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A Survey of Point of Use Household Water Treatment Options for Rural South India

Kendralyn G. Jeffreys

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A Survey of Point of Use Household Water Treatment Options for Rural South India

Kendralyn G. Jeffreys



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High quality water is more than the dream of the conservationists, more than a political slogan; high quality water . . . is essential to health, recreation, and economic growth.

--Edmund S. Muskie, U.S. Senator, speech, March 1, 1966

INTRODUCTION

Water is the very foundation of life, and few would argue that access to clean consumable water is as inalienable a right as breathing clean air. However, for billions of people across the globe, access to safe drinking water is limited and sometimes almost impossible to find. The World Health Organization (WHO) defines safe drinking water as, “water that does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages” (World Health Organization, 2008, p. 1). Lack of safe water creates an enormous burden in the form of waterborne illnesses such as diarrheal disease, cholera, typhoid, and Guinea worm disease. Diarrheal disease itself is a leading cause of mortality and morbidity among children under the age of five and, overall, was the third leading cause of death in low-income countries in 2004 (World Health Organization, 2009).

In the year 2000, the United Nations (UN) set eight Millennium Development Goals (MDGs), one of which is to halve the proportion of the world’s population that does not have access to **improved water sources** (United Nations, 2000). In the eleven years since that goal was set, considerable progress has been made, particularly in China and India, which together contain approximately a third of the world’s population. A 2010 WHO/UNICEF Joint Commission Report notes that 88% of the 1.2 billion people in India now have access to improved water sources, an increase from 72% in 1990. However, the report notes that simply having improved water sources does not necessarily mean that the water is safe to drink (WHO/UNICEF, 2010). This report describes the situation that millions of people in India find themselves in today.

Improved water sources: water from protected tube or bore wells, dug wells, public taps and collected rainwater.

–WHO/UNICEF JMP Report 2010

While the ultimate goal is to have treated water piped into every household, a realistic assessment of the infrastructure of many developing countries suggests that this goal is expensive and years away from being achieved. In the interim is it possible for people in these areas to have access to clean drinking water? Fortunately, the answer is a resounding, “yes!” Treating water at a household level is one way to provide clean drinking water for populations in areas where the infrastructure is lacking. Household water treatment (HWT) has been in existence for several millennia and takes many different forms depending on the locale and resources available. When a continuous supply of electricity is available, the **point of use (POU) household water treatment (HWT)** technologies are numerous; some

Point of Use Household Water Treatment (POU HWT): treating drinking water at the household level to improve its microbiological purity before the water is used. POU treatment can provide clean water for people without access to clean, municipally treated water, a common scenario in the developing world.
–Sobsey et al. 2008

examples of such household level systems are ones that purify the water by reverse osmosis (e.g., Kent Osmosis System) or ones that combine several treatment processes like boiling, ultraviolet treatment and sediment filtration (e.g., Aqua Guard Purification System) (Jain, 2009). However, rural, low-income people in developing countries do not often have continuous access to electricity, and they are often the ones at greatest risk of having an unsafe water supply; therefore, for this report we will focus on examining only field-tested, non-electric, low-cost point of use technologies for household water treatment.

Purpose

The objectives of this report are:

1. To provide the reader with a basic understanding of the household water situation in southern India, including socio-cultural practices that may impact a POU intervention program.
2. To provide the reader with a basic overview of non-electric POU technologies that could potentially be used in rural **South India**.
3. To discuss the different factors to consider when determining which POU technology will work best in a community, using a case study of a village in Andhra Pradesh to illustrate.
4. To provide the reader with a compendium of helpful resources related to introducing and implementing a new POU program in rural South India.

South India: this term refers to Karnataka, Andhra Pradesh, Tamil Nadu, and Kerala states.

The Need for Household Water Treatment

Contaminated drinking water is one of the biggest health challenges facing children and families in the developing world. Impure water is one of the main factors in the deaths each year of 1.8 to 2.5 million children under the age of five from diarrheal disease. In a systematic review of the literature containing child mortality data from diarrheal disease by country, India ranked first in the world, with an estimated 535,000 deaths in children under the age of five due to diarrheal disease in 2004 (Boschi-Pinto, Velebit, & Shibuya, 2008). While India does have a larger population than many of the other countries surveyed, the combined total of the next five countries on the list (including China) is still lower than India's 535,000 deaths (see Table 1). Clearly, the burden of diarrheal disease among children in India is great.

Table 1: Countries accounting for 3/4th of deaths due to diarrhea in the developing world, 2004. From Boschi-Pinto et al. 2008.

Country	WHO subregion ^a	Deaths due to diarrhoea (thousands)
India	SEAR D	535
Nigeria	AFR D	175
Democratic Republic of the Congo	AFR E	95
Ethiopia	AFR E	86
Pakistan	EMR D	77
China	WPR B	74
Bangladesh	SEAR D	69
Afghanistan	EMR D	65
Indonesia	SEAR B	39
Angola	AFR D	34
Niger	AFR D	33
Uganda	AFR E	28
Myanmar	SEAR D	26
United Republic of Tanzania	AFR E	25
Mali	AFR D	24
Total of 15 countries		1384

AFR, WHO African Region; AMR, WHO Region of the Americas; EMR, WHO Eastern Mediterranean Region; SEAR, WHO South-East Asia Region; WPR, Western Pacific Region.

^a WHO subregions are defined on the basis of levels of child and adult mortality: A, very low child and very low adult mortality; B, low child and low adult mortality; C, low child and high adult mortality; D, high child and high adult mortality; E, high child and very high adult mortality.

The chief pathogens associated with diarrheal disease are mainly transmitted when humans ingest food or water that has been contaminated by fecal matter. It is estimated that 94% of diarrheal disease can be attributed to environmental factors, such as a lack of proper sanitation and hygiene and unsafe drinking water (Prüss-Ustün & Corvalán, 2007). While any intervention that aims to greatly reduce diarrheal disease in India should also include a focus on sanitation and hygiene practices, multiple reviews and studies conducted in the last two decades have suggested that improving drinking water at the household level (also referred to as point of use, or POU treatment) can reduce diarrheal disease rates in a community by as much as 30-40% (Clasen, 2009; T. F. Clasen, Brown, Collin, Suntura, & Cairncross, 2004; Thomas Clasen, Schmidt, Rabie, Roberts, & Cairncross, 2007; Lorna Fewtrell et al., 2005). There are multiple POU technologies in existence, but only a few have been extensively field-tested and work without electricity; these particular POU systems will be the focus of this report. The POU systems examined here are: chlorine treatment, chlorine-flocculant sachets, biosand filters, ceramic filters, and solar disinfection treatment. Boiling is also discussed since it is one of the oldest and most well-known water treatment options in the developing world.

Fecal contamination: measured by performing a lab analysis that tests for the presence of *E. coli* in the water.

WATER IN INDIA

The Physical Environment

For centuries India's people have devised creative solutions to adapt to India's highly seasonal pattern of rainfall which, in some areas, sees 50% of the annual precipitation falling in just 15 days (Briscoe, 2005). India's monsoon or "rainy" season is typically from June to September. Especially for southern India, those four months provide precious rainfall that fills tanks, rivers and reservoirs with water which must last until the next monsoon season (Wolpert, 2009). This pattern of rainfall has compelled the native population to devise a variety of ways to harvest and store water.

In a 2005 World Bank report about the water situation in India, author John Briscoe describes some of the major issues threatening India today: a growing population, limited water supplies, inadequate public infrastructure, the growth of urban areas, and the continued major pollution of some of India's rivers. The same water issues faced in other countries might lead to social and civil unrest; however, as a whole, the Indian people have developed coping strategies on an individual level to deal with an unpredictable and often polluted water supply. Some of the most common coping strategies used by the population are storing water in containers, installing household level water treatment systems, purchasing water from private vendors, and digging bore wells to access groundwater (Briscoe, 2005). A bore well (also referred to as a tube well) is a long metal tube that is drilled into the ground until it reaches an **aquifer**; the water is then pumped up by hand or by a motorized pump. There are an estimated 21 million bore wells in India; this has led to a depletion of the water table since the groundwater is being used at a greater rate than it can be replenished (Climate Institute, 2010). It is estimated that 80% of the domestic water supply in India is from groundwater (Briscoe, 2005).

Aquifer: an underground layer of rock that yields ground water for springs or wells. -- www.lexic.us

Politics and Water

The Indian government began focusing on improving water and sanitation in 1972 through the national Accelerated Rural Water Supply Program (ARWSP). This program assists the states and territories in increasing drinking water supplies in rural areas. The Department of Drinking Water Supply (DDWS) was formed in 1999, and placed under the Ministry of Rural Development in order to emphasize the need for focusing on rural water and sanitation development. DDWS is one of the main governmental institutions on a national scale that supports the states and territories in improving sanitation and clean water supplies. In 2007, the national government identified the main obstacles they face in developing rural water supplies: a lack of available water, poor water quality, the large cost of installing, operating and maintaining a water supply, and whether to take a national or local approach to rural water development (Planning Commission, Government of India, 2007).

The Ministry of Rural Development oversees the Department of Drinking Water Supply on a national level.

However, the increased focus of the national government on improving rural water and sanitation does not mean it is always effectively implemented on a local level. The government is supposed to treat all government-owned water storage tanks with a disinfectant, usually a bleaching powder (hypochlorite). However, it is not always certain if the water in the government tanks is being treated. Even in more urban areas where the water supply is supposed to be safer because it is presumed to be treated by both filtration and chlorination, there is no guarantee that these practices are actually being performed by the government on a regular basis (Brick et al., 2004). The primary source of a 1994 cholera outbreak in Vellore, Tamil Nadu, was water from a government-maintained water source that officials had stopped chlorinating due to financial constraints (Ramakrishna, Kang, Rajan, Mathan, & Mathan, 1996). More recently, in a 2004 study of water storage practices in Vellore, all of the water collected from the municipal water taps in the village were contaminated with *E. coli*, which indicates fecal contamination. The government officials would not respond to researchers when asked about their chlorination practices and records (Brick et al., 2004).

The WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation produces a report that is designed to provide a macro-view of a country's sanitation and water situation by measuring the level of access to improved water sources throughout the country based on several non-governmental national level surveys. In the latest report, JMP states that 84% of the population of India has access to improved water supplies, with 94% coverage in urban areas and 80% in rural; both these numbers are lower than the previous 2006 estimates (Joint Monitoring Programme for Water Supply and Sanitation, 2010).

A 2010 study conducted a statistical analysis of the safe water coverage in the state of Madhya Pradesh and also took various water quality samples around the state; the researchers then compared their findings to both the JMP 2007 report and the national government's figures. The researchers found that both the JMP and the Indian government's definition of improved water sources do not take into account the quality of the water. In some areas of Madhya Pradesh, the JMP numbers estimating safe water coverage would be reduced by 40% if the microbiological quality of the water were taken into account (Godfrey, Labhasetwar, Wate, & Pimpalkar, 2010). As these studies indicate, until the government-supplied and other "improved" water sources become more microbiologically reliable, household water treatment systems may be the best solution for providing safe drinking water to the general population in the interim.

Common Water Sources in Rural India

The most common source of water in southern India is groundwater accessed by deep bore wells; the water from the bore well is typically pumped into overhead government water tanks or accessed by stand-alone taps or pumps which are fed water from the bore well through subterranean pipes. Open wells are also common.

Even if the water from the bore well is microbiologically pure, it may become contaminated while being delivered to the surface, as shown by a study in a village in Tamil Nadu. The water from the public taps connected to the main government water tank all showed high levels of thermotolerant coliforms, which indicate fecal

contamination; because the high coliform count was consistently found in further tests, the government tank itself was tested and was also found to have notably high coliform counts (despite the fact that it was scheduled to be chlorinated once a month). The water from the government water tank came from a deep bore well which accessed groundwater far below the surface. While the researchers were unable to test the bore well water source directly, they theorized that the water may have been contaminated by passing through cracked pipes on the way to the surface (Firth et al., 2010). Water contamination from cracked pipes is certainly feasible if the ground surrounding the pipes is tainted with fecal contamination and becomes saturated with water, a common occurrence during monsoon season. For example, in Vellore, Tamil Nadu, the main source of water is surface and groundwater, with the groundwater water coming from bore wells that are located in a dry riverbed. Since the riverbed is dry, it is used for animal waste disposal and human defecation year-round. During the heavy rains of monsoon season, water mixed with human and animal waste supersaturates the ground; if this feces-polluted water reaches the depth of the groundwater, it can lead to contamination of the bore well at its source (Brick et al., 2004).

Water Storage Practices in Southern India

In many developing countries, families often store water in their homes. This practice is due in part to a lack of piped water (thus they must collect the water manually), or, even when water is piped into the house, it may not be available at all times. In India, the intermittent availability of water is a common problem in both urban and rural areas, mainly due to seasonal shifts affecting water sources; thus, many households adopt the practice of storing water in containers inside their homes (Brick et al., 2004).

The literature has shown that water storage is associated with increased fecal contamination of the water even if the water is microbiologically pure when it is originally collected. A meta-analysis looking at studies that measured levels of bacterial contamination at both the water source and stored water in households found that half of the studies analyzed indicated significant contamination of the water after it was obtained from the source. Thus the authors concluded that contamination is a significant risk in the time between collecting water from the source and point of use (Wright, Gundry, & Conroy, 2004).

There are a variety of factors that increase the chance of contaminating the water after collecting it from the source. Factors such as the width of the opening of the container, the material the container is made of, and the manner in which individuals retrieve the water all impact the risk of polluting the water. In a study of water handling and defecation practices in rural India, researchers found that 100% of the study participants reported storing water in wide-mouth containers along with using cups to retrieve water from the containers. This type of practice increases the risk of polluting the water with unclean hands (Banda et al., 2007). People cannot put their hands into a container with a narrow opening, which lowers the risk of fecal contamination; therefore, a hallmark of a safe water storage system is having containers with narrow openings.

In a 2004 study of 37 low-income urban households in Vellore, Tamil Nadu, researchers found that all the surveyed households stored water at home. These water storage

containers all had wide-mouth openings and were made of a variety of materials: aluminum, brass, plastic, steel, and earthenware. The study tested the water at its source (a municipal tap) and then tested the stored water 1 to 7 days after the original collection date.

Significantly, the researchers found that the stored water was more contaminated than the water tested at the source, which suggests that contamination occurred at the household level. Also, the study found that there were significantly lower levels of fecal contamination in brass containers compared to other containers, particularly earthenware ones (Brick et al., 2004). A later study on brass containers in India confirmed that fecal microorganisms in the water are reduced significantly when stored in brass containers for 12-48 hours, perhaps due to the biocidal properties of some heavy metals (Tandon, Chhibber, & Reed, 2005). When considering which type of POU option may be best for a community, it is important to assess the community's current water storage practices and, if they have unsafe storage containers and practices, explore viable options to obtain safe water storage containers.

Sanitation and Hygiene Practices

Sanitation and hygiene practices impact water quality and health in a variety of ways. A meta-analysis review of water, sanitation, and hygiene interventions in developing countries found that improving sanitation and hygiene behaviors can significantly reduce the incidence of diarrheal disease in a community; because of this, it is important to examine a community's sanitation practices and beliefs (L Fewtrell & Colford, 2005). The below diagram provides a visual map describing the different ways in which both animal and human waste can be orally ingested by humans:

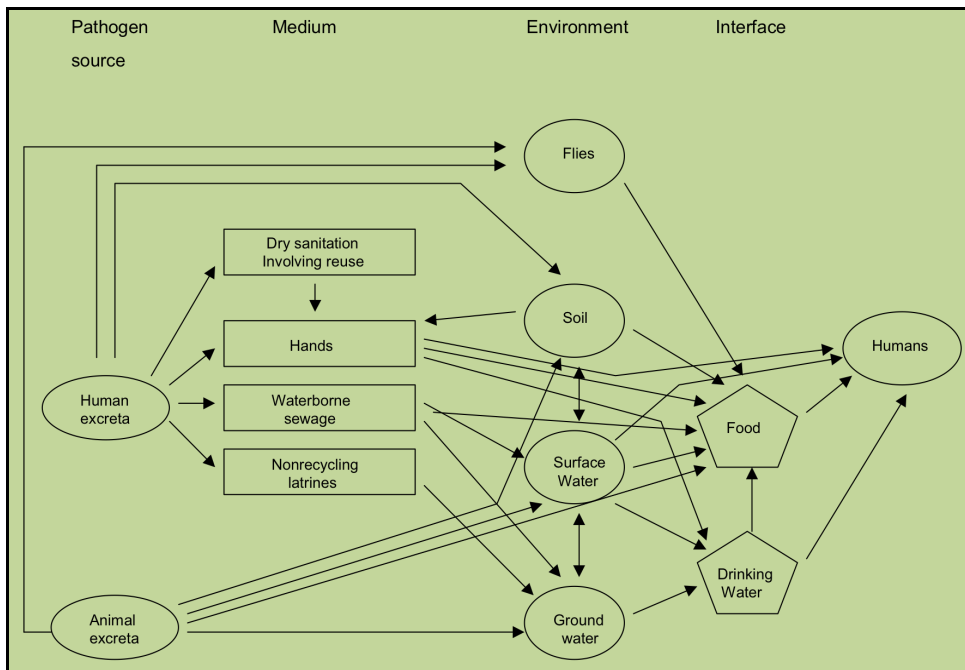


Figure 1: Transmission pathways for fecal-oral contamination (L Fewtrell & Colford, 2005).

Several studies conducted in southern India have identified **open defecation** as a common practice in rural areas. In a 2007 study (Banda et. al) comparing caste differences in sanitation practices in a rural village in Tamil Nadu, researchers found that 74.2% of people in both castes practiced defecation in open areas, even if they had a functioning toilet at home (there was not a significant difference in defecation practices between castes, except that more high caste people had toilets). For those who had a functional toilet at home but still practiced open defecation, their reasons for not using the toilet were as follows:

Open defecation: when human feces are disposed of in fields, bodies of water, bushes, or other open spaces. -- WHO/UNICEF

- It was against their customs, especially among the elderly in the village
- They were concerned about the smell permeating their house
- They were concerned about possible stagnation of the toilet during the rainy season

Interestingly, there were government-built public latrines for the women in the village; however, they were seldom used because the women had to pay a monthly fee to use them and the water in the latrines only worked intermittently. For the women who did use the latrines, they confined their use to bathing and washing clothes (Banda et al., 2007).

This study also unearthed some attitudes about open defecation that may be pertinent in other South Indian villages as well:

- Open defecation is an old tradition and is not stigmatized
- Building a toilet is expensive compared to open defecation, which is free
- Going to defecate together was viewed as a type of social outing
- The idea of keeping human waste so close to the home (i.e. by using toilets) was unacceptable to many
- There was not an association with open-air defecation and diarrheal disease, especially since people defecated in places that were not close to their homes (Banda et al., 2007).

This study also explored hand-washing behaviors and found that a much greater percentage of children under the age of 15 reported routinely washing their hands with soap after defecation (87.5%), compared to the over-60 population (37.5%). The authors attribute the difference between age groups to the regular hygiene lessons in the local schools (Banda et al., 2007). Regarding hygiene, one of the added values of having a point of use household water treatment system is that it can increase the amount of clean water available for washing hands.

In another study in rural South India, researchers found similar results with 72% of study participants practicing open defecation, regardless of caste, along with low utilization of hand soap after defecation (Firth et al., 2010). Furthermore, a study employing spatial mapping of a village in southern India found that there were separate “defecation fields” for men and women, and that these fecal fields were close to both water sources and

fields under cultivation. Consequently, during times of heavy rain in the monsoon season, the village could potentially be flooded with water heavily contaminated with fecal matter from the fields (Gopal et al., 2009).

Cultural Beliefs about Diarrhea

For any health intervention to be effective, it must consider local beliefs about the illness it aims to reduce or treat. The local villagers may not view an illness in the same way as an outsider coming from a Western, biomedical perspective; thus, it is important to learn how the local people define illnesses and their causes. This principle is particularly true in India when dealing with water, sanitation, and hygiene practices. Using the following questions to elicit a person's explanatory model of illness can be very helpful:

1. What do you call your illness? What name does it have?
2. What do you think has caused the illness?
3. Why and when did it start?
4. What do you think the illness does? How does it work?
5. How severe is it? Will it have a short or long course?
6. What kind of treatment do you think you should receive? What are the most important results you hope to receive from the treatment?
7. What are the chief problems the illness has caused?
8. What do you fear most about the illness? (Kleinman, 1988)

In different cultures, people may not consider diarrhea a disease. For those that do identify diarrhea as an illness, the reasons they identify why people get diarrhea may vary substantially. In one study in India, only 12.4% of study participants identified water as a potential source of diarrhea—the other participants identified food, heat, mosquito bites, or accidentally ingesting hair or mud as the causes of diarrhea. Approximately 15% of the study participants said they simply didn't know what caused diarrhea (Banda et al., 2007). Similarly, a POU intervention in neighboring Nepal found that over 40% of study participants did not identify unclean water as a potential source of diarrhea (Rainey & Harding, 2005). These studies illustrate why it is essential to explore the population's perspective about the targeted illness, both in order to have a culturally sensitive intervention and to identify potential areas for health education early in the program.

Cultural Beliefs about Water

Another important factor to consider is local beliefs about water. In India, water holds a special place in the hearts of many of its people, especially Hindus. The Ganges River is considered sacred in Hindu culture and "Mother" Ganga is worshiped as a goddess. Devout Hindus visit the Ganges to ritually bathe, pray and, eventually, have their ashes spread in the river (Wolpert, 2009). Water is associated with purification in Hindu culture, not pollution or contamination; consequently, it may be more difficult for Hindus to view water as a source of disease. During a household water treatment intervention in Nepal, researchers encountered resistance from Hindu participants in believing that the water was polluted and needed to be treated at all, a view that the authors attributed to coming from the strong association between water and purity in Hinduism (Rainey & Harding, 2005).

Several studies in India and neighboring countries have also found that participants tend to view water as clean or unclean based on aesthetic qualities such as smell, taste, and color, with taste being a significant factor (Banda et al., 2007; Firth et al., 2010; Rainey & Harding, 2005). Furthermore, Indian study participants have indicated that there are appropriate times to use boiled water (for babies or during an illness), but they did not see a need to treat water beyond these two occasions (Banda et al., 2007). This is a particularly interesting finding since it suggests an awareness that the water is indeed not clean, but only those with fragile immune systems (the young and the ill) are at risk of becoming ill from drinking it. These are just a few examples of the types of cultural factors that should be considered when doing preliminary research about the most viable POU option for a community.

POINT OF USE HOUSEHOLD WATER TREATMENT OPTIONS OVERVIEW

Each of the following point of use household water treatment systems options has its benefits and drawbacks. One POU system may work well in one community but may not be suitable in another community in the same country. Culture, environment, the physical structures of the dwellings, attitudes about water, sanitation practices, etc.—all must be taken into account when one is evaluating which POU option will be most viable in a community (this presupposes that the community members themselves have expressed the desire for better health or for clean water and are participating in choosing the POU technology).

Whatever the benefits and drawbacks, each of the POU treatment systems reviewed in this report has been shown to significantly reduce the incidence of diarrheal disease by varying degrees (Table 2). While some POU systems are more effective against particular pathogens (like viruses) compared to other POU systems, the fact remains that they each reduce diarrheal disease by a significant amount and are worth considering introducing to a community (Sobsey, Stauber, Casanova, Brown, & Elliott, 2008). The point of use systems reviewed in this report are: chlorine treatment in combination with the safe water system, chlorine-flocculant treatment, biosand filters, flower-pot styled ceramic filters, and solar disinfection. Boiling is also reviewed since it is widely used and well-known in the developing world.

Table 2: Diarrheal Reduction by POU Technology in Controlled Studies (Sobsey et al., 2008)

technology	diarrheal disease reduction estimate (95% CI)	compliance (estimates of self-reported and/or measured % user compliance)
SODIS (solar UV radiation + thermal effects)	31% (26%–37%) (5) ^a	78% compliance during study (24); however, poststudy compliance rates may drop as low as 9% (25)
free chlorine and safe storage	37% (25%–48%) (5) 29% (26) ^b	60–73% of households were self-reported users, but only approximately 30–40% of those who reported use had detectable free chlorine levels (27–29)
coagulation/chlorination	31% (18%–42%) (5) 29% (26)	usage rates may drop to as low as 10% after intervention ends (30)
ceramic filtration through candle filters	63% (51%–72%) (5)	high until filter breaks; in a trial in Bolivia, compliance was 88% over 6 months (31)
ceramic filtration through ceramic water purifiers	46% (29%–59%) (9)	dependent on filter breakage rates (9, 10)
biosand filtration	47% (21%–64%) (32)	>85% post-implementation (33, 34)

^a Summary estimates stratified by type of intervention (from a meta-analysis of drinking water quality interventions and diarrheal disease reductions). ^b Summary estimate from meta-analysis on POU chlorination (includes both free chlorine disinfection and combined coagulation-disinfection).

Chlorine Disinfectant with Safe Water Storage

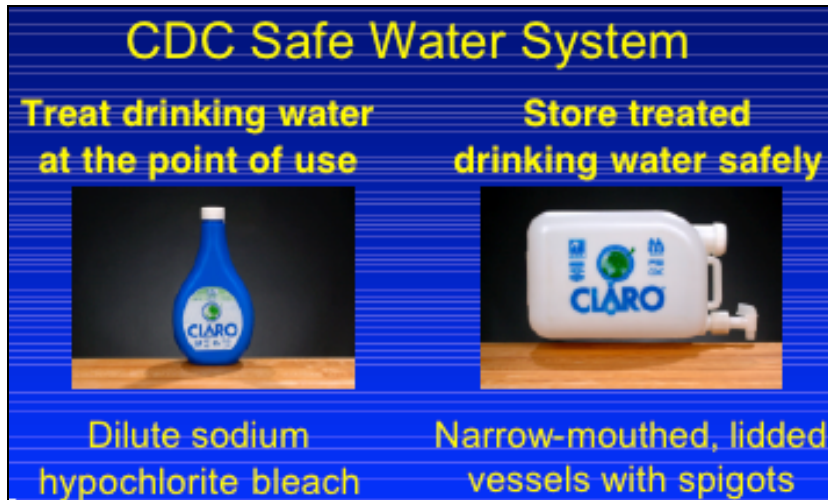


Figure 2: Chlorine bottle & example of a safe water container:
http://www.cdc.gov/safewater/publications_pages/pubs_presentations.htm

Description

Treating water with chlorine on a municipal level has been practiced since the early 20th century and is a major contributor to the decline of waterborne diseases in U.S. cities (Kotlarz, Lantagne, Preston, & Jellison, 2009). Chlorine is most effective against bacteria such as *E. coli* and less effective against parasites (Arnold & Colford, 2007).

Point of use treatment of water with chlorine (usually in the liquid form of sodium or calcium hypochlorite) is quite simple:

- Step 1: Add a measured dose of chlorine to untreated water
- Step 2: Shake or stir the water to ensure adequate distribution
- Step 3: Let the water sit for a measured amount of time to allow the chlorine to act before using

Both the chlorine dosage and the length of time the water needs to sit is determined by the concentration of the chlorine solution, the volume of water being treated, and the level of **turbidity** in the water. The recommended chlorine dosage is often based on 20L volumes, the volume of jerry cans that are common in many parts of the world.

In addition to liquid chlorine, chlorine tablets made of sodium dichloroisocyanurate (NaDCC) under brand names such as Aquatab, have been used in emergency situations for years; in the last decade these tablets have been marketed in developing countries as an alternative to liquid chlorine to treat water on a household level (Clasen, 2009). These tablets dissolve quickly (and visibly, which end-users typically like), and the water can be used within 30 minutes to an hour, depending on the dosage and the amount of water

Turbidity: a measure of the cloudiness of water, often used to indicate water quality. High levels of water turbidity are often associated with higher levels of viruses, parasites, and some bacteria.
-- <http://water.epa.gov/drink/contaminants/index.cfm>

used. A 2007 study examining the use of NaDCC tablets in a Bangladesh village found high levels of compliance among the fifty families using the tablets during the study period (TF Clasen, Saeed, Boisson, Edmondson, & Shipin, 2007). However, there was not a follow-up study post-intervention to determine the rate of use among participants after the study was completed.

Treating water with chlorine and then storing it in a safe water container is an intervention known as the Safe Water System (SWS). This particular intervention also includes an array of water and food handling health promotion activities and was engineered in the early 1990s by the U.S. Centers of Disease Control (CDC) and the Pan American Health Organization (PAHO) in response to a cholera epidemic in Latin America. The storage containers are covered containers that have taps and narrow openings in order to reduce the risk of people contaminating the stored water with their hands. The SWS intervention has been extensively field-tested in over 30 countries since 1998, and studies have shown that SWS can reduce diarrheal disease incidence from 26 to 84% in a participating community (Kotlarz et al., 2009). However, the extent to which the same study population continues to regularly and effectively use chlorine to treat their water after the intervention study period ends is not clear; studies have suggested that it is a lower number than the one measured during the study period (McLaughlin et al., 2009).

A significant challenge to the chlorination method by either tablet or liquid is the issue of treating turbid water. Turbid water contains suspended organic particles and often looks cloudy or murky. When water is turbid, chlorine may be ineffective due to chlorine demand, the consumption of available chlorine by organic matter in the water before it is able to disinfect microbes. This obstacle in treating turbid water can sometimes be overcome by increasing the dosage of chlorine. However, it is often difficult for end-users to accurately gauge how much to increase the chlorine dosage to compensate for the turbidity of the water. Additionally, the distinct taste and smell of chlorine-treated water has been found to be a barrier to end-users; unfortunately, when water is turbid, the increased chlorine and its interaction with the organic materials in the water further increases the unfavorable taste and smell of the water. Furthermore, chlorinating turbid water may make the water drinkable, but it will not reduce the cloudy, dirty look of the water, making it difficult at times to convince end-users that the water has been purified (Kotlarz et al., 2009).

Use in India

Several studies in India have shown resistance from end-users to using chlorine-treated water due to the perceived unpleasant change in taste and smell (Brick et al., 2004; Firth et al., 2010; Gopal et al., 2009). In a Firth et al. study (2010) of different POU interventions in a rural South Indian village, 83% of the women in the chlorine group expressed dissatisfaction with using chlorine due to the smell and taste; only three out of the 126 women in the entire intervention expressed a desire to use chlorine to treat their water, despite the fact that it was the most successful intervention in the study in reducing the level of pathogens in the water. In the same study, villagers reported that, after the overhead government water tanks were treated with bleach powder, they would wait 2-3 days to draw water from the tanks in order to allow the chlorine taste to recede from the water (Firth et al., 2010). This described practice may represent a health hazard, since

chlorine breaks down over time. After no available chlorine remains in the water, there is an opportunity for any remaining bacteria in the water to re-grow.

Additionally, the narrow openings of the safe water storage holders have been problematic for some areas in southern India. One study indicated that, compared to North India, the South has more areas with lower water pressure, necessitating that a manual or a motorized pump is used to fill the water containers in a reasonable amount of time. By using these pumps, the flow of water is often larger than the opening of the safe water storage container, thus spilling over the opening and wasting water. Since water is scarce and treated as a precious resource, wasting it is frowned upon; therefore, water storage containers with narrow openings are not as commonly used in South India (Brick et al., 2004).

Cost

Chlorine in liquid form is widely available throughout southern India, along with effervescent NaDCC tablets in varying dosage sizes (Aquatabs is one widely known brand of tablets). A typical bottle of chlorine concentrate costs around USD \$1 and can treat over 1,000 liters of water. The NaDCC tablets are more expensive and cost around USD \$.01 to treat 1 liter of water (Sobsey et al., 2008).

Since chlorine is a consumable good, it needs to be continually purchased. In cases of economic hardship, end-users may choose to not use as much chlorine as needed to treat the water in order to stretch their supply, which would render the treatment less effective to totally ineffective; or, they may choose to forego buying any chlorine at all (McLaughlin et al., 2009).

Advantages

- Chlorine solution and tablets are readily accessible in India
- Relatively cheap
- Effective against a wide array of pathogens if used properly
- Easy to transport and store
- Treats the water quickly (less than 1 hour typically)
- If combined with a safe water storage container, prevents fecal re-contamination of the water

Disadvantages

- The smell and taste of chlorine-treated water is a problem for many end-users
- The chlorine must be continually purchased
- The level of turbidity in the water can impact the effectiveness of the chlorine (e.g., more turbidity means more chlorine must be used; however, turbidity is a factor that is difficult to measure by sight)
- The safe water storage container specifications may be problematic in parts of South India (Arnold & Colford, 2007; Clasen, 2009)

Chlorine-Flocculant Sachets

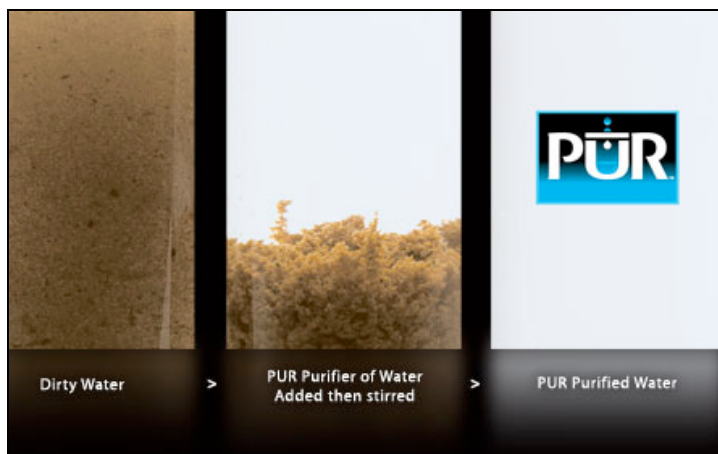


Figure 3: The effect of a PUR chlorine-flocculant sachet on turbid water, http://www.purpurifierofwater.com/product_background.html

Description

In light of the challenges chlorine treatment faces in areas where the water is turbid, a combined chlorine-flocculant (also referred to as a flocculant-disinfectant) point of use treatment system was developed by the American-based company, Proctor & Gamble (P&G). The combination treatment system is based on methods commonly used in large-scale drinking water treatment plants in developed nations. In 2004, P&G partnered with the Centers of Disease Control and other organizations to form the Children's Safe Drinking Water Program (CSDW). In the last seven years, CSDW has distributed approximately 85 million chlorine-flocculant (brand name: PUR) sachets free of charge all over the developing world (P&G Children's Safe Drinking Water, 2011). The chlorine-flocculant treatment system comes in individual packets that contain both a flocculant (a powder that coagulates heavy metals, organic material and microorganisms) and powdered chlorine in the form of calcium hypochlorite. One packet is used to treat approximately 10 liters of water.

The chlorine-flocculant sachet system is relatively easy to use:

- Step 1: Open the sachet and pour all the contents into a container containing the untreated water.
- Step 2: Stir the water for approximately five minutes.
- Step 3: Wait for the suspended organic materials in the water to collect and settle to the bottom of the container.
- Step 4: When the water looks clear and the organic matter has settled to the bottom, pour the water into another (clean) storage container that has a cheesecloth or thin cloth material over the opening to filter out the clumped organic matter.
- Step 5: Allow the treated water to sit for an additional 20 minutes before using in order to allow ample time for the chlorine to disinfect the water (Crump et al., 2005; P&G Children's Safe Drinking Water, 2011; Reller et al., 2003).

One of the main benefits of the chlorine-flocculant system over the chlorine-only approach is that there is a visible change in the look of the water, which may induce people to adopt this POU treatment more readily (Reller et al., 2003). In a randomized control study in western Kenya, all 191 participants in the chlorine-flocculant group preferred the treated water to untreated water; furthermore, there was a 25% reduction in diarrheal disease among the children using the chlorine-flocculant system during the study compared to the control group (Crump et al., 2005).

While some studies suggest that end-users are more enthusiastic about the chlorine-flocculant system than the chlorine-only system, the general uptake of this POU is spotty. In a study in Guatemala, researchers found households' uptake of chlorine-flocculant packets to be quite low (between 27 and 35%), suggesting that ongoing education and advocacy needed to take place (Reller et al., 2003). A later study in Guatemala examined the uptake rate of commercially sold chlorine-flocculant sachets after an aggressive local marketing campaign that included personal in-home demonstrations for customers. Surprisingly, researchers found only a 5% rate of active repeat users throughout the country, which they attributed to several factors with the primary one being cost (Stephen P Luby, Mendoza, Keswick, Chiller, & Hoekstra, 2008).

Use in India

The use of the chlorine-flocculant packets among the population in India is unknown; however, utilization does not appear to be widespread. A study of chlorine-flocculant sachets in Bangladesh found that the majority of study participants (73%) did not report any problems in using this treatment system. Importantly, the naturally occurring arsenic levels in the groundwater there were significantly reduced using this treatment system (arsenic-laced water is a problem in West India as well).

In studies conducted outside of India, the most often reported problems in using the sachets were difficulties in cooking rice with the treated water (the water sometimes discolored the rice and gave it an unpleasant odor), along with the coagulated organic materials floating to the top of the water instead of sinking to the bottom of the container. More concerning, in one study 54% of the treated water samples did not contain high enough levels of residual chlorine to adequately disinfect the water, even though the samples were taken on the same day as treatment. While there may be many reasons behind this finding, the main take-away is that the chlorine-flocculant treatment system produced inconsistent water disinfection results, despite the fact that it comes pre-measured in a sachet (Norton et al., 2009). This suggests that there may be production quality issues or more training needs to be done with end-users to ensure they are only treating 10 liters of water with each sachet.

Cost

One PUR sachet treats 10 Liters of water which breaks down to > USD \$.01/liter in most places (Sobsey et al., 2008), making it fairly expensive compared to other POU options.

Advantages

- An effective treatment for turbid water

- Visibly makes the water clearer which increases the aesthetic nature of the water
- Powders are pre-measured in the sachets, making it easy to use. The only measurement required is to make sure end-users do not use more than 10 L of water at a time.
- The chlorine-flocculant sachet can be easily used in conjunction with a safe water storage system

Disadvantages

- People may still be resistant to using it if the water tastes or smells too strongly of chlorine; also the treated water can impact the taste and appearance of certain foods.
- One of the most expensive of the POU options reviewed, and, as a consumable, needs to be continually purchased and, thus, may be foregone during times of economic hardship.
- End-users need ready access to a supplier
- Treats a relatively small amounts of water at a time (10 liters)

Biosand Filters

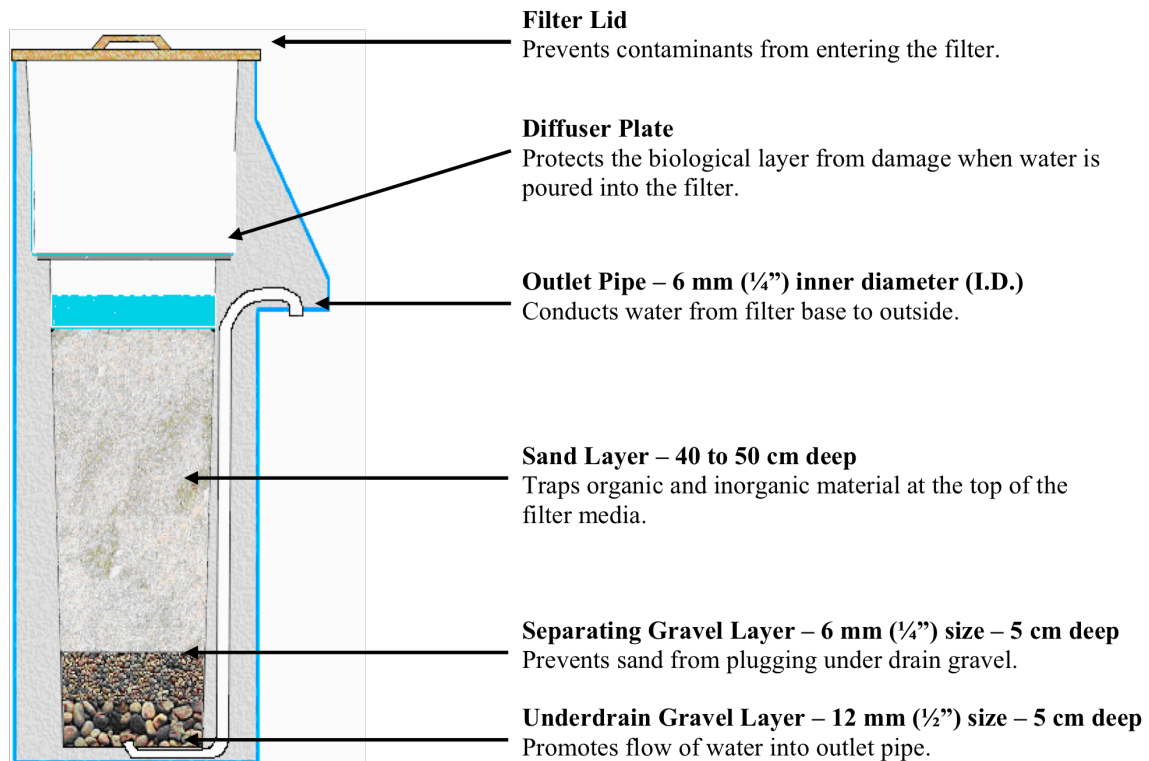


Figure 4: Cross-section of a Biosand Filtration System, courtesy of CAWST

<http://www.cawst.org/en/resources/pubs>

Description

Slow sand filtration treatment of communal water has been in use for more than a century. In the early 1990's, a household-level version of the slow sand filter, the biosand filter (BSF), was introduced by a Canadian researcher with an important design change that allowed the system to operate with only intermittent water flow, unlike the continuous water flow needed with previous slow sand filters (Clasen, 2009; M.A. Elliott, Stauber, Koksal, DiGiano, & Sobsey, 2008). Enthusiasm for the biosand filters by several NGOs (most notably, Samaritan's Purse) has led to it being distributed in over 24 developing countries around the globe.

The biosand filter is one of the more technically complex of the reviewed POU treatment systems. Elliott et al (2008) describe the gravity-fed mechanics of the BSF as follows:

- 1) Water is poured into a concrete or plastic chamber filled with locally available sand.
- 2) The water goes through a diffuser plate (made of either of plastic or metal) that distributes the water more uniformly in the sand and prevents disturbing the biolayer (described in # 4).

- 3) There is an outlet pipe that is elevated in order to allow the filter to maintain a layer of water above the surface of the sand.
- 4) Due to the constant layer of water above the sand, the sand bed remains wet and causes a biolayer of microorganisms (referred to as the *schmutzdecke*) to form. The *schmutzdecke* is one of the key components that removes pathogens in the filtration process. It may take up to 30 days for the biolayer to become well established; during this interim period, it is recommended that the filtered water also be treated with another form of disinfection to ensure that it is microbiologically safe (CAWST, 2010).
- 5) The water filters through the sand and gravel layers and drains to the bottom of the container; there it reaches the outlet pipe, which naturally conducts the water to the outside for collection.
- 6) Biosand filters need to be cleaned periodically; otherwise, the flow rate will slow. Cleaning BSFs consists of removing the top several centimeters of sand and replacing the water on top (M.A. Elliott et al., 2008).

The biosand filter can be made out of local materials and the containers are typically made of either concrete or plastic. The concrete filters tend to be more durable than the plastic ones. With either type, the amount of sand and gravel needed for the filter means this is a heavy product (a concrete version can weigh up to 260 lbs) and can be labor-intensive to produce and install (South Asia Pure Water Initiative, 2011a). Consequently, biosand filters are usually made relatively close to the areas in which they will be used (Clasen, 2009). Once a BSF is installed, however, there is little to no maintenance involved beyond a periodic scouring of the top part of sand and water. The ease of use and relative lack of maintenance may be one reason that BSFs have one of the highest rates of continued use by consumers in follow-up study surveys (approximately >85%) (Sobsey et al., 2008). In a recent follow-up study of biosand filter use in the Dominican Republic, 90% of the households involved in the original intervention were found to still be using their biosand filters one year later (Aiken, Stauber, Ortiz, & Sobsey, 2011).

Multiple studies have demonstrated the efficacy of BSFs in reducing water pathogens like *E. coli* and improving water turbidity, especially as the biolayer grows over time (M.A. Elliott et al., 2008; C E Stauber et al., 2006). In a randomized control trial in the Dominican Republic, the incidence rate of diarrheal disease among BSF households was significantly lower when compared to non-BSF households, indicating a protective effect of using the BSF system (Christine E Stauber, Ortiz, Loomis, & Sobsey, 2009).

One of the greatest advantages of the BSF system compared to other non-electric POU options is that it can produce large volumes of treated water (.25 to 1 liter per minute or ten to hundreds of liters per day), which can then be used for household purposes beyond drinking water (Clasen, 2009; Sobsey et al., 2008). This feature is especially important for households with multiple families occupying the same dwelling.

Use in India

There are biosand filter production facilities in southern India. One example is the South Asia Pure Water Initiative, Inc. (SAPWII), a non-profit organization based in Connecticut

that has a production facility for BSFs in the Kolar District outside of Bangalore, Karnataka. As of November 2010, they have introduced biosand filters to 14 villages in and around the Kolar District (South Asia Pure Water Initiative, 2011a). Another notable group is the DHAN Vayalagam (Tank) Foundation, an Indian-based grassroots organization that focuses on developing water resources in resource-poor areas in southern India. They advocate biosand filters as the POU option of choice for Indian schools and households in rural areas. DHAN leads 3-4 day workshops that teach interested villagers how to build and install biosand filters along with basic hygiene and sanitation lessons (see Appendix C for an example brochure for this training). These workshops have been taught in Karnataka, Andhra Pradesh and Tamil Nadu states (DHAN Vayalagam Foundation, 2006).

Cost

The biosand filtration system has the highest upfront cost of the POU systems examined in this report—the cost for a family to buy a biosand filter typically ranges between \$25-\$100, depending on the country. SAPWII does not list the actual cost of the filters on their website, but they acknowledge that they sell the filters for only half of what it actually costs to produce them and that they raise the rest of the funds from donors (usually Rotary Clubs in America) (South Asia Pure Water Initiative, 2011a). The DHAN Foundation teaches villagers to make the biosand filters themselves; they also do not list a cost for the filters on their website.

Advantages

- Produces a greater volume of water than other POU options
- Easy to use and has very low maintenance requirements after initial installation
- Makes the water look cleaner by reducing turbidity
- Does not break easily
- Once it is installed, no further costs are usually associated with it
- Has the highest documented post-intervention usage of all the non-electric POU options
- Once installed, can be used for years

Disadvantages

- Highest upfront costs of the reviewed POU options
- There is not a safe water storage container built into the design; therefore, the water is subject to re-contamination if not stored in the proper container.
- Dissemination of the BSF system is highly dependent on a production facility being nearby
- The growth of the biolayer takes time, so the filter is less effective in cleaning the water in the beginning stages (M.A. Elliott et al., 2008).

Ceramic Filters



Figure 5: A finished ceramic filter and container with a cross-section of the mechanics of a ceramic filter
Potters for Peace at http://s189535770.onlinehome.us/pottersforpeace/?page_id=9

Description

Using porous fired clay (ceramic) to filter water is a technique that has been used since the mid-19th century; painting colloidal silver on the ceramic to aid in the removal of bacteria is a more recent development. While various “candle” ceramic filters (so named for their hollow cylindrical shapes) have been produced for years by commercial companies around the world, they are typically more costly and marketed to the middle class (Clasen, 2009). This report focuses on the pot-shaped ceramic filters that have been promoted by organizations such as Potters for Peace and IDE for use in low-income populations (Fig. 5).

In this design, the ceramic vessel is shaped like a large flowerpot and has sand and sawdust added to the clay. The sawdust burns out during the firing process, increasing the porosity of the ceramic. After the clay is fired, a colloidal silver solution is painted on both the inside and outside of the pot. The silver acts as an antimicrobial agent and aids in the elimination of pathogens in the water. The ceramic pot is placed in a larger covered container (usually plastic) that has a spigot. The process of filtering the water is simple: one pours the water into the top of the pot and waits for it to filter through the ceramic and collect at the bottom of the plastic container (H. M. Murphy, McBean, & Farahbakhsh, 2010). The ceramic filter unit requires a periodic manual cleaning to remove the impurities left by the water; if it is not cleaned regularly, it is less effective; additionally, the flow rate of the ceramic filter appears to decrease over time even with periodic cleanings (Sobsey et al., 2008).

The effectiveness of the pot-style filter is reduced if the production methods are not strictly adhered to. Both the porosity of the ceramic and the amount of silver applied to the pot impacts the efficacy of the filter; therefore, strict quality control measures must be

maintained during the production process in order to maintain high filtration and treatment standards (Clasen, 2009).

When used properly, several studies have shown ceramic filters to be effective in removing pathogens such as *E. coli*, and reducing diarrheal disease by as much as 40-70% in households that use them (J. Brown, Proum, & Sobsey, 2009; T. F. Clasen et al., 2004; Thomas F. Clasen, Brown, & Collin, 2006).

Use in India

While commercial ceramic “candle” filters have been sold in India for several decades and appear to have a high level of acceptance among the population, less is known about the dissemination of the flower-pot styled filters. In 1996, an estimated 15-25% of middle to upper income Indian households around Delhi, Kolkata, Mumbai, and Chennai were using ceramic filters (Anderson, 1999). The acceptance of ceramic candle filters in the middle to upper income population in India may lend the pot-style ceramic filters an aspirational aura and thus make villagers more willing to use them. A 2005 Potters for Peace activity report stated that IDE and the Practica Foundation (both advocates of ceramic filters), consulted with a small ceramic filter production facility outside of Bangalore in Karnataka state. The same report also notes that Potters for Peace themselves sold a small number of filters to an NGO in South India (Potters for Peace, 2005). Despite these indicators that ceramic filters are being produced (and possibly used) in southern India, published reports on the dissemination of flower-pot shaped ceramic filters in India were not found.

Cost

The estimated cost of a pot-styled ceramic filter and its plastic water container is approximately USD \$8-10 depending on the country. Replacing the filter unit costs around \$4-5 (Sobsey et al., 2008).

Advantages

- Easy to use
- Can filter turbid water and make it look clearer
- One filter can be used for 2-3 years if maintained properly
- The Potters of Peace design incorporates a safe water storage container which helps prevent re-contamination of the water
- There is already a high level of acceptance of ceramic filtration among the middle and upper income Indian population, which may make implementation of pot-style filters in villages easier because they may be viewed as more of a “high-class” item

Disadvantages

- Fragile construction (i.e., the ceramic can break)
- If broken, need ready access to replacement parts which may not be feasible for people in rural areas

- Filter requires regular cleaning in order to maintain effectiveness and flow rate
- Produces a lower volume of treated water, due to the low flow rate of 1-3 liters per hour, depending on the turbidity of the water
- Flow rate may decrease over time, even with regular cleanings

Solar Water Disinfection (SODIS)



Figure 6: Water being treated by the SODIS method, courtesy of www.greenprophet.com

Description

Interest in using solar energy (ultraviolet radiation + infrared heat) to treat unclean water began in the mid 1980s. This method of water treatment has four main steps:

- Step 1: Collect clear, plastic polyethylene terephthalate (PET) bottles that are approximately 1-2 liter in size (e.g., empty Coca-Cola bottles).
- Step 2: Clean the bottles.
- Step 3: Fill the bottles with untreated water and shake them to aerate the water.
- Step 4: Close the bottles and place them horizontally to full sun exposure for at least 6 hours. The amount of sun exposure time needed to effectively treat the water depends on multiple factors: bottle size, cloud coverage, latitude, altitude, season, and the turbidity of the water are the main factors to take into consideration when determining the treatment time. If the weather is rainy or cloudy, it is recommended that the bottles be left out for 1-2 days in order to ensure that the water has been exposed to ample sunlight (Swiss Federal Institute for Environmental Science and Technology/Department of Water and Sanitation in Developing countries (EAWAG/SANDEC), 2002).

Typically, the bottles are stored on rooftops or on the ground during the treatment process. If there is a large amount of turbidity in the water it can affect the UV radiation; as a result, highly turbid water should undergo a filtration process of some kind before using the SODIS method. The amount of treated water produced using SODIS depends on the number and size of bottles a family has (example: 5 liter bottles = 5 liters of treated water after sun exposure).

Several studies have documented the effectiveness of SODIS in reducing the incidence of diarrheal disease in communities. In two studies in India, the estimated diarrheal

incidence rate among children was reduced anywhere from 40 to 75% when the family treated their water with the SODIS method (Rai, Pal, Kar, & Tsering, 2010; Rose et al., 2006). One of the major challenges with SODIS is that study participants' use of the method usually declines (sometimes dramatically) after the study period ends. In a follow-up assessment of households that took part in a SODIS program in Nepal, researchers found that only 9% of study participants had decided to keep using the SODIS method to treat their water in the three months since the program had ended. The main complaints from the villagers were that the SODIS method took too much time and that the water smelled and tasted bad, complaints that have been cited by participants in other studies as well (Rainey & Harding, 2005).

Use in India

A SODIS project was created in the southern state of Tamil Nadu in 2002 in partnership with the League of Education and Development (LEAD). An estimated 275,000 families use the SODIS method in all of India, with approximately 100,000 of those in Tamil Nadu (Swiss Federal Institute for Environmental Science and Technology/Department of Water and Sanitation in Developing countries (EAWAG/SANDEC), 2010).

Cost

PET bottles are widely available in the developing world and can be purchased at low-cost. Bottles need to be replaced once they become worn over time. In a cost analysis of different POU options, the annual estimated cost of using SODIS to treat the water needed for an individual for a year (including training costs to teach people the correct method) is USD \$0.63 (Clasen et al., 2007).

Advantages

- Uses materials that many people already have on hand (empty soda bottles, roof, the sun)
- The only non-commercial of the POU options
- Parts (i.e., soda bottles) are typically easy to replace

Disadvantages

- Effectively using the SODIS method can be difficult due to the multiple variables that impact the length of time the water needs to be exposed to sunlight. It can be especially difficult for end-users to determine if the water is too turbid and needs to be filtered before using the SODIS method (Sobsey et al., 2008).
- Does not necessarily improve the look, taste or smell of the water
- Produces a relatively small amount of water: the amount of water treated is limited to the number of bottles a family owns
- Lack of space for the bottles during treatment phase has been cited as a problem (Rainey & Harding, 2005)
- Can take a long time to treat the water (6 hours to 2 days), so people must plan ahead for their drinking water needs

Boiling



Figure 7: A pot of boiling water. Photo courtesy of http://www.dailyfork.com/2009/03/5_common_cooking_injuries_and.php

Description

Boiling water is one of the oldest and most common household methods used in the developing world to treat water. WHO notes that more than 90% of the population in certain Asian countries use boiling as the preferred method to treat their water (Clasen, 2009). When used properly, boiling is also one of the most effective ways to disinfect water. Although the boiling point of water at sea level is typically 212° Fahrenheit or 100° Celsius (depending on impurities in the water, which can affect the boiling temperature), studies have noted a reduction of bacteria and parasites even when water has been heated to only 70° Celsius (Clasen, 2009, p. 15). While suggestions vary on the length of time the water should be boiled, the WHO's *Guidelines for Drinking Water Quality* states that the water should simply reach a "rolling boil" (WHO 2004).

Use in India

According to a 2005-2006 Indian Demographic and Health Survey, approximately 10.6% of the Indian population said they boiled their water on a regular basis (International Institute for Population Sciences (IIPS) and Macro International, 2007).

Cost

A recent study in rural India suggests that boiling may be an economical way of water treatment for villagers who have adequate access to natural gas, with an estimated cost of US \$0.88 per month for the gas needed to boil 6 liters of water per family per day (Firth et al., 2010). Another study estimated the annual cost of boiling water for a household in India at US \$2.11 for those using petroleum gas and US \$1.66 for those using wood (Thomas Clasen et al., 2008).

Advantages

- Many people are already familiar with the concept of boiling to treat water

- Needed “hardware” (e.g. heat source and pot) already in place in most homes
- Effectively kills most pathogens if water is boiled

Disadvantages

- Does not remove chemicals (like arsenic) or turbidity from the water or necessarily improve taste
- Does not incorporate a safe water storage system component, thus one must be added in order to avoid re-contamination of the water
- Takes time to bring water to a boil and then let it cool to drinking temperature
- Not usually able to produce large quantities of water for a family
- May be cost-prohibitive for low-income families
- Can be labor and time-intensive to collect wood, biomass, charcoal, etc., most of which typically falls upon women and children. The time taken to gather supplies and boil the water may detract from schooling or other productive activities.
- If using wood, contributes to deforestation
- Depending on how and where the water is boiled, may increase danger of other health hazards such as skin burns and indoor air pollution (Clasen, 2009)

POU Options At-A-Glance

Table 3: Various Attributes of Reviewed POU Options

System	Quantity Produced/Time	Removes Turbidity?	Improves Taste?	Does design include a Safe Water Storage Container?	Cost (\$USD)
Chlorine & the Safe Water System	5-10 mL treats 20 L of water	No	No	Yes	~ \$1 per 1,000 liters
Chlorine-Flocculant	1 sachet/10 L	Yes	Sometimes	No	>\$.01 per liter
Biosand Filter	15-60 L per hour	Yes	Yes	No	\$25-\$100 upfront cost and then little to \$0 afterwards
Ceramic Filters (Flower Pot Style)	1-3 L per hour	Yes	Yes	Yes	\$8-10 upfront & replacement filters are \$4-5 every 2 years or so.
SODIS	20 bottles = 20 L, takes about 6 hours to 2 days	No	No	Yes	\$0.63/annual for one person
Boiling	Varies: typically 1-3 liters at a time, as it is dependent on size of pot used	No	No	No	\$1.66 for wood/annual for one person, \$2.11 for gas/annual per person

CASE STUDY: VILLAGE X, NELLORE DISTRICT, ANDHRA PRADESH, INDIA

Imagine a person visiting a rural village in southern India. Through visual observations and conversations with the locals, the visitor notes that many of their health complaints (frequent diarrhea, fevers, typhoid, etc.) may be connected to the quality of their water, along with sanitation and hygiene practices. However, the villagers do not identify water, hygiene, or sanitation practices as causal factors in their illnesses. The visitor observes that the majority of homes are located within a 2-3 minute walk from a water source, usually an open well or a hand pump connected to a bore well. No villagers have water piped directly into their homes, so they collect water in containers and store it in their homes for later use. Upon further questioning, the visitor learns that people do not treat their water before using it. The village has electricity, but the supply is unpredictable, with an average of 8-10 hours of electricity available intermittently throughout the day. The unpredictable supply of electricity makes using electric household water treatment systems (such as a reverse osmosis system) difficult; additionally, the village is lower-income and more than likely could not afford the cost of an electric water treatment system. The villagers are interested in learning about the available non-electric POU options for household water treatment. What factors will this visitor need to consider as he/she plans a potential POU program for this village?

The above paragraph describes a situation similar to one experienced by the author in the summer of 2011. The author gathered information through informal ethnography (e.g., conversations and personal observations) in order to understand the health challenges facing the people in Village X. A former village resident (who still has relatives living in the village) accompanied the author, arranged the appropriate meetings with health professionals, and acted as a translator when necessary. This same former villager also spent several hours talking with the author about his own experiences living in the village. With this link to a village “insider,” the author was able to explore the village and observe the different water sources available to the people, along with their water collection practices. Additionally, the author visited two homes in Kavali and Village X, observed water storage practices, and talked with various people about the disease patterns in the village.

Upon the request of the village insider, the author did not ask any questions related to caste to anyone interviewed; however, studies conducted in southern India have found that caste can impact a person’s health and access to water. For example, Banda et al. (2007) found that the quantity of water was significantly lower in the lower caste area of a village in southern India compared to the higher caste area. The two castes in this study had separate sources of water, a common phenomenon in Indian villages, partly due to leftover structures from the past. The researchers theorized that the historical separation of the different castes in India continues to influence inequalities today, including access to adequate water supplies (Banda et al., 2007). Consequently, caste is an important factor that needs to be considered when designing any health intervention involving water in India.

A major part of planning any POU health intervention program is to conduct a literature review of existing research. The CDC's Safe Water System Handbook (1999) provides a framework of topics to consider including in the literature review before beginning a water or sanitation intervention in a community (for the complete list, see Appendix B):

- **Epidemiological data:** What types of diseases occur in the village? Who gets the diseases?
- **Water infrastructure:** How are people getting water? What is the microbiological quality of the water at the source of collection?
- **Water handling practices:** Is storing water common? In what types of containers are people storing their water?
- **Socio-cultural aspects:** What cultural barriers may exist to a POU intervention? What do they believe about the causes of diarrhea? What are their beliefs about water? Who traditionally controls money in the family (important if the POU intervention will cost money)?
- **Economic aspects:** Can the community pay for the POU intervention? If not, are there donors who are willing to fund a portion of or the entire project?
- **Other possible support and infrastructure:** Are there government or community leaders that can be approached for support? Are other NGOs involved? (Centers for Disease Control, 1999)

In addition to the categories listed above, it is helpful to gather basic descriptive information about an area, such as location, primary industries, climate, etc.

The literature review will likely provide information that is broadly applicable to the region where the community is located. To gather more community-specific information, the researcher may use personal observations, distribute a village survey, or even conduct focus groups/individual interviews with the villagers. Using personal observation and informal



Figure 8: Map of India. Map courtesy of: <http://www.mapsofindia.com>

interviewing, the author compiled the following information about Village X in Andhra Pradesh:

Location

The state of Andhra Pradesh is the fifth largest in India, both in population (74 million) and physical size. The village observed (Village X) is in the Nellore District of Andhra Pradesh and is approximately 20 minutes by car outside of Kavali, one of the largest towns in the district. Nellore District is approximately 4 hours north of the large coastal city of Chennai (formerly known as Madras) in Tamil Nadu. Nellore District is 13,076 sq. km and has direct access to the east coast of India. The Bay of Bengal is 8 km from the town of Kavali; Village X is approximately the same distance from the coast.

Language

The official language of Andhra Pradesh is Telugu.

Economy

Approximately 70% of the population in Andhra Pradesh works in agriculture. Rice, sugarcane, tobacco, bananas, cotton and millet are some of the most common crops grown. In Nellore district dairy milk, sugar, rice, stone polishing, fishing and a Nippon battery factory (an Indo-Japanese alliance) serve as the major industries. While there is not a national survey that collects data on income in India, a 2008 study that included a village in southern coastal Andhra Pradesh put the annual per capita median income at 7,465 rupees (USD \$152) and the annual per capita mean income at 14,341 rupees (USD \$292) (Rawal, Swaminathan, & Sekhar Dhar, 2008). These figures are far below the national per capita income of \$1,340, suggesting that this is an impoverished area (World Bank, 2011). For comparison, thirty Aquatab hypochlorite tablets used to treat water cost approximately 15 rupees; the cost of a Bajaj ceramic candle water filter sold commercially is approximately 1,200 rupees (Jain, 2009).

Climate

The patterns of the yearly monsoon season (late June to October/November) strongly determine the climate in the state. Temperatures vary from a low of 13^o C in the winter to 42^o C in the summer months. It is typically humid (WhereInCity India Information, 2011).

Village Government

India's form of government is a parliamentary democracy. The term, *panchayati raj*, refers to India's governing system at a local level—it is based on democratically elected local councils known as *panchayats*, which are elected every five years. The 73rd amendment to India's constitution (instituted in 1993) reserves one-third of all panchayat seats for women (The Hunger Project, 2011).

Available Health Resources

Hospitals and Primary Care Centers:

There are a variety of health resources in Kavali (approximately 20 minutes by car from Village X) and neighboring villages. There is a government primary health care center

and a government hospital in Kavali; both charge little to no cost for medical care for low-income people (defined as those who have “white cards,” indicating that they make less than 15,000 rupees annually) (Former Village X Resident, 2011). The consensus among the locals interviewed is that people have a low opinion of the government hospital and prefer the private hospitals if they have a serious illness and can afford to go; however, comments made by the RMP and the Village X Resident indicated that seeking care from the private hospital poses a financial hardship for many people in Village X (Former Village X Resident, 2011; RMP, 2011).

Village Health Workers:

There is a primary Registered Medical Practitioner (RMP) who practices in a village near Village X. Village X is a smaller community and does not have its own RMP, so the villagers will often see RMPs from other villages. RMPs are similar to village health workers and may or may not have formal health training. The RMP the author interviewed sees men, women, and children for a wide range of ailments (similar to a general practitioner). However, he does not treat pregnant women; instead a local woman (similar to a village midwife) works exclusively with that population. If the illness appears serious (such as malaria), he encourages the patient to go to the main government hospital in Kavali, approximately 20 minutes away by car. The RMP earns money by selling medicine to his patients.

In 2004, a law was passed in Andhra Pradesh requiring all new RMPs to undergo a year of government-sponsored health training and then pass an exam in order to receive their RMP certificate and practice in a local village. For RMPs already in practice, they have until 2014 to take the required government exam needed to maintain their official RMP status. The RMP the author interviewed has not received health training and is waiting until 2014 to take the exam needed to maintain his RMP certification (RMP, 2011). During the course of the author’s conversation with the RMP, there were several instances where his understanding of the relationship between water, sanitation and disease appeared to be lacking. For instance, he did not identify a lack of hand washing, contamination of stored water, or open defecation as potential causes of the yearly typhoid outbreaks or the common childhood diarrheal disease experienced in the village. Therefore, he is a good candidate for further health training. In general, people who occupy the position of village health worker (like the RMP) are in a natural position to promote water treatment and safe sanitation practices in a community; thus, it is advisable to include them in a POU water intervention program after ascertaining that they are indeed respected in the community and are adequately trained.

Disease Patterns in the Community

“Everybody in their lifetime will get one time, typhoid. It is a common thing. We don’t worry about it because there is good medicine [for it].” – Former Village X Resident

The goal of gathering epidemiological data about disease patterns in a population is to gain a broad perspective of a community’s health. Official epidemiological information from an organization that tracks the community’s health statistics (such as a government agency or a local hospital or clinic) is ideal. However, if that information is unavailable

or difficult to locate, examining statewide data about waterborne diseases can be just as useful.

For example, a 2007 government report lists the following figures for reported incidences in Andhra Pradesh of three diseases that the government identifies as waterborne:

- Diarrheal disease: 1,215,659 cases with 124 deaths
 - Viral Hepatitis: 17,846 cases with 28 deaths
 - Typhoid: 135,550 cases with 12 deaths
- (Planning Commission, Government of India, 2007)

These numbers are based on data that is reported by each state to the Ministry of Health & Family Welfare; unfortunately, the report did not outline the reporting mechanisms each state uses to gather these numbers. It is feasible to believe that, since many cases of diarrheal disease are often treated at home (especially in more rural areas), the actual incidence rate of diarrhea is higher than the one reported in official government statistics.

In lieu of official epidemiological data, doing a village-wide survey about common disease complaints can be useful. However, it is quite an undertaking to design and administer a culturally appropriate survey, let alone to then properly analyze it. Another way to gather information is to conduct an informal ethnography of the village—walk around, observe people and structures, and talk with the villagers themselves to learn more about their culture, beliefs, and health issues. Spending time with the health professionals that treat the villagers can be quite useful as well.

In the author's conversations with various Indian health professionals in Nellore District, several health issues were mentioned that could be linked to unclean water and sanitation and hygiene practices. On the village level, it does not seem that rural villagers are fully aware of the relationship between health and water and hygiene and sanitation practices. The doctors interviewed in Nellore acknowledged the importance of clean water and good hygiene and sanitation practices, probably because these doctors were all highly educated. During a dinner conversation with an internist, a physiotherapist, and a homeopathic doctor (trained in the German tradition of homeopathy), they reported the most common issues they see in their patients from the outlying villages:

- Gastritis—attributed to stress and tension
- Worms and other parasitic infections—attributed to a lack of sanitary conditions
- Anemia—attributed to worm infections
- Skin diseases—attributed to general unhygienic conditions and worms

The physiotherapist grew up in a rural village outside of Nellore and still returns to his home village to visit family. He stressed the poor sanitation practices in his home village and its impact on the villagers' health in the form of intestinal worms:

In villages there is no lavatories, they will go outside only. That will infect one person to another person [with worms]. They don't use soap or water to wash

properly. . . because they don't always have [access to] water. Lack of improper hygiene . . . That is main problem in villages, up to 50% of people there have worm infection because of lack of sanitary conditions (Three Doctors, 2011).

His assessment of the low rate of hand washing is corroborated by other studies on sanitation and hygiene in southern India (Banda et al., 2007; Firth et al., 2010). In a study in northern India about hand washing behaviors after contact with fecal matter, researchers found that approximately 73% of the families observed did not routinely wash their hands after potential fecal contact (Biran et al., 2008). Upon being asked where the people in his home village obtain their water, the physiotherapist reported that they obtain their water from a bore well. He remarked that the well water is clean, in his opinion; however, it becomes dirty during storage because of a lack of education among the villagers about sanitation (Three Doctors, 2011). While the author was unable to verify if the water from this doctor's home village bore well was indeed microbiologically pure, the doctor's assessment that the water is contaminated during the storage phase due to sanitation practices is supported by multiple studies in the literature (Brick et al., 2004; Eshcol, Mahapatra, & Keshapagu, 2009; Firth et al., 2010).

In a conversation with Village X's main care provider, the Registered Medical Practitioner (RMP), he listed the most common diseases he sees in Village X:

- In children: diarrhea and pneumonia
- In women: problems associated with menstruation, arthritis, anemia and hypertension
- In men: hernias and arthritis
- In everyone: skin diseases

When asked what he thinks causes diarrhea among the children, the RMP asserted that he believes contaminated water causes diarrhea. When asked how the water becomes contaminated, he reported that there is a crack in the pipe that brings water from the bore well to the village government water tank; if the water stays for too long in the water tank, dirt comes in through the cracked pipe and contaminates the water. He did not mention the water being contaminated by the people themselves after collection; nor did he mention the potential impact of sanitation and hygiene practices such as unsafe water storage or open defecation. His comment about contaminated water tanks is substantiated by some studies which have documented contaminated water coming from poorly maintained government water storage tanks in India, sometimes with deadly results, such as cholera and typhoid outbreaks (Anand & Ramakrishnan, 2010; Ramakrishna et al., 1996).

Interestingly, the RMP did not initially identify typhoid as a problem until later in the conversation when he mentioned that a typhoid outbreak occurs on a yearly basis in the village when "the water changes during monsoon season" (RMP, 2011). It appears that the RMP and the villagers in general feel that the water quality is poorer during the heavy rains of the monsoon season. This may be true as there is evidence that, if people practice open defecation, the rains of the monsoon season may flood the villages and its water

sources with feces-contaminated water from the outlying fields. According to the RMP, the villagers identify the water changing, mosquitoes, and the flu as all being able to cause typhoid. When asked if the villagers know how to prevent typhoid, the RMP responded:

They don't know what to do in that situation. But whoever come to us [from the government] they will tell them, "take these preventions: like, uhmm, boil the water, and drink and . . . clean your body well and wash your hands before you eat"—things like that (RMP, 2011).

It is worthy to note that the RMP did not appear to believe that the villagers listened to the advice of the government health officials, indicating that they may not believe the government's judgment about the causes of typhoid. This example illustrates the principle that, in order to devise an effective and appropriate POU intervention, it is essential to elucidate a community's underlying beliefs about the causes of illness, as they may be very different from the Western biomedical model.

The author was unable to ask direct questions about defecation practices in the village, as it was not considered appropriate for a foreigner to ask questions of that nature within that particular context. However, the RMP's comment that typhoid occurred when the water changed during monsoon season calls to mind a 2009 spatial mapping study in southern India that documented the close proximity of the villagers' "defecation fields" to water sources and cultivated fields. The researchers found that the villagers' practice of open defecation increased the risk of the village and its water sources being inundated with fecal-contaminated water during monsoon season, thus increasing the risk of serious disease outbreaks (Gopal et al., 2009). Therefore, Village X's assessment of their water quality "changing" during monsoon season may have credence if their water sources are being contaminated by feces-laden water from nearby fields.

In response to a question about the villagers treating their water, the RMP said that the government provides instructions on boiling water before drinking it; however, he did not believe that people practiced this method on a regular basis. During the author's time in India, boiling was the only non-electric water treatment method mentioned by the various people interviewed. The more affluent Indians had elaborate electric water treatment systems in their homes, such as the reverse osmosis treatment system; however, this would be a difficult proposition for Village X because it has only 8-10 hours of intermittent current a day and the price of the electric water treatment systems is beyond the reach of the typical village household.

Water Sources



Figure 9: Villagers accessing water from an open well



Figure 10: Villagers collecting water from a water tap

The houses in Village X are fairly close together, and the average walking distance to a water source appears to be no more than 3-5 minutes (and for many it is under 2 minutes). Based on observation, it appears that the residents in Village X primarily obtain their water from deep bore wells that tap into the groundwater contained in underground aquifers. Walking around the village, the author observed a variety of wells and hand pumps that seem to be government installed

(the villagers could not identify any organizations besides the government that helped them with water matters). Some of the wells could be considered unprotected and unimproved water sources because they are uncovered and require a rope and bucket to access the water (Fig. 9). On the other end of the continuum, there were a variety of improved water sources, such as protected water taps (Fig. 10) that likely access water from the bore well through subterranean pipes; this closed system provides a level of protection from contamination, provided that the pipes are not cracked. There is also a large government tank that stores water brought up from a bore well (Fig. 11). It has been noted that the

government's most common method of treating water in rural southern India is chlorination through adding bleaching powder to the water tanks, such as the one pictured in Figure 11 (Gopal et al., 2009). The author was unable to verify if the government treated the water in the water tank on a regular basis. However, several studies that tested water from government water tanks documented high levels of fecal contamination at the source of collection, possibly due to inadequate levels of chlorine in the tanks (Firth et al., 2010; Gopal et al., 2009). Additionally, in both a typhoid outbreak in Rajasthan state and a cholera outbreak in Tamil Nadu, the primary risk factor identified among the cases was drinking water from the government water tanks, mainly due to



Figure 11: Villager accessing water from water storage tank

the fact that, unbeknownst to the public, the government had stopped treating the water due to financial constraints (Anand & Ramakrishnan, 2010; Ramakrishna et al., 1996). Therefore, even if the water in government tank is supposed to be treated on a regular basis, there is still a chance that it may be microbiologically impure.

Water Storage Practices



Figure 12: Uncovered water storage container for humans in family courtyard

As shown in Figures 10 & 11, residents in Village X use wide-mouth vessels made of a variety of materials to collect their water. These types of water storage containers are considered unsafe because hands can be put through the wide-mouth opening, greatly increasing the risk of contaminating the stored water (Banda et al., 2007; Eshcol et al., 2009). In a home the author visited, three families live together (referred to as a “joint family home”) in a house with approximately five rooms. The dwelling also has a large, walled courtyard area where the family sleeps in the summertime, works, eats, and stores their

water. After collecting water from the nearby well (< 1 minute walking distance from the house), the family empties the containers into a large, uncovered concrete water storage container that has a waterspout on the side (Fig. 12). They then access the water from either the side spout or by dipping a cup into the top of the container, again increasing the chance of contamination by hands (Brick et al., 2004). Figure 12 shows the water storage container for people in the courtyard; directly across from this water container is a similar one that is lower to the ground and is used for the livestock (Fig. 13). From the author’s observations, it appears that this is how people in the village typically store their water if they do not keep it in the original containers used for water collection. The water storage practices in Village X are not uncommon and, indeed, confirm what other studies have documented: widespread use of open or wide-mouthed storage containers, along with accessing the water by dipping a cup into the top of the container (Brick et al., 2004; Eshcol et al., 2009; Gopal et al., 2009; Sharma, Ramakrishnan, Hutin, Manickam, & Gupte, 2009).



Figure 13: Uncovered water storage container for livestock in the same family courtyard, approximately 10 feet from water container for humans

As mentioned earlier, typhoid outbreaks occur on a yearly basis in this village. In a study of typhoid outbreaks in West Bengal, researchers found that using wide-mouth water storage containers and retrieving water out of the containers with a cup were significantly associated with typhoid cases (Sharma et al., 2009). Therefore, a POU intervention for this community should include finding acceptable alternatives to the village’s current water storage practices in order to reduce the chance of re-contaminating the water during storage.

Socio-Cultural Practices

The joint family home the author visited had a working latrine that appeared to be in good condition. However, as previous studies in rural southern India have shown, even with a functioning latrine at home, it is highly likely that the villagers practice open defecation as well which can contribute to diarrheal disease (Banda et al., 2007). Another Village X practice observed by the author were people keeping close quarters with their livestock (including allowing them into the home), a practice that has negative health implications. In a study in rural Bangladesh, researchers found that allowing livestock into the living area was a significant risk factor in young children developing diarrhea (Pathela et al., 2006).

During the evening, the animals are tied to sticks directly outside the walls of the house.



Figure 15: The same calf after walking through the sewage ditch; now in the courtyard area of the house where water is stored and people sleep, eat and work.

There the animals will defecate, which then collects into something similar to a sewage ditch. Usually a “bridge” to the entrance of the house is made out of a piece of wood or concrete and placed over the ditch so people can enter the courtyard without stepping in animal waste (see background in Fig. 14). When animals enter the dwelling, there is the chance that they may have first walked through the sewage ditch before entering the house (Figures 14 & 15), thus tracking fecal matter into the living area where children play, and people eat their meals and sleep.

Clearly, keeping livestock tethered close to home and sharing living space with them increases the risk of contaminating food and water with animal waste. For example, an *E. coli* outbreak in

Scotland in 1999 was traced to fecal contamination of an unprotected water source in an area where sheep were allowed to roam freely (Licence, Oates, Synge, & Reid, 2001). The practice of keeping one’s animals close to home has been noted in another study conducted in southern India, along with the problems posed by the fecal matter dispersed by the animals around the dwelling (Gopal et al., 2009). When heavy rains come, uncovered animal and human waste in the fields and around the home can easily contaminate open wells and lead to disease outbreaks. Therefore, exploring alternative ways to house livestock and deal with animal waste should be considered for Village X.



Figure 14: A calf walking through animal waste on the way into the house (entrance to house can be seen in background).

Local Beliefs about Disease

In the author's conversations with the RMP and other locals about illnesses and their causes, several themes emerged:

- Diarrhea was identified as a common problem among Village X children. Both the RMP and the former Village X resident identified the cause of diarrhea as "dirty water." According to them, the water became contaminated in one of three ways: 1) if the water stays in the government tank too long (Fig. 11), it can become contaminated; 2) the pipe that carries the water into the government tank is cracked, allowing dirt to get into the water; and 3) uncovered wells have things thrown in them that make the water dirty (Former Village X Resident, 2011; RMP, 2011). Interestingly, no one mentioned people's sanitation and hygiene practices as a possible contributor to diarrhea.
- It is common for people to experience fevers. Sometimes they do not know what causes their fevers. If they are very sick, and their fever lasts longer than 4-5 days, they may suspect it is typhoid or malaria and will see the RMP or go to the hospital in Kavali for a blood test. Typhoid strikes the village every year, around the monsoon season, and is viewed as a commonplace event.
- The three doctors in Nellore estimated that the rural villages in Nellore District have as high as a 50% intestinal worm infection rate, which results in a myriad of health issues, including anemia. When asked for the reason behind the high worm infection rate, the doctors attributed it to the villagers practicing open defecation and not using soap and water after defecation (partly because the villagers do not have ready access to water for washing). Interestingly, the RMP also recognized anemia as a problem among Village X women but identified the causal agent as "hard work and not eating enough vegetables"; at no point during the conversation did he mention worms as an issue in the community. The RMP's omission about mentioning worm infections may indicate that intestinal worms are not a problem in this community or, more likely, worms may be so endemic that it may not have occurred to him that it is an issue (or, he may not recognize it as an issue, due to a lack of training).
- Chicken pox and skin diseases were the only illnesses discussed that were attributed to supernatural causes. A curse from a goddess is thought to cause chicken pox, and having the evil eye cast on a person causes them to have skin diseases. For skin diseases, the villagers normally elect to seek care from a religious guru in Kavali (RMP, 2011).
- Both the RMP and former Village X resident identified pneumonia as a common issue among the village children. When asked what causes pneumonia, the RMP responded:

Children eat lot of ice creams, candy, chocolate bars. You know, chocolate bars made with the local water, and that chocolate bar will be sold in the

village-- kids like it very much, they eat too much--so that causes them to [get] pneumonia (RMP, 2011).

The local chocolate “bar” referred to above is actually a chocolate drink sold in glass containers, which was later shown to the author. The several people present in the room during the conversation with the RMP vigorously concurred that this particular drink causes pneumonia in the village children. While investigating pneumonia is outside the scope of this report, interestingly, a study in a rural village in Rajasthan strongly linked drinking local milk products to contracting, not pneumonia, but typhoid. The authors theorized that the milk in the village had untreated water added to it by the suppliers in order to stretch their stock. Additionally, unpasteurized milk can be a source of typhoid, regardless of whether or not water is added (Sharma et al., 2009). While this belief may be an example of a local superstition, the villagers’ insistence about the perils of this particular chocolate drink is intriguing and may be a topic worth investigating in the future.

In conclusion, the three doctors in Nellore, the Registered Medical Practitioner, and various villagers all provided insights that helped the author understand more about the beliefs regarding diseases in Village X. Notably, while water contamination was identified as a cause of diarrhea by both the RMP and other locals, the role of sanitation and hygiene was not discussed by anyone besides the doctors in Nellore; this finding suggests that health promotion activities addressing sanitation and hygiene need to be a key area of education for future health interventions in this community.

Economic Factors

The villagers in Village X appear to be in the lower-income threshold. As mentioned previously, a 2008 study that included a village in southern coastal Andhra Pradesh put the annual per capita median income in that area at 7,465 rupees (USD \$149) and the annual per capita mean income at 14,341 rupees (USD \$287) (Rawal et al., 2008). These figures are far below the national per capita income of \$1,340 (World Bank, 2011). Consequently, this area may be considered more of an impoverished part of India. The RMP noted that many people in the village do not have enough money to buy food beyond rice and chili powder. He also observed that it can be difficult for the villagers to go to the government hospital in Kavali for treatment because, even though the hospital services are low-cost to free, the transportation to the hospital is usually more than the villagers can afford. However, the fact that most villagers own oxen, have sturdy mud homes, and access to improved water sources suggested that there is a measure of economic livelihood in the village. Whether there is enough money per household to pay for a point of use water treatment system is uncertain; however, the villagers may be willing to pay for a POU system with “sweat equity” (i.e., contributing labor to help build the POU system, if applicable).

Potential Partners

According to the RMP, the local government provides education to the villagers on how to treat their water by boiling during the yearly typhoid outbreaks. Beyond that, the villagers could not identify another agency or organization that provides education or

help of any kind pertaining to water and sanitation issues in the community. The author was not able to meet with anyone in the panchayat (the village council), but involving the panchayat in the initial planning stages of a POU intervention is encouraged. Gaining the support and approval of community leaders is vital to the process of obtaining overall community buy-in for any health intervention.

Author's Recommendations

Based on the information presented, the author recommends a multi-pronged water, sanitation, and hygiene intervention, using the CDC's Safe Water System manual as a guide for program planning, implementation, and evaluation. However, based on the research that indicates South Indians are resistant to drinking chlorine-treated water, the author recommends replacing SWS's treatment choice of chlorine with biosand filters (BSF) (Banda et al., 2007; Firth et al., 2010). The benefits of using household level biosand filters as the preferred POU system for Village X are as follows:

- The BSF system can generate the large volumes of water needed for large households with multiple families living together. Having more water also means more water is available for hand washing and bathing, which may help lower the occurrence of skin diseases in Village X.
- BSFs do not break easily and have low maintenance requirements.
- Once purchased a BSF will last many years, and further investment is usually not needed.
- The houses in the village are able to accommodate biosand filters, which are larger than other POU options.
- There is a BSF production factory run by South Asia Pure Water Initiative, Inc. in neighboring Karnataka state, outside of Bangalore. SAPWII is a non-profit based in America that subsidizes half the cost of their filters through private fundraising in order to make them affordable to low-income villages in South India. Therefore, the cost of a BSF from SAPWII may be affordable for the villagers (South Asia Pure Water Initiative, 2011b). The DHAN Foundation also offers workshops in southern India on the mechanics of making and using biosand filters.
- Since the village is only 8 km from the ocean, it may be possible for the villagers to obtain some of the sand needed for the filter, and possibly take part in helping build the filters in order to lower the cost and instill some "sweat equity," something that has been tested with NGOs operating in other countries (Clasen, 2009).

However, simply introducing biosand filters to the community is not enough because, as shown in Figures 11 & 12, safe water storage is a considerable issue in this community. A significant drawback to BSFs is that they lack a built-in safe water storage container. Therefore the water may come out of the filter microbiologically clean, but, if stored improperly, it risks becoming contaminated again. In a study of biosand filters in Cambodia, the water tested directly from the BSF spout was microbiologically pure, but the water stored in unsafe containers after filtration was usually highly contaminated with fecal matter, most likely originating from unclean hands coming into contact with the water (H. Murphy, McBean, & Farahbakhsh, 2010). Therefore, it is vital that a safe water storage solution (Fig. 16) and education about sanitation and hygiene are integrated into any BSF program for Village X. Faith-based NGO, Samaritan's Purse, has integrated hygiene training into their biosand filter program and may be a potential organization to partner with and learn from. Their program requires that potential BSF end-users attend hygiene and filter-use training classes, along with contributing both money and labor towards the building of the filters before receiving one into their homes. Having installed approximately 15,000 biosand filters in Cambodia alone, Samaritan's Purse's BSF program has been well documented by several sources and appears to be doing well from an end-user's perspective (Clasen, 2009; Lantagne, Quick, & Mintz, 2007)



Figure 16: Examples of safe water storage containers from CDC's SWS Handbook

For the villagers not interested in the biosand filter system, the solar disinfection method (SODIS) may also be a viable option. There is substantial roof and outside ground space around each dwelling to store bottles during treatment, and plastic soda bottles were spotted throughout the village as drinking the Indian soda, Thums Up, is very popular (Fig. 17). As mentioned earlier, the SODIS method uses resources that are frequently already available (empty, clear soda bottles); it also provides a safe water storage solution if the family keeps the water in the bottles after treatment. Since Village X is on the coast of southern India, it has adequate sunshine except during the monsoon season, which is 4-5 months out of the year. The main drawback to the SODIS method is the small amount of water produced (since it is limited by the number of bottles a person owns), along with the length of time it takes to treat the water, which depends on many variables. Also, if the water is too turbid, it must be filtered prior to being put in the bottles for treatment. Despite these drawbacks, SODIS may be an effective



Figure 17: Thums Up, a popular drink in the village. The bottle could potentially be used in the SODIS method

way to treat water for households not interested in or able to afford a biosand filter.

However, the question must be asked-- is a point of use water treatment system combined with a safe water storage system enough to significantly impact diarrheal rates and other waterborne diseases in Village X? It has been noted that, while water quality interventions do impact diarrheal rates in a community, the overall sanitary conditions of the environment can reduce the effectiveness of the intervention (L Fewtrell & Colford, 2005). The combination of practicing open defecation and keeping livestock within close quarters of human living space creates a fairly contaminated environment in Village X.

While persuading people to change where they defecate and tether their livestock is a significant undertaking, it is one worth considering, as many health issues could potentially be improved in this community if these two behaviors changed. There are existing programs in India that seek to change people's defecation practices in particular. In 2001, the national government began promoting the Total Sanitation Campaign (TSC) throughout the country, with varying levels of success. There are several examples of rural districts throughout India achieving open defecation free (ODF) status through community participatory programs, including a village in the Mehboobnagar district in Andhra Pradesh. This particular village reached ODF status in 2008, with 100% of the households now using toilets or latrines. One method used by the local panchaya to prompt the community into action consisted of launching an information campaign that highlighted the health costs associated with fecal-oral diseases. The village has maintained their ODF status by instituting fines for people caught defecating outside, along with implementing a defecation monitoring program run by local youth (World Bank, 2010). Clearly, there is evidence of successful sanitation efforts in rural India that can be learned from and built upon. Accordingly, education about sanitation and hygiene should be integrated into any intervention program in Village X, regardless of the POU option chosen.

CONCLUSION

The global burden of morbidity and mortality from waterborne diseases is great. Diarrheal disease alone is a major contributor of morbidity and mortality in many countries; indeed, India has the world's highest rate of under age-five mortality from diarrheal disease (Boschi-Pinto et al., 2008). Unclean drinking water is one route by which the pathogens associated with diarrhea are transmitted. While India has expanded its population's access to improved water sources in the last decade, improved water sources do not necessarily equal clean drinking water (Godfrey et al., 2010). While safe, clean drinking water piped into every home is the ultimate goal, the realization of this goal may be decades off. In the interim, point of use household water treatment systems are a viable alternative to empower otherwise water-disenfranchised people to have access to clean water. However, as illustrated by the case study of Village X in Andhra Pradesh, simply having a POU option in the home is only one of several interventions needed to significantly reduce the rate of diarrheal disease and other waterborne illnesses

in India. In light of the reviewed research and the case study of Village X, the author recommends the following:

- Biosand filtration may be a viable POU option for Village X due to cultural preferences (e.g., distaste for chlorine) and the availability of production facilities and materials. However, any program seeking to introduce POUs to a community needs to be guided by the villagers' preferences, culture, and the feasibility of using the treatment system.
- The villagers do not use safe water storage containers; introducing these types of containers should be integrated into any POU intervention program.
- In conjunction with the chosen POU system, education about hygiene practices should be considered an important part of any POU intervention program.
- The common practice of open defecation and tethering livestock close to the family's living quarters poses significant challenges to disrupting the fecal-oral transmission cycle. Until these larger sanitation issues are addressed, the village will most likely continue to experience preventable illnesses caused by fecal contamination.
- More work is needed to identify the components of successful sanitation and hygiene interventions in rural India, building upon the successes of villages that have reached and maintained open defecation free status.

In conclusion, while India has made significant progress in increasing people's access to improved water sources in the last twenty years, there is still considerable work to be done in the areas of improving water quality and addressing sanitation and hygiene practices. Introducing a culturally appropriate and community accepted point of use household water treatment system is one of several interventions that may reduce rural villages' burden from waterborne diseases.

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APPENDIX A

POU and Water Resource List 101

There are many, many organizations all over the world that focus on water, sanitation, and POU technologies. This is not meant to be an exhaustive list of all organizations and resources, but rather a basic compendium of the major ones pertinent to this report.

General Water and Sanitation Issues:

- World Health Organization--Water, Sanitation and Health: This is a great site for vital statistics and facts about the impact of water and sanitation issues on health from both a global and country-by-country perspective: http://www.who.int/water_sanitation_health/en/
- UNICEF—Water, Sanitation and Hygiene: An excellent site for statistics and other facts about the scope and impact of water and sanitation issues for the world’s children: <http://www.wsp.org/wsp/>
- Water and Sanitation Program: A partnership administered to by the World Bank, this site has a library of free resources that focus especially on the economic side of water and sanitation development. They also have a two-part video available about a sanitation project in Bangladesh: <http://www.wsp.org/wsp/>
- CARE: A non-profit organization, CARE has been involved in global water issues for decades, often in partnership with the CDC. They have developed a useful water “wikispace” that has a host of resources related to their water treatment, sanitation, and hygiene programs, especially focused in schools: <http://water.care2share.wikispaces.net/>

Macro View of Water in India:

- India’s Water Economy, Bracing for a Turbulent Future by World Bank: written in 2005, this report provides an excellent overview of the water situation and its associated economic implications facing the country of India: <http://www.worldbank.org.in/WBSITE/EXTERNAL/COUNTRIES/SOUTHASIAEXT/INDIAEXTN/0,,contentMDK:20674796~pagePK:141137~piPK:141127~theSitePK:295584,00.html>.
- The India Water Portal (available in English, Hindi and Kannada): a great one-stop-shop website that has resources about everything water in India: <http://www.indiawaterportal.org/>.
- Compendium of Best Practices of Rural Sanitation in India (English): Written by India’s Ministry of Rural Development in conjunction with the World Bank, this report contains case studies of local panchayats that successfully led total sanitation efforts in their communities: <http://www.indiawaterportal.org/node/18382>

Macro-View of Point of Use Household Water Treatment Options:

- Scaling Up Household Water Treatment Among Low-Income Populations: Written by Thomas Clasen in 2009, this is an excellent overview of everything one wants to know about field-tested, POU treatment options, along with some of the real-life difficulties encountered in disseminating POU technology in the developing world. A free report worth reading: http://www.who.int/household_water/research/household_water_treatment/en/index.html

University Resources: These university websites often contain faculty and student research, links to other pertinent organizations, and information about trainings in the water and sanitation world.

- Johns Hopkins University | Center for Water and Health: http://www.jhsph.edu/water_health/
- Emory University | Center for Global Safe Water: <http://www.sph.emory.edu/CGSW/index.htm>
- University of North Carolina, Chapel Hill | The Water Institute: <http://www.waterinstitute.unc.edu/>
- MIT | Safe Water for 1 Billion People: <http://web.mit.edu/watsan/>

Chlorine Treatment with Safe Water Storage:

- Safe Water Systems Handbook by the U.S. Centers of Disease Control: The premier guide on the safe water system and a valuable resource for anyone wanting to implement SWS in a community. User-friendly, with step-by-step instructions that range from factors to consider in assessing a community to implementation and partnerships with other organizations: <http://www.cdc.gov/safewater/>
- The Jolivert, Haiti Safe Waters for Families Project: An example of one of the most successful scale-ups of the CDC's Safe Water System, the Jolivert website has pictures, explains the project, and has links to research associated with their project: www.jolivert.org

Chlorine-Flocculant Treatment:

- Proctor & Gamble's Childrens' Safe Drinking Water: A user-friendly site that has videos showing how PUR sachets work. This site also provides links to research articles about chlorine-flocculant use in the field: <http://www.csdw.org/csdw/home.shtml>

Biosand Filters

- Center for Affordable Water and Sanitation Technology (CAWST): located in Canada, this is THE leading organization for promoting and developing biosand filtration systems. It provides training and consulting services to organizations interested in using the BSF system: <http://www.cawst.org>
- DHAN Vayalagam Foundation: An Indian grassroots organization that focuses on a variety of water issues (including agricultural water use and household water treatment systems) in resource-poor rural villages. They promote biosand filters and have conducted biosand filtration workshops for villagers in Tamil Nadu, Andhra Pradesh, and Karnataka states: <http://www.dhan.org/vayalagam/index.php>
- South Asia Pure Water Initiative, Inc.: A 501(c)3 organization based in Connecticut, USA (and backed heavily by a local Rotary Club), this nonprofit company has set up a biosand filtration production plant in the Kellore district in Karnataka state, approximately 60 km outside of Bangalore: <http://www.sapwii.org/>
- Samaritan's Purse Canada: Samaritan's Purse Canada has extensive experience in installing BSFs in both Asia and Africa. Learn more about their program and philosophy at: http://www.samaritanspurse.ca/ourwork/water/biosandfilter_technical.aspx.

Ceramic Filters

- Potters for Peace: A U.S.-based non-profit, Potters for Peace has worked for years to spread ceramic filtration use around the world. Their page on filters has everything one wants to know about the production, dissemination, and evaluation of ceramic filters: <http://www.pottersforpeace.org/>
- IDE: While their main focus is promoting grassroots economic development in low-income communities, IDE often uses water as an entry point to gain access into communities. They work in 11 countries and work with a variety of water technologies beyond the scope of household water treatment (irrigation systems, different types of water pumps, etc.): www.ideorg.org
- Resource Development International (RDI)—Cambodia: This organization focuses on water, sanitation, and community development projects and is another champion of ceramic water filters. Their ceramic filter production handbook is available for free on their website: www.rdic.org
- The American Red Cross: After the 2004 tsunami, the American Red Cross teamed up with local Red Cross/Red Crescent chapters in Sri Lanka to distribute ceramic water filters in Sri Lanka. Read more about their work by going to their website and typing in “sri lanka, filters” into the search field: www.redcross.org
- The PRACTICA Foundation: This organization promotes research and development of technologies related to water and energy in developing countries. They provide training, education, and consulting to NGOs and have a link about their work with ceramic filters on their website: www.practica.org

Solar Disinfection (SODIS):

- SANDEC (Switzerland’s Dept of Water & Sanitation in Developing Countries): One of the original pioneers and researchers of the SODIS method, SANDEC has a website that contains everything one wants to know about using the SODIS method (available in French, English and German): www.sodis.ch
- Project partners with SODIS in India: League for Education and Development (LEAD)
 - In Tamil Nadu:
No. 8/40, 1st Street, Rayar Thoppu, Srirampuram,
Srirangam, Trichirapalli – 620 006
Tamil Nadu, India
phone: +91 (0) 43 1243 2803
Fax: +91 (0) 43 1243 2521
e-mail: radha_lead@rediffmail.com
 - Chennai Office:
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Kanagasabai Colony,
Koyembedu
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APPENDIX B

Community Background Research to Consider Before Choosing a Water/Sanitation Intervention for a Community

Epidemiological data (Sources of data: MOH, special studies)

- How common are diarrheal diseases? What proportion of clinic visits?
- Which populations are most affected?
- Have cholera outbreaks occurred? When and where do cholera outbreaks typically occur?

Water infrastructure (Source of data: Ministry responsible for water)

- What proportions of urban and rural populations are not served with potable water systems?
- Where are underserved populations located?
- What is the microbiologic quality of source water in target populations?

Water handling practices (Source of data: Survey)

- Who collects and handles household water supplies?
- How common is it to store water in the home?
- Is household water storage particularly common in certain populations?
- What types of water storage containers are used?
- Do target populations use unsafe water handling practices, such as dipping?
- What water treatment practices are commonly used, if any?

Socio-cultural aspects (Source of data: Survey research)

- What do target populations understand about disease transmission through water?
- What do target populations understand about causes and prevention of diarrhea?
- Is clean water a high priority for target populations?
- Are there cultural barriers to water interventions (e.g., religious or ancestral associations with water supply)?
- Who makes decisions about household expenditures?

Economic aspects (Source of data: Donor agencies, NGOs, water ministry)

- What are potential sources of external funds?
- What donors have previously funded water projects?
- Can target communities pay for products?
- Is ability to pay seasonal (e.g., in agricultural communities)?

Possible support and infrastructure (Source of data: government, NGOs)

- Which government departments and officials can be approached for support?
- What NGOs are present in country?
- Which areas have a government or NGO infrastructure to build on?
- Which organizations are potentially available for the various aspects of implementation (e.g., hospitals, health centers, NGOs, women's groups, local companies)?

Figure 18: Questions to consider before choosing a water/sanitation intervention for a community (Centers for Disease Control, 1999).

APPENDIX C

DHAN Foundation Brochure for a Biosand Filtration Workshop

Training Workshop for Program Implementers of Bio-Sand Filters
Tamilnadu, India (DHAN Vayalagam Foundation, 2006)

Duration of the Workshop: 3 to 4 days **Venue:** People Academy, Pulloothu, Madurai,
Phone: 0452-2475440.

(The venue is about 10 km. from Madurai Railway Station.)

Participant group: Maximum: 20 people with 2 facilitators

The Workshop is proposed to be held sometime during Jan. / Feb. 2009.

The exact dates will be announced during first week of January 2009.

Course Outline

Workshop Description

The Bio-Sand filter which is a version of slow sand filter is an effective means of filtering water for the removal of microbiological contaminants. Even though the BioSand filter operation is a very simple technology, several key operating parameters must be understood and adhered to it so as to effectively remove the pathogens. Training courses on the BioSand filter are essential to ensure the proper and consistent use of the filters. This training would cover the topics on the importance of sanitation and hygiene, water microbiology, water epidemiology, options available in household water treatment technology and technology of BioSand filter, along with the techniques of Bio-Sand filter fabrication, installation and usage. The workshop will provide hands on experience on construction of BioSand filters, selection of filter media, and installation of filters. The workshop will also introduce the global impact of clean water, and water testing. The participants will get the designs, drawings, manual and a CD with all relevant literature, at the end of the training workshop.



Objectives

Upon completion of the workshop, the participants will be able to build and install the filters on their own. Participants will be able to guide the users about the operation and maintenance of the filter. Participants will gain the skills needed to implement safe water, hygiene, and sanitation program using the Bio-Sand filters.

Participants

- Experienced staff or program managers or programme engineers from development organizations.
- Any individual working or having interest on drinking water and sanitation issues.
- Engineering College Teaching and Lab staff involved in drinking water course or projects.
- No prior technical qualifications are compulsory. However good academic background will be an advantage. Participants must be able to read, write and understand English and eager to learn the developments in drinking water sector.

Pedagogy

- Power point presentation.
- Group work
- Practical work on construction and installation of filters
- Open discussion



Course Content

The following is a tentative list of topics that will be covered in the workshop

Theory	Practical
• Water issues	• Construction
• Pathogens	• Installation
• Transmission of diseases	• Operation
• Household water treatment –options	• Maintenance
• Safe water storage	• Troubleshooting
• Hygiene and sanitation	
• Water quality monitoring	

Course fee

The course fee is Rs.2500/- per person. Fees have to be sent in the form of Demand Draft drawn in favour of DHAN Vayalagam (Tank) Foundation payable at State Bank of India (Branch Code. 7482), Arasaradi, Madurai. The payment covers boarding & lodging, teaching materials and a CD with all designs and drawings of the moulds. All other incidental as well as travel expenses have to be borne by the participants. Trained individuals and organizations

will be enrolled in a network to exchange information and to provide a hand holding support

during their implementation.

Along with your course registration, the participant is required to

- Submit a one page preliminary project plan proposed following the training
- Respond to DHAN's annual survey
- Make best effort to initiate a house hold water treatment project following the training

Use of Cellular phones is strictly prohibited during the class room and practical sessions.

The participants who complete all the four days of the course including workshop practice only will get a completion certificate.

9^h Biosand Filter Training

Name of the Participant	:	
Designation	:	
Educational qualification	:	
Name of the organization	:	
Address of the organization	:	
Telephone / Fax	:	
Email	:	
Field of specialization	:	
Years of experience	:	
Details of payment of fees (Demand draft Bank / Date / Number)	:	

**Last date for
Registration is
30th January 2009**

Send the Registration Form To

Mr. A. Gurunathan / Ms. J. Kanagavalli

DHAN Vayalagam (Tank) Foundation

No.17, Vellai Pillaiyar Koil Street, S.S.Colony Madurai – 625 016, Tamilnadu, INDIA.

Ph: 91-452-2601673, 2610794 Fax: 91-452-2602247 Email: dhantank@airtelmail.in,
dhantank@gmail.com

