine solution is added to the bottom container to ensure that there is enough residual chlorine to keep the water disinfected until it is consumed. The chlorine added to the sediment filter bucket is adsorbed by the activated carbon, and thus the effluent water from the filter does not contain any chlorine.

The addition of 0.6 to 0.8 ppm of chlorine is suggested for best results in using this system. This second disinfection is strongly recommended by IPI since the Haitian climate is optimal for regrowth of microorganisms. However, this may not be required during the winter months in the colder mountainous regions of Nepal.

Accurately adding the right amount of chlorine solution into the water is a difficult task for anyone using this system. IPI developed an easy to use squeeze bottle that a user can use to measure the required amount of chlorine to be added to the filter.

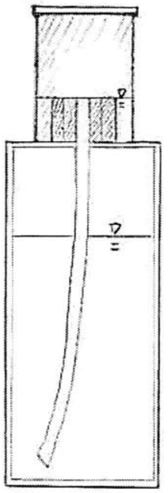

Figure 4.5: Squeeze Bottle

Activated Carbon Filter

The bottom container contains an activated carbon filter. This filter removes chemicals such as pesticides through a chemical adsorption process while ensuring that beneficial trace minerals such as calcium and magnesium remain in the water. The activated carbon also removes chlorine and THMs, the byproduct of chlorination of water. The activated carbon used in the filter is the high quality activated carbon manufactured in US.

The dechlorination of free and combined available chlorine with activated carbon can be represented by the following chemical reactions (White, 1992).

Activated carbon reacts with free available chlorine as shown:

$$C^* + HOCl \rightarrow CO^* + H^+ + Cl^-$$

C^* and CO^* represents active carbon and a surface oxides, respectively. When there are significant amounts of HOCl reacted with the carbon, some of the oxygen attached to the surface of the activated carbon may be emitted as CO or CO_2 gas as described in the following reaction.

$$C + 2Cl_2 + 2H_2O \rightarrow 4HCl + CO_2$$

The activated carbon dechlorinate chloramines by the following reactions:

$$C^* + NH_2Cl + H_2O \rightarrow NH_3 + H^+ + Cl^- + CO^*$$

$$CO^* + 2NH_2Cl \rightarrow N_2 + 2H + 2Cl + H_2O + C^*$$

$$C^* + 2NHCl_2 + H_2O \rightarrow N_2 + 4H^+ + 4Cl^- + CO^*$$

The reactions are dependent on the pressure drop within a contactor, which is depended upon the mean particle diameter of the carbon. The influent water quality, such as pH and organic and colloidal constituents also affect the dechlorination reactions (Task Force on Wastewater Disinfection, 1986).

Filter Replacement

Two ingenious concepts promote proper sediment and activated carbon filter replacements. The sediment filter must be replaced when the filter becomes clogged to the point that the water cannot flow through the filter. As this feature of the sediment filter is obvious regardless of the householders' level of technical skills, its replacement is relatively easy to encourage. However, the replacement of the activated carbon filter is not as easily noticeable for the flow rate of water will remain constant even if the active carbon is used up. When the activated carbon filter is used over beyond its useful life, the filter will no longer effectively adsorb undesirable chemicals, which can result in health problems for the system's users. The activated carbon filter wears out after approximately 6 months of constant use (Warwick, 1999). In order to ensure replacement of the activated carbon filters, excess amount of chlorine bleach is added in the top container. When the filter is performing properly, the filter adsorbs the excess chlorine and the resulting effluent water contains no chlorine. However, when the filter is used beyond its 'life', the excess chlorine makes the water's taste disagreeable such that users know immediately that they must change the filter. This is the second ingenious design feature built into the IPI purifier. The addition of chlorine in this system not only serves to disinfecting the water but also serves an important role in ensuring that people replace the filters periodically.

4.4 BioSand Water Filter

The BioSand Water Filter is a household-scale sand filter developed by Dr. David Manz of University of Calgary. The filter is presently being sold by Davnor Water Treatment Technologies Ltd. in Calgary (Palmateer, Manz, McInnis, Unger , Kwan and Dutka, 1997).

International Development Research Center (IDRC) has been promoting the filter in the Lumbini region, in the southern region of Nepal. The filter claims to be effective in removing iron, manganese, sulfur, low concentrations of gases, bacteria, viruses, waterborne parasites, algae, silt and clay (Davnor Water Technologies Ltd., http://www.davnor.com /no12/htm).

The BioSand filter system is shown in Figures 4.6 and 4.7. This system is set up to spray water into an elevated tank. It is constructed from plastic and is small enough to fit into a small kitchen. The filter consists of two layers; gravel layer and washed sand layer. The gravel layer consists of stones 1-2cm in size, a fine cloth mesh is placed on top of the layer (Palmateer et al., 1997). The sand layer consists of uniform sand particles, from 1 to 2 mm for the coarse sand, to under 1 mm for the fine sand. The water is poured into the filter to cover the layers. At the top of the sand media, a biofilm is formed and the toxicants are removed through the bioaccumulative and biodegradation ability of the biofilm. The water level in the filter must be kept at approximately 5 cm above the sand layer.

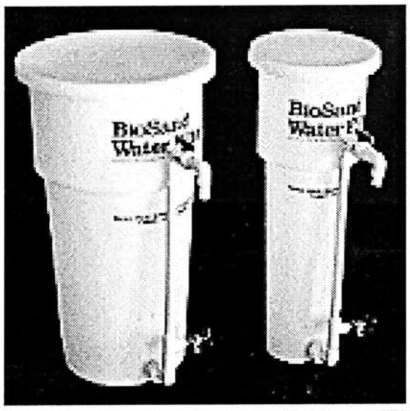

Figure 4.6: BioSand Water Filter

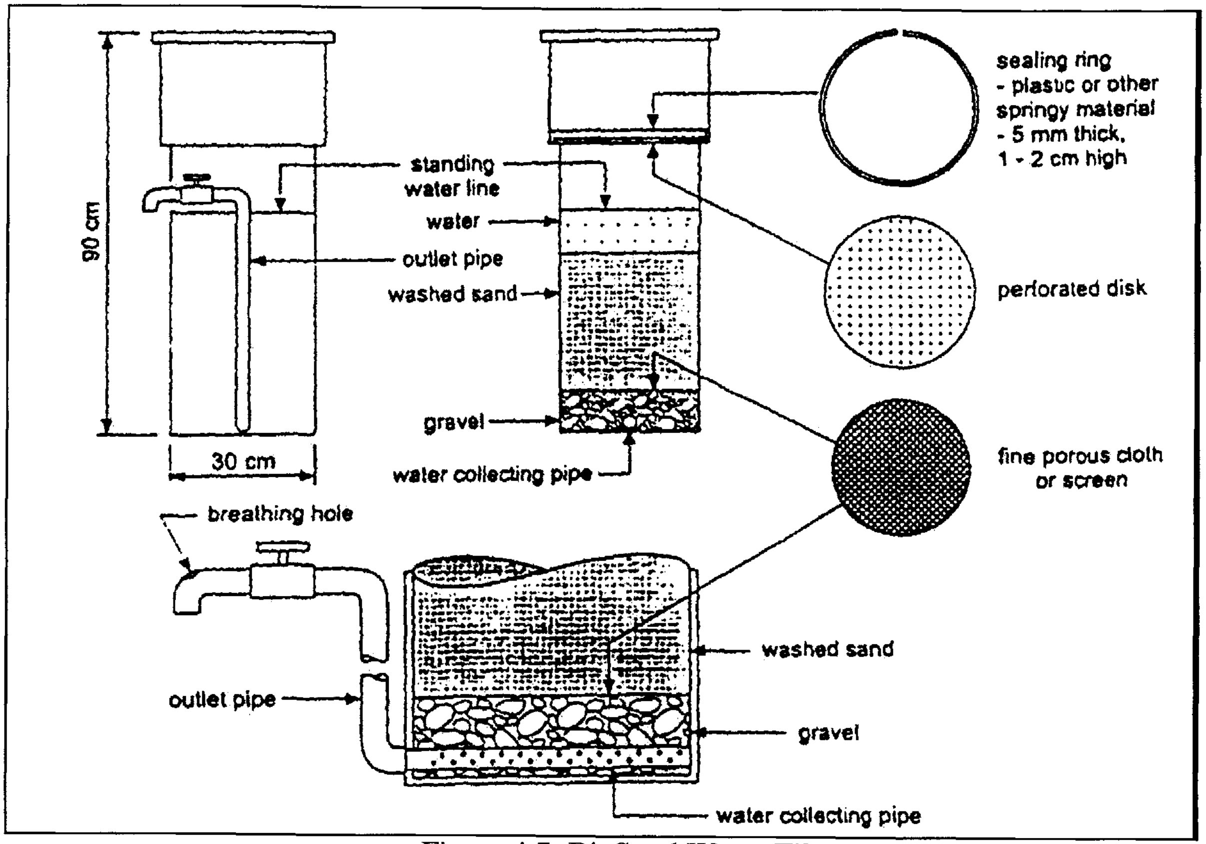

Figure 4.7: BioSand Water Filter

The BioSand water filter is reported to be able to remove more than 83% total heterotrophic bacterial populations, 100% of Giardia cysts, 99.98% of Cryptosporidium oocysts and 50 to 90% of organic (pesticides and others) and inorganic toxicants when administered in concentrations varying from 10 to 100 times environmental pollution levels (Palmateer et al., 1997).

The filter has been tested by several government, research and health institutions as well as NGO agencies. Table 4.1, shown below, summarizes the contaminant removal performance the BioSand water filter.

Table 4.1: Contaminant Removal Efficiency of BioSand Water Filter

Country	Organization	Date	Contaminant	Reported Removal (%)
Nicaragua	Instituto Nicaraguense de Acueductos y Alcantarillados	7/1993	Coliform Bacteria	99.1 – 99.6
Canada	University of Calgary	11/1995	Fecal Coliform	99.1 – 99.7
			Turbidity	94.1 – 96.1
Canada	National Water Research Institute	11/1996	Heterotrophic Bacteria	65 – 90+ (1)
			Giardia Cysts	99.99
			Organic and Inorganic Toxicants	50 – 99.99
			Total Suspended Solids	100
			Total Organic Carbon	14 – 18
			Chemical Oxygen Demand	100
Vietnam	Samaritan's Purse	11/1998	*E.coli* Bacteria	95.8 (2)
Brazil	Samaritan's Purse	11/1998	Fecal Coliform	99.7 (3)
Bangladesh	Proshika Manobik Unnayan Kendra	8/1999	Total Coliforms (river water)	99.8 (4)
			Fecal Coliforms (river water)	99.9 (4)
			Total Coliform (three households)	60 – 100 (4)
			Fecal Coliform (three households)	74.3 – 100 (4)
Canada	Montana Native Reserve	Date not available	Iron (F)	91.5
			Iron (T)	90.5
			Turbidity	85.7

(1) Damage of 10 to 15 % of schmutzdecke discovered at the end of test period
(2) Average of 32 households
(3) Average of 21 households
(4) Raw and treated water not tested on the same days
All samples show zero levels of fecal coliform and minimal levels of total coliform on day of final test
(Source: Davnor Water Technologies, Ltd.)

The maintenance of the system is very simple. No media replacement is required and no chemicals are added. The filter must be in operation for two to three weeks in order for the biofilm to form and to be able to eliminate microbiological contaminants. Once the biofilm is formed above the sand layer, the filter can be used by slowly pouring water over the perforated disk and by allowing it to drain through the filter. The perforated disk allows the water to fall over the whole filtering surface, protecting the upper sand layer and the biological layer from being damaged. The maintenance of the filter is required when the rate of water flow slows down. The water level inside the filter is lowered and 3 to 5 cm of the fine sand layer must be removed. It takes approximately 2 to 3 days to reestablish its normal operation.

The filter can be easily manufactured by assembling a plastic barrel with PVC pipes. Sand and gravel are available virtually anywhere in Nepal, and thus the cost of would be cheap. Since plastic materials are easily transported, the filter can be assembled even in rural areas of Nepal.

Although the BioSand water filter appears to be a possible and appealing option for point-of-use filtration, this slow sand filter was not obtained in time for testing during the course of the study. Thus, BioSand water filters are not further discussed in study. However, it appears to be a promising system, which should be studied further in the future.

5. FILTER EXPERIMENTS

Filtration rates, turbidity and microbial removal efficiencies were tested for the following three filters:

- Indian Ceramic Candle Filter (Bajaj Stainless-steel Ceramic Candle Filter)

The filter candle is cylindrically shaped with a height of 12cm and a diameter of 7cm. The capacity of the upper unit is 6L and holds one ceramic candle filter.

- Nepalese Ceramic Candle Filter (Nepal Ceramics Co-operative Society)

The filter candle is cylindrically shaped with a height of 17cm and a diameter of 5cm. The capacity of the unit is 10 L and holds two ceramic candle filters in the upper container.

- IPI Purifier

The capacity of the purifier is 19L.

The tests were performed at Central Laboratory of Nepal Water Supply Corporation located in Kirtipur, Nepal. The water samples tested were collected on the day of the testing. The samples came from the water tap, which was piped water supplied by the Sundarighat water treatment plant which included the Central Laboratory within its distribution system. Because the Sundarighat water treatment plant water was not chlorinated during all but three days of this study, it offered a representative sample of the level of microbial contamination local people would be exposed to.

5.1 Filtration Rate

Filtration rate is an important factor to be considered in determining the performance of the filter system. Generally, a higher filtration rate is desired for the system to be used conveniently by the users. However, higher filtration rates commonly means that the porosity is high with larger pore size, letting more impurities pass through the filter. Thus, the filtration rate of a filter is often inversely related to the contaminant removal performance.

5.1.1 Methods

The filtration rates were measured for the Nepalese ceramic candle filter. The filtration rates of Indian ceramic candle filter and of IPI purifiers have been studied by various groups and have been documented. IPI purifier is known to have a filtration rate of 19 liters per two hours or 9.5 liters per hour (Warwick, 1999). The Indian ceramic candle filters used for the study are known to have a filtration rate of approximately 0.3 liters per hour (Murthy, 1990).

The Nepalese ceramic filter test was conducted using low turbidity tap water in order to eliminate the effects of the particulate clogging the filter pores. The Nepalese ceramic candle was placed inside the Indian ceramic candle filter stainless steel container in order to measure the filtration rate of one ceramic filter candle instead of multiple of ceramic filter candles at once. This allows for a comparison of the filtration rates of one candle filter for each filter system. The

Indian ceramic candle filter container has a capacity of 6L. The container was filled to the top of the container prior to the filtration.

5.1.2 Results and Discussion

The filtration rate tests revealed that the filtration rate of the Nepalese ceramic filter is very low. When the container was filled with water to the top of the container (6L), the filtration rate was observed to be 0.24 L/hour. This is less than 3% of the IPI purifier filtration rate.

From Figure 5.1 it can be observed that approximately 15 hours is required to filter 2 liters of water through the Nepalese ceramic candle filter. As more water is filtered through, the water level in the container drops, and as a result the filtration rate was observed to decrease over time as shown in Figure 5.2. The filtration rate of Indian ceramic candle filter is also plotted in Figure 5.2 for a comparison.

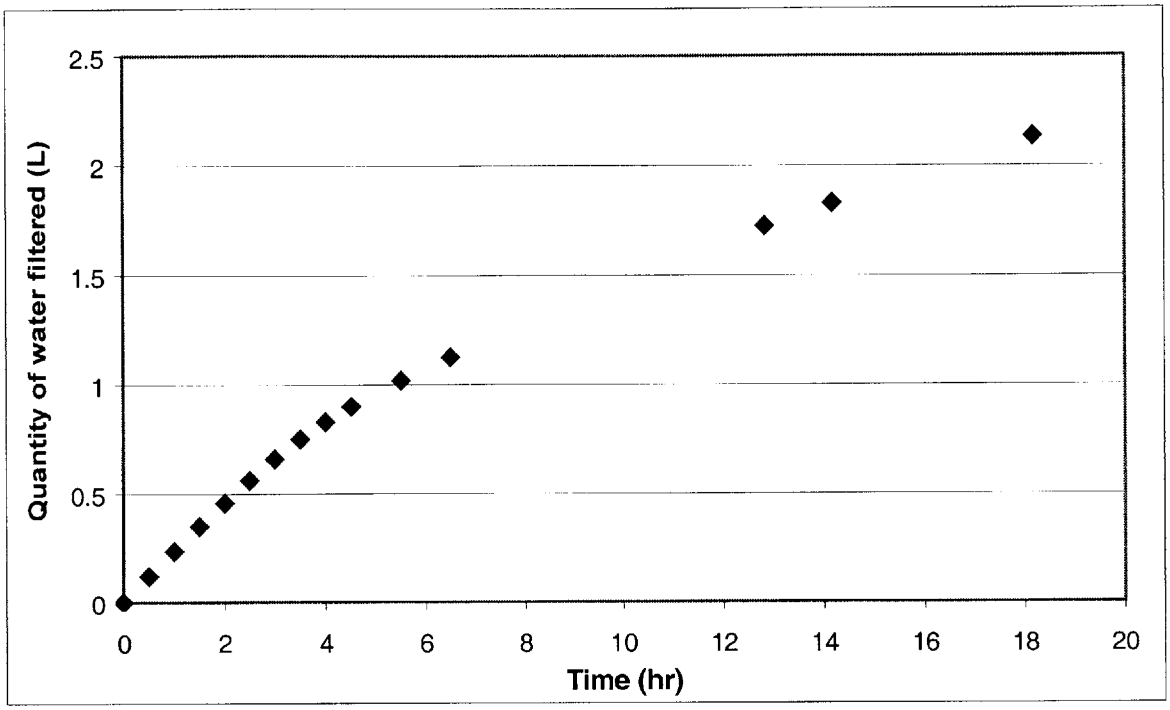

Figure 5.1: Nepalese Filter: Quantity of Water Filtered vs. Time Graph

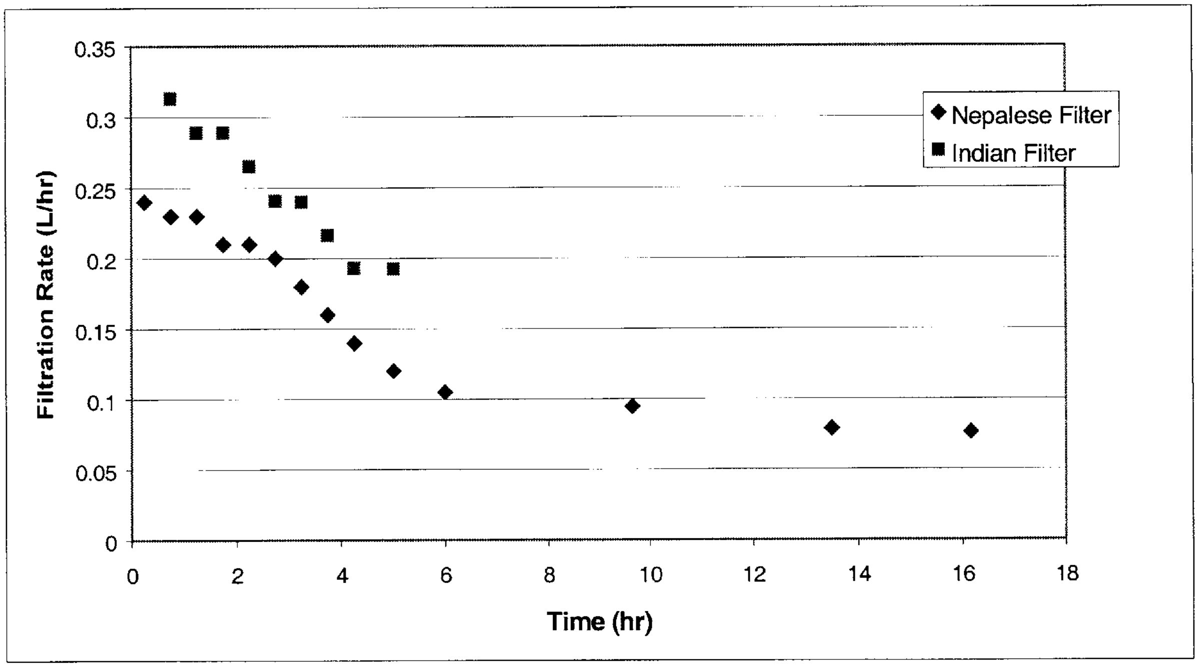

Figure 5.2: Comparison of Filtration Rate: Nepalese Filter vs. Indian Filter

It was observed that the Nepalese ceramic candle filter has a filtration rate that is approximately 30% less than that of the Indian ceramic candle filter. This low filtration rate of Nepalese filter makes it inconvenient for the users. It has to be kept in mind that the filtration rate tests were conducted using very low turbidity water. In Nepal, such low turbidity water is rarely available. Thus, the filtration rate is expected to be even lower than that observed in the experiment. This very low filtration rate of the Nepalese ceramic candle filter suggests that the Nepalese ceramic candle filter must be used with more than one ceramic filter candle. Using multiple ceramic filter candles in one filter system will increase the filtration rate accordingly. Use of a top container with a larger volume and taller container will also increase the filtration rate due to the increased head above the filter candle.

It was observed during the test that when the water level is above the height of the ceramic filter candle the filtration rate was much higher compared to when the water level dropped below the height of the ceramic filter candle. Using a shorter and wider ceramic filter candle could be another method of increasing the filtration rate of the filter. It is recommended that the user fill the filter system with water at night so that the water will be available for use in the morning.

5.2 Turbidity

Turbidity is a water quality parameter which quantifies the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles. The scattering of light increases as the suspended load increases. Turbidity is commonly measured in Nephelometric Turbidity Units (NTU), but may also be measured in Jackson Turbidity Units (JTU).

Organic constituents in water may harbor microorganisms, and thus water with high turbidity generally has a higher concentration of pathogens and a higher possibility of transmitting waterborne diseases. The WHO standard for the turbidity level in drinking water is set at 5 NTU.

5.2.1 Methods

The water samples used for the experiments were from tap water at Central Laboratory and the untreated inflow water of Sundarighat water treatment plant in Kirtipur district near the Central Laboratory. The Sundarighat water treatment plant treats the water that is supplied at the Central Laboratory.

Initially, the water was tested for turbidity before being filtered. The instrument used to measure turbidity was A Hach 2100P portable turbidimeter. Water was then passed through the various filters. The filtered water was collected directly from the filters into sample bottles in order to avoid any contamination of the sample after filtration. This step was especially crucial for Nepalese ceramic candle filter as the brand-new ceramic container that was used to collect the treated water in this system released clay particles into the water, increasing the turbidity of the treated water. The filtered water was then tested for turbidity using the turbidimeter.

5.2.2 Results and Discussion

The test results showed that the turbidity of the tap water from the Central Laboratory during the dry season month of January when these tests were performed was often satisfactory without filtration. It was found that the tap water generally had turbidity ranging between 4 and 9 NTU. However, turbidity levels fluctuated due to the frequent operational and maintenance problems at the water treatment plant. These problems often caused turbidity levels to rise to as high as 28 NTU.

Following filtration, turbidity of the treated tap water was reduced to less than 1 NTU for all three filters tested. This level is well within the acceptable drinking water quality standards of 5NTU as set by WHO. The Indian ceramic filter was observed to remove turbidity with the highest efficiency, followed by Nepalese ceramic filter and then IPI purifier. However, the differences in performance of the three filters were minimal.

The inflow water from the Sundarighat water treatment plant was found to have turbidity levels varying between 8 and 15 NTU. Even when raw water with higher turbidity levels was used, the turbidity of the treated water was found to be below 1 NTU. The average turbidities of the raw water and the filtered water using various filter systems are shown in Figure 5.3

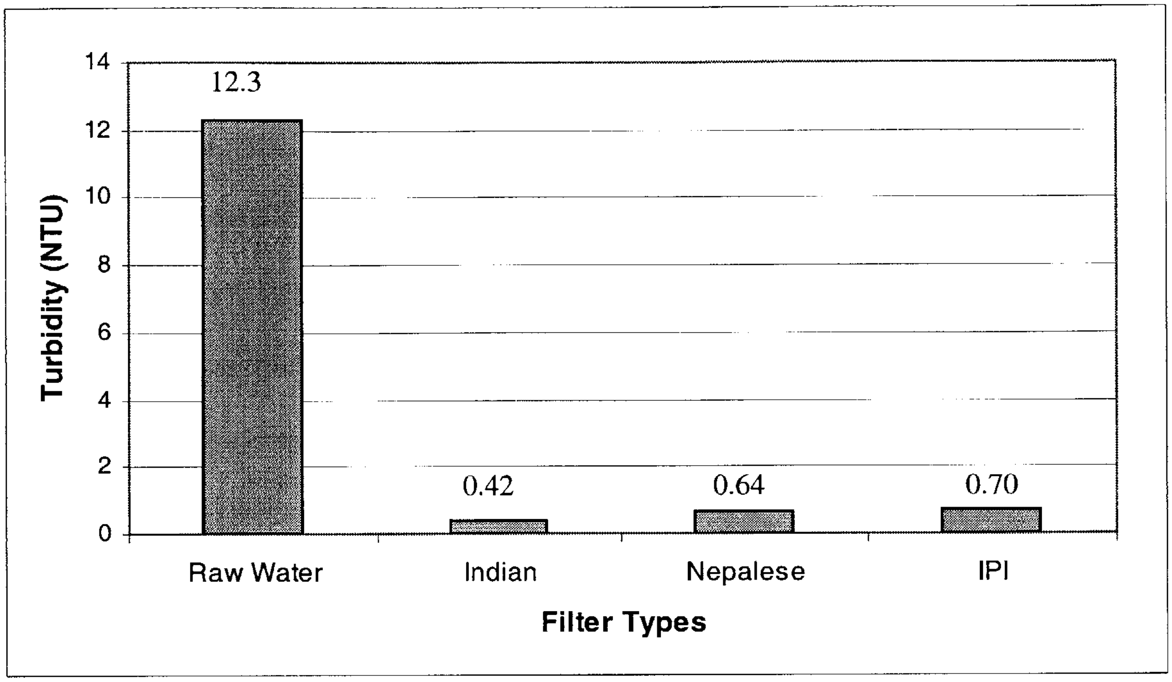

Figure 5.3: Turbidity of Filtered Water by Various Filters

It was also observed that in the case of ceramic candle filters, the higher the turbidity of the raw water, the lower the turbidity of the treated water. This is due to the fact that as the particles in water get filtered by the ceramic candle the effective pore size of the filter gets smaller due to the clogging the pores by the filtered particles.

The turbidity removal efficiencies of the three filters tested are graphed in Figure 5.4. It can be observed that all three filters performed approximately the same in removing turbidity.

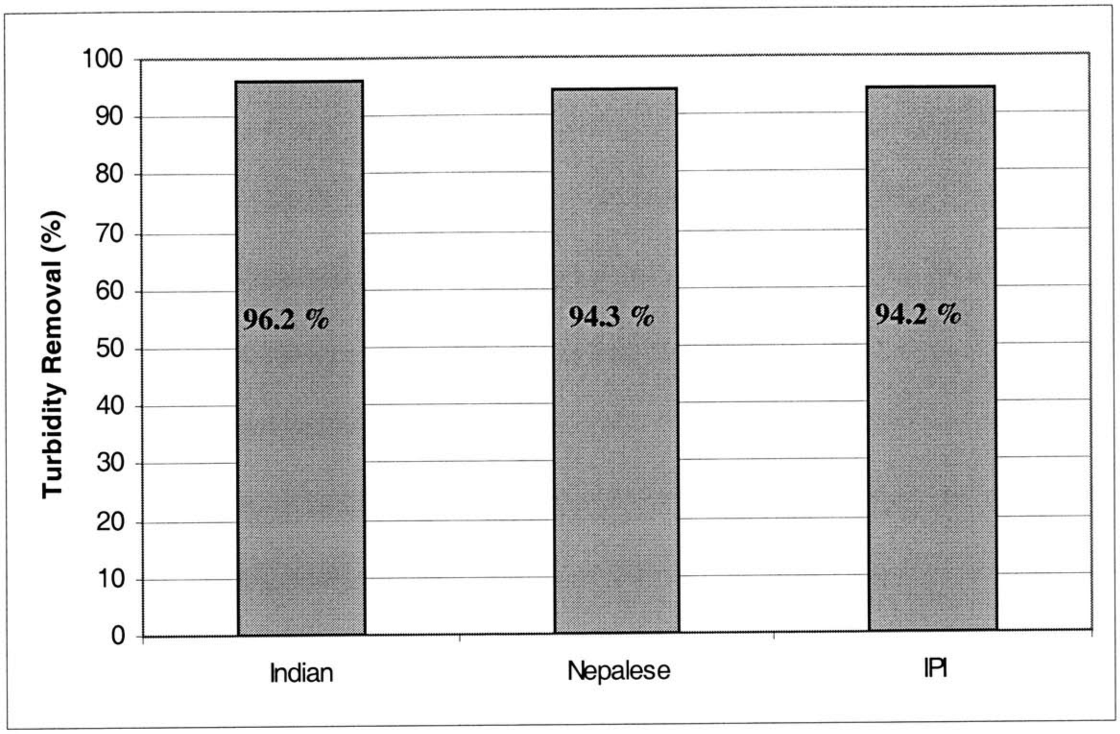

Figure 5.4: Comparison of Turbidity Removal Efficiencies of the Filters

5.3 Microbial Tests

The microbiological contamination is the most important issue concerning drinking water in Nepal (Wolfe, 2000). Therefore, microbiological parameters for the drinking water must be tested in order to ensure that the drinking water is free of pathogenic organisms, which causes the waterborne diseases, the leading cause of childhood death in Nepal.

Two microbial tests were used to determine the performance of the filters in terms of removing microbiological parameters.

Presence/Absence (P/A) Test for Total Coliform and *Escherichia-Coli* (*E. coli*)

The coliform group of organisms is the most widely used indicator organisms for water quality testing. Fecal coliforms, a subset of the total coliform group are associated with the intestinal tract, whose presence in water indicates that the water has received contamination of an intestinal origin. Since the water in Nepal is often contaminated with fecal pollution this is an important parameter to be tested for drinking water. The presence of *E.coli*, a subset of the fecal coliform group, or fecal coliforms, theoretically confirms the suspected presence of pathogenic organisms in the water (DeZuane, 1996). The WHO drinking water guideline states that the total coliform and *E.Coli* concentrations in the water must be zero colony forming units per 100 mL of sample.

Most Probable Number (MPN) Test for Hydrogen Sulfide (H_2S) Producing Bacteria

The H_2S producing Bacteria Tests aids in identification of microorganisms such as *salmonella*, *citrobacter*, *arizona*, *adwardsiella* and *proteus* (Hach, 1997). Those organisms produce H_2S by breakdown of sulfur amino acids or reduction of thiosulfate. MPN test detects H_2S in iron-rich medium by formation of black ferrous sulfide (Brock and Madigan, 1991). H_2S producing bacteria test is less sensitive to temperature changes than tests of other microorganisms, and thus can be performed in rural and remote areas where screening is often difficult (Wolfe, 2000).

5.3.1 Methods

The water samples used were the same water samples used in the turbidity test. In order to avoid contamination, the laboratory workspace was wiped down with chlorine bleach or alcohol before commencing the tests. The glass bottles were sterilized by heat-treating them in the oven for more than one hour. The bottle caps were sterilized by boiling them for more than half an hour.

Three filters were tested for the removal performances of microbiological parameters. The IPI Purifier was tested for two cases: with chlorination and without chlorination. In the case of chlorination, chlorine bleach was added at a 20 ppm concentration as recommended by IPI. The water was allowed to sit for half an hour prior to filtration.

P/A Test

100 mL of water sample to be tested was collected into a sterilized glass container. This water was poured through the filter and collected directly into a sterilized container in order to avoid any contamination of the sample. Once the water sample was collected, P/A Broth mixed with MUG reagent was added. The ampules containing the reagents were opened using a sterilized Hach P/A Ampule Breaker to prevent contamination due to handling.

One P/A test was performed for each filter. The labeled bottles with water sample and reagents were then placed into an incubator for 24 to 48 hours at an incubation temperature of 35°C.

The results of the test were examined the following day. Total coliform results were examined by observing the color of the medium. The positive tests for total coliform show a color change from purple to yellow. If the color of the sample remains purple, the test result is negative.

The results for *E.coli* were determined by examining the incubated samples for fluorescence under a portable UV light. If the sample fluoresced under UV light, it was positive for *E.coli*. If no fluorescence was observed, the sample was negative for *E.coli*.

MPN Test

A 20 mL filtered water sample was collected in a sterilized tube. The Hach PathoScreen Medium MPN Pillow was wiped with alcohol and was aseptically cut open with sterilized clippers. The pillow contents were added to the sample and a sterilized screw cap was placed on the tube immediately. Five samples were collected from each filter. The bottles were labeled appropriately for easy identification. The bottles were then placed into an incubator at 35°C for 24 to 48 hours.

The results of the test were determined the following day. The test results were interpreted according to the instructions provided in the Hach water analysis handbook. Positive reactions were identified by:

- Color change from yellow to black
- Formation of black precipitate

If the sample stayed yellow after 48 hours of incubation the sample was considered negative for H_2S producing bacteria.

The number of positive tubes were counted and the most probable number of H_2S producing bacteria was determined using Table 5.1.

Table 5.1: MPN Determination

Positive Tubes	MPN/100 mL
0	< 1.1
1	1.1
2	2.6
3	4.6
4	8.0
5	> 8.0

(Source: Hach, 1997)

5.3.2 Results and Discussion

P/A Test

The test results revealed that the three tested filters performed with different levels of efficiency with regard to microbial removal. The P/A test results are summarized in Table 5.2.

Table 5.2: P/A Test Results

Filter Type	Total Coliform	*E.coli*
IPI Purifier (with Cl)	-	-
IPI Purifier (without Cl)	+	+
Indian Ceramic Filter	+	-
Nepalese Ceramic Filter	+	+

+ represents positive
- represents negative

The IPI purifier was found to be the best in removing total coliforms and *E.coli* when combined with chlorine disinfection. The test showed that the chlorinated water filtered through the IPI purifier was negative for both total coliforms and *E.coli*. However, without addition of chlorine, the IPI filtered water showed positive results for both total coliforms and *E.coli*.

The water filtered through the Indian ceramic filter tested negative for *E.coli*, however, test showed positive results for total coliforms. The water filtered through the Nepalese ceramic filter tested positive for both total coliform and *E.coli*.

MPN Test

The experiments showed once again that the IPI purifier with chlorine disinfection had the highest efficiency in removing H_2S producing bacteria. All tests showed that the water filtered by the IPI purifier with the addition of 20ppm of chlorine contained less than 1.1 bacteria per 100 ml of water. However, without chlorine disinfection the IPI filter did not remove H_2S producing bacteria adequately. The results are summarized in Table 5.3.

Table 5.3: MPN Test Results

Filter	MPN (bacteria / 100mL)
Raw Water	> 8.8
IPI Purifier (with Cl)	< 1.1
Indian Ceramic Filter	1.6
Nepalese Ceramic Filter	3.9

Among the ceramic filters, once again, the Indian ceramic filter was found to perform better in removing hydrogen sulfide producing bacteria than the Nepalese ceramic filter.

The percentage removals of hydrogen sulfide producing bacteria by the filters were not obtained since the MPN test used could not give any lower value than 1.1 MPN/100mL. Also, only 4 experiments were carried out, out of which one set of the data was invalid due to the fact that the Sundarighat water treatment plant water source that was used for the tests was chlorinated on that particular day. More quantitative results could be obtained if testing methods such as membrane filtration or plate counts were used, where one could actually count the number of colonies. However, due to limited time, modest resources and the sanitary condition of the laboratory in Nepal, the MPN test was considered the best suited for our purposes.

6. IMPROVEMENT OF CERAMIC FILTER CANDLES BY COLLOIDAL SILVER COATING

Due to the imperfect performance of the ceramic filters found through the experiments described in Chapter 5, possible improvements of the filters were investigated. From the microbiological tests performed, it was observed that the filter systems by themselves were not adequate in producing microbiologically safe drinking water. The filter systems are recommended to be used along with a disinfection process. Because of its germicidal effect on microorganisms, colloidal silver coating on ceramic filter candles was studied as a possible improvement of ceramic candle filter for microbiological contamination removal. By applying colloidal silver directly onto the ceramic filter candle, filtration and disinfection steps can be combined into one process, making the system still simple to operate for the users. There is no measuring or addition of disinfectant required to treat the water.

6.1 Colloidal Silver

Colloidal silver is a suspension of submicroscopic metallic silver particles in a colloidal base (Barrett, 1999). In recent years, colloidal silver solution is sold at many health food stores in US as a homeopathic remedy. The effectiveness of colloidal silver for curing diseases is not proven, however silver's germicidal properties is used as disinfectants. In Mexico, for an example, colloidal silver is commonly used as drinking water disinfectant and is available at any pharmacy (Rivera, 2000). Colloidal silver acts as a catalyst, disabling the oxygen metabolism enzyme of microorganisms, such as virus, fungus, bacterium or any other single celled pathogen (Colloidal Silver Discovery Center homepage, http://www.colloidal-silver.com).

Colloidal silver is made by electrolysis. In a colloidal silver solution, microscopic particles of pure, elemental silver are found suspended in water. Each particle of silver carries a positive electrical charge. The particle size of colloidal silver ranges between 0.001 and 0.004 microns (Lindermann, http://www.elixa.com/Silver/lindermann.htm). Due to the extremely small size and the positive electric charge, the particles remain suspended in the solution. Silver is also available in a salt and ionic form, however, colloidal silver is proven to be the most effective disinfectant among all forms of silver due to its extremely small particle size. Using equivalent amounts of silver, colloidal silver provides the largest effective surface area in contact with water compared to any other forms of silver. Colloidal silver kills bacteria in silver concentrations as low as 10 ppb (Earp, 1992).

6.2 Health Effect

Silver is potentially toxic to human health. It can act as a heavy metal poison in the human body (Lindermann). Overdose of silver in a human body can cause Argyria, a permanent blue-gray discoloration of the skin caused by the build-up of silver compounds in the skin, organs and other tissues (Barrett, 1999). According to the WHO, a continuous daily dose of as little as 0.4 mg of silver may produce Argyria. Reports also suggest that the intake of metallic silver can lead to symptoms such as increased tendency toward emotional outbursts and mental excitability (Lindermann). However, the manufacturers of colloidal silver claim that if "pure" colloidal silver is used within the acceptable intake amount there is no negative effect on human health. Most Argyria cases reported were likely caused by the use of silver nitrate, a compound more easily absorbed by the human body. In Mexico colloidal silver is used as a principal disinfectant (Earp, 1992) and is available at any Mexican pharmacy (Rivera, 2000). Although commonly used, no negative health related side effects resulting from the use of colloidal silver have been reported in any of the thirty Mexican states (Earp, 1992). As the human body does not readily absorb colloidal silver, the excess silver deposited in the stomach upon digestion of colloidal silver is precipitated as silver chloride by the stomach bile, and almost immediately excreted through the feces. (Earp, 1992). However, high concentration of colloidal silver can be fatal even with a single dose to humans (DeZuane, 1996). Thus, the use of colloidal silver should be limited within the acceptable intake levels.

6.3 Current Colloidal Silver Application on Filters by Potters for Peace

The ceramic water filter developed by Ecotextura in Nicaragua uses colloidal silver coating as a method for disinfecting water. These filters are promoted among communities in Nicaragua by the NGO organization, Potters for Peace. The colloidal silver that they currently use is called Microdyn and is manufactured and sold in Mexico. It is a colloidal suspension of ionic and molecular silver in soluble and insoluble fractions dispersed in a protein carrier (Earp, 1992). After vitrification, a solution containing colloidal silver is brushed onto the surface of the filter medium. Porosity of the filter should be such that water flowing through its pores can be in contact with the silver compounds for at least twenty minutes to assure proper disinfection (Earp, 1992). Potters for Peace claims that when permeated into a filter medium, a standard dose rate for the silver can be maintained for up to one year, due to it's insoluble component. After one year of continued use, re-coating of the filter becomes necessary.

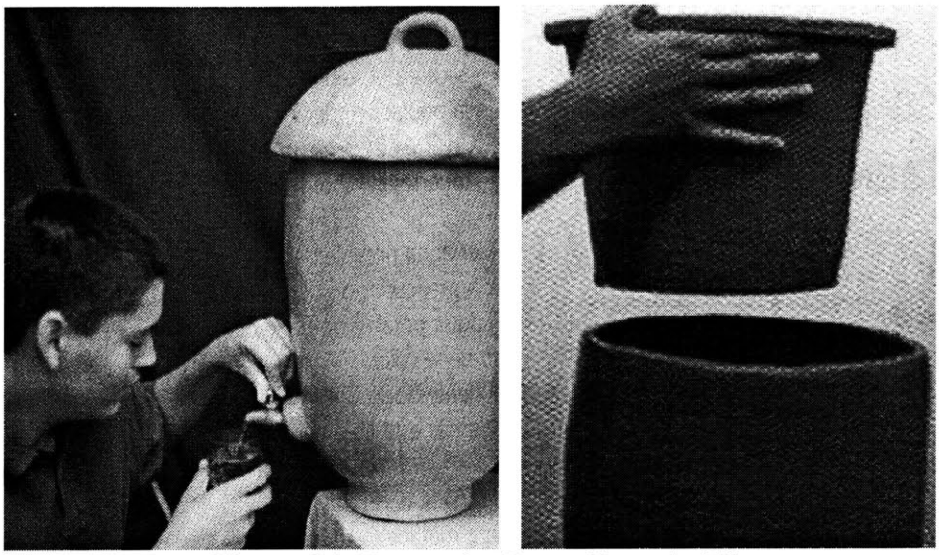

Figure 6.1: Potters for Peace Ceramic Filter

The filters manufactured by Potters for Peace consists of a ceramic bowl, which acts as a filter, attached on top of a ceramic container as shown in Figure 6.1. Water that is poured into the bowl is filtered through the bowl and the treated water is collected into the ceramic container underneath it. Colloidal silver is applied on the upper ceramic bowl component. The colloidal silver solution that is applied onto the ceramic filter has a silver concentration of approximately 110 ppm. The volume of colloidal silver solution that is applied onto the ceramic filter is 300 mL.

6.4 Method of Application of Colloidal Silver Coating on Ceramic Filters

The ceramic filter candles were first boiled in water and then dried. Microdyn, colloidal silver solution with the silver concentration of 0.34% was diluted with distilled water in order to make the colloidal silver solution to coat the filter candles. The silver solution was applied onto the ceramic candle filter by a soft brush.

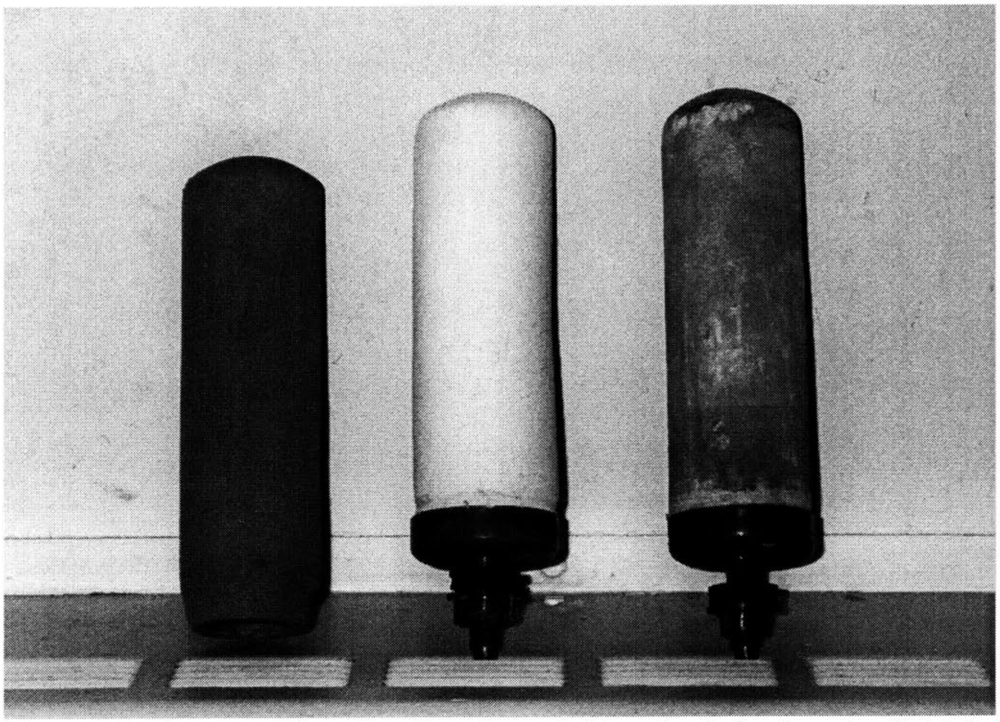

Figure 6.2: Nepalese Filter Candle – from right, unfired, fired, and colloidal silver coated filters

The silver solutions of five different concentrations were prepared in order to determine the change in microbial removal efficiency with differing colloidal silver concentration. 100 mL of distilled water was mixed with 1 ml, 2 ml, 3 ml, 4 ml and 4.5 ml of 0.34 % colloidal silver. Chlorinated water could not be used to dilute the colloidal silver solution since chlroine inactivates the effectiveness of colloidal silver as a disinfectant (Revera, 2000). In each case, the entire batch of colloidal silver solution was used to coat each ceramic filter candle. After coating, the filter candles were left to dry. Clean non-chlorinated water was then filtered through the filter candles in order to remove any excess silver, as the excess silver can cause a metallic taste in filtered water.

The colloidal silver-coated filters prepared are summarized below in Table 6.1.

Table 6.1: Colloidal Silver Coated Filters Prepared

Filter #	Colloidal silver solution used (ml)	Concentration of silver solution (ppm)	Total silver applied (mg)
1	1	34	3.4
2	2	67	6.8
3	3	99	10.2
4	4	131	13.6
5	4.5	146	15.3

The silver concentrations of the colloidal silver solutions were decided based on the colloidal silver concentration used by Potters for Peace. The silver solution weight used for coating one Nepalese ceramic filter candle was chosen to be less than the amount used by Potters for Peace due to the fact that Nepalese ceramic filter candles are much smaller than the ceramic bowls that are used by Potters for Peace.

6.5 Microbiological Testing of Silver Coated Ceramic Filters

6.5.1 Methods

Hach MPN tests were used for the analysis of water samples from the silver coated ceramic filters. The methods of analysis are the same as those described for filter experiments described in Chapter 5. The raw water used in the experiment was collected from Charles River in

Cambridge, Massachusetts on the day of the experiment. Hach P/A test was used to analyze the water that was filtered through filter #4 and #5 to examine the removal of total coliform and *E.coli* organisms.

6.5.2 Results and Discussion

It was observed from the experiments that the application of colloidal silver does reduce the microbiological contamination level of the filtered water. The results of the MPN test is shown in Table 6.2.

Table 6.2: MPN Test Results for Colloidal Silver Coated Filter Candles

Filter #	Silver (mg)	No. of Positive	MPN (/100mL)
1	3.4	3	4.6
2	6.8	1	1.1
3	10.2	0	<1.1
4	13.6	0	<1.1
5	15.3	0	<1.1

It was found that filter candles with silver loading of more than 10.2 mg produced filtered water with hydrogen sulfide producing bacteriological contamination below the detection limit of 1.1 bacterias per 100 mL.

The filter #4 and #5 were also tested for total coliform and *E.coli* by P/A test. The test results showed that both #4 and #5 filters removed both *E.coli*, however, neither removed total coliform.

Table 6.3: P/A Test Results

Filter #	Total Coliform	*E.coli*
4	+	-
5	+	-

The results of this experiment show that the colloidal silver is in fact effective in reducing the microbial contaminant level in water, and is a promising disinfection process to be used along with the ceramic filter candles. A satisfactory colloidal silver coated filter candles fulfills filtration and disinfection processes at the same time, and thus is an ideal configuration for an easy-to-use filter system. However, in this study, the colloidal silver coated ceramic filter candles did not eliminate total coliform contamination completely. A higher concentration of colloidal silver maybe required to be applied on the ceramic filter candle to adequately disinfect the water. Further study is required to determine the necessary silver concentration for the elimination of total coliform contamination.

Furthermore, in this study it was not verified whether the colloidal silver coating remains effective after long-term use of the filter. Potters for Peace reapply colloidal silver on their filters every year. The Nepalese ceramic filter candles must be replaced every 8 to 12 months, however, since the ceramic material of Nepalese ceramic filter is different from that used for the Potters for Peace filters, the long lasting effect of the colloidal silver when applied onto the Nepalese ceramic filter is unknown. There are previous studies on colloidal silver coated filter candles produced in India, which refute the effectiveness of colloidal silver coating for complete disinfection of filter treated water (Kulkarni et al, 1980). Thus further studies are required.

7. CERAMICS ANALYSIS

The filtration rates of the filters depend on the ceramic filter candle characteristics such as porosity and pore size. The turbidity removal also depends on the pore size of the filter. Thus, it is important to analyze the filter candles for the physical characteristics. In this study, detailed physical analyses of the ceramic filters were not conducted due to limited time and resources. In this chapter, the methods of the physical analysis of ceramic filters are described.

7.1 Porosity

The porosity of a ceramic material, particularly a fired ceramic is usually a very carefully controlled property (Jones and Berard, 1972). The greater the porosity, the greater the filtration of water through the material. The porosity is calculated by dividing the total pore volume by the bulk volume. The total pore volume consists of both closed pore and open pore volumes; however, only the open pore volume can be directly measured. Furthermore, since the porosity of concern for filtration process is the open pore, only the apparent porosity, consisting of only the open pore volume, is discussed.

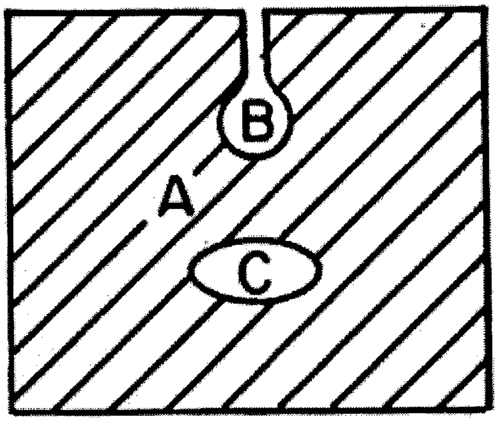

Figure 7.1: Types of Volumes in a Ceramic Body
A – solid volume, B – open pore volume, C – closed pore volume

The apparent porosity of a ceramic material can be calculated by the following equation.

$$\%Pa = \frac{Vop}{Vb} \times 100$$

where Vop and Vb are open pore volume and bulk volume respectively.

The volumes can be measured by submerging the material into a liquid and measuring the volume of liquid displaced. The apparent porosity can also be calculated by:

$$\%Pa = \frac{Ws - Wd}{Ws - Wss} \times 100$$

where Ws, Wd and Wss are saturated weight, dry weight and the weight of the saturated sample when submerged in the liquid. Ws – Wss represents the loss in weight of solid when submerged in the liquid. The loss in weight is equal to the weight of the fluid which the object displaces, and thus is related to the volume of the object. Saturation is usually accomplished by boiling in the liquid or by evacuation of air from the open pores followed by a long soaking period (Jones and Berard, 1972).

7.2 Pore Size

The shape and the size of pores are also important physical parameters that determine the characteristics of the ceramic material. The size and the shape of pores can be determined by observing the microstructure of the material. The most widely used optical methods are observations of thin sections with transmitted light and observations of polished sections with reflected light (Kingery, Bowen and Uhlmann, 1976). The grain size of the ceramic material can also be observed by analyzing the microstructure of the material.

8. COST ANALYSIS

The point-of-use treatment system to be used in Nepal must be cheap and widely available for all the population. The cost and availability of the proposed filters were investigated.

Nepalese Ceramic Filter

The Nepalese ceramic filter system is currently sold for a total cost of approximately US$3 (NRs210) at Nepal Ceramics Co-operative Society. The two containers with a lid and a spigot are sold for US$2 (NRs140) and the ceramic candles are sold for 50 cents (NRs35) each. These prices, however, are the wholesale price that Nepal Ceramics Co-operative Society sells for retail sellers. The filters are currently sold to individual users for US$4 to US$6. The Nepalese ceramic filters are currently handmade, thus the quantity of systems available on the market is limited. However, mass production of filters will be possible if simple automated machinery is incorporated into their manufacturing process. According to Hari Govinda Parajapati, the president of Nepal Ceramics Co-operative Society, if filters can be produced in larger quantities, the price of the filter system could be lowered.

Indian Ceramic Filter

The prices of various Indian manufactured filter candles and filter systems are listed below in Table 8.1. The prices stated are the price of one filter unit if 500 filters were ordered directly from the manufacture. These filters are widely available in Nepal, especially in the Kathmandu region, however, the prices the Nepalese people are currently paying for them are higher than the prices stated in the table. The ceramic candle filters are sold separately for US$1.50 to US$2.00.

Table 8.1: Prices of Indian ceramic candle filters

HIMAL	
Capacity (L)	Price US$ (NRs)
11	10.00 (700)
16	13.20 (925)
21	16.40 (1145)

PURO	
Capacity (L)	Price US$ (NRs)
15	12.00 (825)
20	14.60 (1025)
27	18.70 (1308)
32	23.20 (1623)

KIMAL	
Capacity (L)	Price US$ (NRs)
13	9.30 (650)
16	10.00 (700)
18	11.40 (800)
21	12.90(900)
25	14.30 (1000)

SWAGAT	
Capacity (L)	Price US$ (NRs)
13	8.60 (605)
16	9.30 (652)
18	10.80 (757)
21	12.30 (862)
25	15.30 (1072)
30	16.80 (1177)

MILTON	
Capacity (L)	Price US$ (NRs)
13	8.60 (605)
16	9.30 (652)
18	10.80 (757)
21	12.30 (862)
24	15.30 (1072)
27	17.10 (1200)

Many Nepalese people buy the ceramic candles and assemble them with plastic buckets, which they can purchase anywhere because such plastic buckets are usually available in Nepal. Such a plastic bucket filter system is shown in Figure 8.1. Using the plastic buckets results in a lower cost than buying the stainless steel filter unit. However, this also increases the risk of system failures. Plastic buckets are not as durable as stainless steel containers and are also susceptible to deformation. Furthermore, when drilling holes in the plastic buckets necessary for ceramic candle filter installation, care must be taken so that there is no leakage of water around the hole. The costs of plastic buckets and the accessories are listed in Table 8.2 below.

Figure 8.1: Plastic Bucket Filter System

Table 8.2: Prices of Filter Materials and Accessories

Material	Price US$ (NRs)
Plastic bucket	0.90 (60-65)
Bucket lid	0.30 (20)
Spigot	0.20 (15)
Holes	0.15 (10)
Total	2.75 (170)

IPI Purifier

According to IPI, the IPI purifiers that are currently used in Haiti cost approximately US$15 each. This cost includes material cost as well as shipping and maintenance costs. Also, there is a cost of US$1.88 per filter, which pays the worker's wages at the filter assembly factory in Haiti.

String-wound sediment filters are available in Nepal, although they are not found commonly in the market. One string-wound sediment filter is sold for US$5 (NRs350). Activated carbon is also available in the market for US$5 (NRs350) per kilogram (Karanjit, 2000). However, chlorine bleach solution suitable for drinking water disinfection is not readily available in Nepalese market for household use. The only chlorine bleach available for the households in Nepal is the scented and colored bleach for laundry purposes. Bleaching powder is available from India suppliers but is typically only procured by the Nepal Water Supply Corporation for use in Kathmandu drinking water treatment plants. Thus, if IPI purifier is used in Nepal chlorine procurement strategies or alternative disinfection method must be selected.

Logistics

In order for the filters to be promoted in Nepal, they must be transported to the users from the place where the filters are manufactured. Nepal is a nation lacking an extensive transportation infrastructure. Its mountainous geography makes it difficult to develop an efficient transportation infrastructure network in the country.

Nepal's main highways have the total length of 7,700 km, out of which 3,196 km, less than half, are paved. Only cities are accessible by vehicles. There are also railroads in Nepal with a total length of 101 km, however, they are only in the Kosi region, close to the Indian border.

It could be difficult to transport ceramic filters to rural areas of Nepal since even if there is a road for vehicles, the bumpy road conditions could lead to breakage of the filters. Nepalese ceramic filters are especially susceptible to breakage during transportation since the containers are also made of ceramics. In places where the transportation infrastructures are not developed, goods are transported to villages by foot. Thus, heavy and bulky merchandise is not easily transported to such areas. Nepalese ceramic filters are probably not suitable for rural areas of Nepal for the above reasons. However, by substituting the ceramic containers by plastic buckets that are available virtually everywhere in Nepal, the logistics constraints can be minimized.

The costs of different filtration systems are summarized below in Table 8.3. Several combinations of filter candles with accessories were considered in the analysis.

Table 8.3: Costs of Filtration Systems

Filter System	Cost (US$)
Nepalese Ceramic Filter (2 candle filters, ceramic container)	3.00
Nepalese Ceramic Filter (2 candle filters, bucket container)	3.25
Nepalese Ceramic Filter (3 candle filters, bucket container)	3.75
Indian Ceramic Filter (stainless container)	8.60 – 23.20 (depends on the capacity)
Indian Ceramic Filter (2 candle filters, bucket container)	5.75 – 6.75
IPI Purifier	15.00

Among all the filter systems considered, Nepalese ceramic candle filter remains the most affordable option for the Nepalese people. Replacing the ceramic containers with plastic bucket only slightly increases the cost of the system, however, this option is recommended if the system was to be used in rural areas, since the transportation of plastic containers is so much easier and cheaper than ceramic goods. Use of plastic buckets instead of the ceramic containers also allows the system to be used with more than two ceramic candles. The filtration rate of the Nepalese ceramic candle filters was determined to be very slow in the filter experiments. The greater the number of ceramic candle filters used the higher the filtration rate of the system. This will significantly improve ease-of-use of the filter system. In the filtration rate experiments, Indian ceramic filter candles were found to have higher filtration rates than the Nepalese ceramic filter candles, thus more filter candles will be required for Nepalese ceramic candle filters in order to achieve the same flow rate. However, since an Indian filter candle costs at least three times as much as the Nepalese filter candle, it is still cheaper to use Nepalese filter candle.

The Indian ceramic candle filter with stainless steel containers and IPI purifier were considered to be too expensive for the majority of the population in Nepal. However, the price of the IPI purifier given in Table 8.3 is the cost of the purifier being used in Haiti. If the same purifier were to be manufactured in Nepal or in India, it might be produced at a lower cost.

9. SOCIAL ACCEPTABILITY

One integral aspect of Nepalese society is the existence of the Hindu caste system, modeled after the ancient, orthodox Brahmanic system of the Indian plains. This caste system became the basis of the existing economic structure of Nepal. Many Nepalese customs that exist at the present time in Nepal have been affected by this caste system.

There are four main caste divisions in Nepal, which are listed in Table 9.1.

Table 9.1: Caste System of Nepal

Brahman	Priests and scholars
Kshatriya or Chhetri	Rulers and warriers
Vaisya	Merchants and traders
Sudra	Farmers, artisans and laborers

The caste structure is claimed to represents a rank order of values bound up in concepts of ritual status, purity and pollution. One custom that people in the so-called higher caste group believes in is that if something is handmade or touched by a person of a lower caste that thing is no longer pure and clean and thus it is not suitable for drinking or eating purposes. In Nepal, potters are considered to be in the lower caste, belonging to the caste of Sudra. Thus, the higher caste populations do not use ceramic for cooking, eating or drinking. In Nepal, plates and cups made of stainless steel or copper are used for drinking or eating purposes.

This can be a burden in promoting the Nepal Ceramic Filter, since the filter consists of two ceramic containers. This could be a reason why stainless steel filters imported from India are the most commonly used filters in Nepal. The richer populations in Nepal are mostly from the higher caste, and thus they can afford to purchase expensive Indian filters.

However, according to Ambica Shrestha, the president of the Federation of Business and Professional Women – Nepal, the enlightened Nepalese society should not be concerning itself with caste distinctions, and thus it should not be a consideration for any decision making process (Murcott, 2000).

Contrary to the concern, the solution to this problem was discovered to be simple. The solution is to promote Nepalese ceramic filter to be used with containers other than the ceramic containers. One alternative is to use plastic buckets as a substitute. Plastic buckets are available anywhere in Nepal and are very inexpensive as discussed in the earlier chapter. Furthermore, they are lighter than ceramic so they are easier to be transported.

10. SUGGESTIONS FOR A COMPREHENSIVE POINT OF USE TREATMENT SYSTEM IN NEPAL

Point-of-use treatment systems currently in use

According to numerous sources, most Kathmandu households with sufficient means apply point-of-use treatment to water prior to consumption. This point-of-use treatment consisting of boiling followed by filtration. The most commonly used point-of-use water filter is the ceramic candle filter imported from India. In Nepal, disinfection (by boiling) typically proceeds filtering contrary to standard water treatment engineering practice.

Treating water in this fashion though effective is relatively expensive. Disinfection by boiling adds to cost of treatment in both economic and environmental terms.

Information varies with respect to usage patterns in the Katmandu Valley region, numbers cited for the percentage of population using such a technique range between 30 and 90% (Maag, 2000). However, with the price of a filter system being between 5 to 10% of average annual household income, it is likely that the lower end of the range is more accurate.

In rural areas where most people live below the poverty line and have little or no disposable income, buying a filter is out of the question. Although market distribution channels appear to exist in all areas, penetration of the product into these rural areas is low because the need for water treatment is not well understood, and also because of the high cost. In rural areas filters are often status symbols affordable only to the wealthier stratum of the population, which represents less than 10% of the people.

Alternatives to the current system

A point-of-use treatment system, consisting of a Nepalese ceramic candle filter followed by one of several possible disinfection options, offer a new drinking water treatment regimen for the Nepalese households. This proposed system consists of a two-step process. Water is filtered in order to reduce the turbidity level and disinfected for microbial safety using either chlorination, solar disinfection, or colloidal silver. The advantages such a system offers over those currently in place are its affordability, availability and potential for self-sustainability.

9.1 Water Treatment System Components

Filters

As discussed in the earlier chapters, in tests run in the Katmandu Valley, three different filter types were tested for viability as point-of-use treatment devices. It was determined that though effective in reducing turbidity, microbial removal was incomplete. Of the filter types tested, a locally manufactured ceramic candle filter was discovered to be the most affordable in initial and usage costs.

The currently available ceramic filters in Nepal do not have any disinfection properties. Colloidal silver coating was applied onto the locally manufactured ceramic filter candles in order to improve their microbial removal efficiency. It was proven in the experiments that colloidal silver coating reduces the microbial contamination levels in water. However, during the experiments the complete elimination of total coliform was not attained. Furthermore, it was not determined whether the effectiveness of colloidal silver lasts after continuous use of the filter. Thus, a second barrier of disinfection, discussed below, is recommended in combination with the ceramic filter in order to ensure that the water is free of microbial contamination.

Disinfection

Point-of-use disinfection processes were studied by 'Amer M. A. Khayyat. For further information on point-of-use disinfection, please refer to "Study of Point of Use Water Disinfection Methods for the Treatment of Drinking Water in Nepal", Khayyat, 2000.

Chlorine, when available, is the disinfectant of choice. Chlorination of prefiltered water decreases the risk of THM formation since less amount of chlorine is required for adequate disinfection of the water.

Solar disinfection can be used as a disinfectant in cases where chlorine is not available and where available solar radiation is above a specified threshold. Solar radiation passing through water is attenuated by turbidity. Prefiltration is essential to this process because filtration reduces the turbidity and the initial microbial counts. Water with turbidity level above 200 NTU absorbs as much as 99% of the incident radiation within the first centimeter of optical path, making the disinfection process ineffective (Khayyat, 2000).

10.2 Steps for Application of New System

The use of a two-step, filtration-disinfection process is a simple and effective method of treating drinking water on a household scale. The two-step process appears to be easily adaptable to the daily routine of water collection and treatment can be operated without a power supply.

Hardware Procurement

It is known that ceramic candle filters can be manufactured locally in Nepal. They are currently produced by Nepal Ceramics Co-operative Society in Thimi, a small town located in the east of Kathmandu city. The manufacturing technique utilizes traditional ceramics manufacturing skills, is simple and is potentially transferable to other locations throughout Nepal. The locally available filters are significantly cheaper than the imported filters currently in use.

The requirements of disinfection vary with the method applied. Both chlorination and colloidal silver require the importation or manufacture of chemicals. Solar disinfection requires only transparent bottles that are readily available in Nepal, and might otherwise be a source of garbage pollution.

Education and Training

Due to the decentralized nature of point-of-use treatment, the assurance of compliance of the final treated product is ultimately in the hands of the homeowner. In order to ensure the effectiveness and sustainability of a point-of-use treatment system, a comprehensive program of education and training in both basic hygiene and the manufacture, operation and maintenance of the point-of-use system must be instituted.

The importance of basic sanitation must be addressed prior to the implementation of the point-of-use treatment project. Although not specifically directed towards training in the application of household water systems, UNICEF-Nepal and the Department of Water Supply and Sewerage of the government of Nepal are currently carrying out efforts in communities throughout Nepal. They have assigned so called women "motivators" in each community, whose responsibility is to promote an awareness of clean water and sanitation issues, and to educate the community. Unsanitary household conditions are considered contributing factors to Nepalese drinking water contamination. The improvements in the household hygiene level would reduce the risk of further contamination of the drinking water post-treatment or "between container and mouth".

Traditional pottery manufacturing skills, practiced throughout Nepal, can be utilized for local manufacturing of the ceramic candle filters. A training program for local potters can provide the necessary techniques for manufacturing the ceramic candle filters. The manufacturing process itself is quite simple and thus can easily be acquired by skilled potters.

Furthermore, local manufacturing can also eliminate the needs for long distance shipping of the finished product. The ceramic filters are fragile and susceptible to breakage during transportation, making local manufacturing highly desirable.

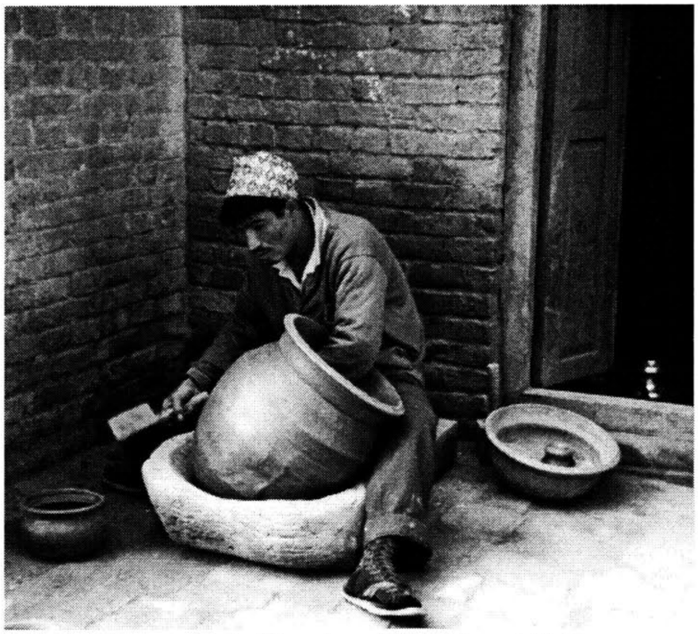

Figure 10.1: Nepalese Traditional Pottery

Chemical supplies required for chlorination and colloidal silver treatment pose a challenge to the sustainablity of this proposed point-of-use treatment system, as they are not currently manufactured and the cost importing the chemicals may be prohibitive. In the case of solar disinfection, transparent containers are readily available throughout the Katmandu Valley and its surroundings

Once the supply of the treatment system components is secured, the education program must be implemented to teach the homeowners to correctly use the point-of-use treatment system. The proposed system consists of very simple processes, however, education is necessary to ensure effective treatment of water and a long-term use of the system by the users. The filter candles must be cleaned and changed regularly.

The Treatment Regimen

This two step process only requires one ceramic candle filter and approximately ten transparent containers.

Raw water is first obtained from a source using a clean container. The water is run through the filter system. The filtered water is subsequently collected in the transparent plastic containers by decanting from the spigot into the plastic bottles. Two or more sets of containers, each set being enough for one day's worth of consumption, are to be used in the solar disinfection step. These sets are to be cycled between exposure and use in a rotating fashion such that as one set in being exposed to the sun a second set that had been exposed the previous day is ready for consumption. Once the cycle is set in place, it is self-maintaining. The Nepalese women and children collect water in the mornings. Instead of consuming the raw water it should be put directly through the filters. At the end of the day, the filtered water is filled into the empty containers that had been in use during the day and the newly filled containers are swapped for the containers on the roof which are brought in to cool overnight for consumption the next day.

10.3 Follow up and support

The dissemination approach of the treatment method advocated here, must be community oriented, open, flexible and continual. It must be based on the knowledge of the targeted communities, their needs and priorities and propose solutions tailor made to their problems.

This approach has little chance of succeeding in the long term without the participation of the potential users of the technology. A project should involve participation right from the beginning and start with an evaluation of the current use of water by the target users.

Strengthening of local skills is essential if the rural Nepalese communities are to efficiently control and manage their own initiatives. Development of human resources, special training programs and periodic field visits by supervising personnel are therefore key elements to any such treatment program. In the Kavre District of Nepal, where the MIT project team visited on January 18 to 19, 2000, the engineers from Department of Water Supply and Sewerage periodically visit the area to promote hygienic water and sanitation practices. They are currently carrying out a project promoting the use of latrines by manufacturing them locally and selling them to the villagers for subsidized price (Shrestra, 2000). A similar involvement of organizations such as Department of Water Supply and Sewerage will be greatly beneficial in promoting point-of-use treatment systems among the Nepalese communities.

Of primary importance is to have a program that allows flexibility within its operational structure. It is essential that communities and program personnel are provided with training to react to changes in local skills, conditions and opportunities. This will require the setting up of special follow up and adjustment programs in accordance with developmental trends.

The members of the communities targeted must be trained in the application of the new water treatment process, preferably by fellow community members. Peer education is an approach that enhances communication on a community level. This approach consists of conducting training sessions for various community members (men and women) to promote the project. These community education workers will transmit through house visits and public meetings clear and simple messages in their native tongue. The women motivators who are being trained by UNICEF-Nepal and the Department of Water Supply and Sewerage is the good example of peer education program. The involvement of teachers and pupils in this process is another promising venue for implementing behavioral change in a community.

11. CASE STUDY: HAITI WATER PROJECT BY INDUSTRY FOR THE POOR, INC. (IPI)

In March 2000, the author took a field visit to Haiti to observe the water project being conducted in Haiti by Industry for the Poor, Inc. (IPI)[1]. IPI purifier was one of the systems studied in this project as a possible system to be used in Nepal. Like Nepal, Haiti is one of the poorest nations in the world. The rural areas of Haiti is hilly and mountainous like the foot hill regions in Nepal. Because of the success of the IPI water project in Haiti, together with the similarities between the countries, it was considered to be a good example of successful water projects to be studied.

IPI, based in Florida, is an NGO with many years of experience in attempting to provide clean water at the household level to rural people in developing countries. Lead by the director, Phil Warwick, IPI is currently working on water supply projects in Haiti and the Dominican Republic, both located on the same island in the Caribbean Sea. IPI has been involved in Haitian water supply projects since 1995, developing point-of-use water treatment devices. Currently they are promoting the use of IPI purifiers among several communities in Haiti and the Dominican Republic.

In Haiti, at the present time, there are approximately three thousands IPI purifiers used in three different communities, Dumay, Brasa and Les Palmes.

---

[1] Industry for the Poor, Inc. 1090 Highway A1A, Suite 101, PO Box 372323, Satellite Beach, FL, 32937-0323 Phone(407) 777-2179

Development of IPI Purifier

IPI has considered four different systems for their point-of-use water treatment system. The first system they considered was a solar distillation system. However, it failed to live up to their expectations, since it was too expensive to be implemented effectively. The system also required all-day treatment to produce only a few gallons of drinking water. In order to treat an adequate amount of water, the system had to be larger, and for communities in Haiti, providing adequate space for such a system was not feasible.

The second system they considered was ceramic candle filters. Ceramic filters, which resemble those made in India, are manufactured in Brazil and were considered for the use in Haiti. However, this approach was not implemented due to the fact that the Brazilian ceramic filters were too expensive for the project to be feasible. The retail price of Brazilian ceramic filter candles in April 2000 is US$2.00 – US$2.75 (Murcott, 2000). Furthermore, the ceramic filters are easily cracked during transportation. Cracks in ceramic filters can be too small to be seen and using the cracked ceramic filters can result in inadequate microbial water treatment.

The string wound filter, which is currently used by IPI, was determined to be the most appropriate filter unit due to its low cost. The string wound filter is manufactured for approximately US$1.00 (Warwick, 1999).

Maintenance and Education Program

IPI believes that the success of their project is due to their extensive maintenance and education program (Warwick, 1999). They have set up a committee consisting solely of the local Haitians, who are responsible for monitoring and assisting each and every household on their household circuits, and also to manage the local manufacturing of the filters. The local water committee hires community technicians in every village where IPI conducts projects. Technicians are trained and certified by IPI. They visit households with water filter systems once a week and check if users are using the filters properly. In each village, there are at least two or more technicians assigned. Household visits are organized so the same technician does not visit the same household every time. By using this system, even if one of the technicians does not perform his/her duty well, every household will obtain support by other technicians. Each technician covers approximately 400 to 1,000 homes, depending on the geographic characteristics of the area (hilly or flat).

At the present time, there are 18 community technicians hired by the IPI supported program in Haiti. IPI has specified that the local water committee and the community technicians must consist of a mix of both men and women. They have found that female community technicians generally can relate to water problems better than male technicians since they are more familiar with the water issues in everyday lives. In Haiti, like in Nepal, water is mainly women and children's responsibility.

The purifiers seem to be very well accepted by the communities. They are well maintained and are handled with care. All users keep the purifier covered with either plastic or clothe covers that they fabricated. Especially in Dumay, where the purifier has been in use for almost 5 years, the users have realized the importance of treating their drinking water. The villagers claim that the incidents of waterborne diseases have decreased significantly since they started using the IPI purifiers and epidemilogical studies bare this out. The percentage of the population using the purifier correctly in Dumay is exceptionally high compared to the other two villages where the purifiers have not been used for long.

IPI has a policy that they do not provide more purifiers to the village if the correct utilization rate is below 75%. The most common mistake in the use of the purifier is the addition of chlorine bleach. Many users either do not add the chlorine or add too much of it. The most common error observed during the author's field visit from March 20 to 26, 2000 was no chlorine addition in the bottom container. Even if the top container is chlorinated, water often tested positive for coliforms if the bottom container was not chlorinated. The users must pay approximately 15 cents to obtain the squeeze bottle filled with chlorine bleach. In Barasa, some users were conserving the chlorine bleach by using just a little amount of chlorine instead of the required amount. In the case of using too much chlorine, the use of the dropper seemed to be the problem. Many users were squeezing out much more than five drops of bleach suggested. During the author's trip, IPI had just started to substitute the dropper by a squeeze-type container, of a type often used to contain eye drops, which should make the chlorine addition to the bottom container much simpler.

Further improvements of IPI Purifier

Currently, IPI is considering improving the performance of the activated carbon filter by mixing high quality activated carbon with coconut shell/walnut activated carbon. High quality activated carbon effectively adsorbs chemicals and organic matter. However, the flow rate of water through the filter is slow. On the other hand, the coconut shell/walnut activated carbon is very aggressive in adsorbing chemicals, and thus the flow rate is faster. However, over time this activated carbon tends to release chemicals back into the water. IPI is considering mixing the two types of activated carbon to make an activated carbon filter with an optimum performance.

IPI is also considering to replace the direct addition of chlorine bleach by placing a chlorine dispenser inside the filter container. The chlorine dispenser will be filled with chlorine bleach power and it will be designed in a way that chlorine is diffused into the water from the dispenser. The addition of chlorine bleach is the most difficult step of treating water using the IPI purifier, and the refinement of this step will make the purifier much easier to use.

The Haiti water project by IPI is a successful project. Their experiences of water projects in Haiti offer tremendous amount of information applicable to the future Nepal water project.

12. RECOMMENDATION AND CONCLUSIONS

In this thesis, three point-of-use filter systems were studied for treatment performances, as well as costs, availability and social acceptability. It was observed from the filter experiments that in all three filter systems, the filtration process alone did not treat water to an acceptable level of drinking water quality set by WHO guidelines. Although manufactures of the ceramic candle filters claimed that their products produced "pure" and "safe" water, they were found to be incapable of removing microbiological contaminants. The IPI purifier by itself did not treat water adequately, however, when used along with chlorine disinfection, as instructed by IPI, it produced water free of total coliform, *E.coli* and hydrogen sulfide producing bacteria. **These results indicate that the filter systems must be used combined with a disinfection process.** The IPI purifier was effective when used with chlorine disinfection, however, chlorine suitable for drinking water disinfection is not readily available at the household level in Nepal. Thus, an alternative disinfection method needed investigation (Khayyat, 2000). Furthermore, IPI is currently investigating the possibility of starting a purifier project in India. If the purifiers can be manufactured in either India or Nepal, project collaboration with IPI is a future possibility.

The Indian ceramic candle filter was shown to be inadequate in removing total coliform and hydrogen sulfide-producing bacteria from Nepalese raw drinking water, despite the fact that it is widely used and is a well-known and trusted system in Nepalese society. It cannot treat water to an acceptable level of drinking water quality unless it is used along with disinfection, such as boiling, as is the middle and upper class Nepalese practice. The price of the Indian ceramic candle filter is very expensive for the majority of the Nepalese population. Furthermore, those who can afford to buy such a system already have such a unit in their households. Thus, it was not chosen as the appropriate point-of-use treatment system for the objective and target population of this project.

Nepalese ceramic candle filters were found to have the least effective level of removal out of all the three filter systems tested. However, it is the most affordable filter for Nepalese people at the current time. Substitution of the Nepalese clay pots, which are the containment vessels for the ceramic candle filters, with plastic buckets will allow easy transportation of the system to the rural areas, allowing the filter to be distributed outside of Kathmandu valley, where it is most needed. The slow filtration rate can be overcome by using multiple ceramic filter candles within one system. Using plastic buckets for the containers also permit the users to assemble the system in the way that it is the most convenient for their use, allowing some flexibility in the system.

To improve the microbial removal performance of the Nepalese ceramic candle filter, application of colloidal silver coating was studied. The test results indicated that the colloidal silver reduces the level of microbiological contaminant in the filtered water. However, due to the fact that only a limited number of tests were conducted, we cannot, at this time, conclude that the colloidal silver coating of ceramic filter candles completely eliminates microbiological contamination in the drinking water. Furthermore, the disinfecting effect of colloidal silver coating after continuous usage of the filter is not known, and thus it must be further studied.

Innovative filtration systems, such as BioSand water filter could be a suitable system for Nepal. Here again, more study needs to occur in order to determine the applicability of this system to the Nepalese communities. For the time being, the Nepalese ceramic candle filter is the recommendation that comes out of this thesis, as it radically improves the turbidity levels in the water. However, since the filter system does not remove all the microbial contamination, it must be used along with a disinfection process.

REFERENCES

Barrett, Stephen. Colloidal Silver: Risk Without Benefit. webpage, http://www. quackwatch.com /01QuackeryRelatedTopics/PhonyAds/silverad.htm

Bell, Frank A. Jr., Donald L. Perry, James K. Smith, and Stephen C. Lynch. "Studies on Home Water Treatment Systems". Journal AWWA, 19

Brock, Thomas D. and Michael T. Madigan. Biology of Microorganisms. Prentice-Hall, Inc. New Jersy, 1991

Chaudhuri, Malay, Sanjeev R. Verma and Anirban Gupta. "Performance Evaluation of Ceramic Filter Candles". Journal of Environmental Engineering Vol.120, No. 6, 1994

CIA Country Factbook, webpage, http://rs6.loc.gov/frd/cs/nptoc.html

Colloidal Silver Discovery Center, webpage, http://www.colloidal-silver.com

Davnor Water Technologies Ltd., webpage, http://www.davnor.com/no12/htm

De Zuane, John. Handbook of Drinking Water Quality. Van Nostrand Reinhold, New York, 1997

Earp, Steve. Drinking Water and Disease Transmission Prevention in Rural and Marginalized Areas of Latin America, The Ceramic Water Filter, A Nicaraguan Case Study. Department of Technology Education, West Virginia University, 1992

Hach, Hach Water Analysis Handbook, 1997

Jacobson, Garry, webpage, http://www.dwr.csiro.au/UGD/DB/Kathmandu/Kathmandu.
Html Dated June, 1996

Jones, J. T. and M. F. Berard, CERAMICS Industrial Processing and Testing. The Iowa State University Press, Ames, Iowa. 1972

Kafle, Maheshwor. "Personal Communication", 2000

Karanjit, Mangala. "Personal Communication". Federation of Business and Professional Women Nepal, 2000

Khayyat, 'Amer Mohamed Adhan. Study of Point-of-Use Disinfection Method for the Treatment of Drinking Water in Nepal, Massachusetts Institute of Technology, 2000

Kingery, W. D., H. K. Bowen and D. R. Uhlmann. Introduction to Ceramics. John Wiley & Sons, New York, 1976

Kulkarni, D. N., D. S. Tajne and N. M. Parhad. "Performance of Domestic Water Filters". Indian Journal of Environmental and Health. Vol. 22, No. 1, 30-41, 1980

Library of Congress, Nepal - A Country Study, webpage, http://rs6.loc.gov/frd/cs/nptoc. html, 1999

Lindermann, Peter A., "A Closer Look at Colloidal Silver". webpage, http://www.elixa.com/ Silver/lindermann.htm

Maag Benoit. "Personal Communication", 2000

Manz, D, G. Palmateer, A. Jurkovic, R. McInnis, S. Unger K.K. Kwan and B.J. Dutka. "Toxicant and Parasite Challenge of Manz Intermittent Slow Sand Filter". Environmental Toxicology, vol. 14, pp217 – 225, 1997

Murcott, Susan. "Personal Communication". Lecturer, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, 2000

Murthy, Narayana. Study on Some Environmental Engineering Aspects of Domestic Water Filters. Department of Civil Engineering, Institute of Technology Banaras Hindu University, India. 1990

Nepal Ceramics Co-operative Society, Ltd., Brochure

Nepal Net, Electronic Networking for Sustainable Development in Nepal, webpage http://www.panasia.org.sg/nepalnet/water/water_contamination.htm

Parajapati, Hari Govinda. "Personal Communication". President of Nepal Ceramics Co-operative Society, 2000

Regunathan, R. Overview of Point-of-Use Water Treatment Technology. Lewis Publisher. Inc. Alexandria, 1985

Revelo, L. Aguilar, and Elias Rosales Escalante. Slow Sand Filters. Fundacion Tecnologica de Costa Rica. Costa Rica, 1998

Revera, "Personal Communication". Ron. Potters for Peace, 2000

Rijal, G. K., R. S. Fujioka and C. Ziel. Assessing the Microbial Quality of Drinking Water Sources in Kathmandu, Nepal, 1996

Shrestra, Pren. "Personal Communication". Engineer, Department of Water Supply and Sewerage of Nepal, 2000

Spruijt, Hans. "Personal Communication". UNICEF-Nepal, 2000

Task Force on Wastewater Disinfection. Wastewater Disinfection Manual of Practice No. FD-10. Water Pollution Control Federation, Virginia, 1986

UNDP. Nepal Human Development Report 1998, UNDP, 1998

Viessman, Warren Jr. and Mark J. Hammer. Water Supply and Pollution Control. Harper Collins College Publishers, New York, 1993

Warwick, Thomas P. "Personal Communication". Director of Industry for the Poor, 1999

Warwick, Thomas P. "Personal Communication". Director of Industry for the Poor, 2000

White, Geo. Clifford. The Handbook of Chlorination and Alternative Disinfections. Van Nostrand Reinhold, New York, 1992

Wolfe, Andrea. Microbial Contamination of Kathmandu Valley Drinking Water Supply and Bagmati River. Massachusetts Institute of Technology, 2000

Yamada, Sakae. "Personal Communication". Coordinator of Japanese Red Cross in Nepal, 2000

APPENDIX A – NEPAL FIELD TRIP

Nepal Trip Report

MIT-Nepal Water Project
January 6th – 29th, 2000

Jan 6 Arrived in Kathmandu with Kim Luu in the afternoon.

Jan 7 Visited Nepal Ceramics Co-operative in Thimi, a small town in the east of Kathmandu. Met Mr. Hari Govinda Parajapati, the president of Nepal Ceramics Co-operative. He took us around the potters' village in Old Thimi to show us the traditional ceramics making process. He also took us to his workshop in New Thimi, where he makes the ceramic candle water filters. Purchase 2 sets of ceramic filters. He makes ceramic filters by hand and he mentioned that he could probably make it cheaper if he could make it by a machine.

Jan 11 Had a meeting with Mangala Karanjit, Mr. Sharma, Mr. Spruijt and Nameste at the office of the Melamchi Water Supply Project. Discussed the schedule for the MIT group while in Nepal. Planned the trips to Parsa, Kavre and Nagarkot. Discussion on Arsenic was presented by Mr. Sharma.

Jan 15 Met with Mangala of the Federation of Business and Professional Women Nepal and Dilli Bajracharya, the deputy director of the Central Laboratory, in the morning at the Kathmandu Guest House. Moved into Staff College dormitory. Lab equipment was moved to the Central Laboratory of Nepal Water Supply Corporation. Lee and Cliff Hersh arrived at the Staff College in the afternoon. Susan arrived in the evening.

Jan 16 First day at the Central Laboratory. Cleaned the lab and set up the filters. Visited Sundarighat water treatment plant. The treatment plant consists of sedimentation, filtration and chlorination. Coagulation is used only if the water is very turbid. The sedimentation tank has not been cleaned for 6 or 7 years. Water samples were taken at different locations of the treatment plant and were tested for turbidity and hydrogen sulfide producing bacteria. Andy, Andrea and Tricia came back from water sampling in Parsa.

Jan 17 Worked at the Central Laboratory. Ran the first microbial and turbidity tests on three filters, Bajaj stainless steel filter, Nepalese ceramic filter and IPI filter. Went to the treatment plant to gather some sand to make a sand filter which would be used in the demonstration in Kavre.

Jan 18 Spent the morning at the lab. Went to UNICEF to leave to Kavre. On the way to Kavre we stopped at New Thimi to see the workshop of Mr. Prajapati. He showed us around his workshop. Lee talked to Mr. Prajapati about applying colloidal silver on ceramic filters. Arrived in Kavre in the early evening. Learned Nepali words, such as "kill small insects", "remove turbidity" from Pren Shrestra, water engineer working for the department of water supply and sewerage of the government of Nepal.

Jan 19 Prepared the sand filter for the demonstration. Met the motivators and gave water treatment demonstration in front of their water source. Later, we were invited at school to give demonstrations in front of school students. Motivators gave demonstrations.

The motivators suggested that the filters are much easier than hand coagulation.

Observed the process of making concrete slabs for latrines, which are distributed in Kavre district.

Jan 20 Worked at the Central Laboratory. Ran turbidity and microbial tests on IPI, Nepal Ceramics Co-operative and Bajaj filters.

Jan 21 Gathered at UNICEF to leave to Nagarkot. Went to Central Laboratory with Susan and Kim to see the test results from the day before. When we got to Nagarkot we did a presentation on each of our specialization. I discussed about IPI, Bajaj, Nepal Ceramics Co-operative filters as well as a bucket filter which Pren brought from his home. Learned a lot from the government technicians and officials at the workshop. They provided us with useful information and provided us with their perspective of what a "good" filter would be. Found that the motivators favored ceramic candle filters, whereas the technicians favored activated carbon filters. Some technicians mentioned about high iron concentration in the drinking water in the southern regions of Nepal. They claimed that the activated carbon filter would be suited for those regions. Pren suggested that in rural areas of Nepal sand filter mixed with charcoal would be suitable.

In the evening we had a culture night, where the participants of the workshop performed dances and songs.

Jan 22 Got up at 5:30am to see the sunrise, however, the bus didn't start and we failed to get to the top of the hill on time.

The people at the Nagarkot Training Center showed us around their laboratory.

Jan 23 Worked at the Central Laboratory. Tested four filters, IPI, Nepal Ceramics Co-operative, Bajaj, and Pren's blue bucket filter. Found that the blue bucket filter was leaky and that contaminated water was leaking into the bottom bucket.

Jan 24 Called Japan Red Cross in the morning to obtain some information on their arsenic testing in Lumbini area. Talked with Mr. Sakae Yamada, the coordinator of Japanese Red Cross Society in Nepal. Set up a meeting for Susan and Mr. Yamada. Worked at the Central Laboratory for the rest of the day. Found out that the tap water samples we used the day before was chlorinated. All the microbial tests came out negative.

Jan 25 Worked at the Central Laboratory. Checked that the tap water was chlorinated once again. Andrea and Amer went to Sundarighat water treatment plant to obtain some contaminated water to be used in the tests. Ran turbidity and microbial tests on IPI, Nepal Ceramics Co-operative and Bajaj filters. In the afternoon I went to the workshop of Mr. Prajapati with Tricia to buy 25 filter candles to be used in experiments later.

Jan 26 Worked at the Central Laboratory in the morning. Ran turbidity and microbial tests on IPI, Nepal Ceramics Co-operative and Bajaj filters. In the afternoon Susan, Lee, Tricia and I met with Mr. Yamada to talk about their well water samples, which are being tested for Arsenic at ENPHO. We went to ENPHO and met Dr. Roshan R. Shrestha. Tricia and Lee stayed to test their water samples.

Jan 27 Went to the office of Nepal Water Supply Corporation to meet Mr. Gautam Bahadur Amatya, the Director General of NWSC and to present our findings. After, we went to the office of Melamchi Water Project to see model and meet some key engineers. In the afternoon we cleaned up the Central Laboratory and packed up the lab equipment.

Jan 28 Went to the Central Laboratory in the morning to finish up packing the lab equipment.

Jan 29 Left Kathmandu to Boston.

Filtration Rate Test

Nepalese Filter

Time (min)	Time (hr)	water filtered during the interval (ml)	filtered water (L)
0	0		0
30	0.5	120	0.12
60	1	115	0.235
90	1.5	115	0.35
120	2	105	0.455
150	2.5	105	0.56
180	3	100	0.66
210	3.5	90	0.75
240	4	80	0.83
270	4.5	70	0.9
330	5.5	120	1.02
390	6.5	105	1.125
770	12.83333	600	1.725
850	14.16667	105	1.83
1090	18.16667	305	2.135

Indian Filter

Time	Filtration Rate (L/hr)
0	
0.25	0.24
0.75	0.23
1.25	0.23
1.75	0.21
2.25	0.21
2.75	0.2
3.25	0.18
3.75	0.16
4.25	0.14
5	0.12
6	0.105
9.666667	0.094736842
13.5	0.07875
16.16667	0.07625

Turbidity Test

Date	water source	Before	Industry for the Poor		Bajaj Filter		Nepal Filter		Notes
			After	% Removal	After	% Removal	After	% Removal	
17-Jan	tap water	4.27	0.22	94.85	0.88	79.39	2.64	38.17	did not take the samples directly into the sample bottles
20-Jan	tap water	8.34	0.57	93.17	0.64	92.33	0.91	89.09	
23-Jan	tap water	14.5	0.87	94.00	0.33	97.72	0.78	94.62	
25-Jan	treatment plant	14.7	0.64	95.65	0.35	97.62	0.4	97.28	
26-Jan	treatment plant	11.7	0.7	94.02	0.36	96.92	0.45	96.15	
		12.31	0.70	94.21	0.42	96.15	0.64	94.29	

Data from Jan 17 was not taken into account for the calculation of the average
units of turbidity = NTU

Microbiology Test

P/A Test

Date	water source	Before		Industry for the Poor		Bajaj		Nepal Ceramics Co-operative		Note
		Total Coliform	E-Coli	Total Coliform	E-Coli	Total Coliform	E-Coli	Total Coliform	E-Coli	
17-Jan	tap water	+	+	+	+	+	+	+	+	samples taken from the bottom containers (samples contaminated?)
20-Jan	tap water	+	+	-	-	+	-	+	+	IFP (5% chlorine soln)
23-Jan	tap water	-	-	-	-	-	-	-	-	tap water chlorinated
25-Jan	treatment plant	+	+	-	-	+	-	+	+	IFP (5% chlorine soln)
26-Jan	treatment plant	+	+	-	-	+	-	+	+	IFP (5% chlorine soln)

MPN Test

Date	water source	Before		Industry for the Poor		Bajaj		Nepal Ceramics Co-operative		Note
		Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	
20-Jan	tap water	0	5	5	0	4	1	1	4	
23-Jan	tap water	5	0	5	0	5	0	5	0	
25-Jan	treatment plant	0	5	5	0	5	0	4	1	
26-Jan	treatment plant	0	5	5	0	3	2	3	2	
						1.1		8		
						<1.1		1.1		
						2.6		2.6		
						1.6		3.9		

APPENDIX B – HAITI FIELD TRIP

Haiti Field Trip Report

March18th – 26th, 2000

March 18 Leave Boston at 8:40pm to Orlando. Phil Warwick, the director of Industry for the Poor, Inc. and Lee Hersh come to greet me at the airport. Stayed at Warwick's residence in Melbourne, Florida.

March 19 Find out that a visa is required for a Japanese citizen to enter Haiti. Obtained Passport pictures and prepared all paper documents required to obtain visa.

Meeting for everybody joining the Haiti field trip. Met Bill Gallo, Sue Sergent, Jim Thorstad and Trudi. Discussed about the schedule in Haiti and Trudi showed me and Lee the laboratory and field testing procedures, which are to be implemented in Haiti.

Packed all field testing equipment and all other necessary items for the trip.

March 20 Left Melbourne at 4:30am with Phil to the Haitian Consulate in Miami. When arrived at the consulate, found out that visa is no longer required for Japanese citizens. Drove to the airport and joined in with the rest of the group flying to Haiti. Left Miami with Bill, Sue, Jim, Lee for Port-au-Prince.

Arrived in Port-au-Prince at 1:30pm. Pasteur Nathan Dieudonne, who will be our host while the stay in Santo greeted us at the airport. Nathan is the head of the water committee in Dumay. Dropped off luggage at Nathan's residence.

Visited the village of Dumay, where IPI started the first purifier project in 1996. Met with local technicians and others who are involved with the IPI project. Between 5:00 and 6:00pm, visited homes in Dumay with Clairdomy, a technician, and performed chlorine P/A testing for the 1-A circuit. There are 16 circuits in the Dumay area and approximately 2000 purifiers are being used.

<u>The method of chlorine P/A test:</u>
Fill the test tube with water from the spigot of the purifier. Rinse the tube and throw away the water. Fill the tube again with more water from the spigot. Add chlorine tablet and check for a color change. Do the same for the top bucket water.

At 6:30pm went back at Nathan and Wanda's residence.

March 21 Went to Dumay in the morning. Visited 7 homes in the circuit 5A (Pont-Dumay) with three local technicians, Clairdomy, Jolette and Marie-Cile. Performed chlorine P/A tests at all 7 homes and LTB test at 2 homes. LTB test is a presence absence test for fecal coliform.

After the testing in the morning visited the purifier factory. The purifier parts are manufactured in US and are shipped to Haiti for an assembly. There are currently 13 people working at the factory.

More testing was done during the afternoon. Testing and sampling was done in 5 circuits with Bill, Jim, Lee, and 4 technicians, Romain, Clairdomy, Milot and Wilberne. At all homes LTB and chlorine tests were performed.

When returned at Nathan's residence, LTB bottles were incubated in a cooler box with warm water inside. The temperature inside the cooler box was monitored and hot water was added whenever required,

March 22 Left Nathan's residence at 6am to go to Barasa, another location where IPI is implementing the purifier project. There are currently 45 purifiers being used in the Barasa community. Took two technicians from Dumay to let them teach and train the technicians in Barasa. On the way to Barasa stopped at Fort .... And met Mat, an American who is teaching English in the local community. He is fluent in Creole. Arrived at Barasa at 11am. Sampling and testing in two circuits 1-A and 1-B in Barasa. Visited 5 homes in each circuit and tested for chlorine and LTB. I visited homes with Jolette and Monsieur Dondon.

March 23 Sight-seeing in the morning. In the afternoon, visited homes in Dumay to test for chlorine. Checked the homes with high chlorine concentration in the bottom bucket for the possibility of the carbon filter failure. Found two filters which had activated carbon filter being used up. The users are supposed to replace the activated carbon filter when the water has a strong chlorine taste (chlorine not being adsorbed by the filter), however, the design failure system seemed to be not working for everybody. Phil and Susan arrived in Dumay. Met a driver/translator, Lamont. Visited few more homes with Susan and Phil.

March 24 Left Nathan's residence for Les Palmes, another village where IPI is implementing the purifier project. Brought Jolette and Wilberne with us again. In the afternoon, visited homes to test for chlorine. Many homes were found to be not using chlorine properly.

March 25 More sampling and testing. There are currently 4 circuits in Les Palmes with 323 purifiers. 4 groups visited each circuit and took samples from four homes. The homes to be visited were chosen randomly. Total of 5 whirlpak water samples were collected. Samples were also collected for LTB and chlorine P/A tests were done at the end.

The sampling procedure:
- collect sample in LTB bottle from the spigot
- collect sample in white whirlpak from the spigot
- collect sample in yellow whirlpak from the spigot
- collect sample in white whirlpak from the top bucket

- collect sample in yellow whirlpak from the top bucket
- collect sample in white whirlpak from the bottom bucket

The sampling for chemical and biological tests were done at 3 homes. At one of the homes the duplicate samples were taken for quality control. At one home only LTB sample was taken.

In the afternoon the plates were prepared for biological tests. The water collected in white whirlpak was used.

In the evening the chemical tests were done with all samples contained in yellow whirlpak. The chemical tests performed were nitrate, free chlorine, pH and alkalinity tests.

March 26 Left Les Palmes at 5:30am to Dumay with Bill, Lee, Wilberne and Jolette. Arrived in Dumay and saw the Dumay technicians. Returned to Nathan's residence and went to the airport with Sue, who was staying at Nathan's while the rest of the group was in Les Palmes.

Left Port-au-Prince at 2:45pm. Arrived in Miami and drove returned to Warwick's residence in Melborne.

March 2000 Data
Les Palmes

	FREE CHLORINE		PLATE COUNT		
SAMPLE	Top/Bottom	LTB	TOP	BOTTOM	SPIGOT
1-4	+/+	-	2	0	NT
1-10	+/+	-	0	0	5
1-55	-/-	NT	NT	NT	NT
1-56	no water/++	+	NT	0	0
1-83	-/-	-	NT	NT	NT
2-1	+/+	NT	NT	NT	NT
2-2	+/+	NT	NT	NT	NT
2-3	+/+	NT	NT	NT	NT
2-4	+/+	-	(0,1)(TNTC*,0)	(0,0)(0,broke)	(1,0)(0,2)
2-5	+/+	NT	NT	NT	NT
2-6	-/-	NT	NT	NT	NT
2-7	+/++	NT	NT	NT	NT
2-8	-/-	NT	NT	NT	NT
2-9	+/+	NT	NT	NT	NT
2-10	+/+	-	4	0	0
2-11	-/-	NT	NT	NT	NT
2-16	+/+	NT	NT	NT	NT
2-56	-/-	+	TNTC	22	6
2-83	+/+	+	NT	NT	NT
3-1	+/+	NT	NT	NT	NT
3-2	-/-	NT	NT	NT	NT
3-5	+/+	-	(2,0)(2,2)	(3,2)(3,1)	(2,2)(0,0)
3-6	+/+	+	1	7	0
3-7	-/-	NT	NT	NT	NT
3-8	+/-	-	1	3	6
3-9	-/-	NT	NT	NT	NT
3-10	+/+	NT	NT	NT	NT
3-36	+/+	NT	NT	NT	NT
3-38	+/++	NT	NT	NT	NT
3-39	-/+	NT	NT	NT	NT
3-40	-/-	NT	NT	NT	NT
3-41	+/+	NT	NT	NT	NT
3-43	+/++	NT	NT	NT	NT
3-56	+/+	-	NT	NT	NT
4-4	+/+	-	1	1	0
4-6		NT	NT	0	NT
4-9	+/+	-	(0,2)	1	(2,0)
4-57	-/-	+	NT	NT	NT
4-61	+/+	+	2	5	4

Positive Control	PC=TNTC
Negative Control	PC=1
Air Control	PC=6

NT = Not Tested PC = Plate Count
TNTC = Too Numerous to Count
* Petrie dish cracked

LTB samples were taken from the spigot.
Plate count samples were taken from the location stated on the chart.

Top	Bottom	ok	LTB	LTB Count	CL Count
1	1	1	1	1	1
1	1	1	1	2	2
0	0	0			3
0	1	0	0	3	4
0	0	0	1	4	5
1	1	1			6
1	1	1			7
1	1	1			8
1	1	1	1	5	9
1	1	1			10
0	0	0			11
1	1	1			12
0	0	0			13
1	1	1			14
1	1	1	1	6	15
0	0	0			16
1	1	1			17
0	0	0	0	7	18
1	1	1	0	8	19
1	1	1			20
0	0	0			21
1	1	1	1	9	22
1	1	1	0	10	23
0	0	0			24
1	0	0	1	11	25
0	0	0			26
1	1	1			27
1	1	1			28
1	1	1			29
0	1	0			30
0	0	0			31
1	1	1			32
1	1	1			33
1	1	1	1	12	34
1	1	1	1	13	35
1	1	1	1	14	36
0	0	0	0	15	37
1	1	1	0	16	38
0.657895	0.684211	0.631579	0.625		

March 2000 Data
Les Palmes

	TDS (mg/L)	**pH**	**Nitrate (mg/L NO3)**	**Free Chlorine (mg/L)**
SAMPLE	top/spigot	top/spigot	top/spigot	top/spigot
1-4	50/140	8.0/8.0	NT/8.8	0.4/0.0
1-4dup	50/200	8.0/8.1	17.6/8.8	0.0/0.0
1-10	120/180	8.1/8.1	NT/17.6	5.0/0.0
1-56	NT/130	NT/8.0	NT/17.6	NT/0.1
1-83	70/57	8.3/8.3	NT/8.8	0.0/0.0
2-4	280/340	8.2/8.3	NT/8.8	>6.0/6.0
2-4dup	280/340	8.4/8.3	NT/4.4	>6.0/4.0
2-10	180/180	8.1/8.0	NT/4.4	NT
2-56	110/120	8.2/8.2	NT/8.8	0.0/0.0
2-83	120/140	8.2/8.2	NT/4.4	6.0/0.0
3-5	210/200	8.2/8.0	NT/8.8	2.0/0.0
3-5dup	210/210	8.2/8.2	NT/8.8	2.0/0.0
3-6	130/140	8.0/8.0	4.4/0.0	6.0/0.8
3-8	90/100	8.2/7.9	2.2/1.1	6.0/0.0
4-4	210/250	8.3/8.1	NT/13.2	4.0/>6.0
4-9	230/200	8.2/8.0	NT/0.0	6.0/0.0
4-9dup	220/190	8.2/8.0	NT/8.8	5.0/0.0
4-57	200/210	8.4/8.2	NT/13.2	0.0/0.0
4-61	160/180	7.7/7.9	17.6/17.6	2.0/0.0

NT = Not tested

March 2000 Data
Barasa

	FREE CHLORINE	
SAMPLE	**Top/Bottom**	**LTB**
1-9	+/+	-
1-12	+/-	+
1-13	+/+	-
1-15	+/+	-
1-16	+/+	-
2-5	-/-	+
2-6	+/++	-
2-8	-/+	+
2-17	-/-	+
2-16	+/-	-
Church Cistern	NT	+
Dondon's Cistern	NT	+

LTB samples were taken from the spigot.

Summary

top	bottom	ok	LTB	
1	1	1	1	1
1	0	0	0	2
1	1	1	1	3
1	1	1	1	4
1	1	1	1	5
0	0	0	0	6
1	1	1	1	7
0	0	0	0	8
0	0	0	0	9
1	0	0	1	10
70.00%	50.00%	50.00%	60.00%	