Clean Water
for Nepal, Inc

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6/1/2003

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Final Project Report: Point-of-Use Water Treatment Technology Investigations in Nepal

Dear Susan Murcott,

Clean Water for Nepal is pleased to submit four studies on point-of-use water treatment technologies.

1. Biosand Filter
2. Ceramic Water Filters
3. Semi Continuous Solar Disinfection
4. Technical and Social Evaluation of Three Arsenic Filters

Please feel free to contact us with questions about out project group report.

Sincerely

Xanat Flores

Melanie Pincus

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Massachusetts Institute of Technology
Department of Civil and Environmental Engineering
Masters of Engineering Program
2002/2003

Point-of-Use Water Treatment Technology Investigations in Nepal

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1 Introduction

Clean Water for Nepal (CWN) is excited to be teaming up with the Environment and Public Health Organization (ENPHO), among a host of other colleagues, to help deliver solutions to the pressing water and wastewater issues that face Nepal. We have been asked to complete seven projects: four related to water and three related to wastewater. The four related to water are the subject of this report as follows:

1. Biosand Filter
2. Ceramic Water Filters
3. Semi Continuous Solar Disinfection
4. Arsenic Technologies

Many of these projects continue the work done by past MIT Nepal Teams; some involve new approaches that have yet to be investigated in the four years that MIT has been working in Nepal. This proposal outlines both our intended plan of action and proposed deliverables as per the requirements defined in the initial Request for Proposal and refined since then through weekly group meetings at MIT.

CWN is committed to sustainability and specifically, to the goal of contributing to human and ecosystem well being both now and into the future. We seek solutions that meet the needs of our clients as well as those of society and the environment; recognizing the essential interdependencies that exist between people and the environment. While our skills are strongly rooted in technology and engineering, we are keenly aware of how vital it is to ensure that our designs are practical and that they meet the needs of those who will ultimately be making use of them.

The first part of this proposal presents some facts concerning global water and sanitation problems to highlight the relevance of our projects not only in Nepal but from a global perspective as well. The second and main part of the proposal, Chapters 2 and 3, summarize the seven proposed projects.

1.1 Nepal

The Kingdom of Nepal is located on the southern slopes of the Himalayan Mountains in South Central Asia (Figure 1). It is bound by China to the north and surrounded by India to the east, west and south. The total land area, approximately 145,391 km^2 (5,6136 mi^2) in size, is comprised of three major topographical regions: the Mountains of the main Himalayan Range, the Hills or Katmandu Valley, and the Terai, which is a narrow flat belt of alluvial land that extends along the southern border with India. The total estimated population is 23.6 million people (WHO/UNICEF, 2000).

The climate in Nepal ranges from sub-tropic summers to mild winters in the southern lowlands and cool summers to severe winters in the higher alpine and mountain regions. The average annual precipitation decreases from 1,778 mm (70 inches) in the east to 899 mm (35 inches) in the west. Average temperature ranges in Kathmandu are from 2 to 20 degrees Celsius (36 to 73 degrees Fahrenheit) in January to 20 to 29 degrees Celsius (68 to 84 degrees Fahrenheit) in July.

Figure 1: Map of Nepal

The Gross National Income for Nepal is $5.9 billion, representing approximately $250 income per capita (World Bank Data, 2001). 81% of the total population is reported to have access to improved water sources and 75% of the urban population has access to proper sanitation. Note that only 12.2% of the total population is urban and the rural population has access to improved water supply and sanitation services. The lack of clean water and proper sanitation has led to many health problems that are related in one way or another to a relatively high infant mortality rate (104.7 per 1000 die before the age of 5) and short life expectancy (58.9 years). It has been reported that some of the most chronic widespread and chronic health problems are due to waterborne diseases such as intestinal parasites, diarrhea, and gastrointestinal disorders (Matles, 1991)[i]. Other factors that may influence these numbers are poor nutrition and sanitation, the general absence of medical care and other social services which are particularly necessary in rural areas.

Some of the main environmental issues that Nepal faces include deforestation due to the overuse of wood for fuel; water contamination, mainly due to human and animal wastes, agricultural runoff, and industrial effluents; wildlife conservation; and vehicular emissions[i].

1.2 MIT Nepal Water Project

The MIT Department of Civil and Environmental Engineering (CEE) has been working in Nepal since 1999 to help provide clean drinking water and improved sanitation to those in need. Our projects have evolved from monitoring and assessing water quality at project sites to researching, testing, and developing low-cost point-of-use household water treatment technologies.

1.3 Project Schedule

Clean Water for Nepal divided the proposed project work in three phases. The first phase consisted on the work done during the Fall Semester at MIT. The second phase consisted of a field research phase in different study regions in Nepal. The third and final phase consisted in the synthesis of the first and second phases, results and conclusions.

1.3.1 Phase 1

Clean Water for Nepal Inc. was assembled in the beginning of Fall Semester of 2002. At this stage, the planning phase of the project, letter of intent, and proposal were presented. During this phase, the team met every Friday to discuss different issues concerning the proposed work, such as: water, political economical and social situations in Nepal, advances of each one of the team members in their specific study field, study of field testing and water quality parameters, and traveling issues.

1.3.2 Phase 2

Clean Water for Nepal Inc. traveled to Kathmandu, Nepal during the first week of January. Each member of the Clean Water for Nepal, Inc. was then situated in a geographical region based on the specific field study needs, and in order to have a broader view and understanding of the water situation in Nepal. From then on, the following three weeks of January, the team members were engaged on a full-time basis in the collection of field data needed for the completion of the investigation and proposed project. Clean Water for Nepal rejoined in the city of Kathmandu at the end of the month and presented to our local partners, Environmental and Public Health Organization (ENPHO, an environmental laboratory and research institute) some preliminary results based on field data collected. Clean Water for Nepal returned to its headquarters at MIT February 3rd 2003.

1.3.3 Phase 3

Back at MIT, Clean Water for Nepal synthesized bibliographic and laboratory research with field data collected during January in Nepal. Final results and conclusions were obtained and presented in an oral presentation on April 18th 2003 and the present final group report was made.

2 Water Projects

2.1 Global Need for Clean Drinking Water

Water is essential for life: both in terms of quantity and quality. As of the year 2000, one sixth of the world's population, roughly 1.1 billion people, lacked access to improved water supply, and two fifths, or 2.4 billion people, lacked access to improved sanitation. Every year, approximately 3.4 million people die due to water-related diseases with the majority being young children under the age of five. Diarrheal diseases alone account for 2.1 million deaths per year. Other types of diseases associated with poor water quality include cholera, typhoid, arsenic poisoning, schistosomiasis or "snail fever", and trachoma, which causes blindness. The risks of contacting these diseases can be considerably minimized with access to clean drinking water, adequate sanitation facilities, and proper hygiene practices.

The link between health, water quality and water quantity is an important relationship that was intuitively understood by ancient civilizations as indicated in this Sanskrit quote from the second millennium B.C.:

> "it is directed to heat foul water by boiling and exposing to sunlight and by dipping a piece of hot copper into water seven times, then to filter and cool in an earthen vessel."

It was not until the mid 1800's that people began to fully understand the scientific link between water quality and health. Epidemiologist Dr. John Snow proved in 1855 that a cholera epidemic in London was attributed to a public well contaminated by sewage. The germ theory of disease later emerged from Louis Pasteur's research into fermentation. Soon chlorine was being used as a disinfectant in water supply systems to kill potential pathogens or microorganisms that cause disease and illness. Industrialized countries moved forward with the development of rather large centralized water supply and treatment systems, which, to this date, have performed relatively well in comparison to the water supply systems that exist in many developing countries.

So why not transfer the technology and knowledge that exists in industrialized countries to developing countries to help solve the mounting water crisis? This may work in theory and in some specific cases, but in reality there are too many political, economic and geographic issues – not to mention issues of population increase – to realistically expect that the one billion plus who lack access to safe drinking water will receive clean potable water from a household tap by 2015 vis-à-vis the Millennium Development Goal for clean water.

2.2 Regional Needs for Clean Drinking Water in Nepal

Administratively, the country is divided into 5 development regions and 75 districts (Figure 2). The Department of Supply and Sewerage (DWSS) has representatives in each of these districts and is the government agency responsible for the development of rural water supply and sanitation services throughout the Kingdom. Other government agencies active in water supply and sanitation projects include the Nepal Water Supply Corporation (NWSC), District Development Committees and Village Development Committees. In addition to these government agencies, there are many non-governmental organizations working within Nepal including the Nepal Red Cross, UNICEF, the Environment and Public Health Organization (ENPHO), Rural Water Supply and Sanitation Support Services (RWSSP), Water Air, and others.

Figure 2: Map of Nepal and Regional Districts

Picture Source: ICIMOD (www.icimod-gis.net)

The population of Nepal as of 2001 was 23,592,000 with an annual growth rate of 2.4%. Approximately 88.2% of the population lives in rural villages and towns loosely scattered throughout the Hills and Terai regions. A 1991 survey of population density by district shows the highest population density in southeastern Terai (Figure 3). Population growth from 1981 to 1991 occurred mostly within the Terai region as well. (Figure 4) and this trend has likely continued through to the present time.

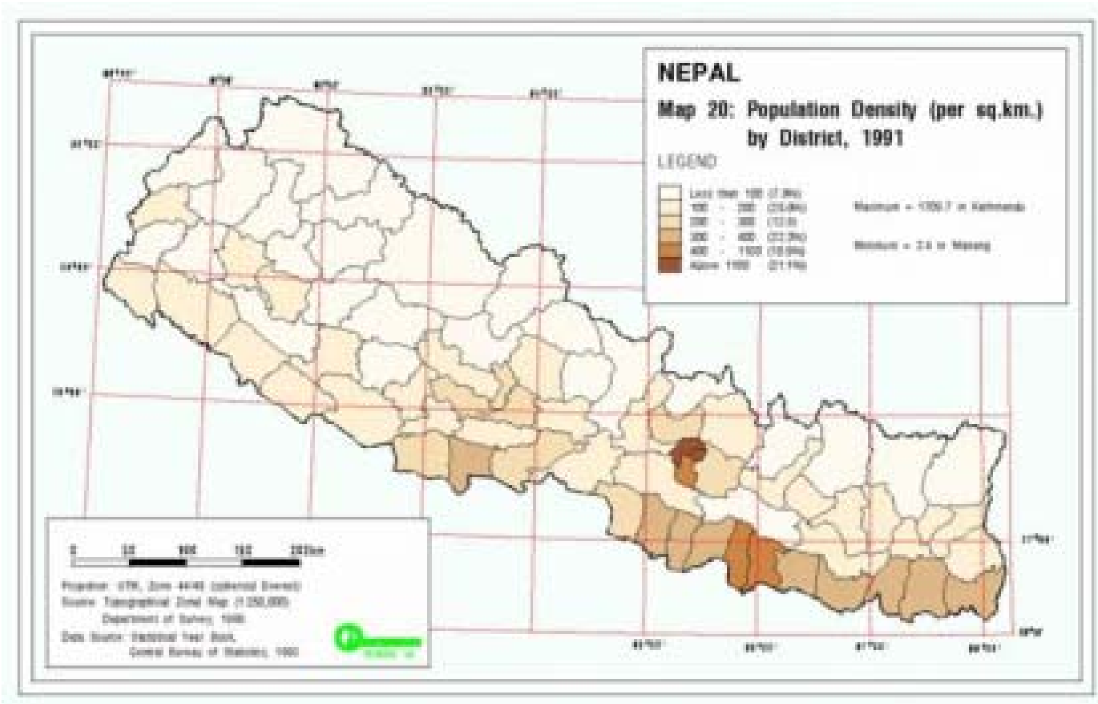

Figure 3: 1991 Population Densities by District

Picture Source: ICIMOD (www.icimod-gis.net)

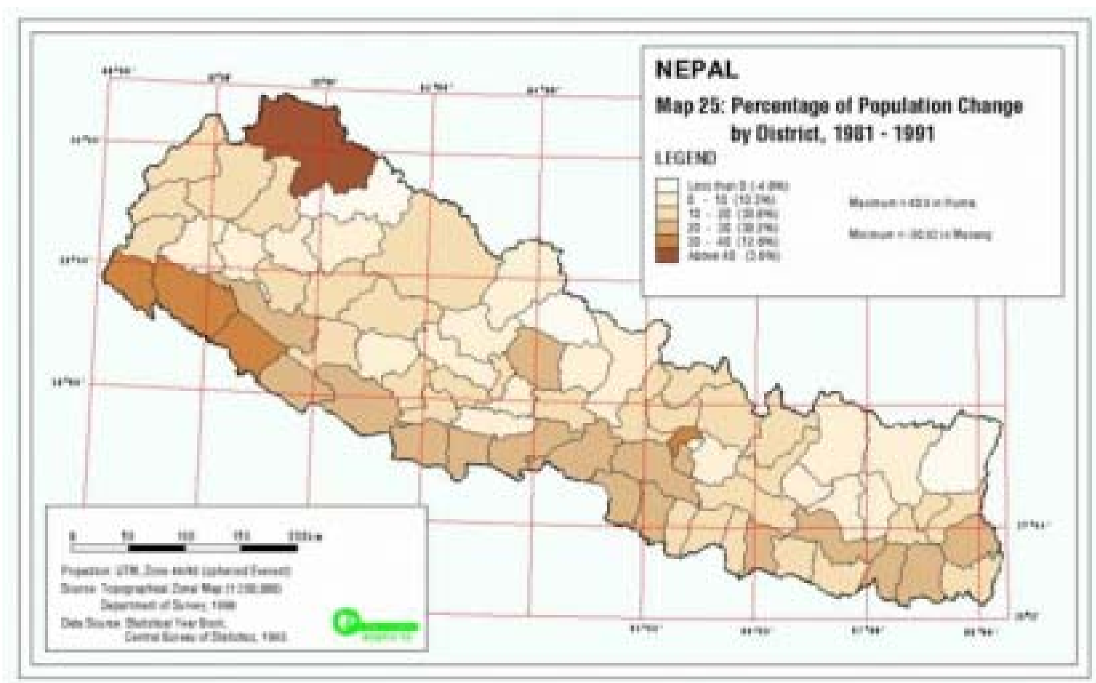

Figure 4: Percentage Population Change by District, 1981-1991

Picture Source: ICIMOD (www.icimod-gis.net)

The United Nations Development Programme Human Development Index (HDI) for Nepal is 0.49, ranking Nepal 142nd out of 173 countries. The HDI is a composite index that is used to measure human development and to compare human development between countries.

Nepal's relatively poor ranking in comparison to the other 173 countries is reflected in the following statistics:

• Life expectancy at birth	58.6 years
• GDP per capita ($PPP)[1]	$1,224
• Literacy Rate[2]	41.8%
• Population below income poverty line $2/day[3]	82.5%
• Children under height for age[4]	54%
• Child under-five mortality rate	91/1000

The International Centre for Integrated Mountain Development (ICIMD) has also developed their own set of 39 development indicators for Nepal and ranked the 75 districts in order of the Composite Index of Development (1 being least developed and 75 being most developed) (Figure 5). The least developed districts, according to the ICIMD report, are located within the northwestern region of the country as well as some areas just east of Kathmandu.

Figure 5: Ranking of Districts in Terms of Development

Picture Source: ICIMOD (www.icimod-gis.net)

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[1] Purchasing Power Parity in international dollars. International dollars are used to account for the relative differences in purchasing power between countries. The Nepal total GDP for 2000 was USD $5.5 billion which is approximately USD $239/capita.

[2] % age 15 and above

[3] 1993 PPP USD$

[4] % under the age of 5

According to the World Health Organization's 2000 "Global Water Supply and Sanitation Assessment Report", nearly five million people in Nepal lack access to safe drinking water and nearly eighteen million lack access to improved sanitation. The ICIMD also prepared a map showing the drinking water coverage by district based on information provided by the Department of Water Supply and Sewerage (Figure 6). According to the map in, the eastern Hills districts have the worst coverage.

Figure 6: Drinking Water Coverage

Picture Source: ICIMOD (www.icimod-gis.net)

When visiting and talking with many individuals and organizations in Nepal, however, it is readily apparent that more than five million people are *vulnerable* to problems with drinking water quality since the majority lack access to adequately treated water. There is virtually no monitoring of rural water supplies and the integrity of the urban systems in places like Kathmandu is often questioned by the general public and media. In May of 1995, for example, ENPHO found that 39 of 42 drinking water samples taken from the Kathmandu municipal water supply system were contaminated with fecal coliform bacteria and that 98% of the samples had no free residual chlorine. A more recent sample taken from a tap on the roof of ENPHO, supplied by the municipality, in January 2003 showed a total coliform concentration of 1550 cfu/100 mL. This sample was, however, taken the day after the water storage tank on the roof had been filled – the day previous to refilling the tank showed a total coliform concentration of 3 cfu/100mL. Nevertheless, this demonstrates some of the problems associated with the municipal water supply system as a whole – even if the water coming directly from the municipal system is clean, many citizens use storage tanks to store this water and these tanks in turn add another level of risk of water contamination.

Essentially, the infrastructure for supplying clean water across Nepal – both rural and urban areas – is minimal compared to that in industrialized countries, leaving citizens to treat their own water if they realize the need to do so and can afford to. Most of the population relies on decentralized water supply systems such as tube wells, open wells, springs, and stone taps connected to local reservoirs. While some of these water sources may be relatively clean, many are not, and those that may be now are still quite vulnerable to contamination in the future as development proceeds and stress on the environment and water resources persists. Springs, as an example, are perceived by many to be a relatively clean source of water; however, a survey of the percentage distribution by mode of drinking water (piped water, handpump/tap, well, spring, and other) of children under five years of age with diarrhea showed that 23% of the cases originated from springs – the second highest percentage behind "other" at 24%, suggesting that springs are more vulnerable to contamination than is commonly perceived. A random test of two hitigah or dhungedhara[5] wells used for both drinking water and cleaning in the Naikap district near Kathmandu in January 2003 showed total coliform concentrations of 1,660 and 2,130 cfu/100mL and *E.coli* concentrations of 5 and 74 cfu/100mL respectively for the two locations; demonstrating again that spring or well water is not necessarily safe, even though it is often perceived as clean by villagers.

[5] "walk-in" wells with stone steps leading into the well.

2.3 Point-of-Use Household Water Treatment Technology

In countries like Nepal, most people – predominately women – spend a portion of their day collecting, carrying and storing water for drinking. The water that ends up in the house does not originate from a typical water treatment plant and supply system, but comes to them from a variety of sources including local dug wells, tube wells, springs and stone taps (Figure 7). If the water is not already contaminated at the source, it often becomes contaminated at some point during transport and/or during handling storage before it is consumed.

Considering the reality in many developing countries like Nepal, where individuals are responsible for ensuring they have safe drinking water, it seems reasonable to focus on household water treatment technology as a means to providing clean drinking water. In fact, household water treatment appears to be gaining recognition within international development organizations such as the World Health Organization which recently published a report on Managing Water in the Home and UNICEF which sponsored an online virtual forum on Household Water Security in cooperation with WHO and the Network for Cost-effective Technologies in Water Supply and Sanitation (HTN). A recent statement issued by the United Nations Committee on Economic, Cultural, and Social Rights goes one step further by declaring water as a human right[6], which, taken into the context of the Millennium Development Goal, puts pressure on governments to live up to their commitment to halve the number of people without access to improved water supply and sanitation services by the year 2015.

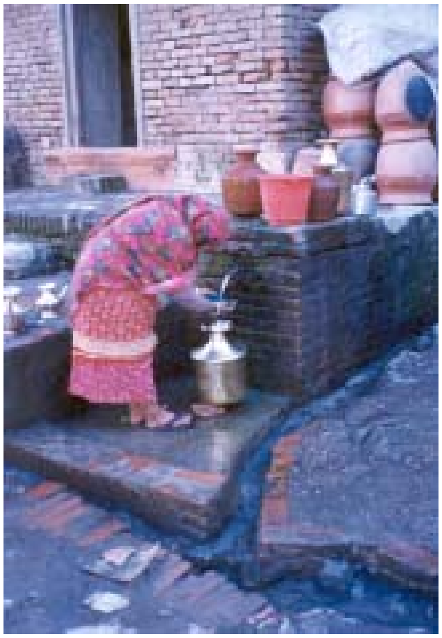

Figure 7: Nepali Woman Collecting Drinking Water from a Stone Tap

Thimi, Nepal. January 2003.

[6] Human Right to Water: http://www.who.int/water_sanitation_health/Documents/righttowater/righttowater.htm

2.4 BioSand Filtration

Project Coordinator: Melanie Pincus

2.4.1 BioSand Filtration Overview

The BioSand Filter is an intermittently operated slow sand filter specifically designed for use by poor people in developing countries. Developed by Dr. David Manz of the University of Calgary, Alberta, the BioSand filter (see Figure 8) is a scaled-down version of a municipal slow sand filter, and optimized for intermittent, household use (as opposed to continuous, community-scale use).

BioSand filter design incorporates two key modifications to traditional slow sand filtration technology. The first is a faster loading rate of 0.6 m/hr (flow rate of 20-40 L/hr for a 0.3 m x 0.3 m concrete unit) as compared to traditional slow sand filtration loading rates of 0.1 to 0.2 m/hr. The second key design parameter is a 5 cm layer of standing water, sufficient to allow adequate oxygen diffusion to the biological layer during pause periods[7] (0.7 – 1.5 m for traditional slow sand filters; AWWARF, 1991).

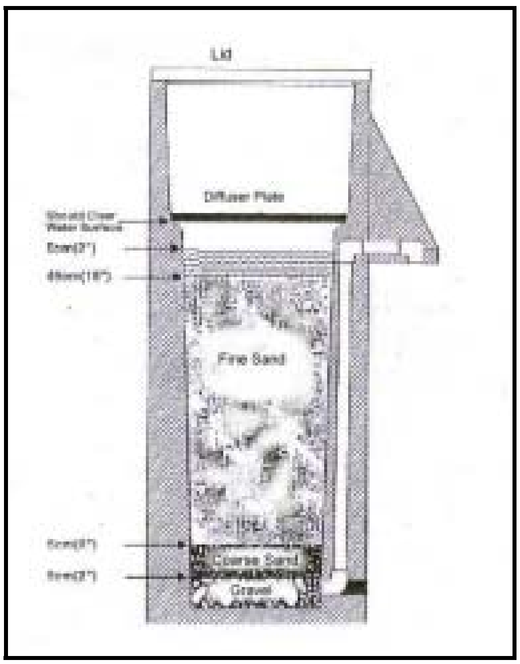

Figure 8: Cross-section of a concrete BioSand filter (Ritenour, 1998)

2.4.2 Particle Removal Mechanisms

Predation by protozoa in the supernatant (standing water layer) as well as the biofilm has been identified as the principle biological removal mechanism of harmful bacteria in source

[7] Dr. Manz's patent is for a "Slow Sand Filter for use with Intermittently Flowing Water Supply and Method of use thereof." Supernatant depth is specified at 1 – 8 cm above the top of the surface sand layer (Manz, 1993).

water.[8] Physical-chemical removal processes include straining (of particles greater than about 2 µm in diameter) and attachment via intermolecular forces between the sand grain surfaces and dissolved and/or suspended particles.

2.4.3 Biofilm Maturation

Newly installed or recently cleaned BioSand filters do not effectively remove bacteria. Bacterial removal efficiency depends on biolayer "ripeness." Ripening refers to the time necessary for the biological community or biofilm to mature such that optimal bacterial and particle removal is attained. Specifically, filter ripening is defined in this context as an improvement in the ability of a filter to remove *Escherichia coli (E. coli)*. *E. coli* were chosen as test particles because they were not expected to multiply in the filter columns (due to low temperatures and insufficient oxygen levels) and thus could be used as tracer particles (Weber-Shirk and Dick, 1997).

2.4.4 BioSand Filter Field Site and Methods

The author traveled to the Lumbini district of Nepal’s southern Terai region to assess the technical performance of 10 recently installed concrete BioSand filters. Filter performance and source water quality were evaluated using membrane filtration for enumeration of *E. coli* and total coliform bacteria, presence/absence tests for hydrogen sulfide (H_2S) producing bacteria, turbidity and flow rate measurements. *E. Coli* and H_2S test results were compared to assess the validity of the H_2S method for detecting fecal contamination in drinking water in colder climates (temperatures at or below 10^{o}C [50^{o}F]).

Field and laboratory experiments on concrete CAWST (2003) and plastic Davnor (2003) BioSand filters (see Figure 9) were performed to elucidate biofilm maturation rates and bacterial removal efficiencies.

Figure 9: Davnor Plastic BioSand Filter (left); CAWST Concrete BioSand Filter (right).

[8] Weber-Shirk and Dick (1997) studied particle and E. coli removal mechanisms in slow sand filters. Introduction of sodium azide (an inhibitor of oxidative phosphorylation) was found to cause appreciable reduction in particle and E. coli removal, indicating biological removal mechanisms to be significant. Bacterivory was identified as the biological mechanism principally responsible for bacteria removal.

The BioSand pitcher filter (see Figure 10) was conceptualized during field investigations as a smaller, cheaper alternative to the concrete BioSand filters. Pitcher filters might also potentially serve as bench-scale models of the larger BioSand filters, or as backups to the full-size units during filter cleaning and subsequent biofilm re-maturation.

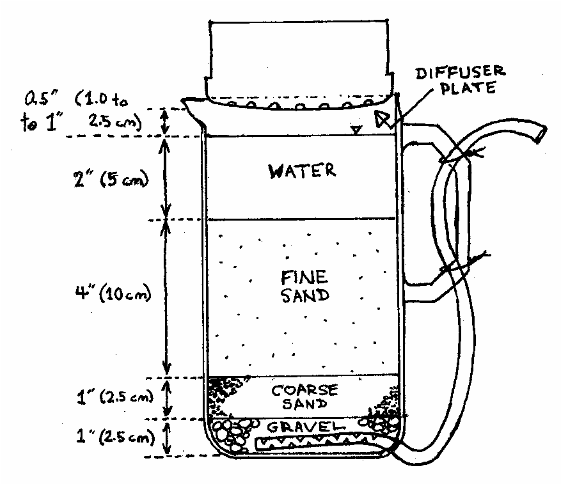

Figure 10: BioSand Pitcher Filter

Field and laboratory experiments were performed to conduct a preliminary evaluation of pitcher filter viability by cross-checking their performance with the concurrent performance of concrete and plastic Davnor BioSand filters.

2.4.5 Discussion of Results

2.4.5.1 Lumbini Household BioSand Filter Survey

Ten concrete BioSand filters in 6 villages were visited. Filter flow rates varied from 1.0 to 37.5 L/hr (see Table 1); improper sand preparation and filter commissioning for some units may be responsible for the variation observed. Turbidity removal was high for all systems; filters treating highly turbid source water (ground water of 176.0 – 360.0 NTU) were observed to remove between 98.7 and 99.8% of turbidity.

Table 1: Turbidity and flow rate data from Lumbini district BioSand filters.

Filter	Flow Rate (L/hr)	Turbidity (± 0.1 NTU)		
		Raw Water	Filtered Water	% Removal
BSF1	5.6	3.9	1.7	57.7
BSF2	1.0	360.0	0.8	99.8
BSF3	14.5	15.0	1.7	88.7

BSF4	24.1	176.0	2.3	98.7
BSF5	2.8	179.0	2.3	98.7
BSF6	2.4	1.2	1.8	(-50.0)
BSF7	2.4	2.8	1.3	53.6
BSF8	37.5	3.4	2.1	38.2
BSF9	34.9	5.0	2.0	60.0
BSF10	0.0	N/A	N/A	N/A

Results from microbial analyses were mixed (see Table 2). Whereas two BioSand filters were removing 99% of *E. coli* from highly contaminated influent water, three were found to be sources of *E. coli* contamination for relatively clean source water.

Table 2: Microbial data from Lumbini district concrete BioSand filters.

Filter	Raw Water		Filtered Water		% Removal *E. Coli*	Log Reduction Value
	E. Coli (cfu/100 ml)	Total Coliform (cfu/100 mL)	*E. Coli* (cfu/100 ml)	Total Coliform (cfu/100 mL)		
BSF1	2.5	10	0.5	1.5	80	0.7
BSF2	0	110	>10	>90	(-1000)	-1
BSF3	0	1.5	>400	>800	(-40000)	-2.6
BSF4	0	20	0	15	N/A	N/A
BSF5	>1000	>2000	10	>1010	99	2
BSF6	>110	>110	0	>120	99	2
BSF7	0.5	29	>1000	>1033	(-199900)	-3.3
BSF8	0	5.3	0	>1000	N/A	N/A
BSF9	1	101	0	1	(100)	N/A
BSF10	N/A	N/A	N/A	N/A	N/A	N/A

While field and laboratory experiments on full-size BioSand filters strongly suggest that fully ripened BioSand filters will significantly improve the quality of influent water, further testing of the Lumbini household filters is appropriate. One day of testing for each filter, which was all the time afforded for that activity, is insufficient to adequately characterize BioSand filter performance. Regular, repeated samplings of source water, filtered water and water in collection buckets still needs to be performed on these pilot household units.

Sampling programs should also include consistent sterilization protocol. For example, if users are suspected of introducing contamination at the source, triplicate water samples should be obtained (a) as collected by the users, (b) by a trained monitor or technician without flaming the spout, and (b) collected in a manner that carefully avoids contamination at the point of withdrawal, e.g., after flaming the spout and collecting into a sterilized container (Carter, 2003).

2.4.5.2 BioSand Filter Bacterial Removal Efficiencies

Results from field and laboratory experiments on concrete and plastic BioSand filters support the use of this technology to provide households with safe drinking water. Data suggest that fully ripened BioSand filters are capable of significantly improving the quality of influent water, reducing turbidity by at least 90% (to less than 5.0 NTU[9]) and influent *E. coli* concentrations by at least 95%. In addition, a strong correlation was observed between biofilm maturation periods and source water quality; lower quality influent water (high turbidity, high levels of nutrients and bacteria, etc.) facilitated biofilm ripening (see Table 3).

Table 3: Estimates of BioSand Filter ripening periods.

BioSand Filter	Estimated Ripening Period (days)	Source Water Quality
Lumbini Experiments		
Concrete Filter 1	8-10	poor/organic rich
Concrete Filter 2	8-10 (uncertain)	poor/organic rich
Green Pitcher Filter	--	--
Blue Pitcher Filter	--	--
MIT Experiments		
Davnor Filter	30-40	high/organic poor
Green Pitcher Filter	30-40	high/organic poor
Blue Pitcher Filter	30-40	high/organic poor

2.4.5.3 Agreement between H_2S and Membrane Filtration Test Results

Very poor agreement (38% false negative rate) was observed between H_2S and membrane filtration test results, even in samples with >1000 cfu *E. coli*/100 mL. Winter temperatures of approximately 10°C (50°F) and lower (to approximately 4°C or 40°F) were thought to significantly decrease the accuracy of H_2S tests as detectors of fecal contamination in drinking water.

Even so, numerous studies have found good agreement between H_2S tests and enumerative bacterial analyses under warmer conditions (see Ratto et al., 1989; Kromoredjo and Fujioka, 1991; Kaspar et al., 1992; Castillo et al., 1994; Venkobachar et al., 1994; Martins et al., 1997; Rijal and Fujioka, 1998; Genthe and Franck, 1999; Pillai et al., 1999; and Sullivan, 2002), and many researchers recommend the H_2S method as a reasonable approach for detecting fecal contamination in drinking water.

[9] WHO guideline for turbidity in drinking water is less than or equal to 5.0 NTU (WHO, 2002a).

In addition, the tests may be ideal for facilitating community involvement in the monitoring and management of drinking water supplies and treatment systems because of their simplicity and ease of interpretation. Because test results are based simply on the observable formation (or lack thereof) of a black precipitate, even poorly educated (e.g., illiterate) individuals may learn to successfully use and interpret the results of H_2S analyses.

2.4.5.4 BioSand Pitcher Filter Viability

Comparable microbial and turbidity removal performance between pitcher filters and concrete CAWST and plastic Davnor filters support the use of a pitcher system testing platform to model the commercially available BioSand technology. Pitcher filters might also be used as an interim measure until a household mobilizes funds for a larger capacity water filter (e.g., a concrete BioSand filter), or as backups to the full-size units during cleaning and subsequent biofilm re-maturation.

Microbial removal performance of experimental pitcher filters was comparable to the existing BioSand filters. *E. coli* removal efficiencies of two field pitcher filters (averaged over 3 days) were 80 and 86%, as compared to 81 and 87% for concrete BioSand filters. Laboratory pitcher filters ripened with *E. coli* spiked Charles River water for 28 days, then challenged with dilute wastewater, showed removal efficiencies of 97%, as compared to 95% for a plastic BioSand filter (see Figure 11).

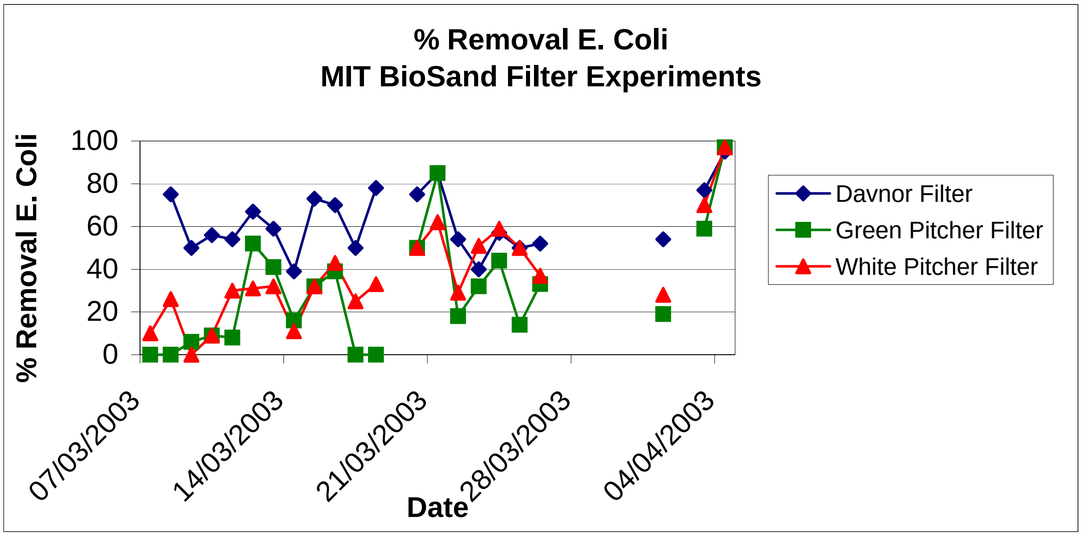

Figure 11: E. coli removal efficiency data obtained during MIT BioSand filter experiments.

Limitations of the BioSand pitcher filter system also deserve consideration. Due to its small size, the pitcher filter biofilm may be at a greater risk of disturbance (i.e., from jostling) than the heavier concrete or plastic BioSand filter. Disturbances to the supernatant may decrease microbial and turbidity removal effectiveness. Secondly, holding capacity of the pitcher filter (approximately 0.5 L as currently designed) is approximately twenty times less than that of the concrete BioSand filter. Filtration times for larger volumes of water will thus be increased.

2.5 Ceramic Water Filters

Project Coordinator: Rob Dies

Ceramic water filters have been used in various places around the world as a means of treating drinking water at the household level. The fact that ceramic filters can be manufactured and produced by local ceramists with local materials makes them particularly attractive as a point-of-use treatment technology that is affordable, appropriate, and sustainable. Some examples include the Potters for Peace[10] Filtron (Nicaragua), the TERAFIL terracotta filter (India), and the candle filter (India, Nepal, Bangladesh, Brazil, etc) (Figure 12).

Figure 12: Types of Ceramic Water Filter

Although the use of ceramic water collection and storage vessels goes back centuries, there is little documentation and testing of the effectiveness of *low-cost* ceramic water filters both in the laboratory and especially in the field in developing countries.

What research has been done suggests that the commercially available ceramic water filter systems in places such as India, Nepal, Nicaragua, and Brazil are a step in the right

[10] Potters for Peace website: www.potpaz.org

direction, but could be improved to better meet the safe drinking water needs of citizens. In particular, many commercially available filter systems are too expensive for the poor who are suffering the most from waterborne diseases.

Several organizations, including MIT, are currently pursuing laboratory and field research on the effectiveness of ceramic water filters. This year, the MIT Nepal Water Project continued research on the feasibility of developing a new disk-filter prototype that could potentially eliminate some of the problems associated with existing filters, at a retail price that is affordable to the poor.

2.5.1 Previous Work

MIT engineering student Junko Sagara was the first student to study ceramic water filters in Nepal in 1999/2000 as part of her Master of Engineering thesis (Sagara, 2000). C.S. Low continued research on ceramic water filters in 2001/2002 as part of his thesis on "Appropriate Microbial Indicator Tests for Drinking Water in Developing Countries and Assessment of Ceramic Water Filters" (Low, 2002). Low worked closely with ceramist Mr. Hari Govinda Prajapati of Madhyapur Clay Crafts in Thimi Nepal, who had originally been located and contacted by Junko Sagara, to develop the first version of a ceramic disk filter.

A number of engineering students have also carried out research on ceramic water filters in Nicaragua. In particular, Daniele Lantagne conducted an in-depth study of the Potters for Peace (PFP) Filtron filter in 2001 (Lantagne, 2001) and Rebeca Hwang recently carried out research on evaluating the effectiveness of a monitoring program in conjunction with the PFP Filtron (Hwang, 2003).

As part of the ongoing effort to understand and improve ceramic water filters in Nepal, Nicaragua and elsewhere, a team of engineering and business students (named CeraMIT) was formed this year to continue working on developing a ceramic water filter for Nepal. Four students formed the CeraMIT Nepal Team:

- Rob Dies, Department of Civil and Environmental Engineering, MEng Candidate
- Steve Perreault, Sloan School of Management, MBA Candidate
- Bobby Wilson, Sloan School of Management, MBA Candidate
- Laura Ann Jones, Sloan School of Management, MBA/TPP Candidate

CeraMIT conducted a three-week-long field study in Nepal during January 2003. This research culminated in several recommendations for the development of a grassroots ceramic water filter business in Nepal (CeraMIT, 2003; Dies, 2003)

On return from Nepal, mechanical engineering senior student Lily Cheung joined the CeraMIT team to develop one of the prototype designs that was recommended by CeraMIT, as part of her senior thesis (Cheung, 2003).

2.5.2 Overview of Ceramic Water Filters

Ceramic water filters can be categorized according to various key parameters:

1. Shape (e.g.: candle element, disk, pot) (Figure 12);
2. Type of clay (e.g.: white kaolin, red terracotta, black clay…);
3. Combustible material (e.g.: sawdust, flour, risk husk…).

Ceramic water filters can also be described by their function(s):

1. Microbial removal (e.g.: Potters for Peace Filtron);
2. Chemical contaminant removal such as arsenic and iron (e.g.: 3 Kolshi filter for arsenic) (Hurd, 2001; Tabbal, 2003);
3. Secondary contaminant removal like taste and odor (e.g.: Katadyn®[11] Gravidyn ceramic candle filter with activated carbon).

Other key variables that influence the properties of ceramic water filters include:

1. Use of additional materials in production (e.g.: grog, sand, combustible materials…);
2. Firing temperature;
3. Mode of production (e.g.: hand mold, wheel, mechanical press).

The entire filter unit is often defined in terms of two components: the filter *element* or *media* through which water passes and the filter *system* which houses the media, usually consisting of an upper and lower storage vessel for holding water (Figure 13).

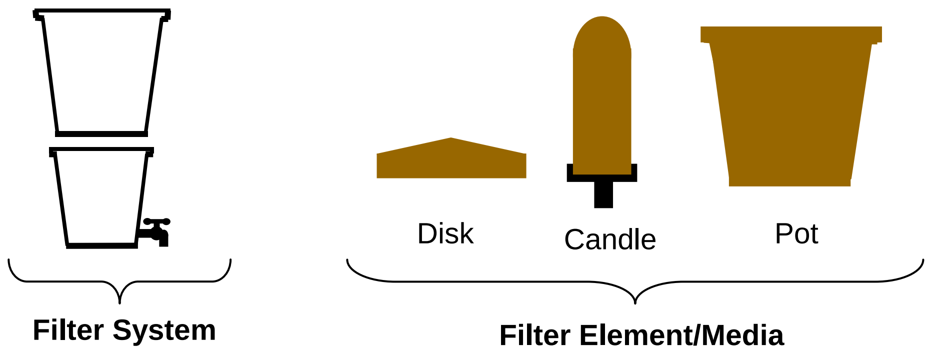

Figure 13: Ceramic Water Filter System and Element/Media

Some general strengths and weaknesses of ceramic water filters are listed in Table 4 below.

Table 4: General Strengths and Weaknesses of Ceramic Water Filters

Strengths	**Weaknesses**
• Relatively cheap to manufacture and produce; • The ceramics trade is well established in many countries; • Materials (clay, sawdust, rice husk…) are often readily available; • If designed and used properly, can remove up to >99% of indicator organisms and reduce turbidity to below World Health Organization guideline values.	• Very slow filtration rates. (typically ranging between 0.5 and 4 L/day); • Filter maintenance and reliability depends on the user – herein lies many non-technical social issues; • Breakage during distribution or use can be a problem since ceramic filters are often fragile; • Requires regular cleaning; • The rate of production as implemented in countries such as Nicaragua and Nepal has tended to be relatively slow; • It is difficult to maintain consistency (quality control is an issue).

[11] Katadyn website: www.katadyn.com

2.5.3 Production Process

The ceramic water filter production process follows some common steps regardless of the type of filter being manufactured. The process typically begins with material selection and processing; followed by shaping and pressing the filter element into a mold; firing; drying and then potentially treating the filter with a disinfectant such as colloidal silver (Figure 14).

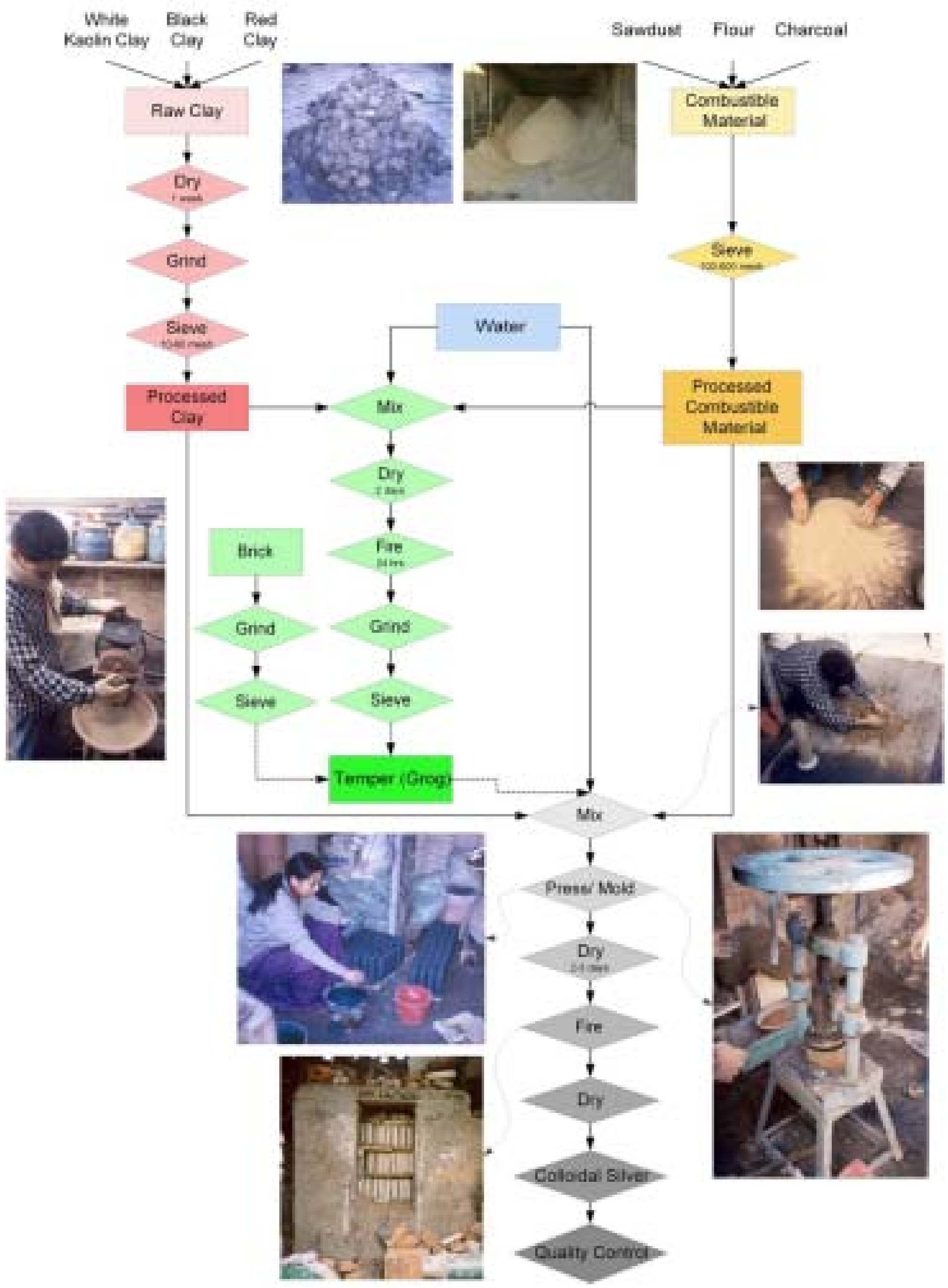

Figure 14: Ceramic Filter Production Process

2.5.4 Laboratory Testing

Laboratory tests of twelve disk filters (three types) and five candle filters were carried out by engineering student Rob Dies at the Environment and Public Health Organization (ENPHO) in January 2003 (Dies, 2003). The purpose of the laboratory testing of various ceramic filter element shapes and media was to do a preliminary comparison of filter shapes (candle versus disk); filter media (white clay versus red clay versus black clay); filter flow rates; production methodology; and to evaluate the effectiveness of colloidal silver at removing microbial contamination across a fairly broad range of materials and products. This testing distinguishes the testing from previous years where only one type of ceramic filter (e.g.: Hari Govinda candle filter, Potters for Peace Filtron, TERAFIL disk filter) was tested.

Based on microbial removal efficiency and flow rate, the most promising filter elements that were tested were the Katadyn® drip filters (Ceradyn and Gravidyn); the modified-Hari Govinda candle filter coated with colloidal silver; and the Reid Harvey red-clay grog disk filter coated with colloidal silver. All four filters had comparable flow rates ranging from 650 to 800 mL/hr/filter. The microbial log-reduction value (LRV) for all three candle filters was 1.9 for total coliform and 1.7 for *E.coli*, given a raw water total coliform concentration of 89 cfu/100 mL and *E.coli* concentration of 56 cfu/100 mL. The LRV for Harvey's disk filter was 2.6 for total coliform and 2.9 for *E.coli*, given a raw water total coliform concentration of 2,500 cfu/100 mL and *E.coli* concentration of 1,561 cfu/100 mL.

No conclusions can be drawn comparing the three candle filters to the one disk filter since different raw-water microbial concentrations were used for the testing of each group; however, these four filters offer a starting point for future product development and research.

The results also support the hypothesis that colloidal silver acts as a bactericide and aids in the inactivation of indicator microorganisms such as total coliform and *E.coli* bacteria; however, more testing is required to determine the effectiveness of colloidal silver over longer periods of time (greater than one day) and after repeated usage of the filter system.

2.5.5 Prototype Development

Based on the research conducted over the past eight months and field work in Nepal, the CeraMIT team formulated a number of important product attributes or performance goals for the design of a ceramic water filter system (Table 5) (CeraMIT, 2003).

Table 5: Product Attributes to Consider for the Development of a Ceramic Water Filter System for Nepal

System	Media
• Low cost; • 20 L capacity and/or a range of capacities; • Container material should not affect taste or smell of water; • Light and durable; • Easy to carry & maneuver; • Easy to maintain & clean; • High-quality tap;	• Low cost; • High flow rate (2L/hr minimum); • Disk filter unit, 9" diameter; • A candle filter unit for legacy systems; • Durable – particularly when cleaning with a semi-abrasive brush/cloth; • Easy to maintain & clean; • Complete seal between the media and the system;

• Compact for transport & storage (ideally, one bucket should fit into the other); • Lid to cover the top bucket; • Optional stand.	• Disk element should be replaceable just like the candle filters; • Coated with colloidal silver.

Mechanical engineering student Lily Cheung took these design recommendations and developed the first working prototype called the "Lily Filter" as part of her senior thesis (Figure 15) (Cheung, 2003).

The Lily Filter consists of three components: an upper container for holding raw water, a lower container for holding filtered water, and a cartridge, which connects the upper and lower containers. The cartridge holds the disk filter, which is cemented into place using white cement. The cartridge rests on top of the lower storage container and the upper container fits into the top of the cartridge as shown in the figures below.

Note that the prototype shown in is constructed of PVC. The final version will be constructed of HDPE or PET plastic material as shown in Figure 16.

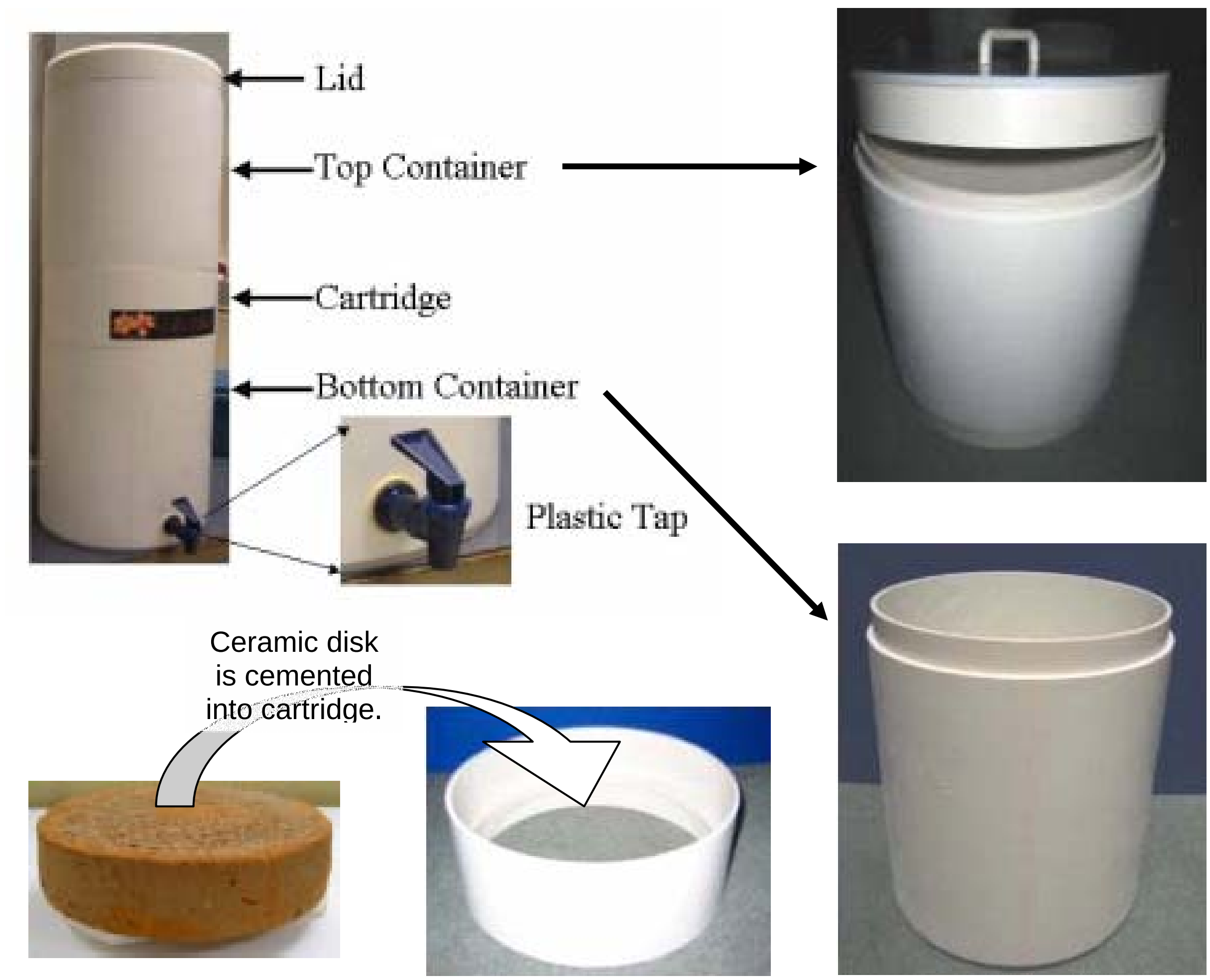

Figure 15: 2003 Disk Filter Prototype Design: The Lily Filter

Figure 16: Examples of Filter Systems and Containers that use Clear Plastic: Kisii Filter System, Kenya (left); Durable Plastic Container (right).

2.5.6 Lab Certification

Field and laboratory testing are indispensable components of product development; especially for a product such as a ceramic water filter where there are human health ramifications. Testing serves the purpose of providing feedback to designers who can then in turn improve product design and performance. At this time, there is no universal standard or certification process for evaluating the technical performance of low-cost point-of-use water treatment technologies such as ceramic water filters. Furthermore, field study methodologies are evolving to include a broader spectrum of performance parameters including the evaluation of health-based indicators, social acceptability, willingness to pay, and technical performance. Thus, the overall performance of a ceramic water filter can, and should, be certified under laboratory conditions as well as verified and evaluated under actual conditions in user households.

In terms of certification, there is an emerging need for an international organization such as the WHO or the National Sanitation Foundation International (NSF)[12] to define POU treatment technology standards for removing microbial contamination that are relevant to the circumstances under which these products are being developed. As a starting point, the United States Environmental Protection Agency (EPA) developed a "Guide Standard and Protocol for Testing Microbial Water Purifiers" in 1987 (US EPA, 1987). NSF International has also developed two standards for drinking water treatment units that are potentially relevant to the certification of ceramic water filters, and new microbiological treatment standards for drinking water treatment units are being developed this year (NSFreMarks,

[12] NSF International, The Public Health and Safety Company™ is a not-for-profit NGO that develops health and safety standards for product certification. Companies who sell products that meet NSF certification can then market their products as NSF certified. This in turn provides valuable information to consumers who make decisions between purchasing different products. NSF is widely recognized worldwide and is therefore a potential candidate for proposing health-based standards for certifying POU water treatment technologies.

2003). Furthermore, First Water® Ltd.[13] has developed a grading system based on the log-reduction value of microbiological organisms (Table 6) (Clasen, 2003).

Table 6: The First Water® Ltd Grading System for Ceramic Water Filters

Grade Level	LRV	Bacteriostasis	Quality Control	Capacity (Liters)	Candle Cost ($US)
A	>6	Impregnated Silver	Total	50,000	9-10
B	4-5	Coated Silver	Some	12,500	2-3
C	2-3	None	None	5,000	1

These standards and guidelines provide a basis for developing a set of laboratory procedures for systematically evaluating filter performance, and possibly certifying a filter in the future. Ideally, the next step would be for an international organization such as the WHO, NSF International, or the emerging Household Water Treatment System Network[14], or some sub-committee thereof, to agree upon appropriate standards for certification. The standards should be strict, but not too strict to impede people from developing POU technologies. Consistency in terms of evaluating performance is more important than having to necessarily meet strict drinking water quality guidelines or standards. The US EPA's required LRV values presented in their suggested guide are justifiably strict, but possibly too strict for some of the POU treatment technologies being developed for developing countries. Thus, a grading system such as that proposed by First Water(r) Ltd in Table 6 is a possible remedy to relaxing the guidelines slightly and to encourage the development of POU treatment technologies.

2.5.7 Field Testing

There is an important distinction to make between technical performance of a filter system under laboratory conditions and actual performance in the field. Aside from evaluating the technical performance of filters subjected to normal day-to-day use, field testing can also reveal many non-technical behavior-based issues that are arguably just as important in terms of measuring "performance" of a filter system, or, more specifically, finding the root causes for why the filter system is or is not performing to the standards that were achieved during certification under controlled laboratory conditions. This is particularly relevant for the developing country context since users are so intimately involved in the treatment of their water. The success of a ceramic water filter in the home, for example, depends on the user's acceptance of the technology as well as behavior with respect to maintenance and general hygiene around the filter system.

Thus, field testing requires more than just measuring the technical performance of a filter system if the root causes for the filter performance results are desired. It is useful to consider

[13] First Water Ltd. is an organization working on developing point-of-use water treatment technologies for developing countries. Their website: www.firstwater.org.

[14] The Household Water Treatment System Network is a public private partnership, coordinated by the World Health Organization.

both technical performance of the filter system and user behavior as separate, yet interdependent, factors that lead to an improvement or deterioration of human health, as affected by the quality of the drinking water. The interconnections between human health, technical performance, and user behavior are demonstrated in Figure 17 as performance gaps. The technical and behavior gaps are defined in terms of the difference between an ideal state, or goal, and the actual state that is measured. A gap then leads to action, which is directed at changing the actual state to meet the intended goal and to eventually close the gap. Some factors that can affect user behavior, like education/awareness, product performance, and product design, are listed in Figure 17. Monitoring and evaluation are the activities that drive this process of improving overall product performance and, more importantly, human health over time.

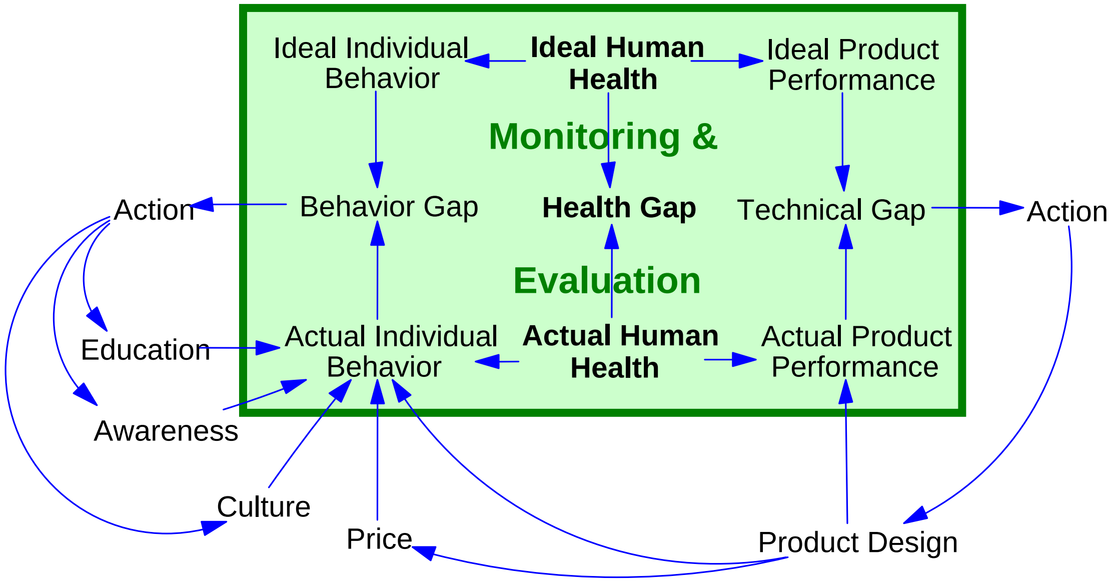

Figure 17: Closing the Behavior and Technical Gaps Associated with Using Point-of-Use Technology to Treat Drinking Water

2.5.8 Conclusion and Recommendations for Future Work

Countries like Nepal face tough challenges in terms of providing safe, clean drinking water for their citizens. Centralized water supply systems may be a solution in the long-term, but the immediate need for clean drinking water necessitates new approaches that can provide solutions and solve the crisis now. Household water treatment technologies, such as ceramic water filters, offer a potentially viable solution to providing clean drinking water by treating water at the point-of-use. Advancements in low-cost ceramic water filter technology coupled with the pressing need for clean drinking water offers an attractive business opportunity for local Nepali entrepreneurs – especially local ceramists who have the resources and capability to manufacture ceramic water filters.

The following recommendations are intended to help guide future work on the development of a ceramic water filter for Nepal.

1. **Colloidal Silver Research**. To determine the effectiveness of CS over time.

2. **Colloidal Silver Production Process**. To our knowledge, CS is not commercially available in Nepal and thus, research into methods of production or importing a product will be required, if the final ceramic filter is to use CS.
3. **Ceramic Media/Material Research.** To understand how the filter works on a microscopic level.
4. **Hydraulic Studies.** To compare theoretical equations of flow rate for a candle filter and a disk filter (Dies, 2003) to observed flow rates. Furthermore, to compare results with previous studies on the hydraulics of the Potters for Peace Filtron filter (Lantagne, 2001; Fahlin, 2003).
5. **Product Certification.** To develop a set of appropriate standards for certifying low-cost point-of-use water treatment technologies such as ceramic water filters.
6. **Field Testing.** To test effectiveness (i.e. technical performance (microbial removal efficiency, flow rate), social acceptability, health-based performance indicators, and willingness to pay) of the current prototype in the field.
7. **Prototype Development**. To continue testing the current prototype and to make improvements as necessary before brining it to Nepal next January.
8. **Ceramic Filter Element/Media**. To develop or choose a ceramic filter element to go with the complete filter prototype.

2.6 Solar Disinfection

Project Coordinator: Xanat Flores

There have been many studies done around the world with a type of solar disinfection of drinking water usually with plastic PET (polyethylene terephthalate) bottles known as Solar Disinfection SODIS. This technology is based on the fact that UV light in a range of 315 to 400 ηm , also known as UVA, is able to cause DNA damage in living cells, and create highly destructive oxygen species (if sufficient amounts of oxygen are present), thus inactivating the pathogen cell. These oxygen species are enhanced by oxygenation (Oates, 2001; Reed, 1996).

It has been known that water also absorbs red and infrared light creating heat, which could lead to pasteurization if it reaches a certain temperature. The combined effects of radiation and heating to temperatures of 50 or 60 °C turn into a combined synergistic germicidal effect against viruses, bacteria and parasites, more powerful than each (Sobsey, 2002).

SODIS consists on putting plastic (PET) bottles filled with water and exposing them to the sun. Studies around the world have shown SODIS to be efficient in the inactivation and destruction of pathogen bacteria. Most of these studies have been made for household level and small water quantities, showing an economical application due to its low cost.

Most of the tests that have been performed to evaluate SODIS effectiveness have used indicators of Total Coliforms (*Klebsiella, Enterobacter, Citrobacter* and *Serratia*) and *Escherichia Coli*. The primary reason to use these organisms is due to the fact that 95% of these are present in fecal materials, and fecal contamination is the main cause of deadly waterborne diseases in developing countries (Martin, 2000).

Earlier studies have been done in Nepal by M.I.T. Master of Engineering students Amer Khayyat (2000), Megan Smith (2001), and Harvard School of Public Health doctoral student

Cathy Pham (Smith, 2001) concerning SODIS, finding satisfactory physical conditions for solar disinfection implementation, and recommending a two-day exposure time. Solar radiation has been found to meet the 500W/m2 threshold through most of the year (Smith, 2001). This is verified by the fact that Nepal is located within the 15N and 35N latitude area, that is known to be one the most favorable areas for solar radiation (Acra Aftim, et al, 1984). However, informal surveys of users in Lumbini, Nepal, who has been taught to use this system, expressed concern about the amount of work needed to be performed every day in order to achieve sufficient radiation exposure, and did not continue with this practice over the medium or long term.

Some of the research done in many places around the world, as well as the research done by previous M. Eng. students, have shown that the key variables are: sun radiation levels, temperature and turbidity in the water, exposure times and type of recipients. The limitations of the SODIS system are:

- It takes two days for SODIS to produce safe drinking water under challenging climate conditions of winter and monsoon in Nepal.
- It’s not suitable to disinfect large quantities of water.
- SODIS cannot assure protection against recontamination
- PET bottles might not be available or might create disposal pollution problems.
- It requires comprehensive training and coaching to correctly apply SODIS.

Another approach that has not been as broadly studied is the continuous solar disinfection system. This system usually consists of a tank, a heat exchanger and a reactor of direct solar exposition. The purpose of this approach is to be able to supply water at any given time continuously, without having to wait for two days to have safe drinking water. However this system has not been so popular due to its complexity and the costs (increased due to the necessity of more sophisticated equipment). Thus, continuous systems have not been implemented at a household level in low-income countries.

2.6.1 SODIS Study Objective.

The invention of a semi-continuous solar disinfection system (SC-SODIS) is an innovation that overcomes limitations and disadvantages of previous point-of-use systems (specifically solar disinfections systems; i.e. SODIS). SC-SODIS promises to become a widely accepted (technologically, economic, and socio-culturally) system.

The purpose of the present SODIS study is to review different SODIS experiments and findings from developing countries with similar social, environmental and political characteristics as the ones seen in Nepal, and to contribute new SC-SODIS field work by performing innovative experiments.

Some of the essential factors to consider in a semi-continuous SODIS system are:

- Environmental and site factors: solar radiation on average guarantees 5 hour 500W/m^2 most of the time throughout the year.
- Characteristics of the water: type and concentration of pollutants (chemical or biological), flux to be treated.
- WHO guidelines for *E. Coli* and hazardous chemicals.

- Social: research done by M.I.T. Master of Engineering student Xanat Flores on the need to educate people in Nepal to learn about the project, how it works and maintenance requirements.
- Selection of the optimal process: the final prototype selected after research and experimentation.
- The project has to be economically viable: this will depend on the process selection and the materials used, trying to get to the most saving solution possible. We have tried to design a system that requires low-tech approaches. For example, in Nepal sometimes there is no electrical power available, so we would like the system to operate independent of electrical power.

2.6.2 Prototype System

This system (Figure 18) consists of arranged PET bottles in parallel fixed together in such a way that water will pass through the bottles with a flow that will allow an exposure time of two days (exposure time recommended to obtain 0 CFU *E. Coli* as recommended by WHO Guidelines (1997)) through each one of the bottles. This system can work by gravity, placed on the roof of the houses where polluted water with turbidity of less than 30 NTU will be fed. There will also be a valve that will be set to a certain flux to assure complete water disinfection; (see Figure 18), and a second valve to close the flow when the system is not in use (i.e. during the night) and is controlled by the householders. As part of the overall system, there will be a need for a storage tank in order to be able to store the water as it becomes purified. However, it is not recommended to have long storage times, since there is the possibility of microbial regrowth and recontamination. Thus a daily average consumption equal to the amount of water produced by the solar disinfection system is recommended. The system (Figure 19) requires the use of a holding tank on a roof or another high elevation spot that can be filled manually or by electric pump.

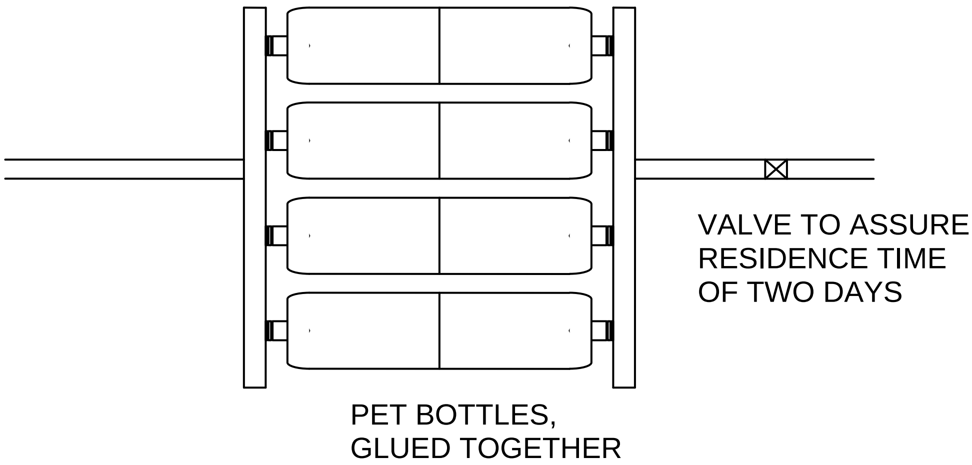

Figure 18: Proposed Solar Disinfection System: SC-SODIS

Within the system other variables can be studied, including the size of the containers, painting of the bottles half black, fully black or use of reflectance materials, different exposure or residence times, temperature effects, etc.. Due to the short time available for experimental work, only exposure or residence time variables have been studied so far.

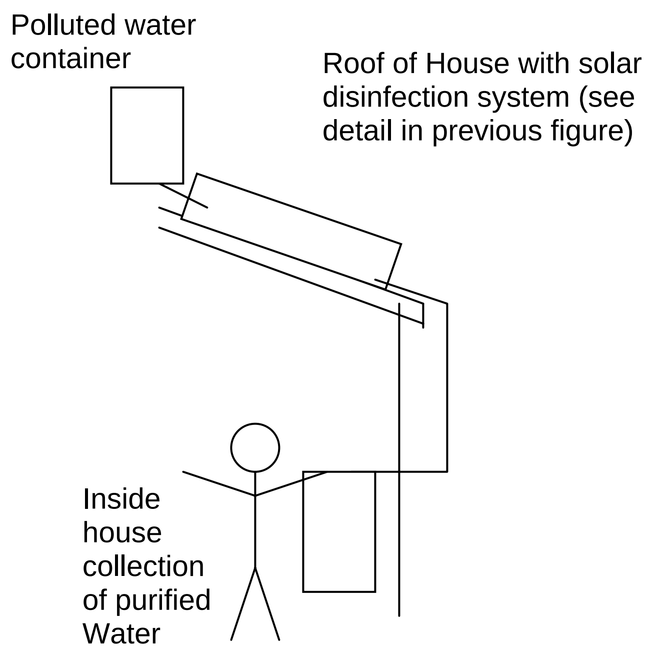

Figure 19: SC-SODIS

2.6.3 SC-SODIS feasibility assessment

Data collected during the month of January 2003 in Lumbini, Nepal, forms the basis for the feasibility assessment of SC-SODIS. The overall purpose of this study was to assess the sustainability of the SC-SODIS system. To that end, the data collected can be divided into three different categories:

1) Technical Feasibility:
    a. Is a disinfection system needed?
    b. Is solar disinfection (based on radiation data) applicable in the area?
    c. Is this system able to kill fecal bacteria effectively in order to reduce the incidence of waterborne related diseases?
    d. What is the minimum residence time necessary to obtain safe drinking water?
    e. How many liters of pure drinking water can be produced a day?
2) Social Feasibility
    a. Is it easy to build, use and maintain?
    b. Can it be locally operated and maintained?
    c. How understandable is the system in order to be used properly?
    d. What other water purification options are there in the area?

3) Economical Feasibility

   a. How much are people willing to pay for disinfection systems?

   b. How much does the building of the system cost?

   c. Operation and maintenance costs?

In order to address these questions, the following studies were made of the SC-SODIS system prototype built in Lumbini, Nepal during the month of January:

- Well measurement of fecal contamination; need of a disinfection technology for Nepal
- Solar radiation measurement to assess feasibility of reaching 500W/m2 for 5 hours in a normal summer day
- Informal survey to get a preliminary sense of the social acceptability of SC-SODIS
- Cost of operation and maintenance.

2.6.4 Results and conclusions

The laboratory and field tests made in Lumbini during the month of January were carried out to address the feasibility of the Semi-Continuous Solar Disinfection System (SC-SODIS) as a sustainable technology. The tests and data collected allow us to draw the following conclusions:

a) Data collected from a well survey indicates the presence of *E. Coli* in 86% of the wells sampled in the 17 villages monitored by IBS and Buddhanagar village, using the membrane filtration bacteriological test (Standard Methods, 1998). However, the concentrations were very low, and may not represent a big threat to villagers. Local people, and some limited data collected in Lumbini, suggest that the number of contaminated wells, as well as the concentration of microbial contamination increases dramatically during the monsoon season, inferring the need of a water disinfection system technology.

b) In what turned out to be one of the coldest months of January that local people could recall, data obtained from solar radiation didn't reach the 500W/m^2 for five hours threshold in any of the days in which the author took measurements in Lumbini during January 2003. This suggests that solar disinfection is not a feasible disinfection technology for Lumbini in the month of January for exposure times of less than one day. In some cases the integrated solar radiation reached 2500Wh/m^2 after two days. In other cases, this threshold was not reached even after two days of exposure. These conditions may serve as a lower limit of effectiveness of the system.

d) In spite of the cold January weather, removal efficiencies obtained by SC-SODIS in the month of January in Lumbini suggest that even under bad weather, SC-SODIS can be a feasible solution if flow rates are adjusted to weather conditions (reduced flow rates have a tendency to increase removal efficiency). However, this preliminary result can be considered just that, and further studies should be made in the winter season at this site in order to assess the efficiency of the system under "worst case" scenarios.

e) Preliminary feedback from local people indicated they would prefer SC-SODIS to SODIS. SC-SODIS reduced laboriousness of solar disinfection and the number of PET bottles required (as well as disposed).

f) SC-SODIS was constructed from 100% readily available materials found in Nepal (Lumbini and Butwal).

g) Construction cost of the SC-SODIS system is below U.S.$0.50 (NRs 300).

Figure 20: SC-SODIS in Lumbini, Nepal during January 2003

2.7 Arsenic Study

Project Coordinator: Georges Tabbal

2.7.1 Arsenic Situation in Nepal

The first arsenic testing campaign was conducted in 1999-2000 by the Department of Water Supply and Sewerage (DWSS) of the Government of Nepal in cooperation with members of the MIT Nepal Water Project team of 2000. In one of its 1999-2000 studies conducted in the districts of Jhapa, Morang and Sunsari, DWSS found that 9% of the 268 tube well water samples contained arsenic above the WHO standard (Nepal Red Cross Society, 2000). An MIT study conducted by Patricia Halsey found that 18% of the tube wells tested in two districts of the Terai region of Nepal contained arsenic over 10 μg/L (Halsey, 2000).

Since then, at least three organizations, Rural Water Supply and Sanitation Support Program (RWSSSP), Environment and Public Health Organization (ENPHO) and the Japan/Nepal Red Cross have been deeply involved in issues related to the arsenic problem in Nepal. The rural population of Nepal started switching their drinking water supply from surface water to groundwater in the early 1980's. RWSSSP and the Japan/Nepal Red Cross installed a big portion of the tubewells that are currently being used by the population to pump groundwater. As such, when arsenic was discovered in the water pumped from these wells, these two organizations felt responsible for ensuring that it is safe to drink. They each engaged in a campaign to test their wells for arsenic content and to distribute arsenic filters to the households using their wells. ENPHO's role has been as the lead water testing lab for arsenic analysis.

2.7.2 Arsenic Removal Technologies

Three types of arsenic removal technologies are currently in use in Nepal. These technologies are: the Three-Kolshi, the Two-Kolshi and the Arsenic-Biosand filter.

<u>THREE-KOLSHI</u>

A "kolshi" is the clay water pitcher used for collecting water throughout Bangladesh, Nepal and much of South Asia. The Three-Kolshi filter consists of three kolshis stacked on top of the other. The top two kolshis are perforated at the bottom to allow water to pass through them. Each kolshi contains different materials with a specific function that allows for arsenic removal:

The top kolshi contains 3 Kg of iron fillings (representing about 1/6 of the total kolshi volume) and 2 Kg of coarse sand. About one third of the kolshi contains materials while the rest of the volume is occupied by raw water.

The middle kolshi contains 2 kg of fine sand and 1kg of wood charcoal of a consistent size, avoiding fine wood ash, which dissolves and produces an undesirable basic water solution. Materials occupy about one sixth of the kolshi.

The bottom kolshi is simply a collection container. Filtered water collects in this recipient and is directly decanted from it for use.

The arsenic removal process associated with this filter is fairly simple. The raw water causes the iron filings to rust thus creating ferric oxide. The arsenic will sorb onto the ferric oxide particles and then percolate down the system with the water. The sand contained in the top two kolshis will trap these particles, along with the arsenic sorbed onto them. The arsenic content of the water collected in the bottom kolshi should then be a tiny fraction of the arsenic content of the original raw water (Murcott, 2000).

TWO-KOLSHI

The system consists of a 20-liter plastic mixing bucket and a filtration unit consisting of two Kolshis placed one on top of the other. In order to operate, the filter requires a regular source of a chemical packet manufactured by ENPHO and distributed by both ENPHO and RWSSSP. In this process arsenic is removed by coagulation and co-precipitation followed by filtration. ENPHO's procedure for training households in the use of this system is as follows:

1. Collect approximately 20 liters of water in a bucket.
2. Pour the contents of 1 packet of chemicals into the collected water.
3. Stir vigorously using a wooden stirring rod for approximately 1 minute to achieve thorough mixing.
4. Allow settling for 30 minutes and then stir again in a similar manner for 1 minute. Repeat the same procedure every 30 minutes until 2 hours have passed since the initial mixing. However, do not stir at the 2 hours mark.
5. Pour the supernatant water into the filtration unit and dispose of the sludge into cow dung.
6. Collect the treated water from the spigot of the collection unit and use this water for drinking and cooking.

Each chemical packet weighs 4 grams and is used to treat 20 liters of contaminated water. The packet contains a 1:1 ratio, by weight, of ferric chloride and charcoal powder and 800 milliliters of 8% sodium hypochlorite solution. In this process the ferric chloride coagulates and adsorbs arsenic in co-precipitation. The precipitate is then filtered by the Two-Kolshi unit. Hypochlorite is used as an oxidant to facilitate the oxidation of arsenite to arsenate as arsenate is more effectively removed than arsenite. In addition, hypochlorite significantly reduces the microbial contamination of treated water. The charcoal powder is used as an adsorbent. It removes residual chlorine resulting from the use of hypochlorite and helps reduce other contaminants in the water (Hwang, 2002).

ARSENIC-BIOSAND FILTER (ABF)

An M.Eng alumnus, Tommy Ngai designed this filter. He won a research prize, the Lemelson International Award, at the 2002 MIT IDEAS competition for his design of the Arsenic-Biosand filter. The prize allowed him to conduct two other field visits to Nepal in September 2002 and in January 2003. His design combines two existing technologies: the Three-Kolshi system used for arsenic removal and the Biosand filter used for bacterial removal.

The combined-filter design consists of a concrete BioSand filter. The construction of the combined-filter is simple. First, a concrete mold is built, with a plastic pipe connected to the bottom. Gravel, coarse sand and fine sand are placed in the concrete mold. Then, a square metal diffuser is constructed. About 5 Kg of iron nails are then added on top of the diffuser. Finally, the filter is capped with a metallic cover to avoid the introduction of any outside contamination into the filter. In about two weeks, a biofilm layer will be fully grown on top of the fine sand layer. This biofilm will kill any pathogens that are present in the raw water that is poured in the filter. The filter is very easy to operate. The raw water is poured into the filter from the top and allowed to percolate through it. The treated water will then come out from the plastic pipe at the bottom. It can be collected by any recipient placed under the pipe.

The arsenic removal process associated with this filter is similar to the Three-Kolshi one. The raw water causes the iron nails to rust thus creating ferric oxide. The arsenic will sorb onto the ferric oxide particles and then percolate down the system with the water. The sand contained in the filter will trap these particles, along with the arsenic sorbed onto them. The arsenic content of the water collected from the plastic pipe should then be a tiny fraction of the arsenic content of the original raw water.

2.6.5 Study Design

Three types of arsenic removal technologies have been distributed so far: Arsenic-Biosand, Three-Kolshi and Two-Kolshi. These filters are currently being tested extensively on a technical level by the various organizations on the ground. However, no comprehensive social acceptability study had been done of these three filters. Georges Tabbal traveled to Nepal in January 2003 as part of the Nepal Water Project team to do such a social acceptability study. His study tried to answer the following two questions:

- What is the level of arsenic awareness of the affected population?
- What is the social acceptability of each of the three types of filters?

In order to answer these questions Tabbal conducted a survey at the household level in three of the affected districts of Nepal: Nawalparasi, Rupandehi and Kapilvastu. The survey instrument was drafted in Cambridge in the fall of 2002 using a combination of a questionnaire style and an interview style methodology.

With the interest of making the study more complete, he also conducted a technical evaluation of the filters, namely measuring their arsenic removal rates and their flow rates. In addition he assembled as much as possible previous technical results of the various NGO's on the ground.

2.6.6 Technical Evaluation

2.6.6.1 Arsenic Removal Rates

The arsenic removal performance of the three filters was measured by four different sources: the author, Tommy Ngai, RWSSSP and ENPHO. The first three sources measured arsenic concentrations by using the Arsenic Check Field Test Kit by Industrial Test Systems Inc. (ITS), whereas ENPHO used a laboratory method called hybrid generation atomic spectrometry (HGAAS).

The author conducted his tests in the month of January 2003 when he visited Nepal with the MIT Nepal Water Project team. Tommy Ngai and his IDEAS competition teammate from Stanford University, Sophie Walewijk, undertook their tests in Nepal in December 2002 while they were conducting a study on the ABF with RWSSSP. Their results come from a report they jointly wrote for RWSSSP: "The ABF Project (Ngai, T and Walewijk, S, 2003)". RWSSSP conducted its tests in the fall of 2002 and the results were given to Georges Tabbal by Kalawati Pokharel, the senior arsenic technician at RWSSSP. The ENPHO test results were taken from Soon Kyu Hwang's thesis, a previous M.Eng student who conducted a study on the Two-Kolshi filter, and were conducted in the fall of 2001 (Hwang, 2002).

One of the two methods, ITS test kit or HGAAS was used to evaluate the arsenic content of the influent and effluent water. The removal rate was obtained by subtracting the ratio of the effluent concentration by the influent concentration from 1.

THREE-KOLSHI

Table 7: Arsenic Removal Rates of Three-kolshi

Conduction of Tests	**Number of Filters Tested**	**Average Arsenic Removal Rate**
Georges Tabbal	2	88 %
RWSSSP	7	91 %

TWO-KOLSHI

Table 8: Arsenic Removal Rates of Two-Kolshi

Conduction of Tests	**Number of Filters Tested**	**Average Arsenic Removal Rate**
ENPHO	9	91 %

ARSENIC-BIOSAND

Table 9: Arsenic Removal Rates of Arsenic-Biosand Filter

Conduction of Tests	**Number of Filters Tested**	**Average Arsenic Removal Rate**
Tommy Ngai and Sophie Walewijk	4	93 %
Georges Tabbal	5	88 %
RWSSSP	5	95 %

2.6.6.2 Flow Rates

The flow rate of the Three-Kolshi was measured extensively by ENPHO over the past two years as part of their pilot study to determine the effectiveness of this filer. The flow rate of the Arsenic-Biosand filter was measured by Tommy Ngai during his January 2003 trip to Nepal. No information is currently available on the flow rate of the Two-Kolshi at this time. The flow rate results of the various filters is shown in Table 8.

Table 10: Flow Rates of Filters

Type of Filter	**Range of Flow Rates**
Three-Kolshi	0.5 to 3L/hr
Arsenic-Biosand	10 to 20 L/hr

2.6.7 Social Evaluation

A survey instrument was devised to try to answer the two social acceptability questions described in section 2.6.5.

2.6.7.1 Background Research

The background research that was conducted to create the survey instrument used in this study involved four components:

- A review of Knowledge, Attitudes and Practices (KAP) surveys;
- A review of Rapid Assessment (RA) surveys;
- A review of three previous M.Eng Theses: Nathaniel Paynter (2000), Hannah Sullivan (2002) and Arun Varghese (2002);
- A review of the research plan of a current project: “Evaluation of Ceramic Microfilter in Bolivia” conducted by Tom Clasen, affiliated with the London School of Hygiene and Tropical Medicine, with input from the Center for Disease Control and the Pan-American Health Organization.

After conducting the background research, Tabbal concluded that two types of survey instrument are usually used: The questionnaire type and the interview type.

<u>Questionnaire Surveys</u>

This type of survey is always rigidly constructed with little or no room for interpretation. Each question is strictly close-ended, and the responses are either in a multiple-choice format or scaled. The different responses are then compiled into statistical charts to provide accurate information on trends in health and population.

<u>Interview-Based Surveys</u>

An interview-based survey has a less rigid format then the questionnaire-based survey. Although the surveyor starts the survey with a set of fixed questions, he is free to add, remove or change questions during the survey to accommodate the specificities of the respondent. Unlike the questionnaire survey, it gives the interviewer room for interpreting people’s answers.

Tabbal decided to create a survey instrument that would combine the two types of surveys. The original survey instrument that he devised prior to his trip to Nepal was strictly a questionnaire type of survey. As he conducted his survey in the field, he altered his survey to reflect some characteristics of the surveyed population that he did not foresee prior to his arrival to Nepal. This modification of the survey instrument is not allowed in a questionnaire survey and is a characteristic of an interview survey. As such, his survey instrument evolved into something he called a questionnaire/interview hybrid as he kept some questions from the original instrument and modified others during the course of his site visit. This unconventional type of survey instrument was attractive to Tabbal prior to his site visit to Nepal. It allows the surveyor of devising an original survey instrument by using the limited knowledge that he has about the surveyed population prior to his site visit. As he conducts his survey in the field, his knowledge of the population increases, and as such he is free to alter this survey instrument to reflect this new knowledge

2.6.7.2 Conclusions of Social Study

ARSENIC AWARENESS

Sixty-three percent of the 45 respondents asked to define arsenic associated arsenic with a health hazard. These respondents defined arsenic as being a "poison", a "disease" or a "danger". Sixty-six percent of the 54 respondents asked if they saw a correlation between removing arsenic from water and protecting their health answered by "Yes". It is therefore safe to assert that about two thirds of the surveyed respondents consider arsenic to be a health hazard.

Since arsenic was discovered in Nepal recently, these results seem to indicate a relatively high level of arsenic awareness in Nepal. It should be remembered that the first discovery of an arsenic contaminated well in Nepal was in 1999. The filters were first distributed to the affected villagers in 2002, or about three years after the discovery of arsenic in the groundwater supply of Nepal. This study was conducted in January 2003, four years after the first arsenic discovery and only a few months after the initiation of the filter distribution. In light of these considerations, the statistics revealed by this portion of the survey are extremely encouraging, and demonstrate a relative high level of arsenic awareness that will presumably only increase in the coming years, or even months.

SOC IAL ACCEPTABILITY OF EACH TYPE OF FILTER

Some of the survey results related to the social acceptability results of each type of filter appeared counter-intuitive. The social acceptability results of the flow rate of each type of filter is a good example of such counter-intuitive results.

Seventy-five percent of the respondents said that they were satisfied with the flow rate of the Arsenic-Biosand filter. This proportion seems to be quite low considering that the Biosand filter has a flow rate sufficient to accommodate a normal size Nepali family (10-20 L/hr). This is especially striking when one compares it with the similar acceptance rate of the Tree-Kolshi (75 %), which has a much lower flow rate (0.5-3 L/hr).

Because of these counter-intuitive results, no conclusions on the social acceptability of the filters will be included in this report.

3 Conclusion

Clean Water for Nepal investigated four point-of-use water treatment technologies: BioSand filter, ceramic water filters, Semi-Continuous SODIS, and three arsenic treatment technologies. A brief summary of these technologies is presented in Table 11.

Table 11: Summary of Three Point-of-Use Water Treatment Technologies

POU Treatment Technology	Specific Goal(s)	Typical Flowrate (L/hr)	Typical Price ($USD)	Comments
Ceramic Water Filters	• Microbial removal • Turbidity removal	1-4 L/hr	$5-$30	• Prices & flowrate for complete filter system. • Most filter systems are closer to $20 in price.
BioSand Filter	• Microbial removal • Turbidity removal	20-40 L/hr	$26.00	• Heavy – difficult to move.
Semi-Continuous SODIS	• Microbial removal	0.5-1 L/hr	$0.5	• Flowrate can change depending on season of year, latitude, and altitude.
Arsenic Filters	• Remove arsenic	0.5-20 L/hr	$6.50-$26.00	• 3-Kolshi flowrate = 0.5-3 L/hr ($6.50) • Arsenic-Biosand = 10-20 L/hr ($26)

Appendix 1. Clean Water for Nepal Team

Clean Water for Nepal consists of seven Master of Engineering Students, in the Environmental and Water Quality specialty, at the Massachusetts Institute of Technology. Its headquarters are located at 77 Massachusetts Avenue, 1-143, Cambridge, Ma, 02139. The team members are Rob Dies, Xanat Flores, Melanie Pincus, and Georges Tabbal. Each team member has focused on a specific area of study as described below.

Rob Dies . He investigated the strengths and weaknesses of various ceramic filters as they apply to point-of-use water treatment in Nepal. He obtained his bachelor's in Applied Science in Civil Engineering (Environmental Option) with a minor in commerce degree at the University of British Columbia. Some of the courses of interest he took as part of his undergraduate studies were: courses in hydrology, open channel hydraulics, geology, aquatic chemistry, microbiology, ecology, sustainability, statistics, economics, and business. He also did a third year exchange program to the University of Western Australia where he completed courses offered in the Civil Engineering Department and the Centre for Water Research. He has had a broad work experience: Association of Professional Engineers and Geoscientists of British Columbia as a sustainability researcher; WaterTrax, Inc. as a Consultant**;** Charles Howard & Associates Ltd as a Junior Engineer; Greater Vancouver Regional District (GVRD), Sewerage & Drainage Department as an Engineer Research Assistant; and at the GVRD, Solid Waste Department as an Engineer Assistant. He completed the following subjects while at MIT: groundwater hydrology, water resources systems, coastal engineering, water quality modeling, GIS, system dynamics, and information technology. His broad experience, combines different areas of study and application that will be very helpful for the technical expertise that will be provided for the ceramics water filter evaluation.

Xanat Flores developed and evaluated the effectiveness, performance, and feasibility of a solar disinfection system that combines the advantages of SODIS and continuous solar disinfection systems. She did the first part of her undergraduate studies in Chemical Engineering at the Universidad Nacional Autonoma de Mexico in Mexico City. She finished her undergraduate studies in the Universidad de las Americas- Puebla, in Puebla, Mexico. Some of her undergraduate related courses were Advanced Biological Processes for Wastewater Treatment and Kinetics of Biotechnological Processes. She did a social service work at the Regional Studies Center in Cholula, Puebla, Mexico, where she sampled water in several rural areas, analyzed water to meet different water quality standards (pH, turbidity, nitrogen and phosphorous compounds, total coliforms, chlorine, electric conductivity), and co-wrote a proposal for governmental actions steps to improve water quality in rural areas (including water treatment plant proposal that involved solar disinfection). She completed the following subjects while at MIT: Groundwater Hydrology, Design of Water Resources Systems, Environmental Engineering Applications of GIS, Environmental Organic Chemistry, and Aquatic Chemistry. Her experience in rural communities in Mexico, as well and water treatment and purification techniques will be of great help for the development of the proposed work.

Melanie Pincus performed laboratory and field experiments to quantify the effects of source water quality, variable ripening periods and pause times on Biosand Filter efficiency. She obtained her bachelor's of Science degree in Civil and Environmental Engineering with a focus on Environmental Chemistry at the MIT, minoring in Literature. Her areas of knowledge include Chemistry (aquatic, atmospheric, biological, environmental, inorganic,

organic, physical); Biology (aquatic, environmental, molecular); Environmental (ecology, environmental education, environmental law, fluid mechanics, fluid transport processes, groundwater hydrology, hazardous waste remediation, limnology, toxicology and public health); and Laboratory Techniques (quantitative and qualitative chemical analysis, pH, kinetics, visible/UV/IR spectroscopy, gas and liquid chromatography, microbial measurement including membrane filtration and H_2S tests). Her work experience includes environmental consulting for the John A. Volpe National Transportation Systems Center, U.S. DOT and GEI Consultants, Inc; teaching recitations in Biochemistry and Organic Chemistry at the Massachusetts Institute of Technology; and research at the Harvard Graduate School of Education in their Cognitive Skills Group. Her broad experience in environmental chemistry and laboratory techniques will be of much help towards development of the proposed work.

Georges Tabbal completed a technical, social and economical evaluation of some of the existing arsenic removal technologies. He obtained his bachelor’s in Civil Engineering degree at McGill University. He has worked for Peter Kiewit Sons Co. Ltd as a project engineer; Camp Dresser and McKee as part of a final year project that consisted of a water resources design plan; and Inspec-Sol as an assistant engineer in the environmental department.

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