THE IMPLEMENTATION OF SUSTAINABLE POINT-OF- USE WATER TREATMENT AND SANITATION SYSTEMS IN RURAL UGANDA

By

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ABSTRACT

The people in rural Uganda lack basic needs (e.g., access to improved water supplies and sanitation facilities). Water-borne diseases such as diarrhea, cholera, and malaria have kept people from working at their full potential and children from attending school. Lack of work and education has led to decreased productivity in farmer's fields and ignorance, respectively. The members of Rural Agency for Sustainable Development (RASD), a non-governmental organization in rural Uganda, have recognized the needs in their community. It is their vision to train local citizen in such matters as water treatment, sanitation, proper hygiene, and improved agricultural practices to improve the quality of life for citizens.

RASD partnered with Engineers Without Borders at the University of California, Davis (EWB-Davis) to help develop and implement sustainable point – of – use (POU) water treatment and sanitation systems. Four POU water treatment systems (i.e., clay filter pot (Filtron), solar disinfection (SODIS), chlorine treatment (WaterGuard), and colloidal silver (SilverDyne)) were tested and implemented at RASD. Two sanitation systems (i.e. Urine-Diversion toilet and Un-reinforced Concrete Dome slab toilet) were implemented at RASD. Education and cultural acceptance were essential factors in determining the sustainability of the systems. Water and sanitation seminars were held at RASD to educate the public. Surveys were conducted to obtain cultural opinions.

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1.0 UGANDA

Uganda, also known as the "Pearl of Africa," is located on the east African plateau. Uganda is 3,250 ft (average) above sea level and borders Lake Victoria on the north. Uganda is known for its natural landscape, its vast range of cultures, and artistic talent (My Uganda, 2008). Table 1.1 displays a general profile of the country. Rural Uganda consists of 87 % of the country's total population of 29.9 million (World Bank Group, 2007). More than two-thirds of Uganda's population that live in poverty is in rural communities (Rural Poverty Portal, 2008). Lack of access to clean water, safe sanitation, and proper hygiene is strongly related to poverty (Reed and Coates, 2003). "Although efforts have been made to reduce rural poverty, urban areas have experienced a significantly greater reduction in poverty than the countryside. In the past decade, poverty has declined by a rate of 43% in urban areas but by only 18% in rural areas" (Rural Poverty Portal, 2008).

Table 1.1: Statistics on society and poverty in Uganda

People	Word Bank Group	CIA	UNICEF
Population (millions)	29.9	31.3	29.9
Population growth (annual %)	3.2	3.6	
Poverty headcount ratio at national poverty line (% of population)	38	35	
Life expectancy at birth, total (years)	50.7	52.34	50
Fertility rate, total (births per woman)	6.7	6.8	
Mortality rate, under-5 (per 1,000)	134.2	65.99	134
School enrollment, secondary (% gross)	18.3	..	..
Prevalence of HIV, total (% of population ages 15-49)	6.4	4.1	6.7
Access to improved water source, urban (% of population)	..	..	87
Access to improved water source, rural (% of population)	..	..	56
Access to adequate sanitation facilities, urban (% of population)	..	..	54
Access to adequate sanitation facilities, rural (% of population)	..	..	41
GNI per capita, Atlas method (current US$)	300		300

Sources: World Bank, 2007; CIA, 2008; UNICEF, 2006

2.0 ENGINEERS WITHOUT BORDERS – DAVIS AND THE RURAL AGENCY FOR SUSTAINABLE DEVELOPMENT

Engineers Without Borders at the University of California, Davis (EWB-Davis) is a part of a non-profit national/international organization that partners with communities in developing countries to implement sustainable technologies that will improve the quality of life. The Rural Agency for Sustainable Development (RASD) is a non- governmental organization (NGO) located in Nkokonjeru, Uganda that is partnered with EWB-Davis. RASD was created to train local citizens in matters such as sanitation, drinking water treatment, agriculture, hygiene, computer/internet skills, and vocational skills.

The EWB process requires an assessment to the proposed project location. The purpose of the assessment trip is to gather data, by observation, conversation, and water quality analysis that would better equip the design team for the formulation of sustainable technical and non-technical solutions.

2.1 EWB-Davis Assessment Trip: Overview

Nkokonjeru is located only 30 km east of the capital, Kampala; however it is over a 2-hour drive. Nkokonjeru is located in the Mukono district and the immediate surrounding area contains 12 villages, with roughly 12,000 inhabitants. Nkokonjeru town central is the business center with a market place and main street with many small shops. The surrounding villages are more rural and much of the economy is subsistence farming. Many orphans (defined in Uganda as a child who has lost at least one parent since single-parent homes are unable take care of all their children) are present in the region, and throughout the country, largely due to the AIDS epidemic. Unemployment rates remain high in the area. Drinking water quality and sanitation continue to be issues that affect the general health and economy of the entire region. Many are not educated about the dangers of these issues, and those that are educated are frequently not economically able to alter their situation.

A total of ten villages were visited during the assessment trip. In each village that was visited, the community leaders were introduced. Frequently, an honorary village meeting was also conducted such that EWB Davis's questions could be answered more fully. Questions in regard to water collection, water consumption, sanitation, and health were asked. The main water sources were tested for Escherichia coli (E.coli), total coliforms, and metals for the majority of the villages.

2.2 Design and Implementation of Sustainable POU Technologies

Teams were assembled after the assessment trip to research, design, and test potential POU sustainable systems at UC Davis. Education and cultural acceptance was a key component of the design. To ensure that the POU systems were maintained after implementation and for the spread of the technologies within the region, it was essential for teams to educate our partner, RASD, on all aspect of the design and their benefits.

An implementation trip was taken after EWB-USA approved the designs of the POU systems. Two of the major goals of EWB-Davis on their trip were the implementation of POU water treatment and sanitation systems at RASD. In addition, EWB-Davis wanted to conducted educational seminars on diseases caused by water-borne pathogens, poor sanitation and hygiene practices, and the proper use of these systems. Surveys were also conducted to obtain people's cultural opinions.

2.3 Sustainability

A key factor that determines the success of any introduced technology is sustainability. Sustainability depends on communities' behavioral, motivational, educational and participatory activities (Sobey, 2005). The affordability, maintenance costs and willingness to pay for household technologies is important for their implementation, use, and sustainability. All systems require an approach for cost recovery to be sustainable (Sobey, 2005). In addition, the

materials used to build and maintain the technologies should be available in the local community. Maintenance is most likely required for the systems. Materials used to maintain the system should be obtainable from the local market to avoid the higher costs of imports. All these factors of sustainability were considered in all the technologies that were implemented at RASD.

3.0 WATER

3.1 Water Issues

The World Health Organization (WHO) estimated in 2002 that 1.1 billion people lacked access to improved water sources and 42% of that population are people who live in sub-Saharan Africa (WHO, 2004). The need for water in developing countries is a growing concern as population and industrial demands increase worldwide. Many developing countries do not have local sources of clean fresh water resulting in the need for long distance travel and hauling of water from shared water sources. Properly constructed and efficient aquifer withdrawal systems require large amounts of construction materials and skilled labor that many developing nations lack. Furthermore, piping and pumping costs increase as more locations require water. Wastewater reclamation is not an option in many locations due the high cost and technical abilities needed to maintain wastewater facilities. In addition, such facilities require large plots of land, which are very valuable in many regions for agricultural or living space.

Only 56% of the rural population in Uganda has access to improved drinking water supplies (UNICEF, 2006). Many of these are wells that were developed by charitable outreach groups that no longer have working pumps and local expertise and economics do not exist for their repair. Other improved sources are protected spring boxes. Both improved systems are subject to low or no flow during the dry seasons. The main reason people in rural Uganda stated they lacked access to improved drinking water was because there were no available sources. Other reasons for lack of access was long distance and high cost (Table 3.1).

Table 3.1: Percentage distribution of reasons for rural Ugandans not using safe water sources

Main Reason	Rural
Not Available	56.9
Long Distance	19.8
Unreliable	7.7
Water Does not Taste Good	1.7
Require Contribution	2.2
Long Queues	4.8
Open Source is Okay	3.2
Other	3.6
Total	100

Source: Uganda Bureau of Statistics, 2004

The climate also affected where people access their water. As supplies diminish in the dry season, more people collect their water at unreliable and unsafe sources (Table 3.2). These sources are more likely to be contaminated by various water-born diseases. The time it takes to collect water also increases during the dry season in rural Uganda (Table 3.3).

Table 3.2: Percentage distribution of water source that rural Ugandans use during seasons

	Dry Season		Wet Season	
Water Source	**Drinking**	**Other Use**	**Drinking**	**Other Use**
Piped Water in Dwelling	1.1	0.9	1	8.5
Piped Water in Compound	0.7	0.7	0.7	12.5
Piped Water Outside Compound	4.4	3.9	4	23.4
Borehole/Protected/ Gravity Flow Scheme	54.1	44.3	46	26.3
Unprotected Source	22.4	25.9	16.5	8.2
Rain Water	0.5	0.7	18.4	15.6
Lake/River/Stream/Pond/Dam	16.7	23.3	13.2	5
Other	0.1	0.1	0.1	0.5
Total	100	100	100	100

Source: Uganda Bureau of Statistics, 2004

Table 3.3: Average distance & time to drinking water source & amount of water used per day

Description	Dry Season	Wet Season
Avg waiting time at water source (min)	50	32
Avg time taken to & from water source (min)	43	31
Avg Amount of water used per day (liters) per household	16	14
Water Collection Time (min)	93	63

Source: Uganda Bureau of Statistics, 2004

Through a survey conducted by EWB-Davis, rural Ugandans said that adults consumed one

to two liters of water per day while children consumed one liter of water. Asked why they did not consume more, they stated the time and energy it took to collect water were the limiting factors. They also reported they would consume more if there were safe, reliable sources available. An estimated 20 % of the people from each village visited claimed to boil their water (McKenzie and Vernon, 2007). No other treatment systems were in use.

3.2 Water Health Related Problems

Malaria is a parasitic disease that is transmitted by mosquitoes. This disease causes flu-like illness and, when left untreated causes death (CDC- Malaria, 2008). In 2002, malaria was the second leading cause of death for the people of Uganda (WHO- Morality, 2006). Hospital and school records gathered from Nkokonjeru indicated that malaria was the major cause of illness for patients and students, respectively. Poor water resource management, including agricultural practices, creates a good breeding area for infected mosquitoes (WHO, 2004). E. coli is a particular fecal coliform bacteria that has been used as an indicator of water-borne diseases. The presence of elevated levels of E.coli in water is correlated with discharges of human or animal waste (EPA, 2006). Currently 1.8 million people, 90% children, die every year due to diarrhea related diseases (including cholera). Unsafe water supplies and poor sanitation account for 88% of diarrheal diseases (WHO, 2004). Hospital and school records gathered from Nkokonjeru indicated that diarrhea and dysentery are the second leading complaint leading to hospital visits and school absences. Table A.1 in the water appendix, displays other pathogens that cause water-borne diseases.

3.3 Post Collection Contamination

People who do have access to improved drinking water sources could be contaminating their water supplies with their transportation and storage containers. Infrequently cleaned transportation containers can harbor and breed bacteria. If the storage facility for the containers is

not properly cleaned, is left uncovered, or is around animal activity, chances of post-contamination greatly increase. Lack of education on how to dispense the water for drinking (e.g., never dipping a cup or a hand into the storage facility to obtain water) also can lead to post-contamination. Microbial data collected on the assessment trip indicated that the water quality of the protected springs was not of poor. However, hospital and school records showed that major cases of illness were due to water-borne diseases. This implicates the devices used to collect water as suspects in disease transmission (McKenzie and Vernon, 2007).

RASD described a vicious cycle involving disease, ignorance, and poverty; each contributes to the others, making it very difficult to escape. For example, consider the poor, uneducated subsistence farmer who orders their children to collect water from the local protected spring. While the local spring is of reasonable quality, post contamination occurs because the farmer does not understand how to properly handle the water. The farmer's child falls sick to a water-borne disease. The farmer spends the little money available on medicine; now there is no money to pay the child's secondary school tuition.

3.4 Overview of Assessment Trip: Water Quality

EWB-Davis made a two-week assessment trip to Nkokonjeru, Uganda (Dec. 29, 2006 to Jan. 10, 2007). EWB members spent 12 days touring the rural villages with RASD members. EWB-Davis had extensive dialogue with RASD and its volunteers, village leaders, and had the opportunity to participate in specially held community meetings. Further information was gathered through field water quality testing for inorganic constituents and microbial contaminants, as well as subsequent laboratory testing (after return to UC Davis) for elemental concentrations. Data regarding health outcomes were collected from very cooperative doctors at the small hospital in Nkokonjeru and from two small schools in the area. The trip provided information that enabled the design of the water and sanitation technologies.

4.0 Water Quality

Uganda's national drinking water standards are the same as the WHO Guidelines. Urban systems have to comply with these standards but rural systems do not (WSSSA, 2000). EWB-Davis team visited ten villages and tested thirteen water sources for their water quality. The Hach surface waters test kit (Loveland, CO) was used to determine the pH, temperature, ammonia, nitrate, phosphate, dissolved O_2, and chlorine (free and total) content. The methods and concentration range for each water quality parameter is summarized in Table 4.1. All analyses were performed in the field.

Table 4.1: Water quality test and range of detection

Parameters	Range (mg/ L)	Smallest Increment	Method
Ammonia	0 - 2.5	0.1	Color Disc/Salicylate
Chlorine, Free & Total	0 - 3.5	0.1	Color Disc/DPD
Nitrate	0 - 50	1	Color Disc/Cadmium Reduction
Oxygen, Dissolved	0.2 -4	0.2	Drop Count Titration/Modified Winkler
	1.0 - 20	1.0	
pH	0 - 14	0.1	Pocket Pal pH Tester
Phosphorus	0 - 1	0.02	Color Disc/Ascorbic Acid
	0 – 5	0.1	
	0 – 50	1	
Temperature	30 to 120 °F		Pocket Thermometer

Source: Hach, 2006

4.1 Microbial Analysis

4.1.1 Materials

The WHO states that either the "*established methods or methods of equivalent efficacy and reliability can be used for the detection or* enumeration *of fecal indicator bacteria* (WHO-Drinking Water Quality, 2006)." Limited supplies and laboratory equipment restricted the analysis of fecal indicator bacteria by using International Organization for Standardization **(**ISO) standards 9308-1:1990 (Membrane filtrations) or 9308-2:1990 (multiple tube). In the field, water microbial analysis was conducted using 3M™ Petrifilm™ E. coli/Coliform Count Plate (St. Paul, MN). Plates are able to distinguish between E. coli and other coliform organisms. "*The*

petrifilms plates were manufactured in an ISO 9001-certified plant. In addition, the method has been collaboratively tested and is included in the Official Methods of Analysis, published by Association of Official Analytical Chemists (AOAC®) International (3M, 2008).” Sillikers Laboratories conducted a comparative study of 3M petrifilm plates and the multiple tube fermentation technique to measure the bacterial count. Results showed that petrifilms plates were accurate in determining actual contamination level and they recovered more bacteria than the MPN method (Figure A.1 in the Water Appendix). Triplicate analysis was conducted for the detection of E.coli/coliforms. Petrifilms were incubated for 24 hr ± 2 hr at 30 °C ± 1 °C. Plates were read shortly after incubation period.

An incubator that ran on the local 240VAC, 50 Hz circuits was transported from the US and assembled at RASD. The incubator was powered by electricity that was at the host site. The team could not determine thermo-tolerant coliforms because the incubator could not reach the required temperature (44 °C ± 1 °C). The microbial quality of water is usually verified by the analysis of a 100 mL sample. The 3M petrifilm only requires 1 mL of water for analysis. The bacterial count that was read from the petrifilm was multiplied by ratio of 100 to 1 in order to compare results to a 100 mL sample analysis.

4.1.2 Plating and Incubation

In the field, 1 mL samples were plated (no dilution) on the petrifilms and immediately incubated on a person’s back (Figure 4.1). Samples were transferred to the incubator once the team arrived back at their host site. Water samples from the same sources were also collected and brought back to the host site. Two sets of triplicate samples were plated at the host site. The first set of samples was not diluted. The second set of samples was diluted (1/10)

Figure 4.1: Human incubator

with phosphate buffered dilution water. The samples were plated and immediately incubated. Electricity was intermittent at the host site and efforts were made to incorporate a large heat sink in the incubator to protect the integrity of the samples. Nonetheless, the temperature of the incubator fluctuated (Figure A.2 in Appendix).

4.1.3 Microbial Results

Water quality analysis was performed on the assessment trip during the end of the wet season for thirteen different water sources. Half of villages tested positive for E. coli, which is an indication of poor quality (WHO - Drinking Water Quality, 2006). All water sources, except for one protected spring (P.S.), tested positive for total coliforms (Table 4.2). The majority of the population collects water with plastic jerrycans. Collection device (e.g., rainwater harvesting tank and a jerrycan) water quality was tested to determine whether post contamination occurred (Table 4.3). Water was tested at the top and at the bottom of the jerrycan. Results showed that there was an increase in total coliforms at the bottom of the jerrycan which remains moist after emptying.

Table 4.2: Microbial result for water sources in Nkokonjeru council

Location	Source Name	E. coli (CFU/100 mL) (n = 3)	Total Coliforms (CFU/100 mL) (n = 3)	Comments
Naziwanga	Surface water #1	1470 ± 400	TNTC [a]	
Buira	Surface water #2	30 ± 60	470 ± 120	Delayed [b]
	Unprotected Spring #1	70 ± 120	530 ± 250	
	Unprotected Spring #2	30 ± 60	530 ± 320	Delayed
	Protected Spring #6	N.D. [c]	N.D	
Nkokonjeru	Protected Spring #3	N.D	170 ± 60	
	Host site pipe	N/A [d]	1867 ± 498	H.S C. analysis [e]
Kigaya	Lake #1 shallow	N.D	330 ± 120	
	Lake #2 deeper	30 ± 60	400 ± 100	
Millajje	Protected Spring #4	N.D	300 ± 170	
Ndolwa	Protected Spring #5	N.D	930 ± 150	Delayed
Ssenyi	Lake #3	270 ± 120	1200 ± 100	Delayed
Kiremba	Hand Pump #1	N.D	330 ± 150	

[a] TNTC- too numerous to count; [b] Delayed- petrifilm plates plated at hosting site; [c] No Detection [d] Not Available; [e] H.S.C: 3M™ Petrifilm ™High Sensitivity Coliform Count Plate; 5 mL water sample

Table 4.3: Microbial results from water in storage containers

Collection Source	E. coli (CFU/100 mL) (n = 3)	Total Coliforms (CFU/100 mL) (n = 3)	Comments
Rainwater Tank	N.D. [b]	N.D.	Delayed [c]
Jerrycan Top [a]	N.D.	70 ± 60	
Jerrycan bottom	N.D.	770 ± 150	

[a] Jerrycan- water collected from protected spring
[b] No detection
[c] Delayed- petrifilm plates plated at hosting site

Nkokonjeru has a piped water distribution system. The National Water and Sewage Corporation (NWSC) conduct water quality testing twice a year. All parameters except total coliforms have recently met national standards. It costs USh50,000 to install the Nkokonjeru water distribution system at a local site. The site is charged USh1,500 per month, regardless if the system is operating or not, plus 1,250 UGX per liter of water used. The monthly bill will also include an 18% value added tax (VAT). Owners of taps charge 100 UGX per 20 liters of water to others. The Nkokonjeru water distribution system is unreliable. It can only meet 25% of the community's demand when in full operation and it has not been in full operation for over 6 months. Results show that the Nkokonjeru region in general has poor water quality. Most people collect their water from protected springs which had fair water quality. During the dry season, the flow rates of the protected springs are low. In some cases, the protected springs dry up. As a result, people have to collect their water from surface waters or unprotected springs, which are contaminated by the surrounding environment (i.e., animals, excreta, food waste).

4.2 Elemental Analysis

Elemental concentrations of all water samples were analyzed at the University of California, Davis using an Agilent 7500i (Palo Alto, CA) inductively-coupled plasma mass spectrometer (ICP-MS). A previously reported procedure was used to analyze the samples (Bambic et al. 2006).

4.2.1 Elemental Results

All elemental concentrations met WHO standards except for cadmium levels at two water sources (Data in Table A.2 and A.3 in the Water Appendix). The concentration of cadmium (Cd) (17.0 ng/L) for the water sample taken from protected spring (# 3) was five times greater than the WHO standard (3 ng/L) and a little over the standard for the Lake Victoria (# 1) water sample (3.55 ng/L). Cadmium is a naturally occurring element. Possible sources of contamination are plastic products that contain Cd pigment from paint, burning of coal or oil, and household waste (US-HHS, 1999 and WHO- Drinking Water Quality, 2006).

5.0 WATER QUALITY IMPROVEMENT

5.1 Objectives of Improved Water Quality: Implementation Trip

The objectives of the water quality improvement project for the implementation trip were as follows:

1. Implement four low-cost POU water treatment systems at RASD
    a. Monitor the quality of the treated water using the petrifilms for one year.
    b. Assess the ease of use of each POU water treatment system
2. Educate the community about water-borne diseases, post-contamination, and proper use of point-of-use water treatment systems.
    a. Members of RASD will continue education after the departure of EWB-Davis
3. Provide eight household with one of the POU water treatment systems for one year in order to access ease of use and cultural acceptability
    a. Members of RASD will collect this information by conducting monthly surveys with each household

5.2 Water Analysis

Water was collected from protected spring and surface water sources in Nkokonjeru.

Microbial analysis was conducted using 3M™ Petrifilm™ E. coli/Coliform Count Plate and 3M™ Petrifilm™ High Sensitivity Coliform Count Plate. Triplicate samples were immediately plated and incubated at the host site. None of the samples were diluted before plating. After experiencing reliability issues with the local power system, an incubator was assembled from materials acquired in the U.S. with provisions to operate on 12-volts DC with a storage battery. The storage battery was equipped with a solar panel to ensure reliable operation (Figure A.3 in Appendix). The water characteristics were not assessed for the water sources.

6 POINT –OF –USE (POU) WATER TREATMENT SYSTEMS

6.1 Filtron (Clay Pot Filter)

Filtron clay pot filters are produced by independent contractors under the direction of the international organization Potters for Peace (Bisbee, AZ). Filtron clay pots are both a physical and chemical treatment. The physical filtering characteristic makes it more suitable for turbid surface water sources, although it comes at increased maintenance and reduced life of the filter pot. The clay pots are made out of 60% dry pulverized clay and 40% screened sawdust mixture (mixtures approximate and vary with material supplies). The dimensions of the filter are 31 cm in diameter, 24 cm high, and 7.1 L volume. Pots are fired at 887 °C and then impregnated with colloidal silver. The pore size of clay pots is approximately 1 μm. The filter sits inside a 20 L bucket that is equipped with a spigot (Figure 6.1). A plastic lid is placed on top of the bucket. The flow rate for the pot is 1 to 2 liters per hr (Lantagne, 2001).

Figure 6.1: Filtron clay pot placed on a plastic receptacle

The clay pots used in Uganda were manufactured in a new facility in Kenya. Kenya's Potters for Peace representatives Reynaldo Diaz and Kaira Wagoner joined the EWB-Davis team for the installation of the pots. They had been in Kenya specifically to establish the new Filtron factory.

Their assistance added support for the overall water treatment implementations and gave them the opportunity to assess the possibility of a future plant in Uganda.

6.1.1 Experimental Method for Filtron Clay Pots

Prior to analysis, water from the protected springs was filtered through the six clay pots twice. This filtering was done to ensure that the filters were operating properly and to remove any dirt that may have come into contact with the clay pots during transport. Clay pots were used to treat two different water sources. The treated water was tested at three different detention times (i.e., first flush, 24 hours later, and 6 days later).

6.1.2 Results

There was no detection of E.coli or total coliforms using the 3M™ Petrifilm™ E. coli/Coliform Count Plate. Using the High Sensitivity Coliform Count Plate there was detection of coliforms after first flush (Tables 6.1 and 6.2).

Table 6.1: Microbial results of water collected from the protected spring and surface near RASD

	Protected Spring (CFU/100 mL) [a]	**Surface Water (CFU/100 mL) [b]**
E. coli **(n = 3)**	33 ± 58	500 ± 100
Total Coliforms **(n = 3)**	167 ± 58	14233 ± 902
Total Coliforms: H.S.C. [c] **(n = 3)**	360 ± 60	TNTC

[a] Water from the protected spring was collected using jerrycan # 2 on August 21, 2007
[b] Water from the surface was collected using jerrycan # 1 on August 22, 2007
[c] Total coliforms detected using High Sensitivity Coliform Count Plate (H.S.C)

Table 6.2: Microbial results of treated water using Filtron clay pots

Source	**First Flush**	**24 hours**	**6 days**
Protected Spring [a]	N.D.	N.D.	N.D.
Surface Water [b]	N/A	Total Coliforms = 113 (CFU/100 mL) ± 23 [c] (n = 3)	N.D.

[a] Five different clay pots were used for the treatment of water from the protected spring;
[b] One clay pot was used for the treatment of water from the surface
[c] Total coliforms detected using H.S.C.

6.2 Solar Water Disinfection (SODIS)

The SODIS is a POU treatment that uses the sun's UV rays (wavelength 320-400 nm) to destroy pathogenic microorganism (EAWAG, 2008). The sunlight also increases the temperature within the plastic bottle, which increase the rate of disinfection. The Swiss Federal Institute for Environmental Science and Technology (EAWAG) and EAWAG's Department of Water and Sanitation in Developing Countries (Sandec) has done extensive research on the treatment effectiveness of SODIS. Previous research has shown that temperatures above 50°C increase the disinfection efficiency by 3 fold ((EAWAG, 2008).

6.2.1 Experimental Method for SODIS

Bottles made from polyethylene terephthalate (PET) plastic were collected during the first two weeks of the implementation trip. Table 6.4 displays the type of bottles collected. A funnel was used to fill the bottles with water from the protected springs. Bottles were first filled with water from a protected spring three-fourths of the way and then shaken for 20 seconds. After shaking, the bottles were filled completely with water. Bottles were placed on top of RASD's tin roof. Water was tested after 6.5 hr of sunlight exposure. Bottles were then placed inside RASD's facility and tested the following morning to determine if bacteria re-growth had occurred. Bottles were placed back on the roof for another 6.5 hours and retested. In a second set of experiments the same test was performed to treat surface water using SODIS. Based on the first set of data, different bottles were chosen for surface water treatment (Table 6.6). Treated surface water was tested after 6.5 hr and again on the second day.

6.2.2 Results

The first day experiments that treated the protected spring water (Table 6.3) took place on a day that was mostly sunny. Both the Coke and Rwenzori (local bottled drinking water) bottle had no detection of coliforms after different times of treatment The Coke bottles are preferred

over the Rwenzori drinking water bottle because of its larger volume. The dark blue-tinted Aqua Sipi (another local bottled drinking water) bottle did not treat water as effectively and there were some viable bacteria left that could have grown back (Table 6.4)..

Table 6.3: Microbial results of the water collected from the protected spring near RASD

Source	**E-coli/Total coliforms plate (CFU/100 mL) (n = 3)**		**H.S.C. (CFU/100 mL) (n = 3)**
	E-coli	Total	Total
Protected Spring [a]	N.D.	267 ±289	340 ± 40

[a] Water from the protected spring was collected using jerrycan # 1 on August 21, 2007

Table 6.4: Microbial result of treated protected spring water using SODIS

Bottle	**Volume (L)**	**Hour & Percentage of Sunlight Exposure**	**E-coli/Total coliform plate (CFU/100 mL) (n = 3)**		**H.S.C. (CFU/100 mL) (n = 3)**
			E-coli	Total	total
Clear Coke Cola (Soda)	2	6.5 hr and 95 %	N.D.	N.D.	N.D.
		6.5 hr and 95 %, Sat overnight	N.D.	N.D.	N.D.
		day 2 and 95 %	N.D.	N.D.	N.D.
Light-blue Rwenzori (Water)	1.5	6.5 hr and 95 %	N.D.	N.D.	N.D.
		6.5 hr and 95 %, Sat overnight	N.D.	N.D.	N.D.
		day 2 and 95 %	N.D.	N.D.	N.D.
Dark-blue Aqua Sipi (Water)	1.5	6.5 hr and 95 %	N.D.	N.D.	N.D.
		6.5 hr and 95 %, Sat overnight	N.D.	N.D.	133 ± 12
		day 2 and 95 %	N.D.	N.D.	N.D.

The second set of experiments that tested treated surface water (Table 6.5) took place on a partly cloudy day. The treatment of water took a longer time on partly cloudy days. There was a higher concentration of total coliforms detected in the 2 L bottles after the 6.5 hr sunlight exposure (Table 6.6). Both the Coke and Fanta bottle had a volume of 2 L. Less sunlight reduced UV and resulted in dose lower temperatures. These factors affected the treatment effectiveness for the larger volume on the second experiment. UV light has to travel further through a larger bottle. The light-blue Rwenzori bottle, with a volume that was smaller than the soda bottles, had the best treatment of all three bottles used in the tests.

Table 6.5: Microbial results of the water collected from the surface near RASD

Source	E-coli/Total coliform plate (CFU/100 mL) (n = 3)		H.S.C. (CFU/100 mL) (n = 3)
	E-coli	Total	Total
Surface Water [a]	1067 ± 153	23467 ± 2466	TNTC

[a] Water from the surface was collected using jerrycan # 1 on August 28, 2007

Table 6.6: Microbial result of treated surface water [a] using SODIS

Bottle	Volume (L)	Hour & Percentage of Sunlight Exposure	E-coli/Total coliform plate (CFU/100 mL) (n = 3)		H.S.C. (CFU/100 mL) (n = 3)
			E-coli	Total	Total
Clear Coke Cola (Soda)	2	6.5 hr and 70 %	N.D.	7233 ± 1050	TNTC
		day 2 and 70 % (cloudy and rain)	N.D.	N.D.	960 ± 171
Light-blue Rwenzori (Water)	1.5	6.5 hr and 70 %	N.D.	3333 ± 929	13200 ± 1200
		day 2 and 70 % (cloudy and rain)	N.D.	N.D.	N.D.
Clear Fanta (Soda)	2	6.5 hr and 70 %	N.D.	5267 ±1201	21200 ± 3020
		day 2 and 70 % (cloudy and rain)	N.D.	N.D.	N.D.

[a] Collected surface water for this experiment was cloudy; was not filtered before treatment

Clear skies and high temperatures were optimal for SODIS treatment. A large volume of water can be effectively treated under these conditions. On partly cloudy days, a smaller clear bottle would be preferable because there is a shorter distance for the UV light to travel. Using dark-colored bottles is not recommended because of the reflection and absorption of light from the tinted plastic. SODIS treatment is not recommended for highly turbid waters (< 30NTU) ((EAWAG, 2008). If no other treatment options are available it is recommended that the water be filtered before putting it into bottles.

6.3 WaterGuard (Chlorine disinfection)

Population Service International (PSI) produces and distributes WaterGuard in Uganda and the same product under different names throughout the developing world. WaterGuard is a

liquid chemical water treatment that consists of 1% sodium hypochlorite. Sodium hypochlorite treatment provides residual disinfect ion capability. A 150 mL bottle can treat 1000 L of water. The disadvantage to this POU treatment system is that sodium hypochlorite does not deactivate Cryptosporidium or Giardia Lamblia (WQH, 2003). Chlorine treatment is also less effective with highly turbid waters (WHO- Drinking Water Quality, 2006).

6.3.1 Experimental Method for WaterGuard

WaterGuard treatment was applied to the two different water sources and the treated water was tested. The two receptacles were each filled with 20 L of water from the protected spring and surface water respectively. A cap-full (~ 3 mL) of WaterGuard was added to each receptacle. The water in each receptacle was stirred and allowed to sit for 30 minutes. The protected spring water was tested after the 30 minute treatment. The surface water was tested at two detention times (i.e., 30 min and 3 days) because it was assumed that the 30 minutes would not be a sufficient time because the water was cloudy (turbid).

6.3.2 Results

There was no detection of E. coli or total coliforms using the 3M™ Petrifilm™ E. coli/Coliform or the High Sensitivity Coliform Count Plate (Table 6.7). Despite the turbidity of the surface water, 30 minutes was a sufficient amount of time for complete treatment.

Table 6.7: Microbial results of water from protected springs and surface before and after treatment with WaterGuard

	Before Treatment (CFU/100 mL) (n = 3)				After Treatment (CFU/100 mL) (n = 3)		
Source Name	**E. coli**	**Total**	**H.S.C.**	**Detention Time**	**E-coli**	**Total**	**H.S.C.**
Protected Spring [a]	33 ± 58	167 ± 57	360 ± 60	30min	N.D.	N.D.	N.D.
Surface water (cloudy) [b]	300 ± 265	14000 ± 624	TNTC	30 min	N.D.	N.D.	N.D.
Surface water (cloudy)				3 days	N/A	N/A	N.D.

[a] Water from the protected spring was collected using jerrycan # 2 on August 21, 2007
[b] Water from the surface was collected using a jerrycan, which was only used for WaterGuard treatment, on August 28, 2007

6.4 SilverDyne (colloidal silver)

SilverDyne, supplied by the World Health Alliance International (Las Vegas, NV), is a colloidal silver based solution that consists of clustered double distilled water compound (WHAI, 2008). Colloidal silver are fine particles of silver held in suspension. Colloidal silver works by disabling the enzymes in viruses, pathogens, bacterium, and fungi, which leads to their death (Kombucha, 2008). SilverDyne also provides residual disinfectant ion capacity.

6.4.1 Experimental Method for SilverDyne

SilverDyne treatment was applied to the two different water sources and the treated water tested. The two receptacles were each filled with 20 L of the water from the protected spring and surface water respectively. One drop of SilverDyne was added for every two liter of water. For very dirty (turbid) water, 2 drops were added for every liter (WHAI, 2008). The water in each receptacle was stirred and allowed to sit for 30 minutes. The protected spring water was tested after the 30 minute treatment. The surface water was tested at two detention times (i.e., 30 min and 3 days) because it was assumed that the 30 minutes would not be a sufficient time because the water was cloudy (turbid).

6.4.2 Results

The protected spring water had a low concentration of coliforms after treatment. It is hypothesized that a slightly longer detention time would eliminate all coliforms, since the more contaminated turbid water tested clean after 3 days. The surface water collected for this experiment had the highest detection of E. coli and total coliforms of all the other surface water samples that were collected. E. coli and total coliforms were both detected after treatment of the surface water. The allocated time for treatment for the surface water, 30 minutes, was not sufficient. A detention time of three days was a sufficient amount of time for treatment (Table 6.8).

Table 6.8: Microbial results of water from protected springs and surface before and after treatment with SilverDyne

	Before (CFU/100 mL) (n = 3)				After (CFU/100 mL) (n = 3)		
Source Name	**E-coli**	**Total**	**H. Total**	**Detention Time**	**E-coli**	**Total**	**H. Total**
Protected Spring	0	133 ± 58	293 ± 31	30min	0	0	6.67 ± 12
Surface water (cloudy)	967 ± 379	22800 ± 1587	TNTC	30 min	200 ± 173	3967 ± 2.40	12800 ± 693
Surface water				3 days	0	0	0

[a] Water from the protected spring was collected using a dirty jerrycan on August 21, 2007
[b] Water from the surface was collected using a jerrycan, which was only used for SilverDyne treatment, on August 28, 2007

6.5 Sustainability and Participation: POU Water Treatment Systems

Overall, there were lower concentrations, measured as CFU/100 mL, with longer detention times. It is recommended for all POU systems that water be filtered before treatment for highly turbid water. The life-span of the Filtron clay pots is approximately two years with the treatment of highly turbid water. Highly turbid water decreases the flow rate and also increases maintenance frequency of the clay pot. It is hypothesized that clay pots would have a longer life-span if turbid water was not filtered on a continuous basis. The advantage of the Filtron system is

that it filters, disinfects, and produces a residual disinfectant from the silver colloid impregnation.

Previous research has shown that concentration of silver (~ 44 µg/L) after the first filtration of water using the Filtron clay pot was a high compared to concentration (~ 11 µg/L) of silver after the second filtration (Lantagne, 2001). This concentration did not violate USEPA or WHO standards (100 µg/L) (WHO- Drinking Water Quality, 2006). Experimental trials have been conducted to determine the decreasing concentration of silver colloid after each filter of water. Results showed a decrease in concentration of sliver in water after each filtration. The data from this research was only collected for a 3 month period. Lantange acknowledge that further research needs to be conducted in order to determine the depletion of silver colloid after months of use.

Filtron can treat approximately 7,500 liters of water during its useful life. The clay pot and the receptacle cost approximately US$10 - 15. Total operational costs, not including maintenance, are US$0.0013 - 0.002/liter for this system.

SODIS treatment is a good system for areas that receive substantial amount of sunshine and low turbidity water (< 30 NTU). Although the SODIS treatment system is relatively inexpensive, treatment was inefficient and difficult to define. The climate within central Uganda consists of two dry (December to February, June to August) and one rainy season (CIA, 2008). The dry season still gets a large amount of rainfall (See Figure A. 4 in Water Appendix on rainfall data). In order to ensure proper disinfection during cloudy days, the bottles would need to be on the roof for 24 hours. Additional time would be needed for the water to cool down after being in the sun.

WaterGuard is sold in urban Uganda for 700-1000 UGX (The exchange rate at the time of the implementation trip was USh1726 UGX to US$1 USD (Oanda, 2008)). A bottle of WaterGuard lasts two months for a family living in rural Uganda. Treatment of water with a bottle of WaterGuard would be US$0.00041 - 0.00058/liter.

SilverDyne currently is not available in Uganda but efforts are on the way to develop

marketing and distribution. SilverDyne has the same residual benefits as the WaterGuard treatment, with the added benefit that SilverDyne has no distinct smell or taste after treatment. A 30 mL bottle of SilverDyne cost US$3.50 – 5.00. A single bottle can treat 1200 liters of water, if properly used. One bottle of SilverDyne would last a little over two months for a family. Treatment of water with a bottle of SilverDyne would cost US$0.0029 - 0.0042/liter.

EWB-Davis, along with the members of RASD, held educational seminars to address water-borne disease, post contamination, and proper use of each POU water treatment systems. Each of these systems incorporated a bucket with a lid and spigot to prevent post contamination. Each of the technologies was implemented in two different homes. Members of the RASD team are visiting each family once a month to survey the acceptability, test the water quality of the product and ascertain long-term effectiveness of each technology.

The SODIS treatment system was abandoned early in the implementation experiment. Families stated that they were concerned about treatment unreliable when testing showed contamination in the product. The families with the WaterGuard complained of a chlorine taste and smell. SilverDyne had good reviews but the since this product is currently not available in Uganda, the families were less accepting of the product. Filtron clay pots received high reviews in cultural acceptance. This system is the most expensive initial investment system of all water treatment systems implemented. The reason why this system was culturally accepted is that people could see the turbid water being filtered. The physical treatment was preferred over the chemical treatment. Physical treatment allowed for people to see their turbid water turn clean. Chemical, even though treatment can be justified with chemistry and the water quality analysis, was still hard for people to accept that their water was truly treated.

7.0 SANITATION

7.1 Sanitation: Lack of Access in the World and Uganda

Adequate sanitation is divided into two categories. The first category is sanitation

hardware, which is the physical structure or designated area that collects waste excreted from humans. The second category is sanitation software, which is the promotion of proper hygiene (e.g., proper hand washing) **(**WELL, 1998). The World Health Organization (WHO) estimated that 2.4 billion people lacked access to adequate sanitation (WHO, 2004). Lack of funds, education, and infrastructure does not allow for a community to successfully implement and operate a sophisticated centralized or decentralized wastewater treatment plant (WWTP). Limited access to freshwater supplies does not give a big incentive to use sanitation systems that require water.

Only 41% of the rural population in Uganda has access to adequate sanitation facilities (UNICEF, 2006). The most common sanitation hardware system, for the population that does have access, is a pit latrine (Pickford and Shaw, 2007). Ugandans that can not afford a hardware system or pay to use public facility use the open field, "bush" (Uganda Bureau of Statistics, 2004).

7.2 Sanitation Health Related Problems

As previously mentioned, poor sanitation is partly responsible for diarrheal diseases. Schistosomiasis, a parasite disease caused by flatworms, causes 15,000 deaths per year due to inadequate sanitation (CDC - Schistosomiasis, 2008). Ascariasis and hookworms, diseases associated with parasitic intestinal helminthes infections, each cause 3000 deaths per year (WHO, 2004). Improved and basic sanitation can reduce diarrhea, schistosomiasis, ascariasis, and hookworm morbidity by 32, 77, 29, and 4 percent respectively (WHO, 2004). Table B.1 and B.2 in the sanitation appendix, displays other pathogens that have been detected in excreta.

7.3 Overview of Assessment Trip: Sanitation

EWB- Davis collected data on sanitation in the Nkokonjeru council through observation, dialogue and hospital records of sanitation related diseases. In general they found that the

majority of the population did not have access to adequate sanitation; people who had access used pit latrines. The most common sanitation system that was observed was a pit latrine with a makeshift wooden slab (Figure 7.1).

Figure 7.1: Pit latrine with a makeshift wooden slab

The common problems expressed with the pit latrine were flooding of the pit during the rainy season and termite invasion of wooden slabs. Downstream contamination to freshwater supplies or home owner properties would sometimes occur due to flooded pits. The safety and life-span of the wooden slab was a big concern. Termites are endemic in the eastern region of Uganda. Wooden slabs are often consumed by the termite which leads to its destruction. The owners of the pit latrine have the options of replacing the wooden slab every two years, which is expensive, or keep the slab for a longer period of time and have the risk of it breaking. Concrete slabs have a long life-span but are too expensive for most people. A small percentage of the community owned a concrete slab. Public facilities had concrete slabs for their pit latrines, but people had to pay a fee to use the facilities.

The directors of RASD stated that there was not a plan for improving the sanitation systems. Pit latrines were quickly filling up and there was limited space to dig new pits. The biggest limitation in the implementation or improvement of sanitation systems was the lack of finances. Some villages and slums do not have enough space to implement individual pit latrines.

8.0 SANITATION IMPROVEMENT

8.1 Objective of Improved Sanitation: Implementation Trip

The objectives of the sanitation improvement project for the implementation trip were as follows:

1. Implement sanitation solutions that have long life spans at RASD
    a. Members of RASD would record people's opinion on preference and ease of the systems for one year
2. Train a local mason to construct the sanitation systems
    a. The mason would be responsible for educating other masons in the construction of the sanitation systems
3. Hold community discussions and surveys at RASD in order to determine cultural opinions about the sanitation systems

8.2 Potential Sanitation Solutions

Decentralized sanitation systems are POU systems that individuals can build and utilize on site to manage their waste own water resources. Decentralized sanitation systems do not require a large amount of time in planning and implementing. As a result, communities can experience direct benefits from a decentralized system faster than a centralized system. Waste from decentralized systems can be quickly processed into a valuable resource. Adequate sanitation for a person living in rural Uganda with low a income and minimal education would be a simple decentralized system that is economically affordable, had a long life-span, is within short walking distance, and does not use any other limited resources (i.e., freshwater, wood). Two systems that met these requirements are the Urine-Diversion (UD) Toilet and the Un-reinforced Concrete Dome (URCD) Toilet.

9.0 SANITATION SYSTEMS

9.1 Urine-Diversion Toilet

An UD toilet is a POU sanitation system that separates urine from the feces - the urine and feces are collected and stored in separate receptacles. The system is constructed out of

bricks, reinforcement steel, and concrete. A 30 L bucket is used to collect feces and a 20 L jerrycan is used to collect the urine (Figure 9.1).

Figure 9.1: UD toilet implemented at RASD

Urine and feces can be valuable resoucres as fertilizers and soil amendments when simply and inexpensively composted. According to WHO, excreted waste (urine and feces) can be used on agricultural sites as long as they do not compromise human health, pose a negative effect on water resources or the environment, and the nutrients are recycled for food production (WHO- Sanitation, 2004).

Excreta is full of nutrients (Table 9.1) and the use of the treated waste closes the nutrient cycle (garden to table and back again). In rural Uganda, 75% of the population are subsistence farmers (Uganda Bureau of Statistics, 2004). After years of cultivating on the same land, nutrients have been depleted and the soil quality has diminished. The use of treated excreta can not only improve the soil quality but also increase food production (WHO- Sanitation, 2004).

Table 9.1: Estimated excreta per capita for Uganda total population

Excretion rate (kg/person per year)			
	Nitrogen	Phosphorus	Potassium
Urine	2.2	0.3	1
Faces	0.3	0.1	0.4

Source: Jonsson and Vinneras, 2004

UD toilets save vast amounts of water over water-based systems. The odor of this system is minimized because the urine is collected before it is mixed with the solid materials and the solids covered with ash, sawdust or soil. The receptacles are filled more slowly because the urine and feces are not collected in the same receptacle. Pits do not need to be dug every few months unlike the traditional pit-style toilets. The UD toilet is an unconventional sanitation system in Uganda, which can be an issue for cultural acceptance. The squat plate does not resemble the

squat plates of pit-latrine slabs (Figures 9.2 and 9.3). The handling of waste is an unattractive quality of the system. The UD toilet at RASD will serve as a demonstration unit. The community will also be educated on proper treatment and use of the excreta.

Figure 9.2: Squat plate for UD toilet at RASD

Figure 9.3: Squat plate for pit latrine Source: Morgan, 2007

9.2 Urine

Urine is rich in available plant nutrients (N/P/K 18:2:5) (Palmquist and Jönsson, 2004). Nitrogen is the major nutrient found in urine. The main form of nitrogen in excreted urine is urea (75 – 90 %). Ammonia, which is the main degradation product of urea, increases the pH of the urine. The high pH assists in the destruction of any microorganisms that may be present in urine **(**Pradhan et al., 2007). The chemical composition of human urine depends on the person's diet, water consumption, body size and environment (Sullivan and Grantham, 1982). It is assumed that unanalyzed urine has a nitrogen concentration of 3 - 7 kg per liter (Jonsson and Vinneras, 2004).

9.2.1 Risk of Urine Use

Pathogens that are often detected in urine are Leptospira interrogans (Leptospira), Salmonella typhi (S. typhi), Salmonella paratyphi (S. paratyphi) and Schistosoma haematobium (Feachem et al., 1983). Table B.3 in the sanitation appendix displays other pathogens that have been detected in urine but their presence is insignificant due to low risk for disease transmission

(Schönning, C. and Stenström, 2004). Leptospira, a bacterial infection, is usually transmitted by urine of infected animals (Arzouni et al., 2002). The occurrence of leptospira in human urine is low (Feachem et al., 1983; CDC- Leptospirosis 2003). S. typhi and S. paratyphi are typically found in urine when a person has been infected by typhoid and paratyphoid fevers (Schönning, C. and Stenström, 2004). The Center of Disease Control and Prevention (CDC) estimated that 12.5 million people per year, mainly in developing countries, are infected with these diseases (CDC-Leptospirosis 2003). Urine-oral transmission is very low and the time it takes to deactivate the bacteria is short (Feachem et al., 1983, Höglund, 2001). A form of schistosoma is excreted as eggs in urine. The larvae from the eggs infect freshwater snails which in turn infect humans through skin penetration. This risk is reduced when urine is stored for a proper amount of time and if the urine is applied to arable land. There is minimal risk associated with using urine as a fertilizer. The risk increases when feces, which contain numerous harmful pathogens, cross-contaminates urine (Schönning, C. and Stenström, 2004).

9.2.2 Treatment of Urine

Optimal storage time and temperature are the key factors in the treatment of urine (Table B.4 in the Sanitation Appendix). Longer storage time increases the amount of ammonia produced, which increases the pH. High temperature increases the rate of treatment. High pH and temperature facilitate the destruction of microorganisms that may be present in the urine. WHO recommends that the urine not be diluted during storage. Undiluted urine provides a harsher environment for microorganisms and it also prevents mosquito breeding (WHO-Sanitation, 2004).

9.2.3 Use of Urine and Case Studies

Undiluted or diluted (with freshwater) urine is applied prior to sowing or initial plant growth

(WHO- Sanitation, 2004). Previous studies demonstrate an increase in growth and yield of lettuce, spinach, tomato, corn (Morgan, 2007), cucumbers (Helvi Heinonen-Tanski, 2007), and cabbage (Pradhan et al., 2007) with the use of urine as the fertilizer. Pradhan et al. (2007) found that application of urine to cabbage crops did not pose a hygienic threat and did not leave any distinct flavor to the cabbage. Pradhan et al. (2007) hypothesized other crops would also produce a greater yield with the use of urine.

9.3 Fecal Matter

Generally, feces have lower concentrations of nutrients than urine (WHO- Sanitation, 2004). Feces do have a higher concentration of potassium and phosphorous than urine, which are the key elements for increased crop yield (Morgan, 2007, WHO- Sanitation, 2004). The organic matter in feces has the ability to retain water and ions, which is a key factor in the improvement of soil structure and the stimulation of microbial activity (WHO- Sanitation, 2004).

9.3.1 Risk of Fecal Matter Use

The main risk associated with using treated excreta is accidental ingestion of feces that contain active pathogens. Most common infection associated with ingestion is gastrointestinal which cause diarrhea, vomiting, and stomach cramps (Schönning, C. and Stenström, 2004). Figure 9.4 displays other possible routes of transmission of pathogens from fecal matter. It is essential for the treatment of excreta to be in a confined place not subject to storm water runoff. If uncontained with pathogens still active, there could be potential pollution to water sources used for consumption or recreational activities. Schonning et al. (2007) assumed that exposure to excreta through composting could occur during: emptying of the container and

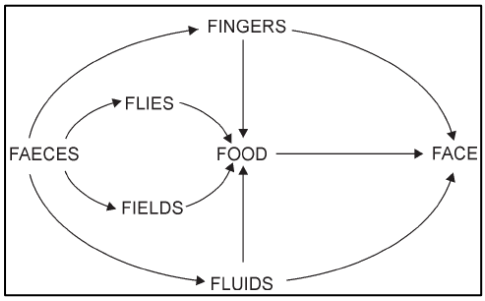

Figure 9.4: "F-diagram" Transmission paths of pathogen in feces (Source: Esrey et al.1998).

distribution of the material, recreational activities in the garden, and gardening (Schonning et al., 2007).

Fertilizer that is not completely free of pathogens is sometimes applied to crops. The handling of the crops can lead to the transmission of pathogens. Table B.5 in the sanitation appendix displays the estimated survival of organisms applied on crops. Helminth eggs take the longest time to die in feces. Table B.6 in the sanitation appendix displays the risk associated with handling excreta from dry toilets. It also displays behavioral practices that will decrease the risks. Cultural beliefs and human behavioral patterns are key factors in the risk assessment.

9.3.2 Treatment of Feces

Treatment processes such as composting, anaerobic digestion, and alkaline addition reduce pathogens found in feces. Anaerobic digestion will not be considered in this research because of its requirement for mechanical energy and skilled labor. Composting is a biological process that takes organic waste (i.e., human and animal excreta and organic food waste) and converts it to stable, pathogen free organic fertilizer ('humus'). High temperature ("thermophilic") composting is achieved under aerobic conditions, which are essential for the destruction of pathogens and parasites. The ideal temperature range for the inactivation of most pathogens in a compost pile is 131-149 °F (Haug, 1993). To achieve high-temperature thermophilic composting, feces can be added to an existing high temperature windrow composting pile or a new windrow composting pile can be started.

Buried waste has limited interaction with oxygen. Bacterial decomposition still occurs but under anaerobic conditions, which is a much slower, cooler, and foul smelling (i.e., if uncovered) process (Jenkins, 2005). Low temperature ("mesophilic": 68-113 °F) composting is known as moldering. Climate, moisture, microbial competition, antagonism, predation, desiccation, and time are factors that determine the rate of destruction of pathogens in excreta.

Mesophilic composting will eventually reach an environment where the pathogens will decompose but it takes six months to a year for this decomposition to occur (Smith, 1992) (Table B.7 in the Sanitation Appendix).

A carbon to nitrogen ratio of 30 to 35 is needed to maintain proper composting. The ratio is achieved by adding a bulking agent such as sawdust, paper product, bark dust, food scraps or ash. The bulking material also serves as a drying agent, which helps control odor and breeding of flies (WHO- Sanitation, 2004, Jenkins, 2005). Adding a bulking material traps interstitial air spaces, which is essential for thermophilic decomposition (Jenkins, 2005**).** The UD toilets confine the excreted waste in its own receptacle. Excreta left in the receptacle, where air circulation is poor, will undergo moldering composting.

The feces are collected in an easily accessible, removable receptacle. After defecation, the new fecal matter is covered with a quantity of dry material (a mix of ash or lime and a high C:N material such as rice hulls or sawdust). The dry material serves several purposes; it absorbs any remaining moisture, thus reducing odors, maintains a high pH, which aids in the destruction of harmful pathogens, and covers the material, which reduces pest problems (WHO- Sanitation, 2004). High pH aids in the inactivation of microorganism (Schönning, C. and Stenström, 2004).

9.3.3 Benefits of Using Treated Fecal Matter

Unconfined excreta has the potential to enter freshwater bodies through storm water runoff. Treated excreta that is applied to agricultural sites reduces the risk of downstream pollution. Percolation of the nutrients into groundwater or flushed into surface waters after excessive rainfall may occur, but this has less of a negative impact on water bodies than direct runoff of excreta into the water bodies (WHO- Sanitation, 2004). The UD toilet is a dry system, surface and groundwater is less susceptible to contamination from dry toilets.

The soil fertility can increase with the addition of composted feces. Essential nutrients for plant growth are released from the compost; compost creates air packs, which help in the soil pH balance, and it darkens the soil which helps with absorption of light. Thermophilic composting does not require any electricity nor does it create waste or toxic by-products (Jenkins, 2005).

9.3.4 Use of Treated Feces and Case Studies

Prior to sowing and planting, treated fecal matter is applied on the surface and integrated in the root-zone of the soil (WHO- Sanitation, 2004). Table 9.2 displays data from analyzed feces from a UD toilet and topsoils in Zimbabwe. The UD toilet soil has a much higher concentration of nutrients than the topsoils.

Table 9.2: Analysis of UD toilet humus composted in 30 L cement jars

Soil source	pH	N*	P*	K*	Ca*	Mg*
UD toilet humus (faeces, soil, wood ash)	6.72	232	297	3.06	32.22	12.06
Local topsoils (mean of 9 samples)	5.5	38	44	0.49	8.05	3.58

Nitrogen (N) and Phosphorus (P*) are expressed as ppm and Potassium (K*), Calcium (Ca*) and Magnesium (Mg*) as ME/100gms (Source: Morgan, 2003)

9.4 Un-reinforced Concrete Dome Slab (URCD) Toilet

The second system designed and implemented was the URCD toilet. The design for the URCD slab was based SanPlat's design (SanPlat, 2007). The URCD is a pit-style toilet. The slab for the pit is made out of a concrete mixture (Figure 9.5). The dome shape of the slab converts all the stress into compression in the concrete, thus making it very strong and eliminating the requirement for reinforcement steel. A circular concrete ring was constructed based on Peter Morgan's

Figure 9.5: URCD toilet with super structure at RASD

design (Morgan, 2007). The URCD sits on top of the concrete ring. "The ring prevents the top of the pit from caving in, it diverts rainwater away from the pit, and it elevates the slab above ground" (Morgan, 2007). The URCD is a portable system. Once the pit is filled, another pit can be dug and the URCD slab and ring can be placed over the new pit. The URCD toilet is traditional based on its pit latrine style and no handling of waste. The nontraditional aspect of this toilet is the slab. Most concrete slabs used for pit latrines are rectangular and require steel reinforcement. Convincing the local community that the URCD slab could withstand an adult's body weight was a challenge associated with the design.

Central Uganda soil is reddish-brown loam (ISHS, 2008). It is relatively difficult to dig a deep pit without the proper tools and labor. Digging a pit can be the most expensive part in the construction of a pit latrine. If a person can not afford to have a deep hole dug for them, they can dig it themselves. There are two, more sustainable alternatives with pit-style latrines. The first one that will be discussed is the Arborloo and the second is the Fossa Alterna.

9.5 Arborloo Method

The Arborloo method uses the concrete ring and URCD slab but the pit for the latrine is very shallow (~0.6 m- 1.0 m deep). It would take 6 months to a year for a medium size family (5 people) to fill the pit with a mixture of excreta, leaves, ash, and soil (Morgan, 2007). Once the pit is filled, the ring, slab, and structure (optional) are moved and placed on a new pit site (Figure B.1 in the Sanitation Appendix) (Morgan, 2007). One of the three alternatives can take place with the contents at the old pit site:

1. Cover the pit with ~15 cm of good soil and wait to plant a tree until the rainy season.
2. Cover the pit with ~15 cm of good soil and plant a tree right away. The tree needs more care if it is planted during the dry reason.
3. Cover the pit with ~15 cm and let it compost for a year. Dig the contents out and apply it to garden or tree.

The filled pit is an organic oasis for the trees and vegetables. Ash or soil is added after each excreta deposit. Dry material does not need to be added after each deposit of urine. The shallowness of the pit allows more oxygen to circulate thus encouraging aerobic composting conditions. The compost within the pit loosens soil and increases soil fertility. The advantages to this system are there is no handling of waste, fruit orchard and wood lots can be planted, and a shallow pit reduces the chances of contamination to groundwater for area with a high water table. The disadvantage of this method is that there must be sufficient land space for multiple pit sites.

9.5.1 Case Studies of Arborloo Method

Nutrients were examined and compared between Zimbabwe topsoils and Arborloo pit soil. Arborloo pit soil consisted of excreta, urine, and poor topsoil. Arborloo pit soil had much higher concentrations of plant nutrients than the topsoil only (Table 9.3).

Table 9.3: Analysis of Arborloo pit soil compared to a mean of various topsoils

Soil source	pH	N*	P*	K*	Ca*	Mg*
Local topsoils (mean of 9 samples)	5.5	38	44	0.49	8.05	3.58
Arborloo (one yr. after tree planting. N=2)	5.95	111	309.5	0.95	11.07	5.1

Nitrogen (N) and Phosphorus (P*) are expressed as ppm and Potassium (K*), Calcium (Ca*) and Magnesium (Mg*) as ME/100g (Source: Morgan, 2003)

Qualitative studies have been conducted examining increase fruit production when using the Arborloo pit soil. Observational data have shown that mulberry avocado, guava, mango, paw paw, banana citrus, eucalyptus, indigenous, and ornamental trees have done well with the Arborloo system. Morgan found that trees excelled when they were planted prior to the rainy season. Vegetables have also been planted in an Arborloo pit. A study conduct by Mayling Simpson-Hebert in Ethiopia found that the pumpkin yield increased by two fold (Mayling Simpson-Hebert, 2006).

9.6 Fossa Alterna

The Fossa Alterna toilet method alternates the URCD slab between two adjacent permanent pits (0.5 m or more apart), that are approximately 1.5 m deep. The slab is moved over to the second pit once the first pit is filled. In the time it takes to fill the second pit, the content in the first pit is naturally composted. The compost from the first pit can be dug out and used as fertilizer for vegetable gardens or trees. The slab is transferred back to the first pit (Figure B.2 in the Sanitation Appendix).

The benefits of this system are that people do not have to handle the un-treated waste directly. The assumption is that the contents in the first pit are fully composted and free of pathogens within a year. Another added benefit is that a person does not need a lot of land space to construct this system. The initial cost for the Fossa Alterna system is greater than the Arborloo system because two concrete rings instead of one need to be constructed.

9.6.1 Case Studies of Fossa Alterna Method

Nutrients were examined and compared between topsoil and Fossa Alterna pit soil. Fossa Alterna pit soil consisted of excreta, urine, and poor topsoil. Fossa Alterna pit soil had much higher concentration of plant nutrients than the topsoil only (Table 9.4).

Table 9.4: Analysis of Fossa Alterna pit soil compared to a mean of various topsoils

Soil source	pH	N*	P*	K*	Ca*	Mg*
Local topsoils (mean of 9 samples)	5.5	38	44	0.49	8.05	3.58
Fossa alterna pit soil (mean of 10 samples)	6.75	275	292	4.51	11.89	5.14

Nitrogen (N) and Phosphorus (P*) are expressed as ppm and Potassium (K*), Calcium (Ca*) and Magnesium (Mg*) as ME/100gms. 1 ppm = 1 mg/kg. To obtain ppm from ME/100gms multiply by 10 and the atomic number (39.1 for potassium) (Source: Morgan, 2003).

A series of experiments were conducted in Zimbabwe using topsoil (Ruwa and Epworth (Morgan, 2003)) and combination of topsoil and Fossa Alterna soil for the growth of various

produced. The mixture of soil gave a greater yield than the topsoil alone (Table 9.5).

Table 9.5: Case study of using a mixture of topsoil and FA soil and topsoil only for the growth of crops

Plant. Top soil type. Growth period.	**Weight at cropping Topsoil only**	**Weight at cropping 50/50 mix topsoil/FA*soil**
Spinach on Epworth 30 days.	72 grams	546 grams (7 fold increase)
Covo on Epworth 30 days.	20 grams	161 grams (8 fold increase)
Covo 2. on Epworth 30 days.	81 grams	357 grams (4 fold increase)
Lettuce on Epworth. 30 days	122 grams	912 grams (7 fold increase)
Onion on Ruwa 4 months	141 grams	391 grams (2.7 fold increase)
Green pepper on Ruwa 4 months	19 grams	89 grams (4.6 fold increase)
Tomato on Ruwa 3 months	73 grams	735 grams (10 fold increase)

Source: Morgan, 2003

9.7 Sanitation Software System

Surveys conducted by the Uganda Bureau of Statistics (UBOS) found that 75% of rural households lacked hand washing facilities (Uganda Bureau of Statistics, 2004). As previously discussed, humans can transmit fecal matter through various routes. Proper hygiene is key in hindering the transmission. Hand washing after use of toilet, handling of compost, and gardening can greatly reduce transmission of pathogens. Figure 9.6 displays how personal hygiene and other practices can prevent the spread of harmful pathogens.

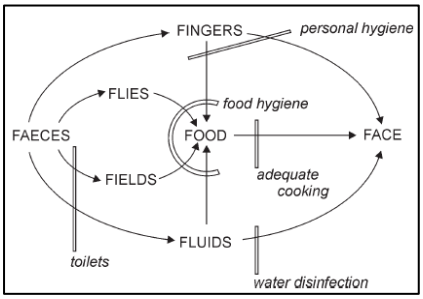

Figure 9.6: "F-diagram" Barriers for of transmission paths of pathogen in feces (Source: Esrey et al. 1998).

A simple hand-washing station was built at the RASD site to promote proper hygiene. The hand-washing station was created out of a 5-Liter jerrycan, rope, sticks from the forest, soap and a small plate (soap dish) (Figure 9.7). The hand-washing station does not require handling of the jerrycan for dispensing of water (Figure 9.8).

Figure 9.7: Simple hand-washing station implemented at RASD

Figure 9.8: Demonstration of hand-washing station at RASD

A hand-washing contest was started amongst the community to promote proper hygiene. Eight families are participating in this contest. The family that gets the most family members, friends, and neighbors to implement the hand-washing stations will get a prize for their efforts. The overall goal of this contest was to reduce transmission of pathogens that cause disease.

9.8 Sustainability and Participation: Sanitation

Community members were asked to participate in a sanitation survey. EWB-Davis gathered information on people's opinions about sanitation, hygiene, and potential financial contribution to sanitation systems, through the survey. Lack of finances was the major constraint for locals in obtaining an adequate sanitation system. The estimated cost to construct a hardware sanitation system is approximately US$75 for a UD toilet and US$35 for URCD toilet..

Microfinance was the best way EWB-Davis thought that these families could afford a sanitation system. It is the goal of EWB-Davis to raise the money through fundraising endeavors to help families make the initial investment for their toilets. EWB-Davis plans to work with the microfinance program, which is run by a RASD volunteer, to help finance the construction of these toilets.

John, the local mason, worked with EWD-Davis during the entire construction process of the sanitation systems. John shadowed members of EWB-Davis in building the first URCD slab

and helped build the UD toilet. John built the second URCD slab himself under EWB-Davis supervision. Funds were left with RASD for John to build two more URCD slabs in the surrounding communities. John and RASD were left with instruction manuals, which were translated into Lugandan (the local language), to guide them in the construction of the sanitation systems. John has the skills to train other masons to build these systems.

Ignitius Boowgi, the director of RASD confirmed that the URCD toilet was preferred over the UD toilet. Ignitius stated that in order for the UD toilets to be accepted, more educational seminars need to be held. URCD toilets have been implemented beyond the money that was provided (Figure 9.9). Money was donated to the Nkokonjeru microfinance business to support the construction of ten URCD toilets. Each loan will be US$35. The fixed interest on the loan will be 2 – 3 % per month. Monthly consumption expenditure for an average size family of five in rural central Uganda is displayed in Table 9.6.

Figure 9.9: The construction of URCD toilet near RASD

Table 9.6 Share of Monthly Household Expenditure by Item Groups in Rural Central Uganda

Items	%	USh
Food, drink, and tobacco	45	68175
Clothing and foot wear	4	6060
Rent, fuel, and power	19	28785
H/hd appliances & equip	7	10605
Transport/communication	8	12120
Education	7	10605
Health	5	7575
Other consumption	2	3030
Non-consumption	3	4545
Total	100	151500

Source: Uganda Bureau of Statistics, 2003

A typical family could readjust their monthly consumption expenditure for a five month period in order to pay for the toilet. Approximately 4 % a family's yearly income would go towards the

investment of the URCD toilet.

10.0 CONCLUSION

Sustainable point-of-use water treatment and sanitation systems were implemented in rural Uganda. The water treatment systems are low-cost solutions to poor water quality and post-contamination issues. The URCD and UD toilets are low-cost solutions to unsafe or lack of sanitation facilities. The relationship that was established with RASD was essential for these technologies to be sustainable. RASD has taken complete ownership of these systems. Members of RASD are responsible for maintaining each of the implemented systems. There is continued education and implementation of these systems across the Nkokonjeru council. Petrifilms were donated to RASD for continued monitoring of water quality. Members have also used the petrifilms as an educational tool. The used petrifilms are passed around in a plastic bag at the water seminars. People can visually observe the E.coli and coliforms on the petrifilms. Members at RASD stated that this made a big impact on people's conception on the importance of water treatment. There are continued efforts in implementation of URCD toilets and training of masons. Training local masons to build the sanitation systems has helped with the employment within the region.

The RASD's vision of training citizens in matters such as water treatment, proper hygiene, and sanitation will help illustrate how to break the cycle of ignorance and disease in rural Uganda. EWB-Davis continues to work with RASD to help reach their goals in improving the quality of life throughout the region.

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12.0 A: WATER APPENDIX

Table A.1: Pathogens that cause water-borne diseases

Organism	Disease	Remarks
Bacteria		
Escherichia coli (E. coli)	Gastroenteritis	Diarrhea
Legionella pneumophia	Legionellosis	Acute respiratory illness
Leptospira	Leptospriosis	Jaundice, fever
Salmonella typhi	Typhoid fever	Fever, diarrhea
Salmonella	Salmonellosis	Food poisoning
Shigella	Shigelloisis	Bacillary dysentery
Vibrio cholerae	Cholera	Heavy diarrhea, dehydration
Yersinia enterolitica	Yersinosis	Diarrhea
Viruses		
Adenovirus	Respiratory disease	
Enteroviruses (67 types, including polio, echo, etc.)	Gastroenteritis, heart anomalies, meningitis	
Hepatitis A	Infectious hepatitis	Jaundice, fever
Norwalk agent	Gastroenteritis	Vomiting
Reovirus	Gastroenteritis	
Rotavirus	Gastroenteritis	
Protozoa		
Balantidium coli	Balantidiasis	Diarrhea, dysentery
Cryptosporidium	Cryptosporidiosis	Diarrhea
Entamoeba histolytica	Amebiasis	Diarrhea, bleeding
Giardia lamblia	Giardiasis	Diarrhea, nausea, indigestion
Helminths		
Ascaris lumbricoides	Ascariasis	Roundworm infestation
Enterobius vericularis	Enterobiasis	Pinworm
Fasciola hepatica	Fascioliasis	Sheep liver fluke
Hymenolepis nana	Hymenolepiasis	Dwarf tapeworm
Taenia saginata	Taeniasis	Beef tapeworm
T. solium	Taeniasis	Pork tapeworm
Trichuris trichiura	Trichuriasis	Whipworm

Source: MEI, 1991

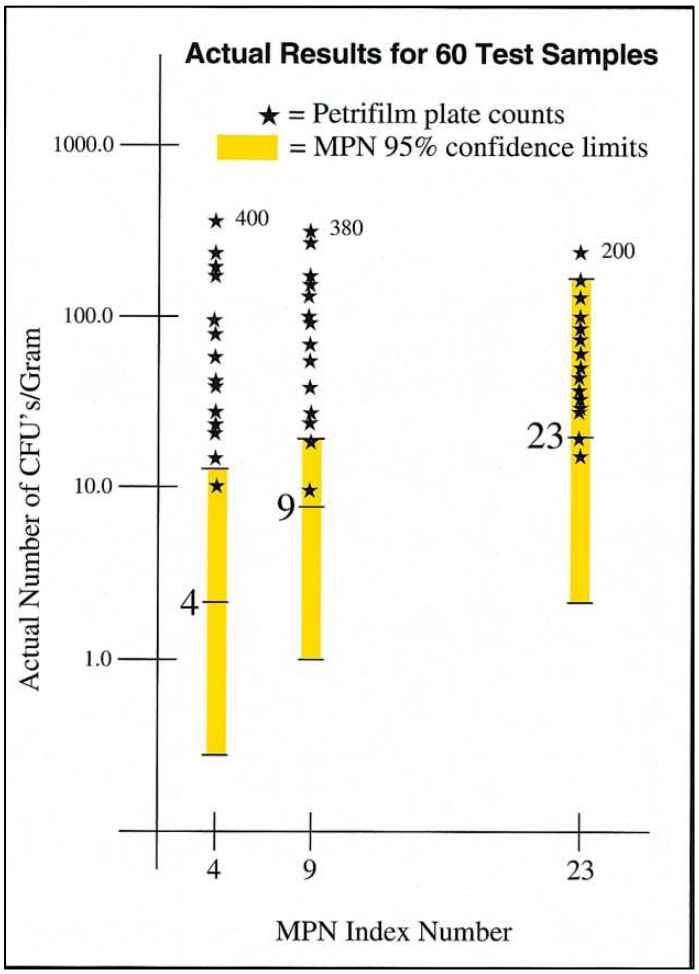

Figure A.1: The performance results of petrifilms plant versus MPN. Study conducted by Sillikers Laboratories (Source: 3M, 2008).

Table A.2: Elemental Concentration for water sources in the Nkokonjeru council Part 1

Elements	RASD Tap	Protected Spring #3	Protected Spring #6	Protected Spring #1	Protected Spring #2	Protected Spring #4	Protected Spring #5	WHO Standard µg/L [a]	Exceedance
Cr	-	-	-	-	-	-	-	50	no
Ni	1.68	2.58	1.89	0.64	1.11	1.66	0.85	20	no
Cu	31.2	0.362	0.162	-	-	-	0.149	2000	no
As	-	0.0113	-	0.00259	-	-	-	10	no
Se	0.134	0.499	0.145	0.311	0.0941	0.197	0.00290	10	no
Mo	-	-	-	-	-	-	-	70	no
Cd	0.104	17.0	0.121	-	0.237	1.20	0.171	3	yes
Ba	44.4	112	72.2	31.6	41.9	44.0	26.6	700	no
Hg	-	-	-	-	-	-	-	6	no
Pb	1.47	-	-	-	-	-	-	10	no
U	-	-	-	0.285	-	-	-	15	no

[a] WHO- Drinking Water Quality, 2006

Table A.3: Elemental Concentration for water sources in the Nkokonjeru council Part 2

Elements	Hand Pump #1	Spring #1	Lake #1	Lake #2	Lake #3	Stream #1	WHO Standard µg/L [a]	Exceedance
Cr	-	-	-	-	-	-	50	no
Ni	0.546	1.815	-	-	0.063	1.307	20	no
Cu	42.8	0.282	0.441	-	0.0394	0.537	2000	no
As	-	-	0.125	0.100	0.154	0.155	10	no
Se	0.100	0.00290	0.220	0.106	0.174	0.134	10	no
Mo	-	-	-	-	-	-	70	no
Cd	0.00250	1.29	3.55	-	-	-	3	yes
Ba	24.2	96.9	31.7	30.4	33.6	37.1	700	no
Hg	-	-	-	-	-	-	6	no
Pb	-	-	-	-	-	-	10	no
U	-	-	-	-	-	-	15	no

[a] WHO- Drinking Water Quality, 2006

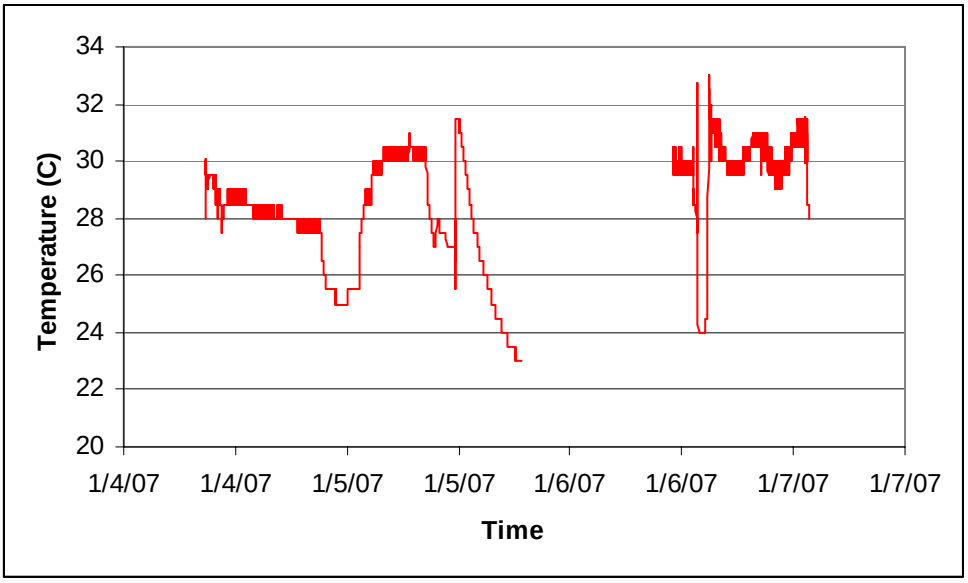

Figure A.2: EWB-Davis assessment trip data of temperature of the incubator versus time.

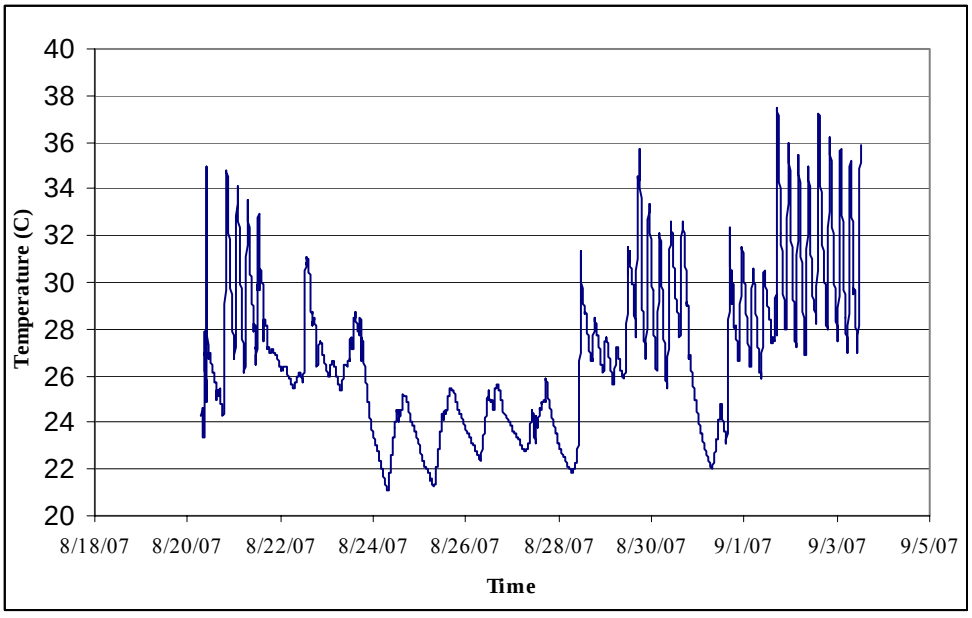

Figure A.3: EWB-Davis implementation trip data of temperature of the incubator versus time

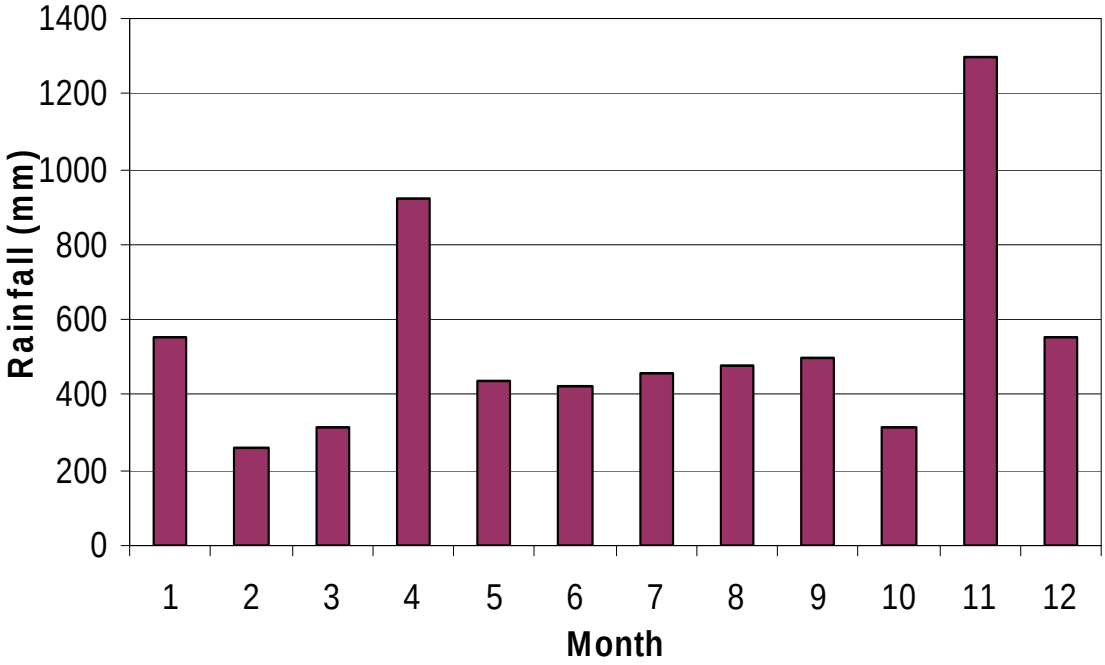

Figure A.4: Rainfall data for Nkokonjeru 2006-2007

13.0 B: SANITATION APPENDIX

Table B.1: Possible bacteria, parasites, and viruses found in excreta and the associated diseases

Organism	Disease	Remarks
Bacteria		
Aeromonas spp.		
Plesiomonas shigelloides		
Esherichia coli	Enteritis	Inflammation of the small intestine
Campylobacter jejuni/coli	Campylobacteriosis	Diarrhoea cramps, abdominal pains, fever, nausea, arthritis; Guillan-Barre syndrome
Legionella spp.	Legionellosis	Fever, chills, and a cough, which may be dry or may produce sputum
Mycobacterium avium complex	Respiratory symptoms	
Pseudomonas aeruginosa	Varying	
Salmonella typhi/paratyphi	Typhoid/paratyphoid fever	Headache, fever, malaise, anorexia, cough
Salmonella spp.	Salmonellosis	Diarrhoea, fever, abdominal cramps
Shigella spp.	Shigellosis	Dynestery (bloody diarrhea), vomiting, cramps, fever, Reiter's syndrome
Vibrio cholera	Cholera	Watery diarrhoea, lethal if severe and untreated
Yersinia	Yersiniosis	Fever, abdominal pain, diarrhoea, joint pains, rash
Organism	**Disease**	**Remarks**
Parasites		
Acanthamoeba spp.	Varying	
Ascaris lumbricoides	Loeffler´s syndrome, enteritis	Fever, dry cough, chest pain, shortness of breath, wheezing, rapid respiratory rate, rash
Cryptosporidium parvum	Cryptosporidiosis	Watery diarrhoea, abdominal cramps and pain
Cyclospora cayetanensis	Often asymptomatic;	Diarrhoea, abdominal pain
Entamoeba histolytica	Amoebiasis	Often asymptomatic; dysentery, abdominal discomfort, fever, chills
Giardia intestinalis	Giardiasis	Diarrhea, abdominal cramps, malaise, weight loss
Organism	**Disease**	**Remarks**
Viruses		
Adenovirus Unspecified		
"	Encephalitis	Acute inflammation of the brain: fever, headache and photophobia with weakness and seizures
" (Ead 40 and 41)		
Astrovirus		
Calicivirus, including Norwalk	Enteritis	Inflammation of the small intestine

Source: Ottosson, 2003

Table B.2: Possible like viruses found in excreta and the associated diseases

Organism	Disease	Remarks
Like Viruses		
Coxackievirus	Various respiratory illness; enteritis; viral; Meningitis	
Echovirus	Aseptic Meningitis' encephalitis; often asymptomatic	
Hepatitis A virus (HAV)	Hepatitis	
Hepatitis E virus (HEV)	Hepatitis	
Poliovirus	Poliomyelitis	often asymptomatic, fever, nausea, vomiting, headache, paralysis
Rotavirus	Enteritis	Inflammation of the small intestine
Small round viruses (SRV)		
Rotavirus	Encephalitis	Acute inflammation of the brain: fever, headache and photophobia with weakness and seizures

Source: Ottosson, 2003

Table B.3: Detected pathogens in urine, route of their transmission, and significance

Pathogen	Urine as a transmission route	Importance
Leptospira interrogans	Usually though animal urine	Probably low
Salmonella typhi and Salmonella paratyphi	Probably unusual, excreted in urine in systemic infection	Low compared with other transmission routes
Schistosoma haematobium (eggs excreted)	Not directly but indirectly, larvae infect humans in fresh water	Needs to be considered in endemic areas where snail intermediate hosts are present
Mycobacteria	Unusual, usually airborne	Low
Viruses; cytomegalovirus, polymaviruses JCV, BKV, adenovirus, hepatitis virus and others	Not normally recognized other than single cases of hepatitis A and suggested for hepatitis B; more information needed	Probably low
Microsporidia	Incriminated but not confirmed	Low
Sexually transmitted pathogens	No, do not survive for significant periods	Insignificant
Urinary tract infections	No direct environmental transmission	Low to Insignificant

Source: Schönning, C. and Stenström, 2004

Table B.4: Recommended storage time for urine mixture [a] treatment based on estimated pathogen content [b] and recommended crops for large systems [c]

Storage Temperature (°C)	Storage (months)	Possible pathogens in the urine mixture after storage	Recommended crops
4	≥ 1	Viruses, protozoa	Food and fodder crops that are to be processed
4	≥ 6	Viruses	Food crops that are to be processed, fodder crops [d]
20	≥ 1	Viruses	Food crops that are to be processed, fodder crops [d]
20	≥ 6	Probably none	All crops [e]

[a] Urine or diluted urine (water). When diluted, it is assumed that the urine mixture has a pH of at least 8.8 and a nitrogen concentration of at least 1 g/L

[b] Gram-positive bacteria and spore-forming bacteria are not included in the underlying risk assessments, but are not normally recognized as a cause of any infections of concern.

[c] A large system in this case is a system where the urine mixture is used to fertilize crops that will be consumed by individuals other than member of the household from whom the urine was collected.

[d] Not grasslands for production of fodder

[e] For food crops that are consumed raw, it is recommended that the urine be applied at least one month before harvesting and that it be incorporated into the ground if the edible parts grow above the soil surface.

Sources: Jonsson et al. (2000); Hoglund (2001)

Table B.5: Survival of pathogen on crops

Organism	Survival on crops (days)
Viruses	
Enteroviruses [a]	< 60 but usually < 15
Bacteria	
Thermotolerant coliforms	< 30 but usually < 15
Salmonella spp.	< 30 but usually < 15
Shigella spp.	< 10 but usually < 5
Vibrio cholerae	< 5 but usually < 2
Protozoan cysts	
Entamoeba histolytica cysts	< 10 but usually < 2
Cryptosporidium oocycts	< 3 but usually < 2
Helminths	
Ascaris eggs	< 60 but usually < 30
Tapeworm eggs	< 60 but usually < 30

[a] Poliovirus, echovirus and coxsackievirus

Sources: Fechem et al., 1983; Strauss, 1985; Robertson et al., 1992; Jenkins et al., 2002; Warnes & Keevil, 2003)

Table B.6: Possible exposure of pathogen with dry fecal and urine reuse

Risk activity	Major exposure route	Groups at risk	Risk management considerations
Emptying the collection chamber/vessel	Contact	Entrepreneurs, Residents, Local, Communities	Provision of protective clothing and suitable equipment for persons involved
			Training
			Facility should optimize on-site treatment
			Design of facility and selection of technology to facilitate safe emptying
			Avoid spillage
Transportation	Contact	Entrepreneurs, Local, Communities	Avoid spillage
	Secondary spread through equipment		Equipment not used for other purposes without proper disinfection/cleaning
Off-site secondary treatment facility (dry fecal only)	Contact (all)	Workers, Nearby communities	Ensure treatment efficiency
	Vectors		Protective clothing
			Facility should be fenced off
Application (dry fecal only)	Contact	Entrepreneurs, Residents, Local, Communities	Use "close to the ground application," work the material into the soil directly and cover
	Inhalation		Reduced access should be ensured if quality is not guaranteed; in such cases, application to parks, football fields or where the public have access should be avoided
			Protective clothing
			Minimum one month between application and harvest
Crops, Harvest, Processing, Safe	Consumption	Consumers	Crops eaten raw pose the most risk; industrial crops, biofuels or crops eaten only after cooking pose less risk
	Handling	Workers	Adequate protection clothing (gloves, shoes)
		Vendors	Provide safe water in markets for washing and refreshing vegetables
Consumption	Consumption	Consumers	Practicing good personal, domestic and food hygiene
			Cooking food thoroughly

Source: WHO-Sanitation, 2004

Table B.7: Recommended storage time for dry excreta and fecal sludge before use at the household and municipal levels [a]

Treatment	Criteria	Comment
Storage; ambient temperature 2 - 20 °C	1.5 - 2 years	Will eliminate bacterial pathogens; regrowth of E. coli and Salmonella may need to be considered if rewetted; will reduce viruses and parasitic protozoa below risk levels. Some soil-borne ova may persist in low numbers.
Storage; ambient temperature >20 - 35 °C	> 1 year	Substantial to total inactivation of viruses, bacteria and protozoa; inactivation of schistosome eggs (< 1 month); inactivation of nematode (roundworm) eggs, e.g. hookworm (Ancylostoma Necator) and whipworm (Trichuris); survival of a certain percentage (10 - 30 %) of Ascaris eggs (≥ 4 months), whereas a more or less complete inactivation of Ascaris eggs will occur within 1 year.
Alkaline treatment	pH > 9 during > 6 months	If temperature > 35 °C and moisture < 25 %, lower pH and/or wetter material will prolong the time for absolute elimination.

[a] No addition of new material
Source: WHO-Sanitation, 2004

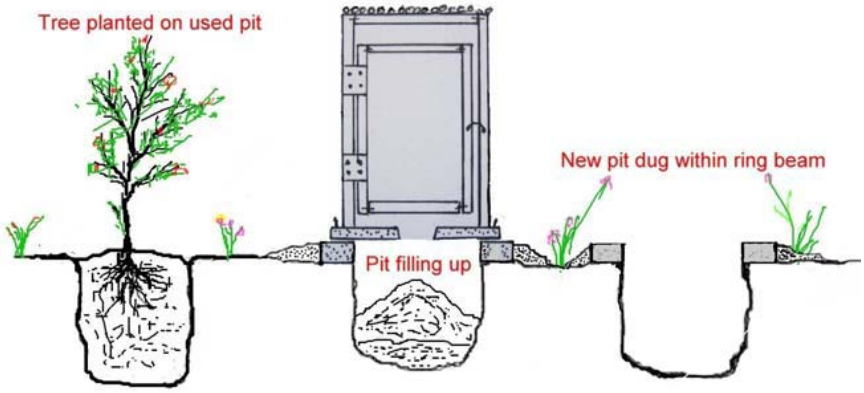

Figure B.1: Arborloo Alterna System (Source: Morgan, 2007)

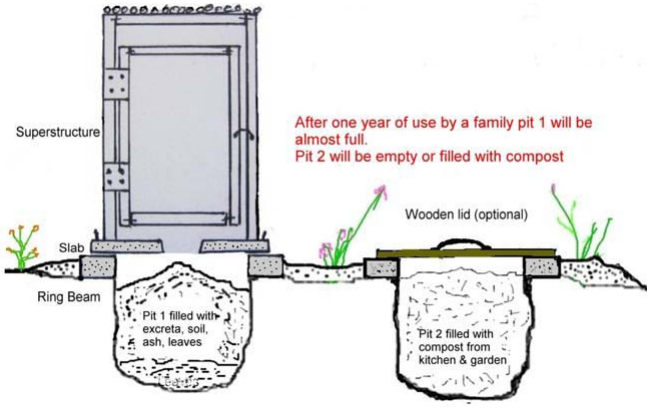

Figure B.2: Fossa Alterna System (Source: Morgan, 2007)