Massachusetts Institute of Technology

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Decentralized Household Water Treatment and Sanitation Systems

MIT Kenya Project
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1. Introduction to Water-Related Disease

Water is essential to the survival of humans and the planet. Yet over one-sixth of the world's population (1.1 billion people) currently lacks access to safe water (WHO/UNICEF, 2000). Each year, water-related diseases claim the lives of 3.4 million people, the majority of whom are children (Dufour et. al, 2003). In fact, the second leading cause of childhood mortality is disease transmitted through water or feces (Lenton et. al, 2005). Water-related diseases can be grouped into four categories based on the route of transmission: waterborne diseases, water-washed diseases, water-based diseases, and insect vector-related diseases.

Table 1.1: Water-Related Diseases

Waterborne diseases: caused by the ingestion of water contaminated by human or animal faeces or urine containing pathogenic bacteria or viruses; include cholera, typhoid, amoebic and bacillary dysentery and other diarrheal diseases.
Water-washed diseases: caused by poor personal hygiene and skin or eye contact with contaminated water; include scabies, trachoma and flea, lice and tick-borne diseases.
Water-based diseases: caused by parasites found in intermediate organisms living in contaminated water; include dracunculiasis, schistosomiasis, and other helminths.
Water-related diseases: caused by insect vectors, especially mosquitoes, that breed in water; include dengue, filariasis, malaria, onchocerciasis, trypanosomiasis and yellow fever.

Table taken from Bradley, 1977

Not surprisingly, residents of developing nations (the poor) are the most likely to experience water-related illness; half suffer from one or more water-related diseases. Approximately 80% of all diseases in the developing world are caused by contaminated water (GDRC, 1999). Of the 1.8 million people that die annually from diarrheal disease, the majority are children in developing nations (WHO Facts, 2004).

In an attempt to curb these numbers and provide a better quality of life for those lacking improved water and sanitation, the United Nation (UN) Member States set a target under Goal 7 of the Millenium Development Goals (MDGs) in 2000 to "halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation (WHO/UNICEF, 2004)." This target builds upon the target of "full access to water supplies and sanitation for all," which was established by the UN General Assembly for the International Drinking Water Supply and Sanitation Decade of 1981-1990 (Mintz et. al, 2001).

Since the 1990s, significant improvements in safe water coverage and sanitation have been made. Approximately 816 million people have gained access to improved water sources, which include household connections, public standpipes, boreholes, protected dug wells, protected springs, and rainwater. Approximately 747 million people have gained access to improved sanitation facilities, such as pour-flush latrines, simple pit latrines, ventilated improved pit latrines, and connections to a public sewer or septic system (WHO/UNICEF, 2000, 2004). However, this increase in coverage has been just sufficient to keep pace with population growth. In fact, the number of people lacking access to safe water has remained relatively constant since 1990 (Mintz et. al, 2001).

2. Background

2.1 Kenya

One of the countries in which the water and sanitation problem is particularly apparent is the developing nation of Kenya. Located in sub-Saharan Africa, the Republic of Kenya is bordered by Ethiopia and Sudan to the north, Uganda and Lake Victoria to the west, Tanzania to the southwest, the Indian Ocean to the southeast, and Somalia to the East. The country has a land area of 566,970 square km (218,907 square miles), making it roughly the size of the state of Texas. Kenya has two rainy seasons, which occur from April to June and from October to December. Despite this, and the fact that Kenya is located in the tropical region on the equator, annual rainfall in Kenya is very low and erratic from year to year. Both droughts and floods pose serious problems (World Atlas, 2005).

Figure 2.1: Map of Kenya
Taken from WorldAtlas.com

Kenya has a population of around 32 million, and a growth rate of 1.14%. Coupled with erratic rainfall and droughts, the quickly growing population has led to a steady decline in the availability of renewable freshwater. According to the United Nations, a country is considered to be "water stressed" if its renewable freshwater supply ranges from 1,000 to 1,700 cubic meters per person per year (UNEP, 2002). Countries possessing a supply below 1,000 cubic meters per person per year are considered to be "water scarce." In 1990, twenty nations were added to the "water scarce" list (Engelman and LeRoy, 1993). Kenya was one of them; its annual per capita renewable freshwater supply was 647 cubic meters as of 1999 (Kiongo, 2005).

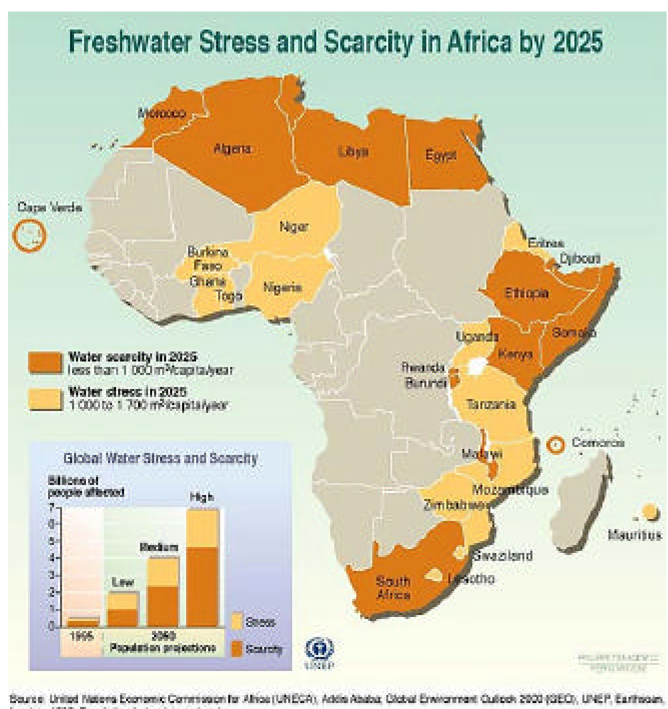

Figure 2.2: Freshwater Stress and Scarcity in Africa by 2025

The water scarcity situation makes it difficult to obtain safe water and to practice good hygiene and sanitation behaviors. In Kenya, 62% of the people use improved drinking water sources.

Approximately 39% of the total population occupies urban areas; 89% of the urban population has access to improved water sources and 56% has access to adequate sanitation[1]. Comparatively, of the remaining 61% of the population that occupies rural areas, only 46% has access to improved water supplies and a mere 43% has access to adequate sanitation (UNICEF, 2002).

2.2 Decentralized Systems

2.2.1 Point-of-Use Water Treatment

The lack of safe drinking water[2] and adequate sanitation for a large percentage of Kenya's population reveals the need for serious action. Decentralized point-of-use treatment systems, a.k.a. household drinking water treatment and safe storage systems[3], offer an immediate solution to the water problem; in recent years these systems have gained new-found popularity as solutions to water issues in the developing world (Mintz et al 2001; Clasen et al., 2004). It should be emphasized that safe drinking water is only one part of a multidimensional approach geared toward reducing the spread of water-related disease; other aspects include sufficient water quantity, hygiene, and sanitation (Loux, 2005).

As a short-term solution to the need for safe drinking water, and in addition to the long-term goal of large-scale treatment plants for water and wastewater, treating water at the point of consumption can effectively eliminate the chance of recontaminating water once it has been delivered to the household. The increased amount of clean water coming into the house also increases the likelihood of water being used for hygienic purposes; household water treatment and safe storage systems are therefore more effective at reducing disease rates overall. Childhood diarrhea rates drop by 44% among communities with in-house systems, as opposed to 6% for a clean public water source (Brown, 2004).

2.2.2 Sanitation

In addition to the lack of safe water, it has long been recognized that people in developing countries such as Kenya suffer from lack of hygienic sanitation (Kalbermatten, 1980). In the international development field, the dominant paradigm in addressing sanitation has been to provide more communities with industrialized sewage systems. However, these types of systems are often a poor technological fit for many places in developing nations (Kalbermatten, 1980). The initial capital cost of installing piped sewerage networks often makes them too expensive to be an affordable or viable option (Esrey, 2001). Even when a community builds a piped network, it is not always accompanied by a wastewater treatment system: 90% of the wastewater in developing countries discharges into receiving water bodies untreated (Esrey, 2001; Schlick, 2001). Other disadvantages of conventional forms of centralized sanitation include large

[1] Those considered to possess access to adequate sanitation are those using improved sanitation facilities.
[2] "Safe drinking water" is defined as "water that is safe to drink and available in sufficient quantities for hygienic purposes (Lenton et al., 2005)."
[3] Safe water storage systems are vessels that possess a narrow mouth, lid, and spigot to prevent recontamination of stored water (CDC, 2000). See Section 3.3 for more information.

operation and maintenance costs, high rates of water consumption, frequent service to the wealthy and neglect of the poor (GTZ, 2004; Harleman and Murcott, 2001).

Decentralized, on-site sanitation is an alterative or complement to the centralized wastewater treatment paradigm. Excrement is processed and disposed of locally with a type of facility and technology that is appropriate for the given setting (Kalbermatten, 1980). In developing countries, decentralized sanitation can offer a viable alternative to conventional systems for dispersed rural populations and informal urban/periurban settlements due to its low cost and limited use of technology (Robinson, 2005).

2.3 MIT Kenya Project

Decentralized systems, with regard to both water treatment and sanitation, were the main foci of the water and sanitation in developing countries team that traveled to Kenya in January of 2005; the team was known by the name "MAJI," which means "water" in Swahili. While in Kenya, MAJI team members gathered information through research, surveys, and interviews to ascertain the effectiveness of a variety of decentralized water and sanitation systems.

Amber Franz and Brian Loux were stationed at the Ministry of Water's Pollution Control Division in Nairobi. Here Franz performed laboratory tests on several locally available brands of **ceramic candle filters**. Franz examined flow rate, turbidity removal, and bacterial removal for each of the filters (Franz, 2005). Loux developed and tested modified **solar disinfection systems** (Loux, 2005).

Suzanne Young and Mike Pihulic visited various pottery organizations in and around Homa Bay to document the ceramic pot-making process and to develop a **standardized safe storage container** that could be used with disinfection products (Young, Pihulic, 2005). Young and Pihulic worked with the Centers for Disease Control (CDC) and CARE-Kenya.

Pragnya Alekal and the business team, Ellen Sluder, Jody Gibney, Mark Chasse, and Rachel Greenblat, worked with the Society for Women and Aids in Kenya (SWAK), CARE and Population Services International (PSI) in Kisumu. Alekal performed household surveys and tests on household **chlorine disinfection** (Waterguard®) and **coagulation/flocculation** products (PuR®) (Alekal, 2005). The business team evaluated the business and marketing operations of organizations distributing Waterguard® and PuR®.

Robert Baffrey and Harvard School of Public Health Masters student Jill Baumgartner interviewed multiple water and health-related organizations, gathering information on various organizations' **implementation characteristics and approaches** and their **household drinking water treatment methods** (Baffrey, 2005). Their work supported the activities of the Implementation Working Group of the WHO International Network to promote household drinking water treatment and safe storage. Hosted by the Ministry of Water, Baffrey and Baumgartner traveled to several locations in Kenya, including Nairobi, Mombasa, Maseno, Machakos, Nakuru, Eldoret, and Kisumu (See Figure 2.1).

Brian Robinson examined **ecological sanitation** (ecosan) toilets as an improved sanitation facility option in the district of Kombewa (Robinson, 2005). Robinson worked in conjunction with the Kenya Water for Health Organization (KWAHO), performing household surveys and urine testing at each of the ecosan sites he visited.

After performing fieldwork in Kenya and research at MIT, MAJI team members compiled their results and observations with the objective of identifying sustainable use of studied technologies within the constraints of the local setting (organizational, economic, social, and environmental). Knowledge gained through this project may serve to better inform the Kenyan government, NGOs, and international development organizations about their choices with regard to available small-scale water and sanitation technologies.

Following are the methodologies, results, conclusions, and recommendations formulated by each MAJI team member. In addition to the aforementioned objective, it should be noted that this research contributes to the bigger aim of reducing the spread of water-related disease. By encouraging and identifying methods that are capable of reducing the transmission of disease-causing organisms through drinking water and sanitation facilities, the quality of life of the world's most vulnerable citizens will improve. Illness and death caused by consumption of contaminated water and improper sanitation will decline and people will have the opportunity to live happier, healthier, more productive lives.

3. Studies Performed in Kenya

3.1 Ceramic Water Filtration

3.1.1 Background

Ceramic water filtration has emerged as a useful household drinking water treatment option. Ceramic water filters are recognized as "one of the most promising and accessible technologies for treating water at the household level (Clasen et. al, 2004)." These filters can be made from locally available materials in a variety of shapes, such as disks or candles. Ceramic water filters act mainly by physically removing particles from solution. Many have the ability to remove disease-causing bacteria and parasites from contaminated water. For these reasons, ceramic water filtration appears to be a viable household drinking water treatment method.

During the course of this research, several different ceramic candle filters that were locally available in Kenya were examined. The AquaMaster (Piedra candle), Doulton Super Sterasyl, Stefani São João, Pelikan, and Pozzani candles were evaluated and compared based on flow rate, turbidity removal, microbial removal, and cost. Research was conducted at the Ministry of Water's Pollution Control Division in Nairobi and at MIT with the aim of identifying the ceramic candle filter most effective at purifying water.

Figure 3.1: Doulton Super Sterasyl Candle

3.1.2 Methodology

Two of each of the aforementioned brands of ceramic candle filters were subjected to testing in Kenya and at MIT. In Kenya initial and final flow rate tests were performed on each filter for two runs using highly polluted Nairobi river water (Average Turbidity = 23 NTU; Average total coliform = $8.4x10^5$ CFU/100 mL, Average *E. coli* = $6.1x10^5$). At MIT, only one flow rate test was performed for each of nine runs using moderately polluted Charles River water (Average Turbidity = 5.1 NTU; Average total coliform = $3.8x10^3$ CFU/100 mL; Average *E. coli* = $3.5x10^2$). Turbidity tests were performed in triplicate on filtered water collected from each flow rate test. These turbidity readings were compared to turbidity readings for unfiltered water to determine percent turbidity removal. Membrane filtration (MF) was used to detect and enumerate bacterial indicators of fecal pollution in filtered and unfiltered samples. For each water sample, duplicate tests were performed. Bacterial colonies were grown using m-coliBlue24 broth, a nutritive, lactose-based medium capable of differentiating between total coliforms and *E. coli*, the bacterial indicators of choice used for this study. In addition to testing all filters for bacterial removal, the Pelikan filters were also subjected to viral removal tests utilizing MS2 coliphages. Viral removal studies were performed at MIT using the Double Agar Layer Procedure (Method 1602, 2001). Results from turbidity, flow rate, and microbial tests were compared to the World Health Organization (WHO) guidelines[4] for drinking water quality and to the U.S. Environmental Protection Agency's (EPA) National Primary Drinking Water regulations[5] in order to determine filter efficacy (WHO, 2004; Howard, 2004; USEPA, 2005).

3.1.3 Results, Conclusions, and Recommendations

Results of the studies performed at MIT indicated that the Pelikan filters were significantly better than other filters at removing turbidity. These filters reduced turbidity of Charles River water by 97%. Turbidity removal by other filters ranged from 88% to 94%. Results from studies utilizing more turbid Nairobi water showed filters to reduce turbidity by 97% to 99%. Results from flow rate studies performed at MIT revealed the Doulton Super Sterasyl to possess a significantly greater flow rate (0.55 L/hr) than the other brands of filters tested. The flow rates of the other filters ranged from 0.14 to 0.26 L/hr. Filter tests utilizing the more turbid Nairobi water showed flow rates of 0.09 to 0.24 L/hr. Results of the coliform removal studies performed at MIT showed the AquaMaster (Piedra candle), Doulton Super Sterasyl, and Pelikan filters to remove significantly more total coliform and *E. coli* than the Pozzani filters. Percent removal by all filters tested at MIT ranged from 93% to <100%. Filter tests performed in Kenya under laboratory conditions showed percent total coliform and *E. coli* removals of up to 99.995%. The Pelikan filters were the cheapest filters purchased, retailing for $2 in Nairobi. The Doulton

[4] WHO recommends that median turbidity "be below 0.1 NTU for effective disinfection" to occur (WHO, 2004). Additionally, WHO recommends that drinking water should contain no indicator organisms (such as total coliform, *E. coli*, or F-RNA coliphages). WHO also supports the notion that 7.5 L is the minimum necessary volume of water required per person per day for both consumption and food preparation purposes (Howard, 2004).

[5] The USEPA states that turbidity of treated water should not exceed 1 nephelometric turbidity unit (NTU), and that 95% of daily treated water samples tested must be less than or equal to 0.3 NTU (USEPA, 2005). The maximum contaminant level goal (MCLG) for total coliforms (including *E. coli*) in a water sample is 0 CFU/L. However, the enforceable standard, or maximum contaminant level (MCL) for total coliforms in a water sample requires that no more than 5% of total water sampled monthly test positive for total coliforms. Additionally, the USEPA enforces 99.99% removal or inactivation of enteric viruses (USEPA, 2005).

Super Sterasyl was the most expensive filter studied, retailing for a cost of $40. Results of viral removal studies indicated that the Pelikan filters are not effective at removing viruses from solution. It should be noted that none of the filters achieved the water quality guidelines and standards issued by WHO or the EPA. Study results are summarized in Table 3.1.

Table 3.1: Summary of Data Obtained for Each Brand of Filter Tested

	Turbidity Removal (%)		Flow Rate (L/hr)		Total Coliform Removal (%)		*E. coli* Removal (%)		
Filter	**Kenya**	**MIT**	**Kenya**	**MIT**	**Kenya**	**MIT**	**Kenya**	**MIT**	**Cost ($)**
AquaMaster	98.3	88.6	0.093	0.160	99.8	99.6	<100	<100	10.00
Doulton	98.3	92.0	0.235	0.546	99.8	99.0	<100	99.7	40.00
Stefani	98.8	93.1	0.101	0.241	99.7	97.5	<100	97.6	2.25
Pelikan	98.3	97.3	0.182	0.203	<100	99.6	<100	99.9	2.00
Pozzani	97.1	89.9	0.101	0.180	99.7	95.6	<100	93.0	20.00

Out of all the filters studied, the Pelikan candle filters performed the best. The Pelikan filters possessed the greatest turbidity removal at MIT and showed high total coliform and *E. coli* removals both in Kenya and at MIT. These filters also had the second fastest flow rate in Kenya. Surprisingly, this brand was also the cheapest, retailing for $2 in Nairobi. The performance and affordability of this filter as a water purifier is good news for people in developing countries.

However, despite the impressive performance of the Pelikan, ceramic candle filtration is recommended as only one step in a complete household scale water-purifying process. Highly turbid waters, such as the Nairobi river water used in this study, should be treated pre-filtration. Sedimentation in a safe storage vessel or coagulation are two possible treatment options capable of reducing suspended particles. Upon removal of larger particles, flow rate through a ceramic candle will increase and a greater volume of water will be produced. However, if water is not turbid, as was the case with Charles River water, this step is unnecessary.

Additionally, it is recommended that the water level be as high above the filter element as possible (i.e., fill to the top of the container). If the water level is high, more water will be filtered due to the greater pressure. A recommendation is also made to manufacturers to make and distribute longer filters. Filter surface area is related to flow rate, and so longer filters will be capable of faster flow rates. This was observed in Kenya, where data indicated that flow rate was proportional to candle length. Another possible option for increasing the volume of filtered water entails buying and installing multiple (2, 3, or 4) candles in one container.

The results of the coliform removal studies indicate that water filtration may be only one step in a complete water treatment process. It is recommended that water be treated post-filtration to remove any residual microbial contamination. For example, chlorine disinfection (Section 3.4) and solar disinfection (Section 3.2) are two possible options.

Despite the failure of the filters to meet the EPA standards and/or WHO guidelines, it should be noted that these filters immensely improved the quality of water subjected to treatment. Thus although ceramic water filtration is not 100% effective as a water purifier, study results show that it can be an integral step in the attainment of a sufficient volume of clean, safer drinking water (Franz, 2005).

3.2 Solar Disinfection: Spirasol

3.2.1 Background

One of the more novel approaches in the world of household drinking water treatment technology is household solar disinfection in transparent bottles, or SODIS as it was named by SANDEC (Water & Sanitation in Developing Countries) of the Swiss Federal Institute for Environmental Science and Technology. The process employs the disinfection processes of ultraviolet radiation, photo-oxidative reactions, and temperature working in tandem to kill or inactivate microbiological organisms to create clean and safe drinking water. The most frequently recommended method for SODIS projects involves using a clear Polyethylene Terephthalate (PET) plastic bottle between one and two liters, filling the bottle approximately two-thirds full with water of maximum turbidity less than 30 NTUs, shaking vigorously to disperse oxygen within the water, filling the bottle completely, then leaving the bottle in direct sunlight for an extended period of time dependant upon the intensity of the sunlight (EAWAG/SODIS, 2002).

While the technology has been hailed for its effectiveness and low cost, some user concerns have arisen that could be addressed by innovating the technology (Flores-Cervantes, 2003; EAWAG/SODIS, 1998). One of the largest concerns is that the process is tedious to perform, and therefore reduces the likelihood that households will adopt the process. In order to supply a family of four or more, a family would need upwards of 17 two-liter bottles or more for each day. Additionally, the liter bottles may not be the most convenient vessels for household water use. Ideally, all disinfected water could be stored in one large container without any process-defined constraint on volume. Lastly, as the author observed in the Nairobi slum of Kibera, using drinking water bottles discouraged the users from employing the clean water for anything besides direct drinking from the bottle. Uses of clean water for food preparation and hygiene, which tend to be more critical to curbing illness in communities in the developing world (Brown, 2004), were overlooked because of the container's association with a vessel for drinking water. Thus, SODIS programs, as commonly practiced today, may not be the best or only solution for water treatment.

Deborah Xanat Flores Cervantes attempted to develop a more feasible solution in her Masters of Engineering project (Flores-Cervantes, 2003). Her system, entitled Semi-Continuous SODIS (SC-SODIS), was an innovation on the concept of SODIS which involved gluing PET plastic bottles bottom-end-to-bottom-end and connecting them to polyvinyl chloride (PVC) piping at the spouts. A number of these bottle pairs – usually four – were then arranged in parallel. Two valves regulated the flow of raw water into the treatment system and the treated water to the house. While Cervantes determined that the cost of the system was under $1 in Nepal, the author found the costs to be significantly higher in Kenya and the United States. While PVC pipe is relatively inexpensive (about $0.70 per foot), pipe bends and connectors tend to cost more than $1 a piece. Additionally, in order to ensure a perfect seal, pipe-to-hose adapters must be purchased for each bottleneck, as PET bottles are created with hose threads and not pipe threads.

Most importantly, each additional part increases the likelihood that locals would not be able to replicate the system with parts available to them.

Thus, the intent of this study was to innovate upon the setup designed by Cervantes and further improve the efficiency and cost-effectiveness of semi-continuous flow SODIS systems with a new innovative design termed "Spirasol". The Spirasol system uses only clear PVC plastic tube coiled in a spiral to disinfect the water and then deliver it to a household with as few pieces as possible (Figure 3.2).

Figure 3.2: A Spirasol System

This prototype Spirasol system (foreground) used for experimentation in Nairobi, Kenya. The bucket at the top slowly discharges contaminated water through the clear PVC tube and is disinfected through reactions directly and indirectly involving UV radiation.

3.2.2 Methodology

The goal of this study was to examine the Spirasol tube's effectiveness at removing microbial contamination in comparison to the more traditional method of using the SODIS PET plastic bottle. This was tested first in Nairobi at the Ministry of Water's Central Laboratory facilities, and later on in Cambridge, Massachusetts in the Masters of Engineering laboratory in Building 1 of the Massachusetts Institute of Technology.

In Nairobi, the two disinfection systems of Spirasol and SODIS were placed on a table slanted 15 degrees and facing north to expose the systems to the maximum amount of sunlight throughout the day. The systems were then filled with contaminated water from the nearby Nairobi River. The disinfection treatment occurred between hours of peak solar intensity: 10 a.m. and 4 p.m. Residence times of each test were varied in the attempt to generate a profile of disinfection rates over time.

In Cambridge, the two systems were also placed on a similar table slanted 15 degrees facing south located on the roof deck of MIT building NW30. For the final experiment, the table and systems were moved to the Baker House roof deck because occupants of NW30 sought to use the roof deck for activities incompatible with the experiment. While the table was not slanted to the optimal 35 degrees for Cambridge's latitude, it was presumed to absorb more radiation throughout the day had the systems been laid flat. The Charles River, a known source of fecal bacteria due to combined sewer overflows, was used as a source of contaminated water. The hours of disinfection moved to 11 a.m. to 5 p.m. in order to accommodate other users of the roof deck. As the number of anticipated trials would be small and data consistency was considered a necessity, all experiments were run with a six-hour residence time.

Microbial analysis of *E. Coli* and total coliform counts was performed on samples collected both before and after treatment using the membrane filtration method with m-ColiBlue24 broth, a lactose-based medium that allows for simultaneous colorimetric detection of both *E. Coli* and total coliforms (HACH, 1999). After incubation of the samples at 35 degrees Celsius for 24 hours, the colony-forming units were counted to determine the microbial concentrations and the resulting disinfection from each system.

3.2.3 Results and Conclusions

PVC tube and ¾" PVC ball valves were found commonly in the Nairobi hardware stores visited, making the components of the system readily available to urban Nairobi residents. Pipe-to-hose converters for the SC-SODIS system were not found in any hardware store in Nairobi, and were found only in one hardware store out of five visited in the United States. A cost analysis performed at a local Home Depot located in Somerville, Massachusetts is summarized in Table 3.2. The Spirasol system is approximately 40 percent cheaper to construct than an SC-SODIS system in the United States. However, the costs of the materials in Kenya do not significantly depreciate, making the Spirasol system cheaper by approximately 43%, but keeping both systems out of the price range for the local residents who live on the equivalent of $1 a day. It is more likely that a system with these intrinsic costs would be more applicable in an area where capital is not as scarce.

Table 3.2: Comparison of Costs of Solar Disinfection Systems

Cost Estimates			
Spirasol		**SC-SODIS**	
PVC Tube (20 ft.) x 1	$21.50	PET Plastic Bottles x 8	Free
¾" PVC Ball Valve x1	$2.94	¾" PVC Ball Valve x1	$2.94
Silicon Caulk x 1 tube	$2.99	¾" PVC Pipe x 10 ft	$7.50
		¾" PVC 4-way fitting x 2	$1.38
		¾" PVC T fitting x 2	$0.98
		¾" PVC 90 degree bend x 4	$1.56
		¾" Zinc pipe-to-hose converter x 8	$28.42
		Silicon Caulk x 1 tube	$2.99
		Plumber's Tape x 1 roll	$0.99
		Glue sticks x 1 Pack	$0.99
TOTAL	**$27.43**	**TOTAL**	**$47.75**

If purchased completely in average United States hardware stores, a Spirasol system would cost under $30 and would provide 2 liters/day of disinfected water.

The five sets of tests performed in Nairobi from January 13 to January 18, 2005 were extremely variable, as shown in Figure 3.3. In Tests 1 and 2, the Spirasol tube performed much better than the SODIS bottle, but in later tests, the reverse was true. Test 5 results found the removal rates for the bottle to be remarkably high, which was dramatically inconsistent with the results of Test 2. Additionally, it appeared that the *E. Coli* disinfection rates within the tube, which outperformed the SODIS bottle significantly during Test 2, performed worse than the SODIS bottle in Tests 3, 4, and 5.

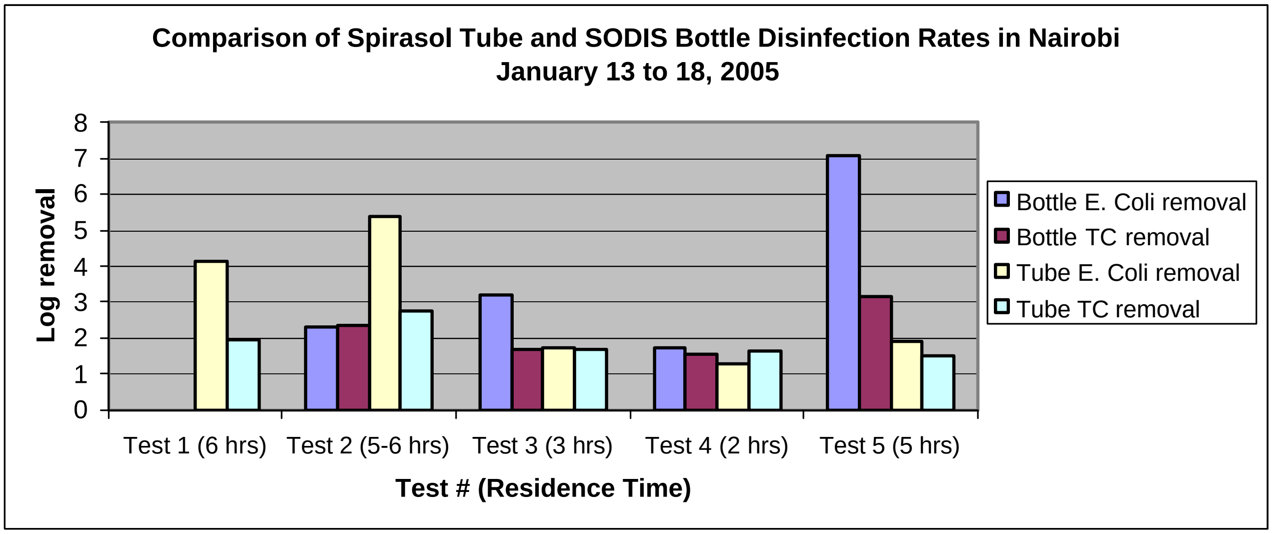

Figure 3.3: Disinfection Rates in Nairobi
The variation in the results forced the author to declare the study inconclusive.

There were a number of hypotheses for the variation in data seen. Likely concerns were variations in the source of water used for diluting the raw Nairobi River water, unclean laboratory conditions in the Central Laboratory facilities, and shadows obscuring parts of the table during the experiment despite attempts to annul that concern. Overall, the data was generally dismissed as inconclusive and unable to determine whether the spirasol tube was as viable a disinfection method as the SODIS PET bottle in Kenya.

Further tests undertaken at MIT in the spring of 2005 used the same methods of analysis as described earlier. While the removal rates would clearly not be as effective as those seen in Kenya because of the decreased intensity of the sunlight in Cambridge, it was expected that the spirasol tube would perform near or at the disinfection levels of the PET bottle.

During the first experiment, it became quite evident that the silicon caulk used to secure the faucet and tube in place was leaking into the tube and mixing. After the six-hour residence time, turbidity measurements showed that the water in the tube had risen from < 3 NTUs to approximately 100 NTUs. Such a high level of turbidity hinders UV penetration into the water, and SANDEC recommends that turbidity should not exceed 30 NTUs in solar disinfection treatment systems (SODIS, 2002). While there were no turbidity measurements taken after the trial runs in Kenya, given the similarity of the setups in Nairobi and Cambridge, it is likely that the silicon began to break down and leak into the system during the Nairobi experiments as well.

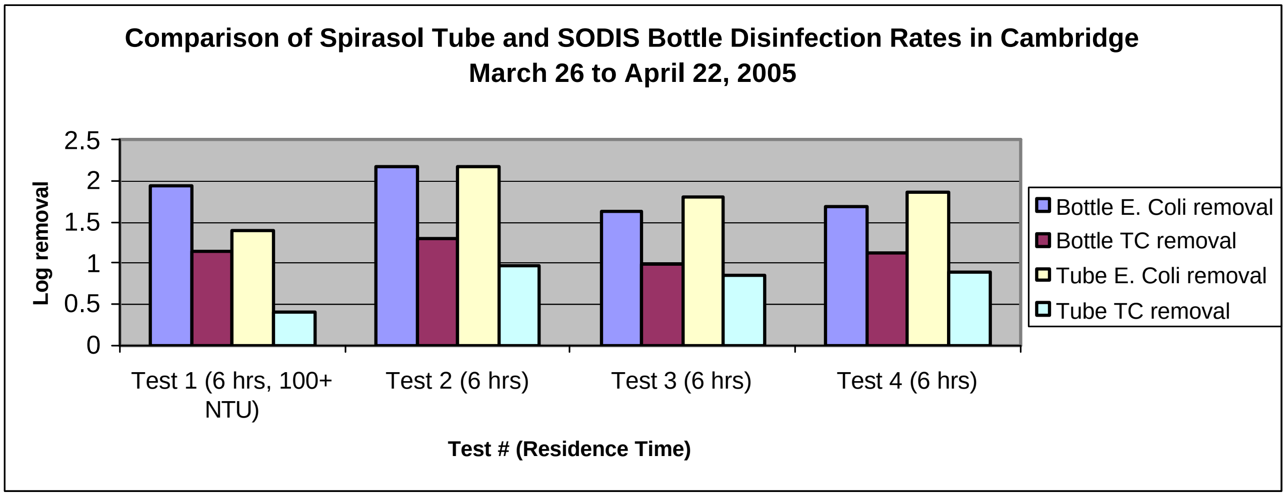

Figure 3.4: Results of Solar Disinfection Tests in Cambridge
The removal rates of the tube during Test 1 were attributed to the increased turbidity in the system by leaking silicon caulk. Once removed, the differences in removal rates between the two systems decreased.

A new round of tests was initiated without the use of any adhesives. The tube and faucets were instead held in place with clamps and washers, respectively. As shown in the results for tests 2 through 4 in Figure 3.4, the levels of *E. Coli* and total coliform removal are about equal in the spirasol tube and the PET bottle. Total coliform concentrations tend to be reduced more in the PET plastic bottle than the tube, but by relatively small margins. These findings appear to indicate that Spirasol could be competitive with traditional SODIS as a method of solar disinfection on the household level.

While trial runs of the Spirasol system will need to be continued to attain statistical significance, one should also examine the manner in which Spirasol may be implemented for home use. Clearly, pieces of the Spirasol system are still not optimal for treatment. For example, the valve controls employed in testing were standard three-quarter inch pipe valves, which are not meant to deal with the creeping flows intended for the Spirasol system. Constant monitoring of the flow rate is unacceptable for an effective household treatment system, and a more effective valve would need to be considered. More interestingly, the amount of water that one can treat is limited only by the length and width of the tube one has available. It is therefore conceivable that one Spirasol system would be able to serve a great number of people without taking up significant space. The potential for adopting Spirasol systems at community and municipal buildings clearly exists, and pilot studies in this area could be undertaken after additional laboratory experiments. Lastly, a thorough comparison of typical plastics and their ability to effectively carry out solar disinfection should be undertaken to ascertain which media would be of the most benefit to households that look to solar disinfection for their water (Loux, 2005).

3.3. The Modified Clay Pot

3.3.1 Background

One of the main components necessary for providing access to safe water is the ability to safely store it. Whether the water is obtained from an improved source, such as a protected well, treated by way of a particle removal process such as filtration or coagulation, or disinfected through SODIS, household chlorination, or some other method, the potential for contamination undermines and negates the resources spent ensuring that water is safe to drink at the point of consumption.

People in the Nyanza Province of Kenya (see Figure 3.6), located along the shores of Lake Victoria, have a tradition of storing their water in wide-mouth clay pots. Locals like using clay pots because of the evaporative cooling effect such vessels have on water and because the clay makes the water palatable (Bovin et al. 2004). However, the wide mouths encourage the drawing of water with cups; often, the hands holding the cups are contaminated. So, even pristine water stored improperly can be easily contaminated, leading to a high incidence of diarrheal diseases.

One approach to addressing these issues is the use of a designated safe water storage container. Safe water storage containers are designed to eliminate potential routes of contamination when used properly, by providing a fully enclosed container with a spigot that enables safe access to water. Recently, CARE-Kenya, an NGO, developed a modified clay pot (see Figure 3.5) that includes the following changes:

- lid
- narrow mouth
- sediment pouch
- metal spigot to access water
- flat base

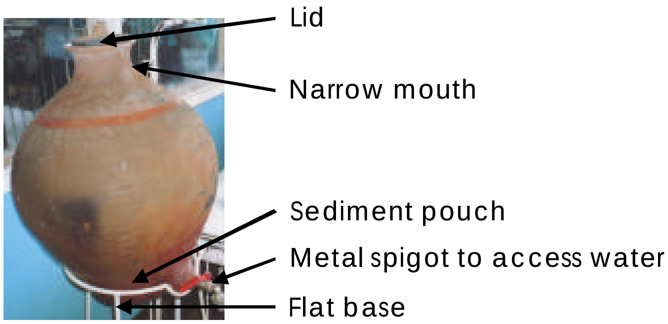

Figure 3.5: The Modified Clay Pot

However, the design needs improvement. The tap leaks, and is very expensive, costing as much as 500 Ksh (U.S. $ 6.25)[6], which is equal to or greater than the cost of all of the other materials combined. In addition, the size and shape are non-standard. A standard size is essential for proper chlorine dosing, and a standard shape is ideal to ease tap attachment.

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[6] $1 = 75 Ksh

3.3.2 Methodology

Two groups under the auspices of CARE-Kenya: the Oriang Women's Pottery Group and the Amilo-Rangwe Pottery group, and a third independent group, Kinda E Teko, produce and locally distribute modified clay pots. Dissemination of the modified clay pot has been hindered by the price and inconsistent quality of the product. In an effort to aid the women in improvement of the modified clay pot design and manufacture process, each of the organizations was visited by team members Suzanne Young and Michael Pihulic, with assistance also provided by Centers for Disease Control (CDC) staff and former M.Eng. student ('01) Daniele Latagne: Oriang Women's Pottery Group in Oriang (5 days); Amilo Community Based Organization in Rangwe (5 days); and Kenda E Teko Pottery Group in Asembo (1 day). These locations are shown in Figure 3.6.

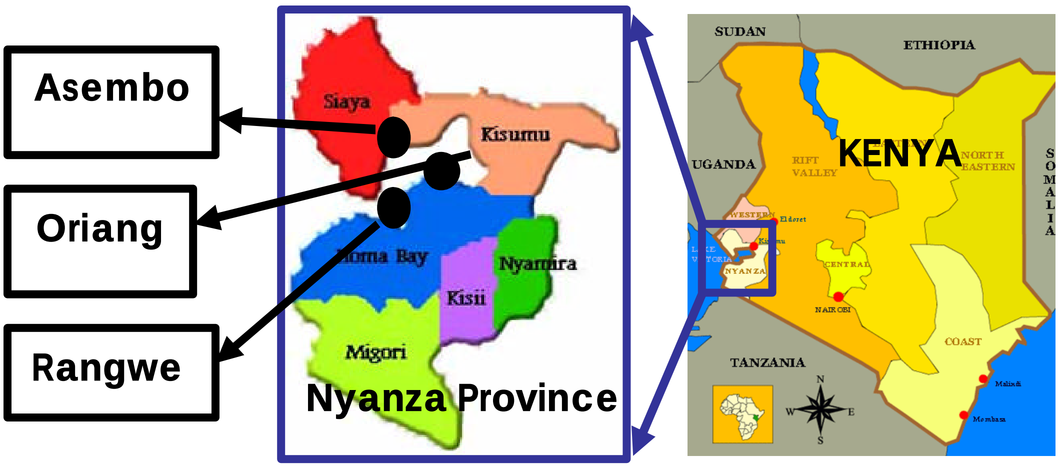


Figure 3.6: Map of Kenya's Nyanza Province and Field Site Locations

Field methods included observation, interview, trial-and-error problem-solving, and the use of focus groups. Essential to the field methodology was getting the women potters to try new things and to think outside of the box. In addition, the entire production and manufacture process, from start to finish, was documented using a combination of field notes, photography, videotape, and interviews conducted with the potters at each of the three locations.

3.3.3 Results and Conclusion

Standardization

After measuring the volumes of several pots that were supposed to be either 20 L or 40 L pots, it was found that the volume variability for both sizes is within +/- 10%. The CDC determined that less than or equal to 10% variability is acceptable to dose the volume of water with the prescribed amount of chlorine (CDC, 2004). A metered rope tool was developed to help control the dimensions of the modified clay pot. Specifically, the rope was marked off to specify the height to the widest circumference of the pot belly, the widest circumference of the belly, and the inner diameter of the mouth. The use of a tool such as the metered rope should be encouraged, but it is important to account for shrinkage that will occur over the two-week drying period (the amount of shrinkage has yet to be determined). The researchers also had the women mold new clay pot shapes, such as a cylindrical milk-bottle shape (Figure 3.7), because a flatter surface eases the insertion of the tap. Further studies are needed to determine whether or not a cylindrical-shaped pot is feasible, marketable, and socially acceptable.

Figure 3.7: Cylindrical (milk-bottle) Shaped Vessel

Taps

After evaluating several different design possibilities using a Pugh chart, it was determined that the plastic spring-loaded tap was the best option. The plastic tap consists of a jam nut, two rubber washers, a threaded shaft, and a spring-loaded handle. One of the improvements suggested before attaching the tap was to make a flat point of attachment on the unfired pot to simplify attachment (Figure 3.8). A plastic tap attached to such an improved pot at Oriang was found not to leak. The next step, beyond the scope of this work, involves field testing of the plastic tap.

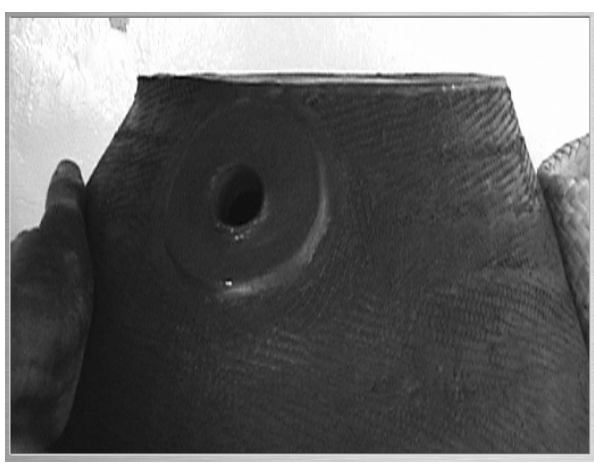


Figure 3.8: Flat Point of Attachment for Tap

Cost Recovery

Cost recovery of all of the materials used to make the modified clay pot is a key component, because one of the goals of designing a new tap is to address affordability. Cost data at Amilo was obtained via interviews; however, the data is questionable because it was clear that the numerous interviewees were giving very rough estimates. In fact, the numbers at Amilo do not seem reasonable because they show that the cost of grass, which is used to fire the clay pots, comprises more than half of the total cost of the pot. It is necessary, therefore, to validate these numbers with CARE-Kenya. Cost data at Kinda E Teko was obtained by a teammate via an interview. These numbers seem more reasonable, as they show that the metal spigot comprises almost half the cost of the pot, which matches with the researchers' understanding from the Bovin et al. (2002) report. Cost data for Oriang was incomplete (Young, 2005).

Production and Manufacture

Variations in the finished product were primarily determined to be due to material inputs and manufacturing techniques. Material inputs that are naturally available exhibit a high level of variability and are predominantly responsible for defects such as cracking and leaking in the vessel body. Manufacturing techniques were primarily responsible for leakiness associated with the attached spigot.

Overall, the production process is highly variable between and within the three groups. Each of the groups has developed their own techniques to address attaching the spigot to the vessel wall. On an individual level, few, if any, measurable standards exist that serve to impose consistency and quality during the production process of traditional ceramics groups such as the ones observed. Additionally, there are no written or formal records that identify the effects of variances in the production process on the final product (Pihulic, 2005).

3.4 Appropriate Water Treatment: Chlorine Disinfection

3.4.1 Background

In 2000, the Centers for Disease Control (CDC) introduced their Safe Water System (SWS) program in Kenya to combat increasing levels of water-related morbidity and mortality. SWS is a three-pronged low-cost water safety strategy that includes household chlorination, safe storage, and behavioral change techniques. They partnered with several local NGOs (Non-governmental Organizations) to implement this system. One such NGO is the Society for Women and AIDS in Kenya (SWAK).

SWAK is the Kenyan subsidiary of a larger African organization called the Society for Women and AIDS in Africa (SWAA). Their main aim is to provide support for people who have been affected by AIDS, and for women who are caring for children and families of HIV/AIDS victims. SWAK has offices in each province, and they operate in a decentralized manner.

In October 2002, SWAK's Nyanza office partnered up with CDC to promote SWS within its communities. SWAK is hoping to improve and expand sales into all their communities. They approached MAJI, through CDC, in order to improve their sales strategies.

SWAK markets two water treatment products:

- WaterGuard®: A liquid disinfectant consisting of 1% NaOCl (sodium hypochlorite). WaterGuard® is sold in 500 mL bottles and can disinfect about 2500L of water. It sells for 45 Kenyan Shillings (Ksh.) ($0.60).
- PuR®: A granular coagulant/disinfectant consisting of $Fe_2(SO_4)_3$ (ferric sulfate) and $Ca(OCl)_2$ (calcium hypochlorite). PuR® sells in small sachets that can each treat 10 L of water. It sells for 8 Ksh ($0.11).

The goal of the MIT team's SWAK project was to outline a set of recommendations that would improve penetration of water treatment products in the SWAK communities. The overall goal had two components:

- A technical component whose goal was to recommend the most appropriate water treatment methodology for the SWAK communities.
- A business component whose goal was to outline a set of best practices/recommendations to improve sales of the water treatment products in the communities.

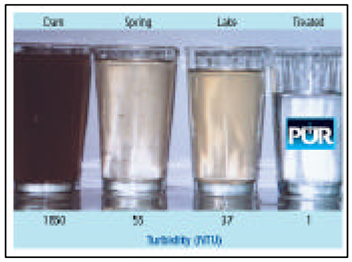
This section of the report focuses on outlining the technical component. The business component was addressed by a four-person team from the MIT Sloan School of Management: Mark Chasse, Jody Gibney, Rachel Greenblatt, and Ellen Sluder. Their report is available online at http://web.mit.edu/watsan and as an appendix in Alekal, 2005.

3.4.2 Methodology: The Technical Component

The goal of the technical component was to find the most appropriate water treatment product for the SWAK communities in Nyanza. Three water treatment products (Figure 3.9) were assessed – WaterGuard®, PuR®, and as an alternative, a naturally occurring coagulant made of seeds from the Moringa tree. The Moringa tree is indigenous to Kenya, and in many parts of Africa, India and elsewhere[7].

[7] http://www.mobot.org/gradstudents/olson/moringahome.html

Bottle of WaterGuard®
Courtesy: CDC



PuR® can treat waters at very high levels of turbidity
Courtesy: PGHSI

Seeds from a Moringa Tree
Courtesy: www.treesforlife.org

Figure 3.9: Water Treatment Products: WaterGuard®, PuR®, and Moringa Seeds

In order to find the most appropriate water treatment, three strategies were outlined and corresponding tools were developed as shown in Table 3.3.

Project work took place in three phases:

- Preliminary Research, October-December 2004: Research on the region and water quality issues, laboratory test preparation, telephone meetings with stakeholders, tool development and team meetings.
- Data Collection, January 2005: Data collection in SWAK communities in Nyanza, Kenya, preliminary presentations of recommendations to stakeholders.
- Concluding Research, February-April 2005: Analysis of collected data, conclusive research, and final report to stakeholders.

Table 3.3: Outline of Strategy and Implementation Tools

Strategy	Tool used
Gauge consumer preferences, current practices, and if treatment is being implemented correctly	Household surveys Chlorine tests on household drinking water
Gauge source water quality	Turbidity tests on source water
Assess possible alternatives	Feasibility study on Moringa

3.4.3 Results, Conclusions, and Recommendations

Results and Conclusions

Field Survey Community Summary:
Total number of communities assessed = 14 (Figure 3.10)
Overall number of households visited for assessment = 74
Average number of households per community = 5
Average profile of a household:

- Household consists of 6 members

- Family uses about 6 Jerry Cans[8] of water per day (120 L total)
- 1 Jerry Can of drinking water lasted a family 3.5 days
- Household income < Ksh 960 ($12.80) per month

Utilization of Water Treatment Products: Figure 3.11 shows that WaterGuard® was the most utilized product. This could largely be because of its relatively low-cost, ease-of-use, and effectiveness at reducing stomach-related illnesses. All respondents self-reported an elimination of stomach-related illnesses upon continued and correct use of WaterGuard®. It can therefore be concluded that WaterGuard® should be incorporated into the most appropriate water treatment regime for SWAK communities in Nyanza.

Turbidity: Turbidity levels were much lower than expected. Turbidity data compiled by CDC in 2003 showcased an average turbidity of 205 NTU in Western Kenya; it is also known that only the most turbid sources of water were sought out for this study (Crump, 2003). Source water turbidities measured by the researcher during January 2005 showed a weighted average of 11 NTU (Table 3.4). Figure 3.12 shows turbidity levels for each source. CDC recommends WaterGuard® usage only up to 100 NTU (Lantagne, 2005). With a weighted average of 11 NTU and the highest turbidity measured at 96 NTU, it can be concluded that WaterGuard® is more critical to SWAK communities than PuR®.

Rainwater: Figure 3.12 gives a clear pictorial description that rainwater is the best water source for the people. It is the most preferred source because of its convenience and cost; in addition, it has the second lowest average turbidity of all the sources listed. However, 49% of rainwater users did not boil or treat their rainwater, putting themselves at risk for disease. They did not understand that while the rain itself is clean, it runs the risk of contamination during collection and prolonged storage. It can be concluded that rainwater is the best water source for the SWAK communities in Nyanza, and therefore rainwater harvesting should be encouraged.

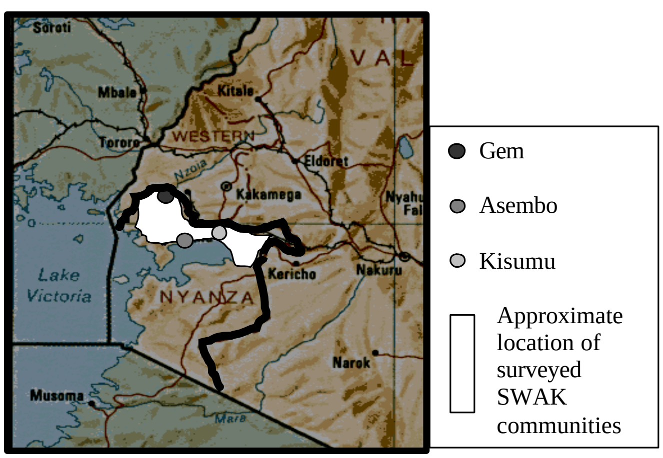


Figure 3.10: Map of Area Surveyed for Data Collection
Courtesy: http://www.kenyalogy.com/eng/mapake/mapfpc.html

[8] 1 Jerry Can = 20 L

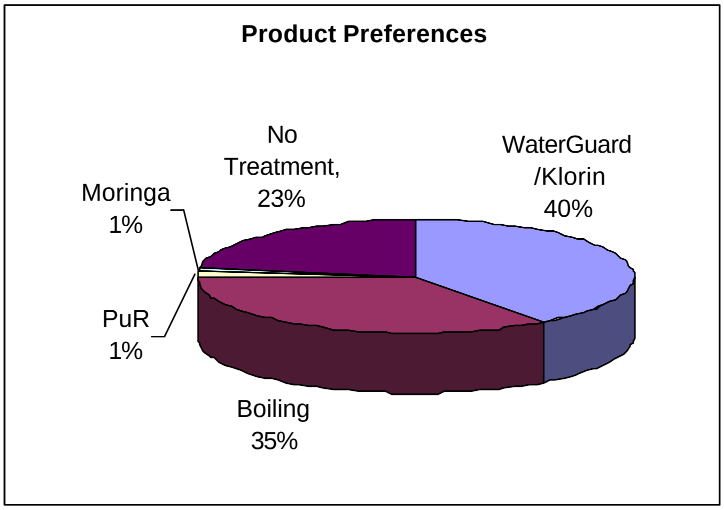


Figure 3.11: Percent Breakdown of Product Preferences

Table 3.4: A Breakdown of Turbidity by Source

Source	No. of communities that used source	No. of Households that used source	Highest turbidity measured (NTU)	Lowest turbidity measured (NTU)	Weighted average turbidity of source (NTU)
Tap	4	18	2.0	0.76	1.1
Borehole	6	23	95.7	0.45	9.6
Lake	1	4	22.4	22.4	22.4
Spring	2	6	4.8	2.5	2.9
River	3	10	59.6	3.7	38.0
Tank	1	1	25.4	25.4	25.4
Pond/earthpan	5	24	42.0	4.1	24.3
Rainwater	13	59	6.0	0.1	2.4
	Average Overall Turbidity=				**11.09**

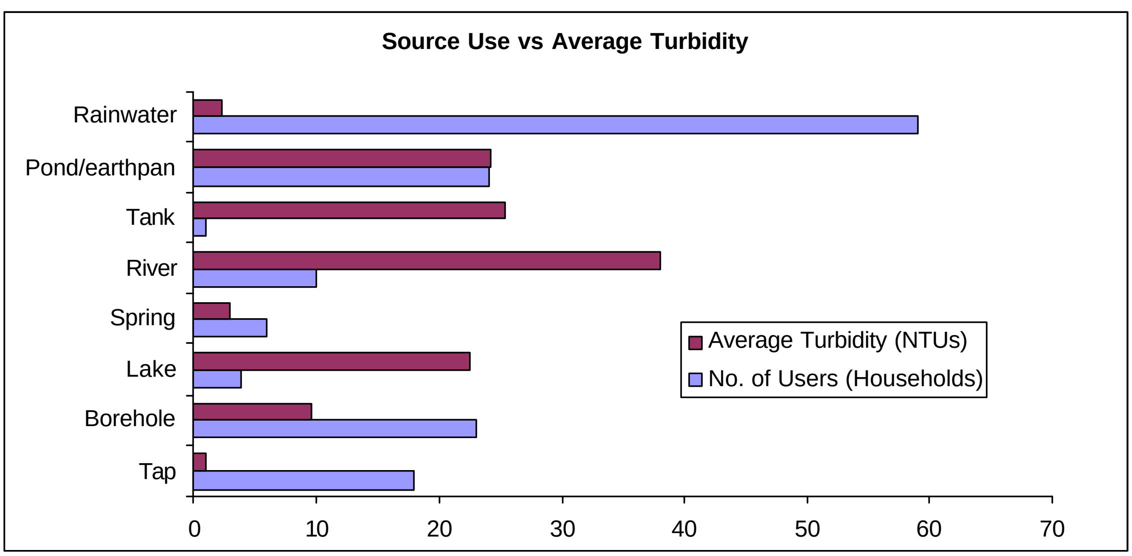


Figure 3.12: Source Use vs. Average Turbidity

Free Chlorine Levels: Less than 50% of WaterGuard® users showed traces of free chlorine; however 100% showed detectable levels of total chlorine, indicating that the water was indeed treated. WaterGuard® users typically used 20 L of water for 3.5 days. This was an issue because WaterGuard® at 1% concentration of NaOCl can last as residual for only about 24-36 hours after treatment (Lantagne, 2005). It can be concluded that the concept of retreatment must be introduced into the SWAK communities.

Moringa: Moringa was hardly visible in the surveyed communities. Its use as a coagulant was cited as being a very time-intensive procedure by those who were familiar with it. Some community leaders said that Moringa trees were a waste of land space since cash crops were more income-generating. Additionally, the most common species, *Moringa Stenopatela*, has not been researched much for its effectiveness at turbidity removal. It can be concluded that more research on *Moringa Stenopatela's* availability and efficacy must be conducted.

Other: There was a persistent lack of health and product information in the communities. People did not understand the linkages between water and disease, or product function. This was crucial because product penetration was higher in communities where health education was higher (Chasse et al, 2005). Another issue was the incorrect application of household water treatment. For example, residents in two communities using WaterGuard® consistently complained about the strong taste and smell of chlorine in their water. Upon further investigation, the researcher found that the residents of both communities were chronically overdosing the WaterGuard® in their water. In another case, community residents who preferred to boil their water had problems with stomach ailments despite using boiled water. Further research revealed that many of these residents often removed the boiling pot of water before or just as it hit a rolling boil, largely to save fuel, thereby drinking contaminated water.

Recommendations

The following is a set of recommendations outlined for SWAK, based on this technical research of the three available local drinking water treatment products.

1. The most appropriate treatment regime for SWAK communities in the Nyanza Province is shown in Table 3.5. This regime is based solely on levels of turbidity of source water.

Table 3.5: Selection Tool for SWAK Communities in the Nyanza Province

If turbidity (NTUs) is:	Then use:			
	Gravity Sedimentation	Cloth Filtration	WaterGuard® Disinfection	PuR®
<5 or “clear”		☑	☑	
5<T<30 or “somewhat clear”	☑	☑	☑	
30<T<100 or “somewhat muddy”	☑	☑	☑☑ (double dosage)	
>100 “very muddy”				☑

2. Water should be retreated with WaterGuard®, or replaced with a new batch of treated water, every 24-48 hours.

3. All rainwater should be treated as outlined in Point 1.

4. Correct treatment or boiling procedures should be taught.

5. Basic training on health, disease, waterborne illnesses, prevention of waterborne diseases, etc., should be given to all communities.

6. An information resource bank should be established by SWAK. This should include Frequently Asked Questions (FAQs), resource material, and resource persons such as community health workers, teachers, doctors, pharmacists and engineers.

7. Rainwater harvesting techniques should be further developed and implemented in the community. As shown in Figure 3.12, rainwater has the highest usage for a source with a lower average turbidity, making it the best water source for the communities.

8. *Moringa Stenopatela* should be researched further as to whether it is an effective, financially practical, and user-friendly coagulant.

Considering that the measured turbidity levels averaged (based on a weighted average) approximately 12 NTUs, the most appropriate method based on current practices involves gravity sedimentation, cloth filtration and WaterGuard® disinfection. This project can be considered a success given that recommendations cited in this report are already being implemented by SWAK in their communities (Alekal, 2005; Chasse et al., 2005)

3.5 Program Implementation, Evaluation, and Selection Tools for Household Water Treatment and Safe Storage Systems

3.5.1 Background

The primary objective of this component of the project was to generate program implementation and selection tools to aid in the implementation of household water treatment and safe storage systems for local communities in developing nations. The tool generated is comprised of two separate components: (1) HWTS implementation organization survey and (2) a HWTS technology selection tool. The implementation organization survey is to be utilized primarily for evaluating the effectiveness of currently implemented HWTS programs. The technology selection tool is meant to aid stakeholders in the choice of the most appropriate HWTS technology, or combination of technologies for a given potential implementation area.
The tools are intended to take into account all facets of program implementation and are to be designed with inherent flexibility in order to be used by local communities as well as global agencies, organizations, and enterprises involved in program implementation. The tools are explained further in the following sections.

The HWTS Implementation Organization Survey

In late 2004, in collaboration with the Implementation Working Group of the WHO "Network," the MIT team developed a draft HWTS implementation organization survey. During January 2005, this survey instrument was vetted and iterated through interactions with eleven different HWTS implementing program groups working in five of Kenya's eight provinces. The resultant survey instrument is intended primarily for information collection of currently implemented HWTS programs, but is also applicable for pre-implementation scenarios. The targets considered, Health Outcome, Water Quality, Technology Performance, and Behavior/Use, are those identified by either the World Health Organization (WHO) 3rd Edition Guidelines for Drinking Water Quality and/or the Implementation Working Group of the WHO Network. Additionally, another potential target, "Finances and Economics" has also been included in the survey instrument.

The survey consists of the following sections:

- General Information
- Implementation Program / Product Description
- Target Population and Current Water Use Practices
- Resource Availability
- Education and Training
- Funding
- Operational Monitoring
- Target: Health Outcomes
- Target: Water Quality
- Target: HWTS System Performance
- Target: Behavior/Use (Social Acceptability)
- Costs
- Other Types of Approaches and Questions
- Final Thoughts
- Publications

The HWTS Technology Selection Tool

In the previous section, a technology selection tool or framework was developed for SWAK communities in the Nyanza Province based on four treatment options (gravity sedimentation, cloth filtration, Waterguard®/household chlorine disinfection, and PuR® coagulation/ disinfection). Technology selection was based solely on the level of turbidity of source waters.

For this component of the project, it was proposed that a technology selection tool be generated to include all of the HWTS technologies observed in different regions of Kenya. Some of the parameters considered by the tool are listed as follows:

- Target Population
- Water Source

- Water Use Practices, Access, and Transport
- Occurrence of Disease
- Local Government
- Presence of Implementing Organizations
- Presence Local Community Groups
- Presence of Schools
- Presence of Health Clinics
- Infrastructure
- Economic Considerations

It is clear that such a tool has the potential for numerous applications. Furthermore, the tool addresses one particular method of facilitating program implementation: technology selection. It is intended that the tool be modified incrementally in the future to suit different goals and types of program implementation.

3.5.2 Methodology

Research for this component of the project has been accomplished through the following approach: (1) a review of current literature and past projects focused on HWTS program implementation; (2) development of a survey instrument with potential global applicability, to collect data on HWTS program implementation; (3) pre-testing of the survey instrument through phone interviews; (4) conducting this survey in Kenya during January 2005 through interviews with Kenyan agencies involved in the implementation of various household water treatment technologies; (5) survey analysis; (6) survey refinement to improve this as an instrument of program implementation/evaluation; and (7) development of a technology selection tool.

The HWTS implementation organization survey was utilized for data collection during the site visit to Kenya. Local agencies and international organizations with branches in the country were visited personally to conduct interviews and to observe general methods of program implementation. A list of the agencies and organizations visited is provided as follows (Table 3.6):

Table 3.6: Organizations Visited in Kenya

Organization	Technology	Location
Population Services International (PSI)		
Nairobi	Waterguard	Nairobi (Headquarters)
Mombasa	Waterguard	Mombasa, Coast Prov.
Kenya Water for Health Organization (KWAHO)		
Nairobi	SODIS	Kibera District, Nairobi
Maseno, Western Province	EcoSan Toilets	Maseno, Western Prov.
MEDAIR / Bushproof	BioSand Filters	Machakos, Eastern Prov.
Network for Water and Sanitation (NETWAS)	Ceramic Candle Filter	Nairobi (Headquarters)
World Vision International (WVI)	Safe Water System	Nairobi (Headquarters)
Kenya Ministry of Water Resources	Boiling	Nairobi (Headquarters)
Kenya Ministry of Health	-	Nairobi (Headquarters)
Catholic Diocese of Nakuru (CDN)	Defluoridation Filters	Nakuru, Rift Valley Prov.
Anglican Church of Kenya (ACK)	SODIS	Eldoret (Headquarters)
Society for Women and Aids in Kenya (SWAK)	Waterguard / PuR / Modified Clay Pots	Kisumu (Headquarters) / Western Prov.
CARE	Safe Water System / Modified Clay Pots	Kisumu (Headquarters) / Western Prov.

All research conducted and data collected was organized and analyzed for consideration in the generation of the HWTS technology selection tool. The final product is a comprehensive tool that takes into account practices and experiences from the agencies and organizations visited in Kenya. Past research pertaining to household water treatment and storage systems were also assimilated into the said HWTS technology selection tool.

3.5.3 Results, Conclusions, and Recommendations

The HWTS Implementation Organization Survey

The survey is currently in its eighth version, is 19 pages long, and requires one to two hours to conduct.

The WHO Implementation Working Group of the "Network" has utilized the survey to create a "short form" web-based survey and database of HWTS implementation experience. The final version of the web-based collection tool is in MS Excel format and is available on the WHO website[9]. The web-based tool has the primary function of obtaining a better understanding of where household water treatment and safe storage is occurring, what types of technologies or systems are being implemented and what organizations are active.

Recommendations for the further development of the survey are presented as follows:

- Refinement of the survey through application to HWTS implementation organizations in other developing nations.
- Standardization and acceptance of the survey for global use and applicability.

[9] www.who.int/household_water/implementation/en/

- Modification of the survey to suit other water/sanitation/hygiene implementation programs, and not just those dealing specifically with HWTS technologies.

The HWTS Technology Selection Tool[10]

The HWTS technology selection tool is presented in two formats: paper and electronic. The paper format of the selection tool is a document meant to be used in the field or in areas where computer facilities are not readily available. The paper format takes the form of a checklist or questionnaire that may be filled out by hand. The electronic format of the selection tool is provided in the form of an MS Excel spreadsheet intended for use by organizations with access to the software.

The technology selection tool developed is a "work in progress". It sets forth a framework that anticipates further revision and iteration prior to being considered implementable in a real world scenario. The selection tool is presented as a proposed method of determining the applicability of certain HWTS technologies to specific target areas. The tool is not meant to critique methodologies or HWTS technologies currently being implemented. It is intended that the tool may act as a springboard for the consideration, discussion, and identification of parameters that need to be evaluated prior to the implementation of HWTS programs.

Recommendations for the further development of the technology selection tool are presented as follows:

- Refinement of the selection tool through detailed review and evaluation by organizations with experience in HWTS technology implementation.
- Improvement of the tool through trial application to HWTS implementation organizations in other developing nations.
- Further modification of formats through supplemental descriptive information such as pictures and typical examples regarding the parameters to be entered.
- Modification of the tool to suit other programs, and not just those dealing specifically with HWTS technologies (Baffrey, 2005).

[10] The underlying rationale behind the creation of the tool originates solely from the author's own ideas and observations during the site visit to Kenya in January of 2005.

3.6 Ecological Sanitation

3.6.1 Background

Ecological sanitation, or ecosan, refers to a host of decentralized technologies that recover and recycle human waste. Ecosan systems deal with human excrement in a manner such that 1) it does not pollute water systems; 2) the excreta is processed to a point that it is safe for human handling; and 3) it can be utilized in ways that take advantage of its nutrient properties (Esrey, 1998; Esrey, 2001; GTZ, 2003).

In Kenya, one of the most wide-spread types of ecosan available is the skyloo toilet. The skyloo (Figure 3.13) is a urine-diverting toilet that stores feces and urine in separate containers in the chamber beneath the toilet structure. The urine is diverted into a bucket, while the feces are typically collected in a plastic bag-lined basket. When a basket (or bag) is full, the feces and/or urine are removed from the toilet and left to "process" (stored in a safe place for a period of time to allow for pathogen die-off) in another location. For adequate pathogen die-off in Kenya, six months of storage are needed for feces and about one month is needed for urine.

Figure 3.13: The Skyloo

While the agricultural potential for these kinds of toilets is readily seen, it is not well understood how valuable the agricultural material is, or why households would choose to use this kind of toilet over more commonly available options such as open defecation in the "bush" or a pit latrine. This is especially notable when the culture does not have the tradition of reuse of human excrement.

3.6.2 Methodology

Two methods of research and analysis were applied. First, laboratory analysis was conducted to gauge the agricultural value of the urine from the toilets, specifically for nitrogen and phosphorous concentrations in the urine. Second, a semi-structured interview instrument was developed to characterize households' reuse practices and to collect information on why people do and do not like their skyloo toilet. The interview instrument consisted of both close-ended and open-ended questions.

3.6.3 Results, Conclusions, and Recommendations

The nitrogen and phosphorous values from the urine samples showed that an average household in the area would produce about 4 kilograms of nitrogen and about 0.6 kilograms of phosphorous in one year.[11] The nutrients produced by one family's urine, therefore, is equivalent to the amount of nutrients found in the edible portions of a hectare of equivalent amounts of fresh corn, spinach, and watermelon. The economic value of the material is quantified by how much money one would need to purchase the same amount of nutrients in commercially available fertilizer. Equivalent amounts of nitrogen and phosphorous can be purchased as diammonium phosphate

[11] In the average household, 4.8 people used the skyloo.

(DAP) for less than $1 USD per month. While this may appear somewhat low, this cost savings covers an average of 22 percent of the amount spent on DAP by households that use fertilizer. For the households that do not purchase DAP (about 60 percent), the nutrient production of the toilet could be considered a material profit of US $11.70 per year, which also results in better crops.

Perhaps for the advantages of the processed urine and feces, about 2/3 of the households reported reusing the feces and urine in their household farm. The remaining 1/3, in the case of urine, dumped it to the ground when the container was full and, in the case of feces, buried in the ground. Thus 1/3 of the households intentionally did not reuse the material. Regarding storage time for pathogenic die-off, households actually stored their urine longer than the recommended time (stored 2 months as opposed to the recommended 1 month). Feces, however, were stored on an average of 4.5 months, compared to the recommended 6 months.

There were many reasons why households liked their skyloo toilet. The top reasons reported were (in this order) the agricultural product; the toilet did not smell; the facility is aesthetically pleasing; and that the owners gained some status within their community. The most frequently reported negative aspects of the skyloo toilet were training issues such as: children are difficult to train; the elderly have trouble going up the stairs and squatting; and one must handle the feces. These responses showed that the agricultural product was important to users, but that other aspects of the toilet were also very influential in households' adoption of the technology.

There are three main benefits of the skyloo that seem to be driving the demand for the technology in the community that was visited: 1) the agricultural product; 2) the aesthetic and social status that accompanies the curious and new structure; and 3) the materials subsidy that is provided by the NGO promoting the toilet in this community. In a "faecophobic" (Winblad, 2004) community (a community that has an excreta-unfriendly attitude), reuse of feces and urine can be viewed very negatively by a household's surrounding community. It is interesting that households were still excited about the processed material even given the lack of local cultural context regarding the reuse of human excrement. Therefore, we can assume that the agricultural product itself, along with the aesthetic and social status, and the materials subsidy must be compelling advantages of the toilet.

It is undeniable that a toilet like the skyloo addresses environmental problems such as nutrient pollution to water resources and fecal contamination of drinking water sources, thus highlighting its potential contribution to integrated water resource management strategies. To the household, however, the toilet imposes a large maintenance commitment and gives the owner full responsibility for safe processing of the excrement. It is therefore recommended that all of the skyloo's advantages be promoted in marketing the toilet, not only the fact that the toilet recycles human excrement. More focus could be placed on the aesthetic, social, and hygienic aspects of the facility, as well as the production of agricultural material.

Finally, follow-up training that highlights the amount of time needed to safely process the feces should be conducted. Training sessions on how to appropriately distribute the material on farms and gardens when the material is ready for reuse should also be undertaken.

4. Overall Conclusions

While in Kenya, a variety of household water treatment systems and a decentralized sanitation option were explored. The study results obtained support the goal of reducing the spread of disease-causing organisms transmitted through safe drinking water and adequate sanitation facilities. Contributions, applications beyond Kenya, and future research specific to each project are summarized below.

- **Ceramic Water Filtration**
  - – Identified most effective ceramic candle filters currently available in Kenya;
  - – Provided basis of comparison for future ceramic candle filter research;
  - – Test more ceramic candle filter brands, especially with regard to filter performance over time and viral removal.

- **Solar Disinfection: Spirasol**
  - – Improved upon SODIS design;
  - – Concluded that Spirasol may be more valuable in areas with less solar intensity;
  - – Test SODIS and Spirasol variables; scale up Spirasol system; determine first world applicability.

- **The Modified Clay Pot**
  - – Identified best practices for each pottery site;
  - – Improved modified clay pot may have applications to other African countries, in refugee camps and hospitals but more generally in households in need of safe storage;
  - – Test plastic tap in field.

- **Appropriate Water Treatment: Chlorine Disinfection**
  - – Developed a product selection tool based on turbidity that was appropriate for SWAK groups in Nyanza Province;
  - – Identified appropriate products for use in various conditions in Africa;
  - – Investigate Moringa seeds with regard to their effectiveness at removing turbidity, the effects of coupling the seeds with chlorine, and their cost compared to PuR.

- **Program Implementation, Evaluation and Selection Tools for Point-Of-Use Household Water Treatment and Safe Storage Systems**
  - – Developed implementation organization survey and technology selection tool;
  - – Created evaluation survey and technology selection tool adoptable by organizations such as WHO;
  - – Apply implementation organization survey and technology selection tool to other programs.

- **Ecological Sanitation**
  - – Evaluated agricultural potential and usability of ecosan-generated humus;
  - – Discovered that people want *nice* toilets in addition to practical/resourceful toilets;
  - – Determine nutrient content of feces; evaluate application methods.

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