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Pure Home Water: Household Water Treatment and Safe Storage Implementation in the Northern Region of Ghana

MIT Ghana Master of Engineer Team
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CHAPTER 1. INTRODUCTION

1.1 The Need for Safe Water and Sanitation

Globally 1.1 billion people lack access to safe drinking water, and 2.6 billion people lack access to adequate sanitation (WHO, 2004). Primarily from unsafe water and sanitation, approximately 5000 people die everyday from diarrheal illness, mostly children under five and virtually all in developing countries. The seventh of the eight United Nations Millennium Development Goals (MDGs) is to “halve by 2015 the proportion of people without sustainable access to safe drinking water” (U.N. MDGs, 2004). Water supply, safe drinking water, adequate sanitation, and hygiene have an incredible potential to save and improve lives.

1.2 Ghana

Ghana is located in West Africa, bordered by the Gulf of Guinea (South), Cote D’Ivoire (West), Burkina Faso (North), and Togo (East). The land area is about the size of Oregon at 239,000 square kilometers with a population of 21 million people (Briggs, 2004). English is the official language, though there are over 60 local languages. The Pure Home Water (PHW) Project is taking place in the Northern Region of Ghana, one of the poorest regions in the country and with a population of 1.8 million people. The Northern Region consists of 13 districts, and the project targets six of these districts (population 851,000), with a current focus on the three districts of these districts: Tamale, Tolon-Kumbungu, and Savelugu-Nanton (population 520,000) (GSS, 2004). See Figure 1.1 below for the geographic focus of the Pure Home Water Project.

Figure 1.1. Pure Home Water Target Districts in the Northern Region of Ghana.
Map by Jenny Vancalcar, 2006

CHAPTER 1

According to the World Bank, the infant mortality rate in Ghana is 57/1000 and the under five mortality rate is 100/1000 (World Bank, 2003)[1]. Diarrhea prevalence is at 19% for children under five. In Ghana, diarrhea has been identified as the second most common health problem treated in outpatient clinics, and one of the most common causes of infant deaths (Gyimah, 2003). It is widely recognized that diarrhea results from exposure to a variety of environmental factors, particularly pathogens in water and toilet facilities.

1.3 Project Background

Pure Home Water (PHW) is a social business enterprise to implement, monitor, and evaluate household drinking water treatment and safe storage technologies in the Northern Region of Ghana. The project is the full-time effort of two social entrepreneurs named Hamdiyah Alhassan, a civil and environmental engineer, and Wahabu Salifu, a development planner. Additional team members include MIT students: three Master of Engineering students (Jenny VanCalcar, Claire Mattelet, and Rachel Peletz), four business students (Rachel Lawson, Casey Gordon, Brendan Monaghan, and Kenichi Honna), and project advisor Susan Murcott, senior lecturer at MIT. The project has been generously assisted by World Vision-Ghana and funded by the Conrad N. Hilton Foundation for two years, 2005-2007.

Hamdiyah and Wahabu, the two Ghanaian social entrepreneurs, are selling household drinking water treatment and safe storage technologies (HWTS) through door-to-door sales, community meetings, and retail sales. The purpose of the project is to demonstrate the potential to sell a range of technologies to low-income users in urban and rural areas of Ghana.

1.3.1 Goals and Objectives of Pure Home Water Project

Pure Home Water aims to provide safe drinking water to the Northern Region of Ghana as a sustainable business selling drinking water treatment and safe storage devices.

1.3.2 World Vision and WAWI partnership

Our project has an informal partnership with World Vision-Ghana. World Vision is an international Christian relief organization that began working on rural development in Ghana in 1979. In 1985, World Vision began the Ghana Rural Water Project (GRWP) which has provided over 1700 wells for over 1000 communities and 176 institutions in Ghana (World Vision). World Vision is part of the larger West Africa Water Initiative (WAWI) partnership, which is a collaboration of ten international institutions dedicated to improving the lives of poor vulnerable populations in Ghana, Mali, and Niger (World Vision).

1.3.3 G-Lab Team

MIT Sloan Business students joined the engineering team as part of the Global Entrepreneurship Lab (G-Lab) 15.389 course. The G-Lab team helped to develop the business model of Pure Home Water as a social entrepreneurship business. The business students focused on promotion and sales, product development, the set up and refinement of a financial accounting system and pricing strategies. While in Ghana, the business students spent the majority of their time with the two social entrepreneurs, focusing on the "4Ps": product, place, price, and promotion of the technologies.

[1] According to the World Factbook, infant mortality is 51/1000 for 2005 (The World Factbook, 2006).

1.3.4 *Household Water Treatment Products and Safe Storage (HWTS)*

A systematic review of 64 studies concludes that household treatment systems significantly reduce waterborne illness by improving drinking water quality (Fewtrell and Colford, 2004). Though NSF/ANSI (National Science Foundation/American National Standards Institute) does not have specific standards for HWTS, the World Health Organization (WHO) has initiated a HWTS technology verification process as part of its rolling revisions of the *Guidelines for Drinking Water Quality*. Various HWTS technologies have proven to be available and feasible for implementation in Ghana (See Table 1.1).

Table 1.1. Household Water Treatment Systems and Safe Storage.

#	Safe Household Water Product	Retail Price (US$)
1	Ceramic “Potters for Peace” Filtron (known locally as the “CT Filtron” manufactured by Peter Tamakloe or Ceramica Tamakloe	$16
2	Ceramic Candle filter (known locally as the “Nnsupa Filter,” manufactured by Michael Commeh)	$21
3	Solar Disinfection (SODIS)	$1/year
4	Biosand Filter	$11
5	Modified Traditional Clay Pots for safe storage with 3/4” brass taps, manufactured by Kukuo Village women potters	$10
6	Plastic Safe Storage Container (50 L size) +Spigot	$9
7	Household Chlorination*	$7.20/year
8	PUR**	$73/year

* Assumes $0.60 per 500 ml bottle, each bottle lasting 1 family 1 month. $0.60x12=$7.20/year. In practice, the amount used would likely be lower.
** Assumes $0.05 per sachet treating 10 L, requiring 4 sachets per day per family x 365 days/year. In practice, the amount would likely be lower.

Though this range of technologies was considered during the first six months of market analysis, the main products as of January 2006 are the Tamakloe ceramic filter, Nnsupa candle ceramic filter, and safe storage container. These products were chosen for their feasibility and practicability in Ghana. The C.T. Filtron filter is manufactured by Peter Tamakloe in Accra and the Nnsupa filter is made by Michael Commeh in Kumasi, so both are available in-country. The two different safe storage products do not treat the water, but prevent contamination by providing a covered container with a spigot.

1.4 The World Health Organization *Guidelines for Drinking Water Quality* (WHO, 2004)

The World Health Organization *Guidelines* provide the background and foundation for the project. The World Health Organization has established *Guidelines for Drinking Water Quality* (GDWQ) to provide a common point of reference for all countries. These guidelines define what can be considered ‘safe’ by establishing a basis for most national, regional, and agency level water-quality requirements worldwide.

The first step involves *health based targets* including health burdens and priorities. An epidemiological evaluation and risk assessment should initially be performed to establish the reductions in disease burdens from a given intervention. The disease burden is the estimate of disease level from water and sanitation, and is generally expressed in terms of disability-adjusted life years (DALYs). As first presented in the 1993 World Bank Development Report, DALYs measure both the global burden of disease and the effectiveness of health interventions, as indicated by reductions in disease burden (World Bank, 1993). (Section 2.2 of this thesis further discusses DALYS.) The health-based assessment also includes baseline water quality data, the establishment of performance targets, and the identification of specific technologies. For this project, the epidemiological study serves as the first stage in evaluating the disease burden.

The second step in determining GDWQ is developing a system or technology specific *Water Safety Plan (WSP)*. The goal is to ensure drinking water quality through source protection, effective treatment, and safe storage. The WSP will organize systematic management practices, ensure process control to exclude hazards, and incorporate hygiene education. In the WSP, a system assessment should be performed to determine whether the drinking water supply can deliver water to meet the health-based targets. The targets are health outcome targets, water quality targets, performance targets, and specified technology targets. Currently, the Pure Home Water project is working towards effective treatment and safe storage, but while recognizing its importance does not address source protection as one of its organizational goals.

The third step includes *independent surveillance* to verify that the system plan is operating properly. This stage includes continual public health assessment and review of the safety and acceptability of the drinking water supply system. The surveillance can be in the form of an audit or direct assessment. The assessment is often a cost-effective way to provide clear objectives for the surveillance program.

CHAPTER 2.COLLECTION AND REPRESENTATION OF GIS DATA TO AID HWTS IMPLEMENTATION IN THE NORTHERN REGION OF GHANA

2.1 Research Objective

This past January was the first time that the MIT branch of Pure Home Water had traveled to the Northern Region of Ghana. Thus, there was the need for a data gathering effort to learn as much as possible about the demographic, health, and water and sanitation infrastructure status within the region. Because of the geographic nature of the project, it was decided that a Geographic Information System (GIS) would be the best tool to store, analyze and represent the data. More than just simple maps, GIS allows for geographic locations to be connected to relevant information about the features shown on the map. For example, a point feature representing a village could have information on the population, number of boreholes and percentage of the population practicing proper sanitation. Separate features can then be layered on top of each other to show interrelations which may have not been otherwise apparent. Querying of the data can also be done to answer questions concerning the spatial relationships between features as well as the linked statistical information. In terms of this project, the GIS system was envisioned as an organizational tool to collect all relevant project information into a single database. The system could be used to help plan relevant business strategies and maps could be created to visually communicate important information among the Pure Home Water team and other interested parties.

2.2 Data Gathering

On a previous trip to Ghana in June 2005, the project's principal investigator, Susan Murcott, visited both the national and Northern Region office of the Ghana Geological Survey Department as well as the Northern Region Town and Country Planning Department in search of paper maps of the region. Unfortunately, all maps found were from the 1970s and 1980s which contained basic information but were too outdated and general for our intended uses. However, in January 2006 it was discovered that the Ghana Statistical Service (GSS) has a wealth of statistical information pertinent to the project and which they were very generous in sharing. This information is gathered through the census and other surveys of the population. Of particular interest to our project was the 2003 Health and Living Standards Survey. This document along with the year 2000 Census gave an abundance of information on the demographic, economic, cultural and health aspects of the population. The information was all in tabular form, but through GIS could be displayed visually. Some GIS work has been started within Ghana, especially by a group called the Centre for Remote Sensing and Geographic Information Services (CERSGIS) at the University of Ghana. However, the majority of this work is currently focused in the southern portion of the country and particularly around the capital of Accra. The GIS work which was obtained for the Northern Region included borehole mapping done by World Vision, the Community Water and Sanitation Agency (CWSA) and the Rural Water and Sanitation Agency (RWSA) as well as mapping of disease incidence by the Guinea Worm Eradication Program.

CHAPTER 2

Data creation was accomplished using an eTrex Venture GPS device manufactured by Garmin. The data points marked included the locations of various businesses and organizations within downtown Tamale, the location of households where Pure Home Water members conducted epidemiological surveys (Peletz, 2006), and the location of water sources tested for microbial contamination (Mattelet, 2006). Some boreholes, rivers and roads were also marked to check the accuracy and completeness of datasets which had been received from other organizations

2.3 Regional Statistics

Much of the pertinent information collected from the Ghana Statistical Service is presented in this section. Before beginning an implementation project, it is important to know the current state of affairs within a community. This way, appropriate options can be selected and effects of the implementation can be tracked. This section lays out some of the current demographic, economic, health and infrastructure conditions in Ghana, particularly for the Northern Regions and the districts of Tamale, Savelugu-Nanton and Tolon-Kumbungu where Pure Home Water is currently focusing.

2.3.1 Geographical Orientation

In order to understand the area of Ghana where the project takes place, the following two maps were created. The map on the left shows the ten regions of Ghana along with major cities and large rivers. The map on the right spits up the Northern Region into its 13 districts and highlights the three districts of Tamale, Savelugu-Nanton and Tolon-Kumbungu where Pure Home Water is currently focusing.

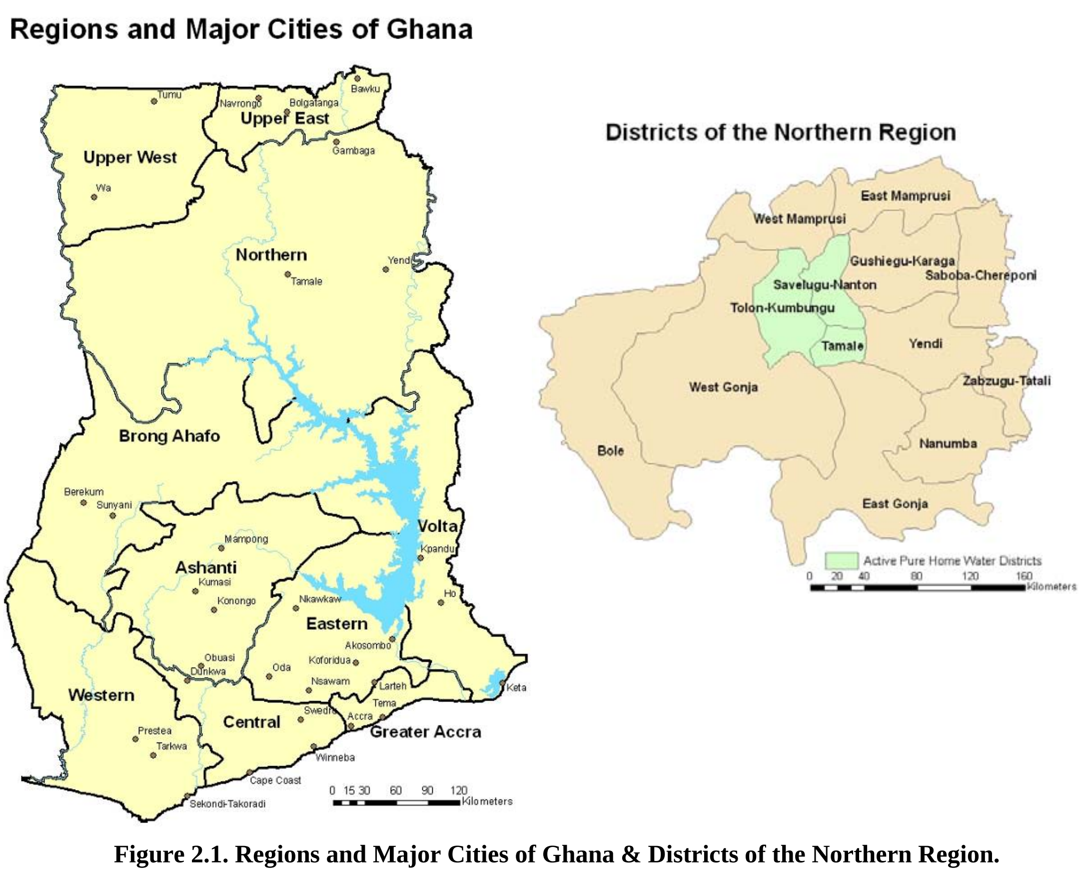

Figure 2.1. Regions and Major Cities of Ghana & Districts of the Northern Region.

According to the year 2000 census, the three districts where PHW is currently focusing have a population of 517,000 people (GSS, 2005). The original business plan of Pure Home Water was to have six target districts which also included West Mamprusi, Gushiegu-Karaga and Saboba-Chereponi. This would have given a target population of 851,000 people. However, due to transportation restraints, the target area needed to be decreased to its current three districts. To solve the transportation issue, a motorbike is being purchased to allow easier travel throughout the project area. Pure Home Water holds the rights to distribute the CT Filtron throughout all of the Northern Region as well as the Upper West and Upper East Regions. Thus, solutions of how to scale up the project are of great interest.

2.3.2 Demographics

According to the 2000 Population and Housing Census, 1.8 million people live in the Northern Region (GSS, 2005). Tamale municipality which contains Tamale, the third largest city within Ghana, accounts for 16% of the population, while the rest is spread evenly throughout the remaining 12 of the 13 districts of the Northern Region. Within the Tamale municipality, 67% of the population is considered to be urban, while the average for the region is only 26.6% (GSS, 2005). The increased urbanization of Tamale compared to other Northern Region districts means that many services such as piped water, sanitation, electricity, waste disposal, education and health care are more available within Tamale than in the surrounding districts.

The major ethnic group in the Northern Region is the Mole Dagbon which makes up 52.2% of the population. Other large groups include the Gurma at 21.8% and the Akan and Guan each accounting for 8.7% (GSS, 2005). Each of these groups has their own indigenous languages which vary between districts. The Dagbani language, however, is the most prevalent in the region and is spoken in nine of the thirteen districts (GSS, 2005). The predominant religion of the region is Islam with 56.1% of people being Muslim, while 21.3% follow traditional religions and only 19.3% are Christian. This is vastly different than the country as a whole in which Christianity is largest religious group, accounting for 68% of the population (GSS, 2005).

Education in the region is low with only 22% of the population being literate and only 7.9% of the population, 15 years and older, having been to secondary or tertiary school. The population is also young with 46.2% under the age of fifteen (GSS, 2005). This is due to there being both high fertility and mortality rates, with the average woman giving birth 6.7 times (GSS, 2004).

2.3.3 Economics

If Pure Home Water is going to be a sustainable business, the HWTS technologies must be economically feasible for the population to purchase. Within the Northern Region, 71.2% of the economically active population is employed in agriculture. This means that the income of these families is seasonal and that money for the purchase of a Pure Home Water filter or other product may only be available after a harvest. Some of these workers may, in fact, not be paid at all. In the region, 23% of the economically active population is classified as unpaid family workers while 68% are self-employed and 6% are employees (GSS, 2005). It is only the employees who are likely to have a regular and reliable paycheck and this must be a consideration when promoting the HWTS technologies.

The cost of the HWTS technologies must also be a consideration. In 1999, 69% of the Northern Region population was classified as living below the poverty line of 900,000 cedis a year or around US$100 (Gyan-Baffour, 2003). Currently the CT Filtron is selling for 150,000 cedis (US$18) which makes it beyond the price range for the majority of the population. To address this issue, Pure Home Water offers to sell their filters on credit. This way poorer household can pay over the course of three months, instead of in a single lump sum.

2.3.4 ***Health***

The driving force behind implementing HWTS technologies is improvement of health through the reduction of waterborne disease. This section gives current health statistics for Ghana applicable to HWTS implementation. It is important to know which types of diseases the population suffers from, so that the proper interventions can be made and improvements can be tracked.

Diarrhea and Mortality Rates in Children under Five

Children have an increased susceptibility to waterborne diseases because their immune systems have yet to develop resistance to many common pathogens. They also bear an increased chance of death because their bodies are small, allowing the effects of dehydration to come about quickly. Children thus carry the overwhelming majority of the disease burden and many health indicators focus on them specifically.

One common health indicator is mortality rate. Mortality is measured as the number of children under the age of five who will die for every thousand children born. Currently the average in Ghana is that 111 deaths occur for every 1000 live births, or that 1 out of every 9 children will not make it past their fifth birthday (GSS, 2004). By contrast in a developed country like the United States, the under five mortality rate is 8 deaths out of 1000 live births (UNICEF website). The mortality rate is not uniform throughout Ghana. In the following map, it can be seen that the under five mortality rate is significantly higher in the Northern and Upper West regions than in the rest of the country. Even within a specific region, the mortality rate can be variable within districts and even from village to village depending on the current health and sanitation conditions.

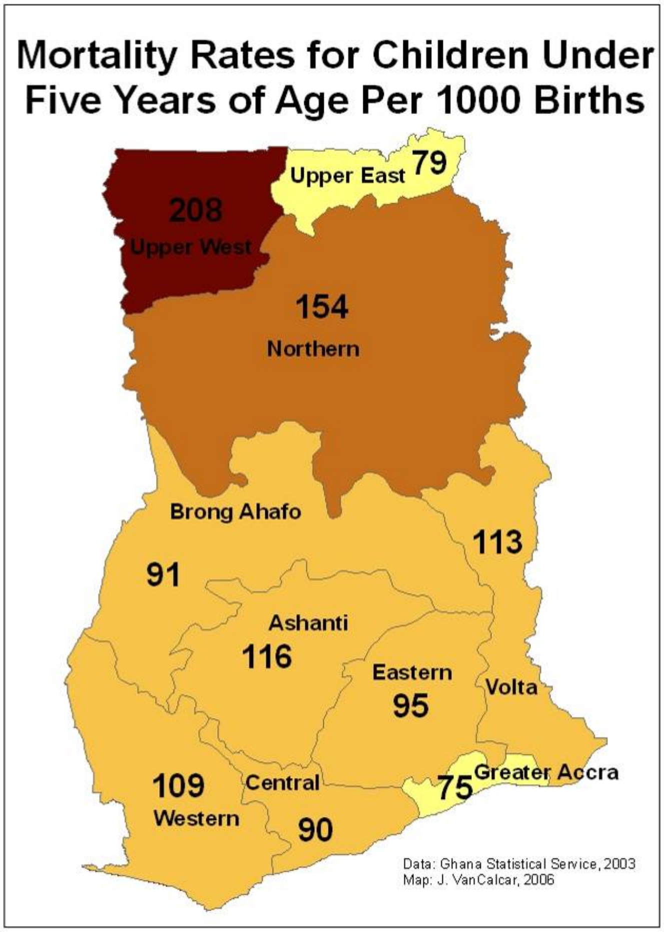

Figure 2.2. Mortality Rates for Children Under Five Years of Age.

While the mortality rates are high in the Northern Region, the good news is that the rate has been dropping. The Demographic and Health Surveys of 1993 and 1998 showed the mortality rate of the Northern Region to be 237 and 171 respectively (GSS, 2005), so progress is being made.

Another common health indicator is the prevalence of diarrhea in children under the age of five. While there are a large variety of waterborne diseases, diarrhea is one of the most common and widespread illnesses. It causes dehydration and also necessitates that the caretaker of the family put time and resources into helping the sick child. Thus, diarrhea can place a significant burden on families and communities. The following map shows the percentage of children who had diarrhea in the period two weeks prior to the 2003 Health and Living Standards survey.

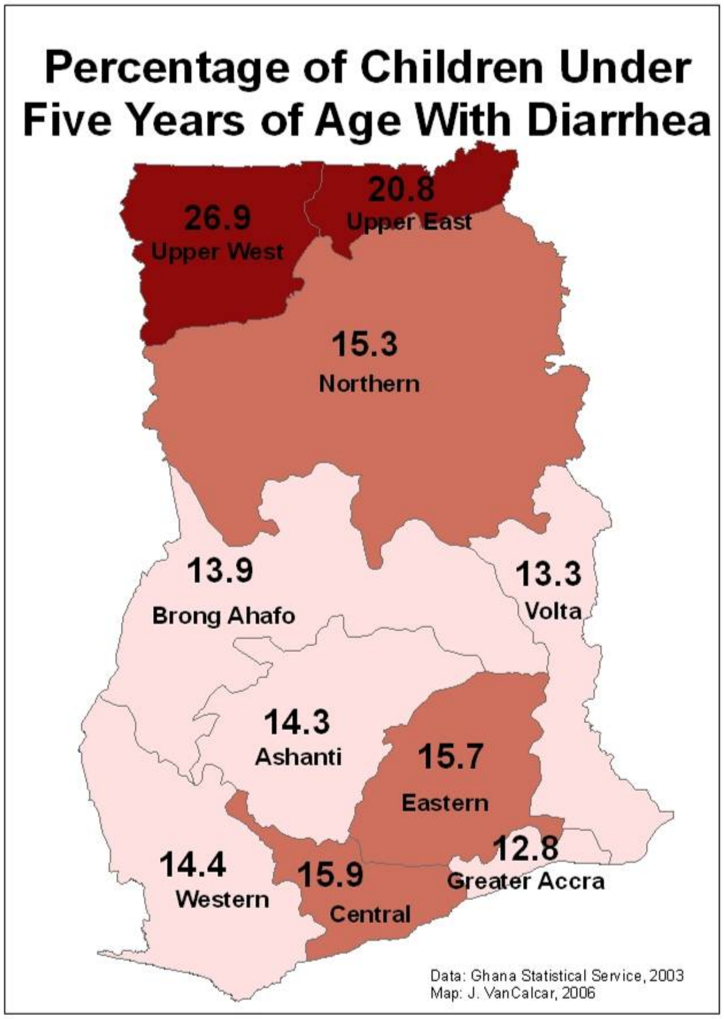

Figure 2.3. Percentage of Children Under Five Years of Age with Diarrhea.

Diarrhea rates are high throughout Ghana with the largest problem occurring in the Upper East and Upper West Regions. One issue affecting this trend is that these regions are both poor and rural, two factors which often lead to a lack of water and sanitation infrastructure. The regions also have a largely uneducated population and thus may not know proper hygiene techniques. In the Upper West Region, 72.3% of the population six years and older has never been to school. This is the highest regional percentage in the country of never having attended school, with the national average at 38% (Ghana Statistical Service, 2005).

To get an idea how these cultural factors are related to the disease indicators, Pearson's correlation coefficients were determined. Pearson's correlation reflects the degree to which two variables are linearly related. The value can range anywhere between +1.0 to -1.0. A value of +1.0 means that the two variables have a perfect positive linear relationship, as one variable goes up, so does the other. A value of -1.0 indicates a perfect negative relationship; as one variable goes down, the other goes up. A value of 0.0 signifies no linear relationship at all. Values in between zero and one indicate how strong the relationship is; it should be noted that a correlation does not indicate causation, only that the two variables are interrelated. The following table shows the correlation between a variety of factors with mortality rates and the prevalence of diarrhea. The calculations were done by the author using data from the Ghana Statistical Service (GSS, 2004).

Table 2.1. Correlation Coefficients between Cultural Factors, Mortality and Diarrheal Prevalence.

	Correlation with Mortality	Correlation with Diarrhea
% of the population which is rural	0.46	0.58
% of the population with no education	0.52	0.65
% of the population with no access to media	0.73	0.71
% of households without hand washing material	0.25	-0.01
% of children under five with fever	0.36	0.41
% of children age 12-23 months with no vaccinations	0.49	0.08
% of children under five with diarrhea	0.65	

Some caution should be noted when looking at this table since the correlations are only based on ten data points, corresponding to the ten regions within Ghana. The low number of data points leaves room for uncertainty. When a 95% confidence interval was calculated for the correlation between diarrhea prevalence and mortality, the range was 0.04-0.90. This means that it is 95% certain that the true correlation coefficient is between this range of values; there is no guarantee that it is actually 0.65.

Guinea Worm Prevalence

Guinea worm is a disease that nowadays is largely limited to Ghana, Sudan and a few other countries. It is contracted when a person drinks water containing microscopic water fleas that have guinea worm larvae living inside them. Inside the stomach, the water fleas are digested and release the guinea worm larvae to mate, mature and grow. After a year, the mature female worm, up to 3 feet in length, travels through the body to typically the foot or lower leg of her host. The worm then breaks through the skin and slowly emerges in the form of a painful blister. To soothe the pain the host will often immerse their foot in water; when this happens, the female worm releases her larvae which can then infect more fleas. Fortunately, the cycle can be stopped if people drinking from surface water use a cloth or another material to filter their water. This retains the water fleas and stops their ingestion. Using this technique and other eradication methods, guinea worm is close to being eradicated completely.

The disease is debilitating to communities because people with guinea worm are unable to walk, much less harvest their crops or take care of household duties while the worm emerges. In 1986 the Carter Center began a campaign to stop the disease and has accomplished a 99.5% reduction with only 10,674 cases reported worldwide in 2005. This number is down from 3.5 million cases when the program first began. The remaining cases are concentrated in Sudan and Ghana with 3,981 cases being reported in Ghana during 2005. To see where the problem is focused, the map below shows the number of villages within each district that have endemic guinea worm.

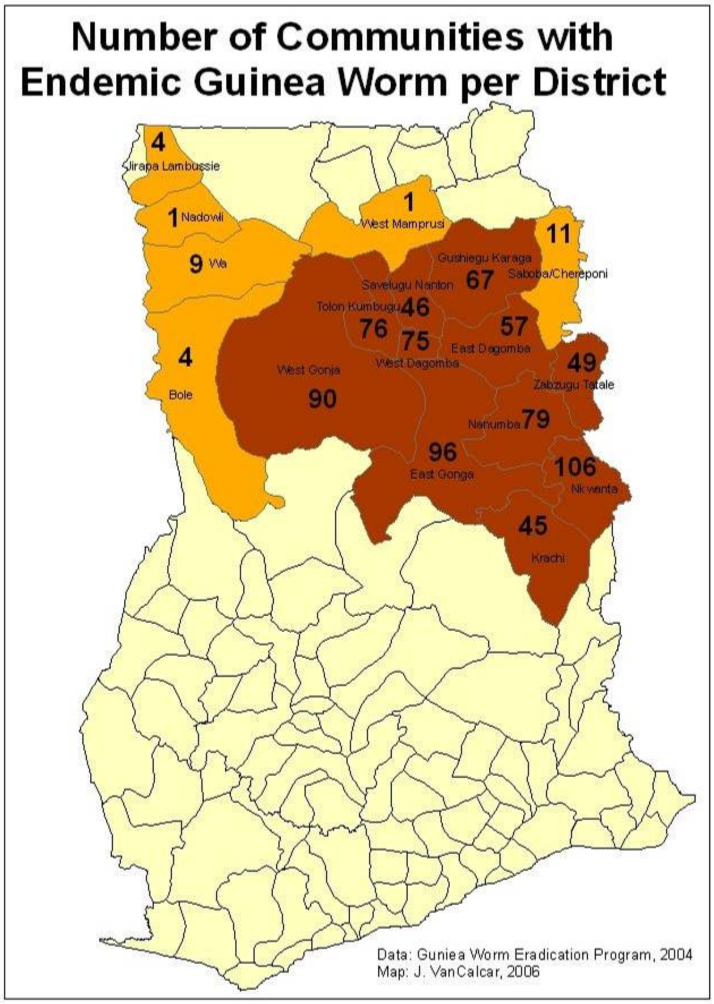

Figure 2.4. Number of Communities with Endemic Guinea Worm per District.

To get an idea where the individual villages are, the Guinea Worm Eradication Program has created the following map of the Northern Region. This map differentiates between villages where guinea worm is endemic and those villages which have an imported case of the disease. This means that someone in the village has guinea worm but it is not prevalent throughout the whole community, rather it was picked up during travel.

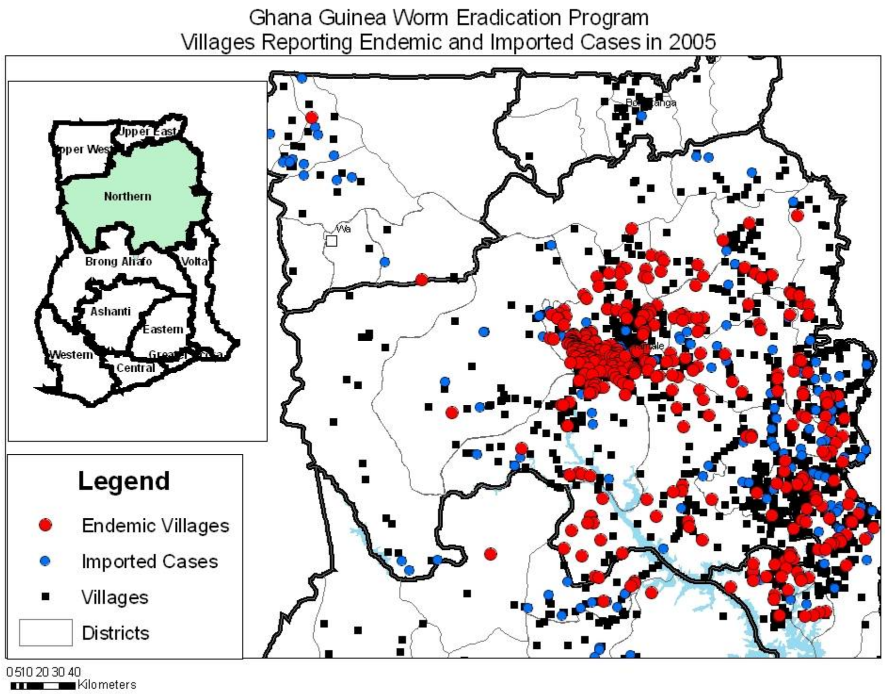

Figure 2.5. Villages Reporting Endemic and Imported Cases of Guinea Worm in 2005 (Guinea Worm Eradication Program, 2005).

2.3.5 Infrastructure

Knowing the water sources and sanitation approaches communities use gives valuable information about the need for HWTS technologies and other forms of water and sanitation intervention.

Water Infrastructure

In the developed world, most people receive the water they need for drinking, cooking and washing from a piped supply or a private well. This water is generally always available, abundant, and of a high quality. However, this is not the case in most of the world. Piped supplies do exist in developing countries, but they are prone to breakdown, intermittent delivery and potentially poor water quality. Another issue is that distribution systems typically only serve people within the immediate urban areas, leaving most of the population to rely on alternative sources.

The alternative sources available include surface water, hand dug wells, boreholes, springs, rain water harvesting and tanker trucks. Surface water sources are the most dangerous and unfortunately the most commonly used. Streams, lakes and ponds are all open to contamination through human and animal fecal material as well as chemicals picked up from overland runoff. In Ghana, dugouts are a common surface water source. They are created by forming depressions in the ground which collect water during the rainy season and store it throughout the dry season (see Figure 2.6).

Figure 2.6. Local Dugout in Ghana (Photo by C. Mattelet) right: Women Using a Hand Dug Well (Photo by R. Peletz).

Groundwater is a safer source than surface water since it is protected from direct contamination and filtered through the soil. One way to access groundwater is through hand dug wells. These wells are low cost and can be a wise choice if the water table is not far below the ground surface. However, to prevent contamination they need to be protected. This includes placing a cover over the well along with a headwall and drainage apron to stop surface water from running into the well. A system should also be in place so that it is not necessary to touch the rope or bucket when retrieving water. If people are using their hands to raise and lower buckets, then contamination may transfer from hands, to the bucket and then to the water. Figure 2.6 shows an example of a hand dug well that has a cover but no fetching system.

Boreholes are another way to access groundwater. They must be installed by professional drillers and are thus more expensive then hand dug wells. However, they can reach deeper groundwater and have pumps to bring the water to the surface (see Figure 2.7). One drawback to boreholes is that the mechanized parts need to be maintained. Typically villagers do not have the knowledge for proper maintenance and must be trained if the borehole is going to operate succesfully in the long term.

Groundwater can also be accessed where it naturally comes to the surface and seeps out in the form of a spring. Analogous to the hand dug well, for a spring source to remain pristine it should be protected. The area around the spring should not be developed and a box should be built around the spring to collect water and store it safely. Figure 2.7 shows a spring source which has not been protected.

Figure 2.7. Left: Girls Using a Borehole in Ghana (Photo by J. VanCalcar) right: Unprotected Spring (Photo by S. Murcott)

Besides surface water and groundwater, rain water can be collected and stored for drinking. Rain water is of a high quality but must be stored carefully to insure enough supply and prevent contamination. One concern with this technique is that if not enough water can be stored, lesser quality water sources must be relied on. Metal roofs are typically the surface used for water collection; however, in Ghana most roofs are thatch and thus rain water harvesting is currently uncommon.

Another drinking water option is tanker truck delivery. These trucks are typically run by the government or private companies and deliver water to households or communities for a fee. However, there is no guarantee of where the water has come from. In an ideal situation it would come from a water treatment plant in a clean truck; however, in many cases it simply comes from a large surface water source (see Figure 2.8).

Figure 2.8. Left: Rain Water Harvesting Container from Bangladesh (Photo by S. Murcott) right: Tanker Truck Refilling from a Dugout in Ghana (Photo by J. VanCalcar).

The map below shows the percentage of households within the three districts where Pure Home Water is currently focusing which use the various water sources mentioned above along with piped supplies.

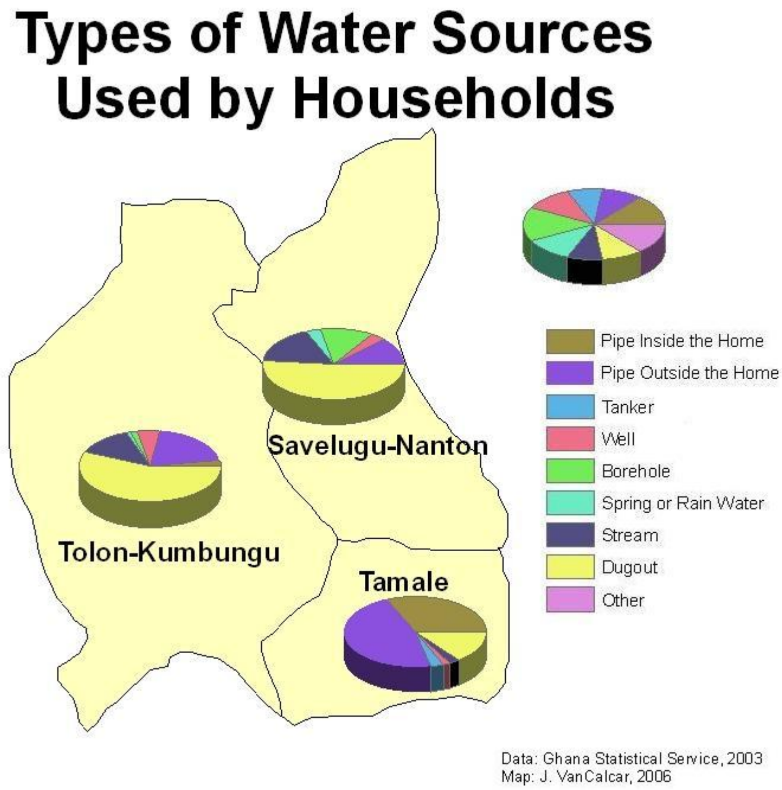

Figure 2.9. Types of Water Sources Used by Households.

It can be seen that the majority of people in the rural districts of Savelugu and Tolon are using surface water sources, particularly dugouts. These sources are not safe. Water samples taken from dugouts within Tamale district showed total coliform levels between 757 and 25,000 CFU/100 mL (Mattelet, 2006). Ideally, drinking water should have no coliform present since it is an indicator of fecal contamination.

The World Health Organization and UNICEF Joint Monitoring have categorized drinking water sources into improved and unimproved sources. Examples of improved water sources include household connections, public standpipes, boreholes, protected dug wells, protected springs and rainwater harvesting (WHO/UNICEF Joint Monitoring Program, 2005). Examples of unimproved water sources are any surface water source, unprotected wells, unprotected springs and tanker trucks. If the distinctions between improved and unimproved sources are used, the following map shows the percentage of the population which has access to these sources throughout the Northern Region.

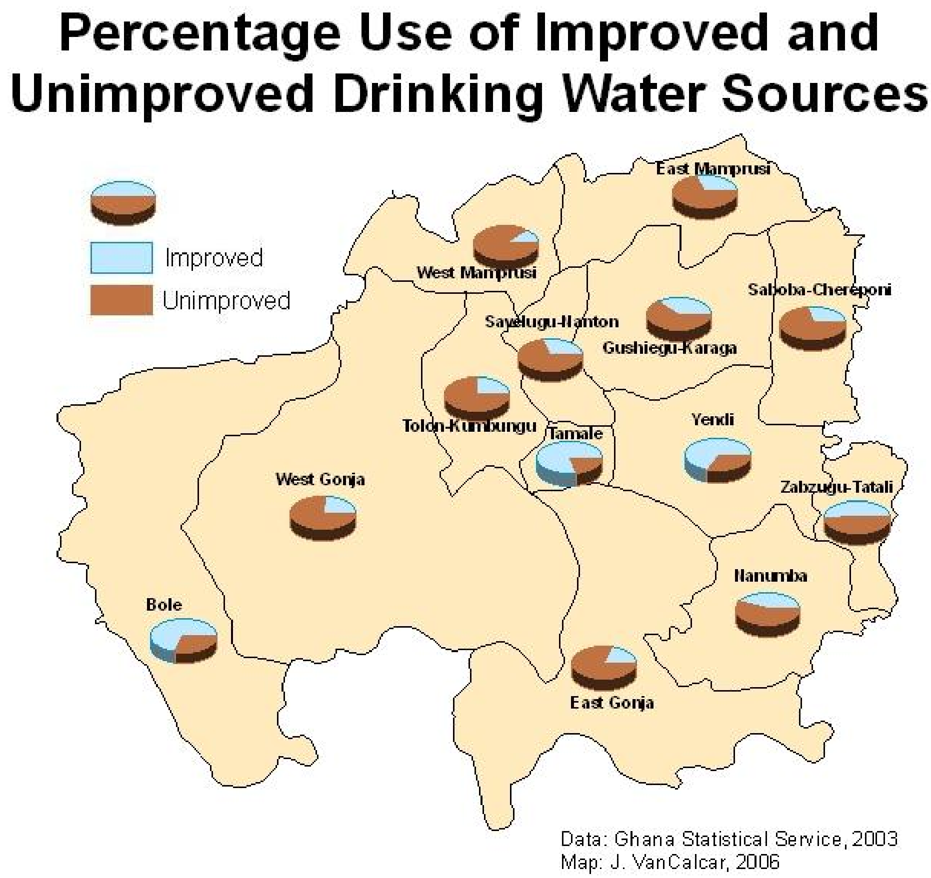

Figure 2.10. Percentage Use of Improved and Unimproved Drinking Water Sources.

It can be seen that currently more than half of the population in each district is using water from an unimproved source. Exceptions include Tamale where there is a significant proportion of the population with a piped supply, as well as Bole and Yendi Districts which are fortunate to have good coverage through borehole drilling. Taking into account the population of each district according to the year 2000 census, the map above indicates that approximately 1 million of the 1.8 million or 56% of people living in the Northern Region are currently drinking from an unimproved source.

It is these people without a safe drinking water source who are most in need of an improved water supply and/or household drinking water treatment and safe storage. However, even the portion of the population with access to an improved source is still a potential customer. This is because contamination of water can often occur in the distribution of piped supplies or during storage of drinking water within the home.

Borehole Coverage

Boreholes are on the list of drinking water sources considered improved by the UNICEF/WHO Joint Monitoring Program. One of the benefits of boreholes is that they allow people to access groundwater, which is typically of higher microbial quality than surface water. If geologically feasible, boreholes can also be located within individual villages. This saves people, especially women and children, large amounts of time previously spent walking to and from water sources. Since the boreholes are closer, it also becomes easier to transport larger quantities of water. This can increase health benefits due to hygiene practices becoming easier to maintain.

However, groundwater is not available everywhere and the hydrogeologic characteristics of an area must be taken into account. The Northern Region is comprised of mainly shale and mudstone beds which tend to have a low groundwater potential yield (MacDonald et al, 2005). However, drilling rigs in the area have been successful in reaching water. The map below was created by the World Vision office in Savelugu and shows some of the borehole drilling progress throughout the Northern Region.

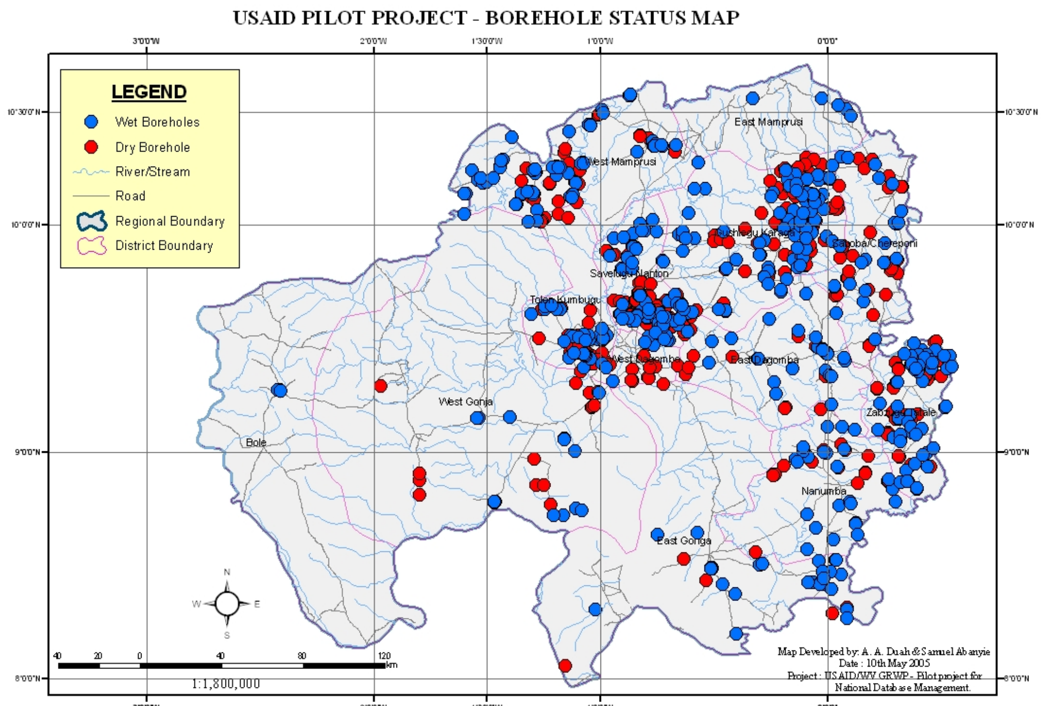

Figure 2.11. Wet and Dry Boreholes Drilled by the WAWI Partnership.

Figure 2.11 shows a total of 964 boreholes being drilled of which 497 were successful and 467 turned out dry. This gives a success rate of just over 50%, which is not ideal but shows that drilling in the area is feasible.

The following map gives a more complete picture of borehole coverage throughout the region. It was created using the data points supplied by World Vision in the map above along with data sets collected from a European Union funded group known as the Rural Water and Sanitation Agency (RWSA) as well as the semi-autonomous Community Water and Sanitation Agency (CWSA), which is a government agency responsible for rural water and sanitation services.

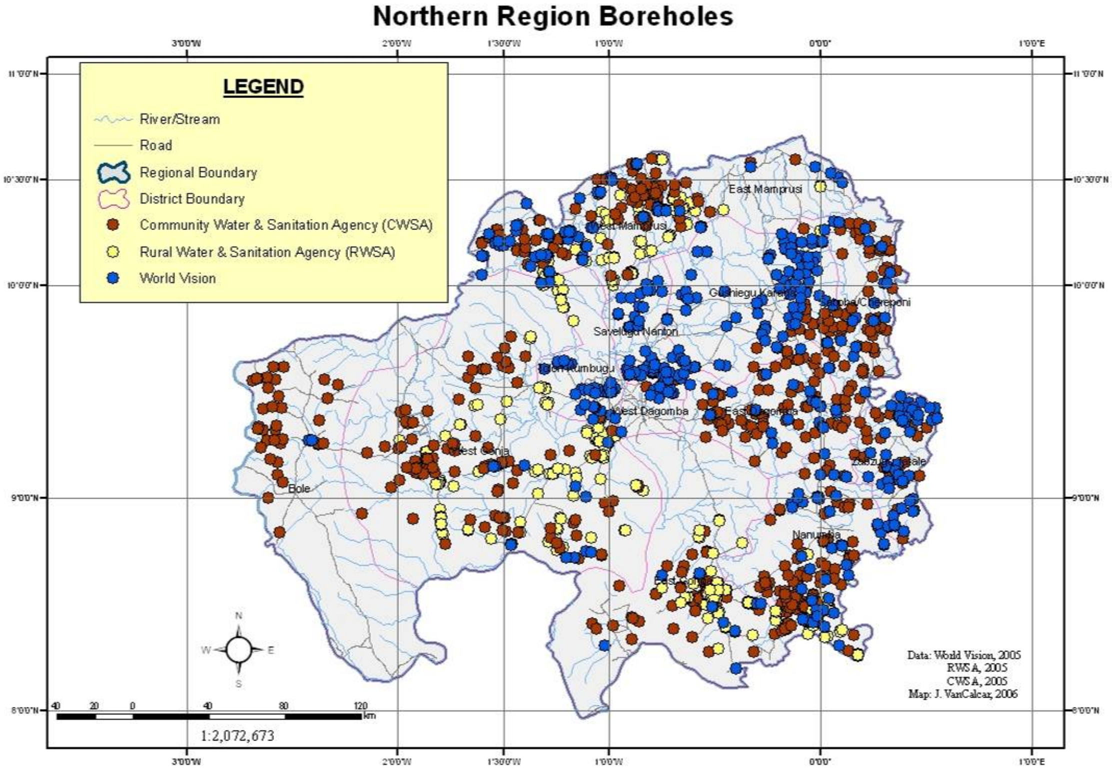

Figure 2.12. Northern Region Boreholes.

The World Vision and RWSA data sets indicated which of the boreholes drilled were successful and which turned out dry; however this information was not known for the CWSA drilled boreholes. Since the success rate for both World Vision and RWSA were comparable at 50% and 47% respectively, a similar rate can be assumed for CWSA. This map then shows that there are slightly more than one thousand boreholes operating successfully throughout the Northern Region. However, the dataset is likely incomplete. Figure 2.10 showed the percentage use of improved and unimproved drinking water sources throughout the Northern Region and indicated that Bole district has a comparatively high percentage of improved water sources. This should be from borehole coverage, but is not indicated above in Figure 2.12.

Sanitation Infrastructure

Sanitation is intimately linked with water quality. Improper sanitation practices can lead to surface water sources and groundwater supplies becoming contaminated with fecal matter. But even if the drinking water of a community is protected, the disease burden may not significantly drop. This is because improper sanitation increases other disease pathways such as food contamination or disease spread through insect populations. In order to get an idea of the sanitation practices used in the Northern Region, the following map shows the types of sanitation facilities families have available to them within the districts of Tamale, Savelugu and Tolon.

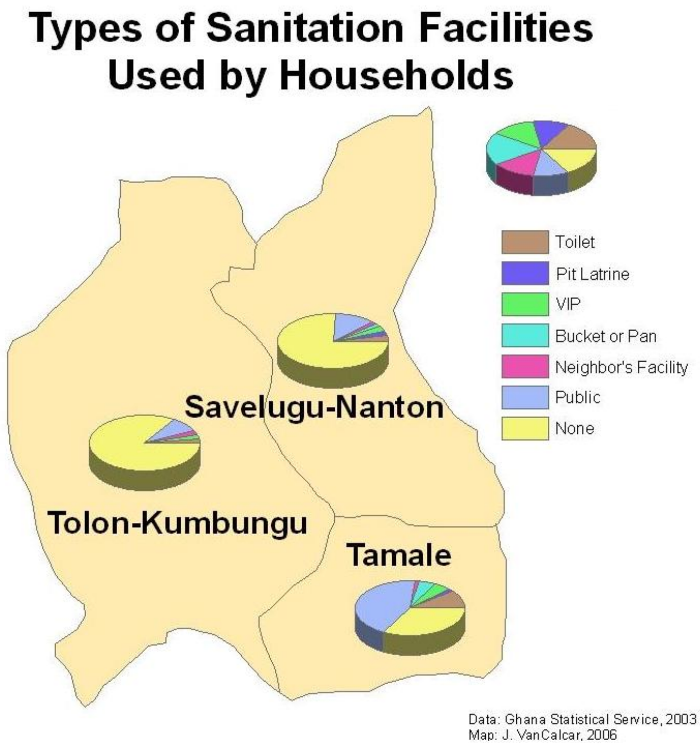

Figure 2.13. Types of Sanitation Facilities Used by Households.

It can be seen that in the rural districts, sanitation facilities are lacking in more than three-fourths of the communities. While sanitation infrastructure is outside of the scope of Pure Home Water activities it is important to note that health benefits from an improved quality of drinking water may not be fully realized within these areas in which adequate sanitation has not been addressed.

Comparable to drinking water, the World Health Organization and UNICEF have distinctions between what is considered an improved and unimproved sanitation facility. Improved facilities include a connection to a public sewer or septic system, a pour-flush latrine, a simple pit latrine and a ventilated improved pit latrine. Unimproved facilities include public or shared latrines, open pit latrines and bucket latrines (WHO/UNICEF Joint Monitoring Program, 2004). The key to being considered an improved facility is that privacy and hygienic use are maintained. Taking these definitions into account, the following map shows the percentage of people throughout the Northern Region who have access to improved sanitation.

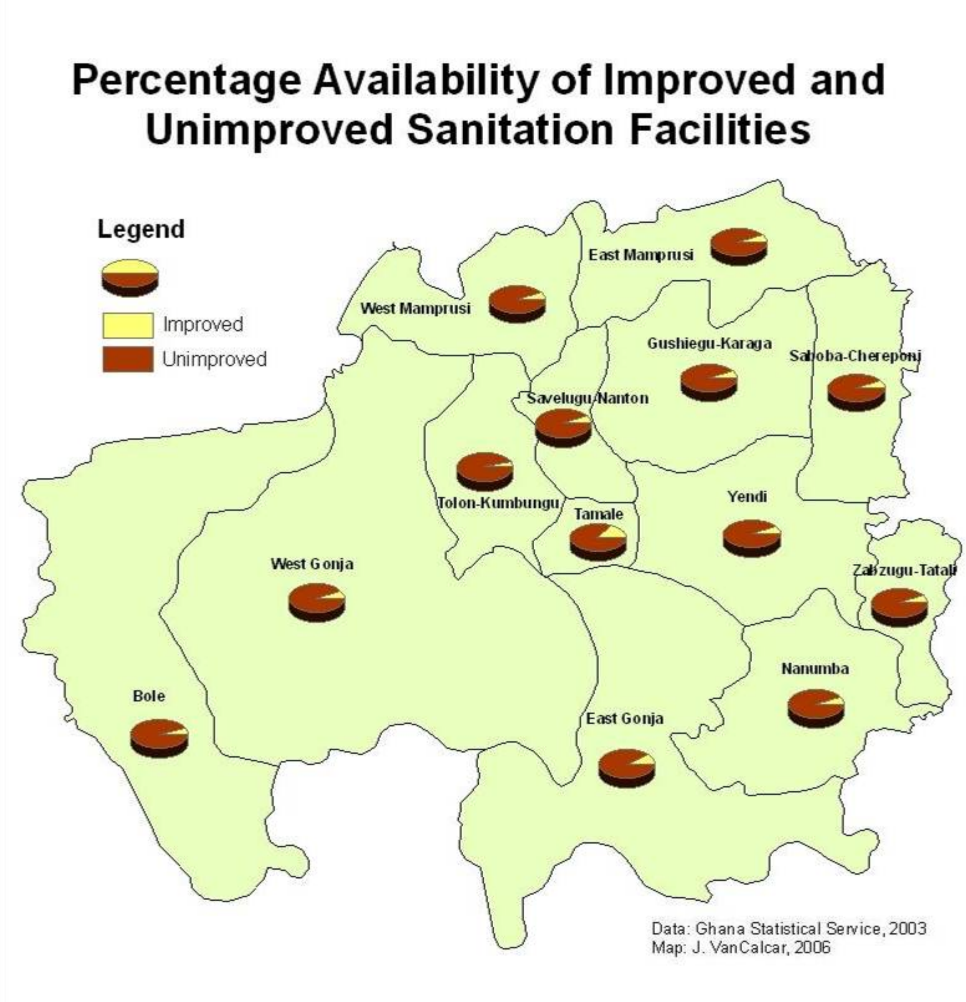

Figure 2.14. Percentage Availability of Improved and Unimproved Sanitation Facilities.

It can be seen that throughout the whole region, the majority of the population lacks access to improved sanitation facilities. This is even the case within Tamale, where many people rely on public toilets for their sanitation needs. Since privacy and hygienic quality cannot be guaranteed in the developing world's public latrines, these facilities are not considered a suitable sanitation alternative. Taking into account the population of each district according to the year 2000 census, the map above indicates that 92% of the population does not have access to an improved sanitation facility and 71% of the population has no sanitation facility available at all.

2.4 Tools for Implementation

The previous maps are useful in conveying important information about the region; however, another effort was made to see if GIS could be useful in the actual process of HWTS dissemination. In order to test this, a database of villages was created within Pure Home Water's current area of operation. It was hoped that this database would be useful for strategic marketing purposes. .

2.4.1 Village Database

The village database took as a starting point the gazetteer or official list from the Ghana Statistical Service of all the villages in each district (GSS, 2005). However, the problem emerged that there was no geographic location associated with each village. To put together a map, both a name and a geographic location are needed. Going out and marking points manually throughout the district would have taken more time than was available for this thesis. So instead, a database was created by combining previous mapping efforts.

The data sources which contained both village names as well as locations included a worldwide set of populated places from the National Geospatial-Intelligence Agency, a dataset of villages which World Vision provided, and borehole data from various agencies. Each borehole often had associated with it the village for which it was drilled, thus the boreholes could be used as approximate village locations. These datasets were combined to get the most inclusive map of villages possible. However, the points on the maps were simply geographic locations. In order to get more information, the gazetteer was consulted to determine the population of each village and available facilities such as schools and health clinics. Unfortunately though, the match between the gazetteer and villages found in the database was far from perfect. Many of the names in the gazetteer did not show up on any of the location sources and thus data about them could not be included on the maps. Also, many villages on the map did not appear in the gazetteer. This could have been for a variety of reasons. One is that the name given on the map was so different from the name in the gazetteer that it could not be recognized as representing the same village. This could happen due to the variety of tribal languages with each have different spellings and names for villages. Another explanation is that the gazetteer list is from the year 2000, so there could be villages which may show up on older maps that no longer exist or have changed their names. There may also be new villages which have been formed since the list was created.

Despite these discrepancies, it was important that the maps provided a picture accurate enough to be useful to the Pure Home Water entrepreneurs. In an effort to ensure the largest cities were included, local students from the School of Hygiene were consulted. These students often traveled to local villages to take surveys and teach basic hygiene, and were thus believed to be knowledgeable about the local geography. They were given a list of the villages which appeared in the gazetteer but not on the map and had populations greater than one thousand people. While the students were instrumental in locating a variety of villages, there were many large villages, within their own district, of which the students had not even heard. Since these students were better traveled than the average citizen, it can be assumed that local geographical knowledge tends to be lacking and only covers immediate areas of interest. Another observation which came from interacting with the students is the unfamiliarity with written place names. One student would say the village name aloud, often trying different pronunciations until it was recognized.

Although the village database is far from perfect, it is still the most complete map of locations along with village information that I have encountered. As a gauge of how inclusive the maps are, the following table shows the number of villages listed in the gazetteer, the number displayed on the map and the percentage of the population this represents. The comparatively low percentage of the population represented on the Tolon map is due to the lack of large cities in this district. In contrast, by simply putting the city of Tamale on the map, 69% of the population was accounted for within its district.

Table 2.2. Percentage of the Population Accounted for in the Village Database.

	Number of Villages According to the Gazetteer	Number of Villages on the Map	Percentage of the Population Accounted For
Tamale	140	85	86%
Savelugu	148	109	82%
Tolon	251	137	58%

Population

A basic map of villages can be useful to implementers as a planning strategy. Without knowing how many villages exist, there is no way to know when all have been visited. There will be local knowledge, but this is often concentrated around a specific area, and a systematic system is better to keep track of progress and make sure there are no exclusions. Knowing the population can also be an asset to Pure Home Water in order to determine what kind of a demonstration may be appropriate or how many materials need to be brought along during visitations.

The following three maps show the villages and major connecting roadways for Tamale, Savelugu-Nanton and Tolon-Kumbungu districts. There is a separate map for each of these three districts, with symbols proportional to the village populations. It should be noted that the villages with the smallest symbols are those locations for which an entry could not be found in the Gazetteer, and thus no population data is available.

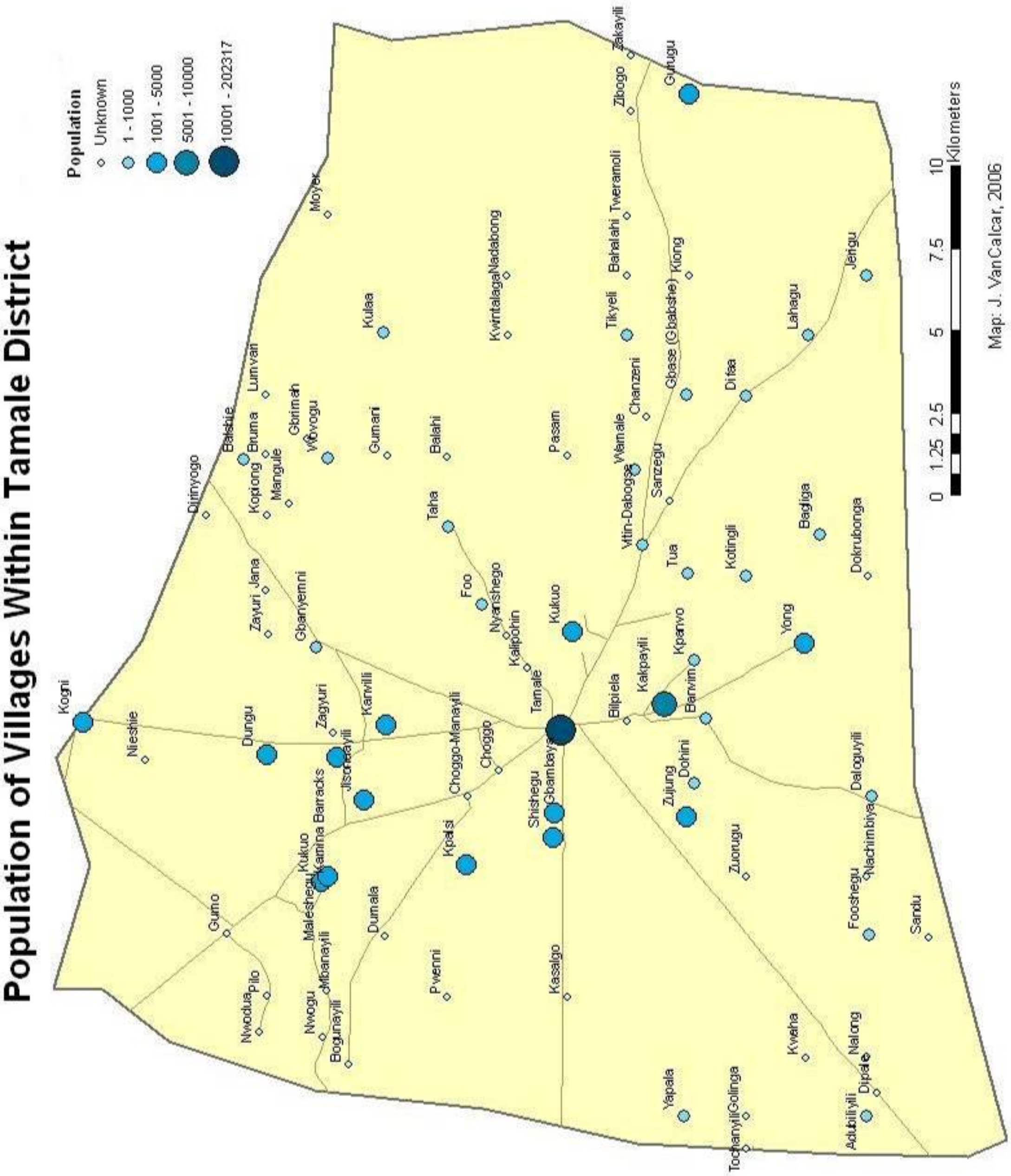

Figure 2.15. Population of Villages within Tamale District.

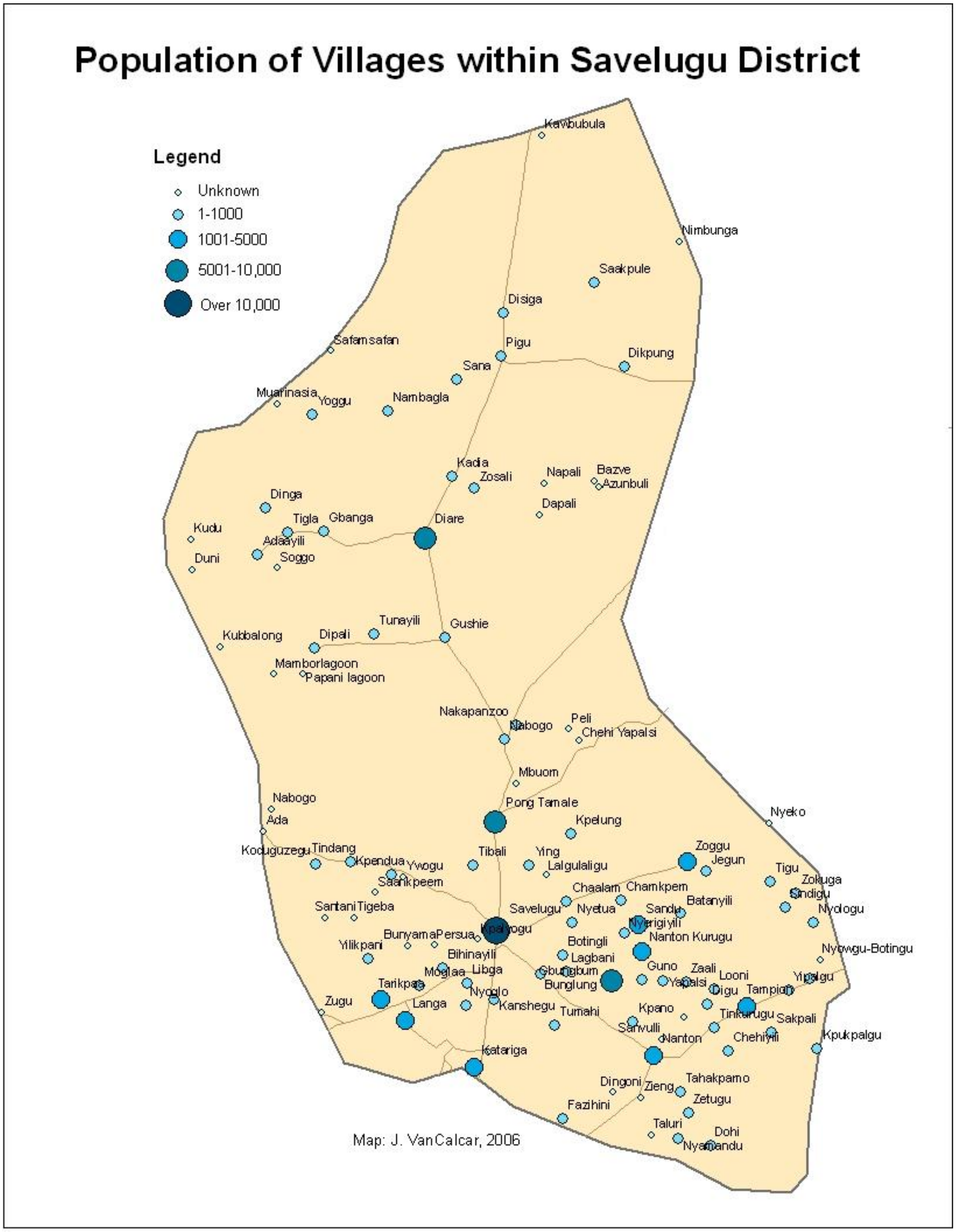

Figure 2.16. Population of Villages within Savelugu District.

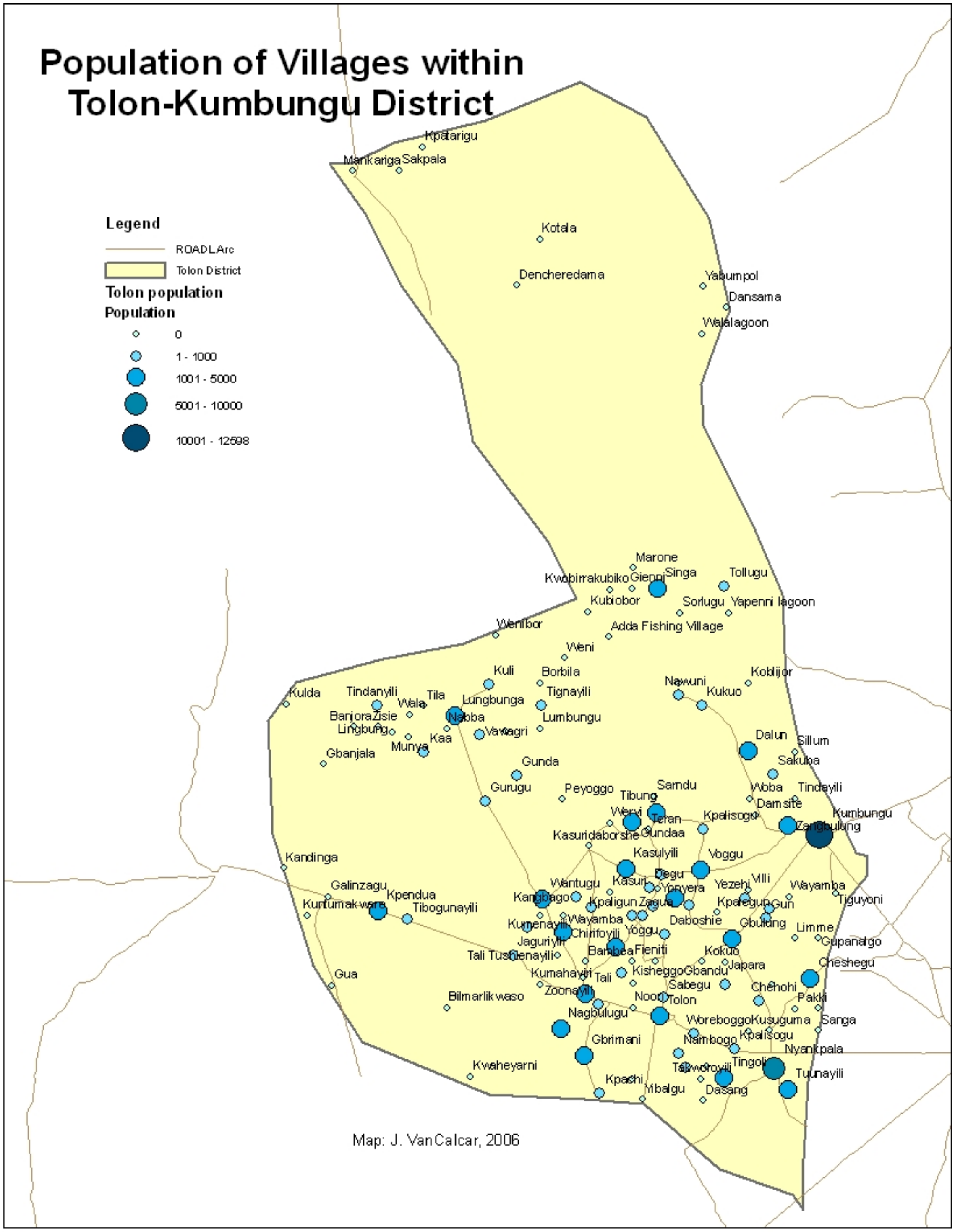

Figure 2.17. Population of Villages within Tolon-Kumbungu District.

Available Facilities

One common mechanism for HWTS implementation is to work in collaboration with other organizations, allowing the technology to spread through their clients and contacts. As an example, the CT Filtron manufacturer, Ceramica Tamakloe Ltd, provided a group of midwives from Northern Ghana 150 filters to sell and distribute to their patients. This was part of an arrangement with the original filter manufacturing trainers and funders, the Stichting De Oude Boek Foundation. Another relationship currently under discussion, is to market the filters at Shell gas stations throughout the Northern Region. Similar relationships could be started among health clinics or even among schools. In an effort to see the geographical distribution of these facilities, the following maps were created. The first map shows health clinic locations within Tamale and the second map shows the schools within each community. Within Ghana, the second level of schooling is referred to as Junior Secondary School (JSS), followed by Senior Secondary Schooling (SSS).

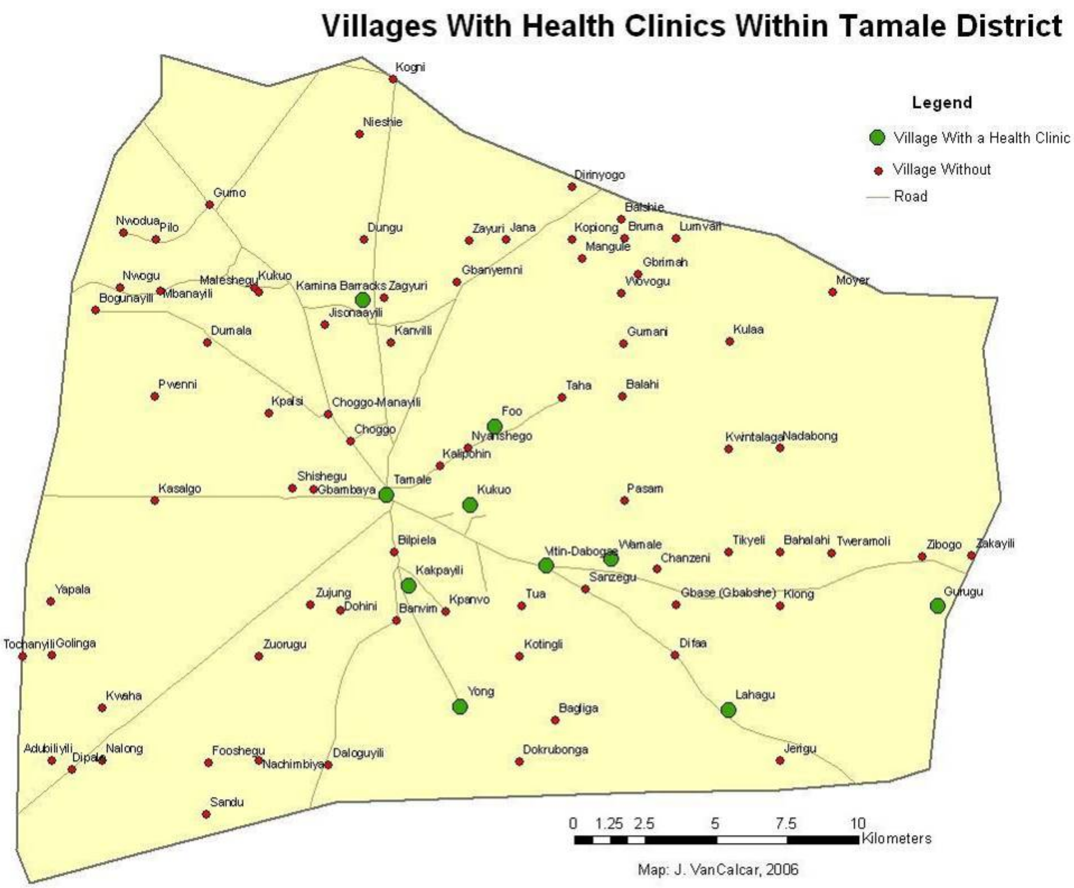

Figure 2.18. Health Clinic Locations in Tamale District.

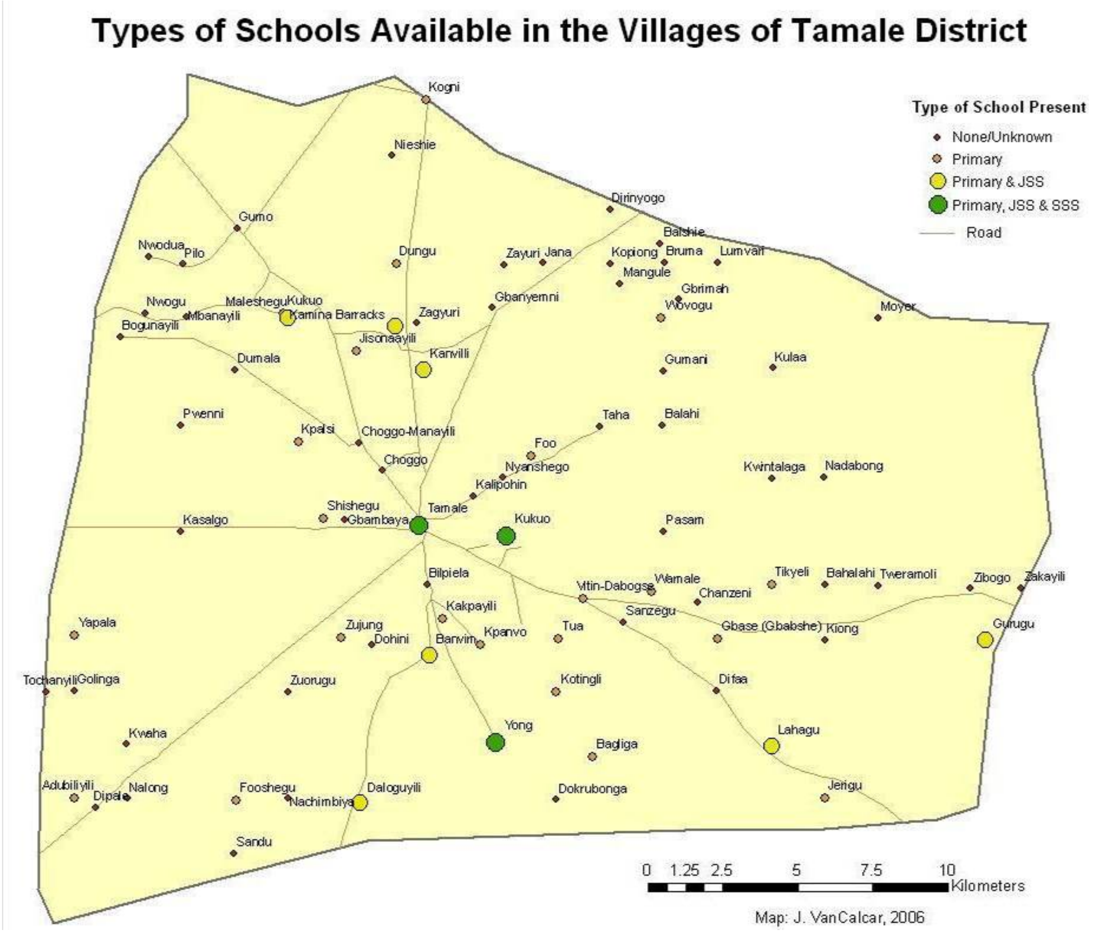

Figure 2.19. Types of Schools Available within the Villages of Tamale District.

Looking at these maps is not only useful for Pure Home Water, but displays the coverage of essential infrastructure in the region. It can be seen that while primary school coverage is reasonable, the availability of secondary and tertiary school drops off. This lack of infrastructure is likely a contributor to the low rate of only 7.9% of the population over the age of 15 who has received education past the primary level in the Northern Region (GSS, 2005). The following figure show areas which have access to primary, secondary or tertiary schools within Savelugu district. For these maps, access was defined as within a 10 kilometer walk. This may seem far but is reasonable within a developing world setting. While coverage is not the only aspect to be considered when setting up a partnership, there is importance in making sure retail locations are available for the most customers possible. In this case, it seems that primary schools would be a good target as a partnership opportunity.

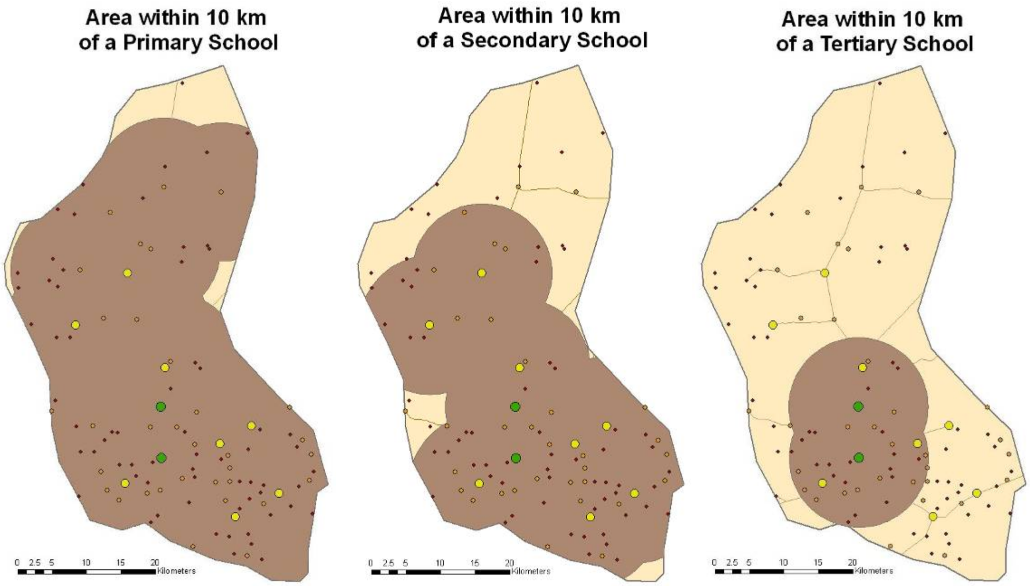

Figure 2.20. Access to Primary, Secondary and Tertiary Schools in Savelugu District.

Another infrastructure problem is that the rural nature of the region isolates people from life outside their communities. For example, in more than 60% of communities people must travel, typically walk, more than 10 kilometers to reach a post office. And in all districts accept for Tamale, less than 2.8% of communities have access to a local phone (GSS, 2005). This lack of communication infrastructure hampers the spread of new ideas and technologies, such as household drinking water treatment. The villages which need the technologies the most will not have access to radios, newspapers or other common advertising techniques. Currently, Pure Home Water is trying to spread word of their products through market days and other outreach activities. Every six days, rural villagers come to larger urban cities to sell goods and buy supplies for their families. Pure Home Water has taken advantage of this by renting a prominent booth in the Tamale central market to display their products and raise awareness of the need for safe drinking water storage and treatment. While this effort produces few sales, the hope is that it raises awareness of the product so that future sales may be made. Currently, this effort has only taken place within Tamale; however, travel to other market locations such as Savelugu, Nanton and Diare are planned.

2.5 Discussion

There can be no argument about the usefulness of GIS for planning purposes and data management. However, the technical expertise and computational requirements necessary for this kind of analysis may be too advanced for typical developing country implementation projects. Just as large centralized water systems are not always the best solution in the developing world, the software and planning tools from the developed world may also not transfer effectively.

Typically it is governments which initiate the use of GIS within a country. This is because the central government has a keen interest in geographical information for planning and decision making purposes. However, more and more GIS technology is being decentralized to the district and local government arenas. It has been argued that it is these smaller and underrepresented groups which have the most to gain from GIS implementation. This is because the use of GIS can alter how knowledge is processed, displayed and discussed and thus who it preferentially favors (Elwood, 2002). For example, if the inequitable distribution of resources within a community can be clearly seen through simple visual maps, then perhaps future allocation will be based upon reducing the discrepancy rather than mainly on political influence.

The decrease in capital cost of a GIS system is one of the ways that the technology is becoming more available to community based users. It used to be that acquiring the necessary components would cost thousands of dollars. Now computers and the internet are more widely available and at costs which are sometimes within the reach of those in the developing world. The cost of acquiring data has also decreased. This used to be one of the major obstacles of a GIS system. In the past, much geographical data was digitized from old paper maps. This meant that besides a computer, a digitizer was also required. Fortunately most digitization has now been completed and geographical data is more readily available. Many online sites have basic satellite images, topography and climatology data free for download. Also, if governmental agencies already have GIS databases in place, then they may be willing to share basic data layers such as political boundaries, roadways and zoning information free of charge. GPS technology has also experienced a dramatic decrease in cost and increase in accuracy over the last decade so that manual creation of data has now become a cost effective option as well.

Besides the hardware and data issues, the availability of cheap or even free software has also done a great deal to aid the spread of GIS. While the ArcView software from ESRI is the typical tool used in the developed world, its licensing fees exceeding thousands of dollars eliminate the feasibility for community-based users, especially in developing world contexts. However, there are other options. For example, Brazil's National Institute of Space Science has created a GIS environment known as SPRING which can be downloaded from the web at no cost (see http://www.dpi.inpe.br/spring/english/ index.html). Google Earth has also opened up a new pathway to share and view geographical information over the web.

A final obstacle to GIS implementation is technical expertise. This area is also improving as more universities in the developing world incorporate GIS into their class offerings. A unique offering at Vista University in South Africa combines in-class GIS theory with real world internships within the community (Ramasubramanian, 1999). This saved the university from needing to expand their own computer resources, while providing students valuable experience and organizations and companies with much needed GIS help.

Even if all the aspects needed for GIS are readily available, a system should only be adopted if it is accomplishing a specific purpose. If the major function is going to be record keeping or display of statistics, these functions can be accomplished with much simpler data management systems or even with paper and pencil. However, as the tasks get more advanced, the labor put into creating and maintaining a GIS system may prove instrumental. For example, World Vision-Ghana maintains a GIS database for their borehole drilling efforts in the Ghana Rural Water Project. If bringing together information on geologic conditions, soil types, extent of aquifers and other pertinent data can improve the success rate of borehole drilling, currently a few thousand dollars per drill attempt, GIS will likely be economical. Since the system is already running and expertise available, it then makes sense to use the system for other purposes such as storing borehole locations, water quality information and other associated data. With larger organizations like World Vision maintaining GIS databases, the hope would be that information gathered could be passed to smaller organization such as Pure Home Water.

2.6 Conclusion

The objective of this portion was to bring together GIS data in a fashion that could benefit Pure Home Water. One benefit hopefully achieved was the display of regional statistics for the Northern Region which highlights the extensive need for an improved water supply and/or household treatment and safe storage technologies. Currently 56% of the population does not have access to an improved source of drinking water and 92% do not have access to improved sanitation. This is clearly playing a role in the high diarrhea and mortality rates throughout the region and Pure Home Water should be strengthened in their conviction to spread HWTS technologies.

As seen through the village database, the population in need of an improved water supply and/or HWTS technologies is widely dispersed in many small villages and away from important infrastructure. While this is a challenge in the effort to distribute HWTS, it is not insurmountable. Motivation should be taken from the Guinea Worm Eradication Program; this partnership organization was able to distribute cloth filters and educational information to these same villagers. Their GIS system is now tracking the final remaining endemic locations in a region which used to be overcome by the disease.

However, GIS may not currently be the most practical method of storing project information and focusing team efforts for Pure Home Water. Currently, the main objective of the entrepreneurs is to sell water filters and not to maintain a database. From the larger perspective of water and sanitation planning, a GIS system can prove extremely useful. The challenge of providing people with potable water is highly geographic in nature and knowledge concerning the location of people, water sources, technologies and diseases can encourage thoughtful planning and maximize resources.

In retrospect, the scale of this thesis straddles the two groups. The work presented is potentially too detailed and time-demanding for Pure Home Water, however, not encompassing enough for development planning. A recommendation for any further work would be to scale the collected information either down or up. A simplified system could be created with free online tools to see if its use could help the efforts of Pure Home Water in a more direct fashion. On the other hand, more information about the location of dugouts, hand dug wells, springs and other water sources could be collected along with improved village information to create a system to be used on the regional level for development planning.

With improved village information, data could also be collected from agencies similar to Pure Home Water who are trying to address water, sanitation and hygiene needs. These companies are unlikely to have GIS data but should have a list of villages with whom they have worked. This data would show the types of educational material and water and sanitation programs communities have been exposed to in the past. This way adoption rates could be tracked not just of Pure Home Water's products but of numerous other health interventions. However, if this work is undertaken, there should be a specific end user in mind or specific planning purposes and goals put in place so that the database's usefulness is ensured.

CHAPTER 3

CHAPTER 3.CROSS SECTIONAL EPIDEMIOLOGICAL STUDY OF WATER AND SANITATION PRACTICES IN THE NORTHERN REGION OF GHANA

3.1 Research Objective

The purpose of this study is to obtain baseline data on drinking water and sanitation practices for households in the Northern Region of Ghana in order to aid the Pure Home Water Project to achieve its objectives. Through household questionnaires, data was gathered to compare households with and without the technologies and to obtain baseline information on communities that have not had exposure to the HWTS treatment options. This data is analyzed as an epidemiological cross-sectional study and basic risk assessment. The results are available to the two Ghanaian entrepreneurs and future MIT teams that will continue this project in Ghana.

3.2 Introduction

Cross-sectional studies are snapshots of a population's status that simultaneously assesses information on exposure and disease (Hennekens and Buring, 1987). Because all of the data is collected at once, this method is unable to establish a temporal relationship between the presumed cause and effect. Cross-sectional studies are descriptive methods, generally used to gather baseline data rather than perform formal analytical hypothesis testing. For analysis of cross sectional-studies, disease prevalence can be calculated and compared to other exposure factors. Prevalence is the percentage of people with the disease in the total population. Relative risks can also be calculated to compare disease to the different types of exposure.

Epidemiological studies have demonstrated the positive health impacts of household water treatment systems. From a review of recent epidemiological studies, household treatment systems have been found to reduce the incidence of diarrhea up to 48% (Crump et al., 2005; Brin 2003; Varghese, 2002). Hand-washing also has the potential to reduce diarrhea rates up to 50% (Parker, 2004). A six-month intervention study by Clasen et al. (2004) on ceramic drinking water filters in Bolivia was found to reduce diarrheal disease risk by 70% for individuals and 84% for children under five (Nath et al., 2006).

3.3 Methods

3.3.1 ***Survey development***

In order to perform epidemiological analysis, a household questionnaire was developed to obtain the necessary data. Various survey examples were considered in the development of the Pure Home Water household questionnaire. The main format is a modification of the UNICEF Baseline Household Survey: Household-Based Drinking Water Treatment (UNICEF, 2005), the Population Services International (PSI) Questionnaire for Clean Drinking Water in Burundi, and the WHO IWG Household Survey Tool developed by the 2004-2005 MIT Master of Engineering Kenya team of Robert Baffrey, Jill Baumgartner, and

Susan Murcott in 2005 (Baffrey, 2005). Over ten other surveys were reviewed and considered during survey development.

Categories and questions were chosen based on their relevance to the Pure Home Water project. For example, initially questions were included about the main concerns of the community, but this was omitted because the response, though interesting, would not directly benefit the Pure Home Water project. The focus of the survey is to provide useful background knowledge that will aid the Pure Home Water Ghana team in project implementation.

3.3.2 Survey Review

Prior to implementation, the survey was reviewed to provide feedback and necessary modifications. The questionnaire was reviewed by Susan Murcott, the project advisor, and the MIT Ghana team, including the engineering and business students. In order to word questions in accordance with the Pure Home Water Ghanaian team and with the Ghanaian culture, feedback was given by Hamdiya Alhassan and Wahabu Salifu, the social entrepreneurs in Ghana, and Ato Ulzen-Appiah, a Ghanaian MIT student through email contact. The epidemiological format of the study was reviewed in a personal interview with Julie Buring, professor of epidemiology at the Harvard School of Public Health. Dr. William Duke from CAWST (Centre for Affordable Water System Technology) reviewed and recommended modifications to the survey conduction plan by email. Before survey implementation in Ghana, the survey was assessed by MIT's Institutional Review Board (IRB), the Committee on the Use of Humans as Experimental Subjects (COUHES)

3.3.3 Survey Modification in Ghana

The questionnaire was further modified in-country with the help of Hamdiyah Alhassan and Wahabu Salifu. After a few initial runs through the survey, certain questions were omitted or modified based on cultural understanding. For example, rather than ask people when they wash their hands in general, the survey was modified to ask about hand-washing before or after certain activities, such as cooking, going to the toilet, and eating. After careful consideration, observations of hand-washing and sanitation facilities were omitted from the study because of cultural appropriateness and accuracy, since individuals may wash hands more carefully if observed and may bring guests to other cleaner nearby sanitation facilities rather than their own. Additionally, questions were added by the business students to gain information about product selection and advertising, such as why consumers chose their product and where consumers learned about Pure Home Water.

3.3.4 Population Selection in Ghana

The community, household, and participant selection process defined the study cohort.

Community Selection Strategy

The surveys were conducted in households in the Tamale and Savelugu Districts in the Northern Region of Ghana. The study population was selected with the assistance of the two local entrepreneurs from Pure Home Water in Ghana. Originally, the study was designed to compare 25 households that had purchased PHW technologies to 25 households without technologies. However, the entrepreneurs recommended that we also obtain baseline data on communities that have not yet been exposed to the Pure Home Water technologies. In Ghana, it was also discovered that many of the products were sold to people at the workplace, rather than within a neighborhood, so that the consumers were from a variety of communities. Often the home addresses of the consumers were unknown, and it was not realistic to survey them during their time at work. With the help of Wahabu Salifu and Hamdiya Alhassan, we were able to identify four communities with three or more people with treatment technologies, which were the Kamina Barracks, Vitin Estates, Jisonayili, and Libga. Additionally, three more communities were identified that did not have exposure to treatment technologies, which were Kaleriga, Bunglung, and Diare. The communities surveyed are mapped in Figure 3.1.

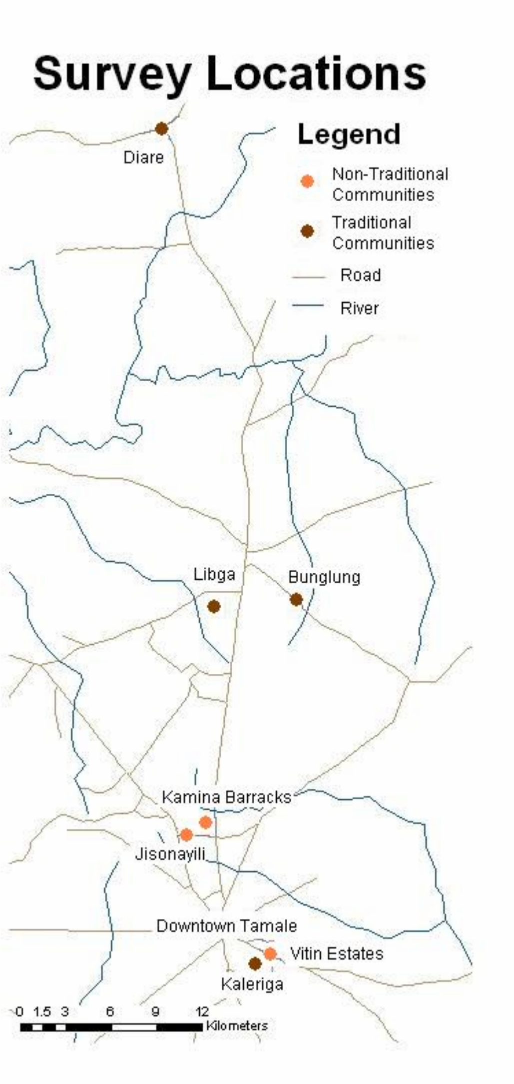

Figure 3.1. Survey Locations in the Northern Region of Ghana.
Map Created by Jenny VanCalcar, 2006 (VanCalcar, 2006)

Household Selection Strategy

In communities with Pure Home Water technologies, households were chosen that had purchased technologies and comparison households were chosen from the same neighborhood. Generally, each community had a limited number of people with the treatment technologies, which simplified the selection decision. Households were targeted with children under five, which is standard practice for water and sanitation studies since children under five are most susceptible to waterborne illness. In some communities, the limited number of consumers made it necessary to survey households without children under five; in this case, these households were matched with subsequent households without children under five without the technologies.

In communities without the Pure Home Water technologies, a random sampling of households was surveyed to obtain baseline data. Households were targeted with children under five. The actual households were often chosen by a local community guide, since they were knowledgeable about which households had children under five and which women were home and available. In the traditional communities, sometimes it was culturally required to initially survey the wife of the chief upon our entrance into the community. Though a random sampling was attempted, the selection was difficult because of language barriers and cultural requirements, and there is a potential for household selection bias.

Participant Selection Strategy

To minimize the differences in responses, the woman of the household (generally mother, or grandmother if mother was not available) was chosen as the participant in the survey. Women are generally responsible for the water of the household, including water collection, cooking, and cleaning. Therefore, women were chosen since they are assumed to be the most knowledgeable about household water practices. In the traditional households, extended families live together and often many women were present, in which case the household members made the selection, which was assumed to be random.

3.3.5 ***Implementation of Surveys in Ghana***

Initially, the implementation plan of the overall survey was discussed with Pure Home Water and revised as necessary. Ten copies of the survey were brought from MIT, since future revisions were anticipated, and the final version was printed and copied in country. After the population selection was decided, a schedule was drafted determining which days each community would be visited, considering transportation convenience and efficiency. Because most households did not own telephones, prior notification through calling was not feasible. In traditional communities (including Libga, Kaleriga, Bunglung, and Diare), it was culturally necessary to visit the chiefs and leaders at least a day in advance. In these situations, the chiefs would first approve the visit of Pure Home Water to the community and then select a day for survey implementation. All chiefs were receptive to the project and approved our visitation. In modern communities (including Kamina Barracks, Jisonayili, and Vitin Estates), it was not necessary to notify the households prior to visitation.

For each community, the survey was conducted with the help of either Hamdiya Alhassan or Wahabu Salifu, based on their availability, familiarity with the community, and fluency with the local dialects. Hamdiyah accompanied the author to Jisonayili and Kamina Barracks, and Wahabu accompanied the author to Bunglung, Diare, Kaleriga, Libga, and Vitin Estates. Though the difference of their presences may have affected the participants' responses, it was decided that this affect was minimal and was necessary for the survey conduction. The presence of outsiders (particularly Westerners) visiting the community may have influenced the participants' responses and is considered in the analysis. Though the woman of the household was chosen as the participant, often all members of the household would chime in to help answer the questions. This family participation was unavoidable. It is attributed to the familial culture of the community, and it was assumed to minimally affect the survey results. The surveys were conducted in English if possible or in a local dialect with the help of translators (Hamdiyah Alhassan, Wahabu Salifu, or local guides)[2]. The entire survey took twenty to forty-five minutes, depending on the level of language barrier. In each community, six to ten households were surveyed, and subsequent water samples were collected and GPS coordinates were recorded.

The participation rate was 100%, extremely high for household survey conduction. A few household participants were not available initially, but were available when we returned later in the day. This high participation rate can be attributed to prior notification in the traditional communities and general cultural acceptance of household visitors.

The communities surveyed are mapped in Figure 3.1

3.3.6 Conduction of Water Testing

At each household, water samples of the source water and filtered water (if applicable) were collected directly from the container used for drinking and then tested in the MIT team field laboratory set up at our place of residence in Tamale for bacterial contamination, using H_2S and membrane filtration tests. During the household visits, the participants were asked to offer some drinking water. Because the water samples were taken directly from the cup offered, the sample was assumed to be representative of the water quality being consumed by the household. The water testing was able to detect contamination, regardless of whether the contamination occurred at the source, during transit, or during storage.

The samples were collected from the households at the end of the interview, placed in an ice cooler with ice packs during transport, and refrigerated in the laboratory until they were analyzed. These tests were performed at the laboratory in Ghana during the same day as water sample collection. All tests were performed within six hours of collection, as recommended by the water testing protocol.

3.4 Results

The cross-sectional epidemiological survey collected baseline data on water and sanitation practices in the Northern Region of Ghana. The survey results are summarized in Table 3.1. Categorical data is compared with percentages, and continuous data is compared with the averages, which are taken as the arithmetic mean of the data.

[2] Though English is the official language, over 60 local dialects are present in Ghana (Briggs, 2004)

CHAPTER 3

Table 3.1. General Profile of Survey Results.

Communities surveyed	Traditional	28/50= 56%
	Diare	7/50 = 14%
	Kaleriga	6/50 = 12%
	Bunglung	7/50 = 14%
	Libga	8/50 = 16%
	Modern	22/50 = 44%
	Kamina Barracks	10/50 = 20%
	Vitin Estates	6/50 = 12%
	Jisonayili	6/50 = 12%
Household Information	Average number of people in household	14 people
	Average number of children under 5	2 children
	Average age of respondent	35 years old
	Average number of years of education of respondent	5 years
	Average expenses per person per month	250,000 cedis ($28)
Diarrheal Prevalence and Knowledge	Diarrheal Prevalence (people)	39/724 = 5.4%
	Diarrheal Prevalence (households)	19/50 = 38%
	Diarrheal Prevalence for children under 5	17 /109 = 16%
	Knowledgeable about diarrheal causes	42/50 = 84%
	Cost per diarrheal treatment	
	Hospital	133000 cedis ($15)
	Oral Rehydration Therapy	1000 cedis ($0.10)
	Salt/Sugar solution	1000 cedis ($0.10)
	Medicine	21200 cedis ($2)
Hygiene and Sanitation	Appropriate Hand-washing	43/50 = 86%
	Adequate sanitation facility	23/50 = 46%
	Average time to sanitation facility	4 minutes
Water Use Practices	Primary Water source	
	Tap	22/50= 44%
	Standpipe	7/50= 14%
	Borehole	19/50 = 38%
	Dam	2/50 = 4%
	Always using Improved Water Source	32/50 = 64%
	Average time to source	
	Dry season	26 min
	Wet season	10 min
	Primary water sources while traveling	Sachet and tied water
Water Storage	Storage containers*	
	Barrel/plastic drum	2/50=2%
	Ceramic vessels	23/50 = 46%
	Cooler	1/50=2%
	Jerry can	3/50=2%
	Metal tank/drum	2/50=4%
	Plastic bucket	5/50=10%
	Plastic bottles	13/50 = 24%
	Safe Storage	4/50=8%
	Proper Storage	32/50 = 64%
Water Quality Perception and Household Water Treatment	Believe water is safe without treatment	38/50 = 76%
	Main complaint about water	Particles/turbidity
	Treatment method: some type **	40/50 = 80%
	Tamakloe	8/50 = 16%
	Nnsupa	3/50 = 6%
	Cloth	27/50 = 54%
	Boiling	1/50 = 2%
	Settling	5/50 = 10%
	Glucose	1/50 = 2 %
	Alum	1/50 = 2%
Water Testing Results	H2S bacteria in source water	20/50 = 40%
PWH Technology	Households with PHW Technology	15/50=30%
	Interested in Producing PWH Technology	47/50 = 94%
Family Decision-Maker	Who in family decides what to buy	
	Mother	12/50= 24%
	Father	4/50 = 8%
	Mother and father	7/50 = 14%
	Entire household	21/50 = 42 %
	Elders	1/50 = 2%
	No Data	5/50 = 10%

*Totals over 100% since 3 people using 2 different types of containers
**Totals over 100% since some respondents are using more than one type of treatment

3.4.1 Communities Surveyed

The percentages of respondents from each respective community are listed in Table 3.1 and categorized as traditional and modern. The dichotomy of traditional and modern households is based on house type and community layout. The modern communities are comprised of households constructed of cement, whereas traditional communities consisted of homes arranged in a circular fashion (See Figure 3.2) and are generally ruled by a head chief.

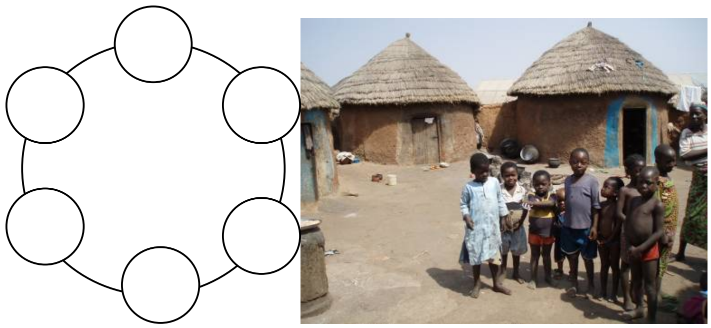

Figure 3.2. Diagram and Photo of Household Arrangement in Traditional Communities.
Photo courtesy of Casey Gordon

3.4.2 Household Information

The survey included general questions to gather background information about the household and respondent. In traditional communities, "households" consist of many dwellings arranged in a circle and surrounded by a wall (See Figure 3.2). The compound in the middle of the circle is used for cooking and other activities. Sometimes there were so many children around that the respondents were unsure of the exact number of members in the household, and in these cases, the best estimate was recorded. As a result of the definition of "household" in traditional communities, the average number of people for households surveyed is quite high at 14 members, including both traditional and modern households.

The average age of the respondent was recorded, generally the mother or the grandmother of children under five of the household. This average is increased by the few grandmothers that were interviewed. Years of education was recorded as well. The average expenses per person per month were calculated by summing the total expenses and dividing by the number of household members. The total expenses were determined by asking about monthly costs of food, transportation, education, health, utilities, and other expenses; these questions often ignited a debate among the entire household. Though this data is a rough estimate, it generally profiles the study cohort as people that live on less than a dollar a day. See Table 3.1 for detailed responses.

- Expenses per person per month = $\frac{\text{Total expenses of each household}}{\text{Number of members in household}}$

3.4.3 Diarrheal Prevalence and Knowledge

The diarrheal prevalence is defined in the Pure Home Water survey as the percentage of people that were suffering from diarrhea within one week of the time of the study. The prevalence of the total number of people was calculated by dividing those suffering with diarrhea by the entire population in all households surveyed. Similarly, the prevalence in the children under five was calculated by dividing those under five suffering from diarrhea by the children under five in all households surveyed. The diarrheal prevalence in households is defined as the households with one or more individuals suffering from diarrhea divided by the total number of households. Households were determined to be knowledgeable about diarrheal causes if they responded affirmatively when asked if dirty water, dirty food, and poor hygiene could all be causes of diarrhea. In general, it seemed that households were knowledgeable about the causes of diarrhea; however, the participants' willingness to respond to please the interviewer must be considered. The costs of the most common treatments were recorded and averaged for the data set (see Table 3.1). Additionally, respondents were asked about the caretaker for the sick family members, and it was found that this burden fell almost entirely on the mothers and grandmothers of the household.

- Diarrheal Prevalence (people) = $\frac{\text{Total number of people with diarrheal illness within week of survey}}{\text{Total number of people in all households surveyed}}$
- Diarrheal Prevalence (households) = $\frac{\text{Total number of households with at least one person with diarrheal illness}}{\text{Total number of household surveyed}}$
- Diarrheal Prevalence for children under five = $\frac{\text{Number of children under five with diarrheal illness}}{\text{Total number of children under five in households surveyed}}$
- Knowledgeable about diarrheal causes = $\frac{\text{Respondents that acknowledged dirty water, dirty food, and poor hygiene as causes for diarrheal illness}}{\text{Total number of respondents}}$

3.4.4 Hygiene and Sanitation

Respondents were asked about hand-washing practices and adequate sanitation facilities. The general assessment about appropriate hand-washing was based on whether mothers washed their hands at appropriate times and always used soap. In order to be classified as "appropriate," participants had to respond affirmatively when asked if they always used soap, currently had soap in the household, and if they washed their hands before eating, before cooking, and after going to the bathroom. Though there may have been discrepancies between the responses and actual practices, this method of assessment was thought to be the most appropriate. In general, mothers seemed fairly knowledgeable about the importance of hand-washing based on their responses; of the respondents, 86% practiced appropriate hand-washing.

The general survey results determined that 46% of the households surveyed had access to adequate sanitation facilities. Sanitation access is defined as having a flush toilet or private/shared latrine that is always available. Public latrines are not considered improved sanitation facilities as defined by the UNICEF/WHO Joint Monitoring Programme (JMP, 2005). The respondents were also asked if hand-washing was available at the sanitation facility, but this information was not used in the assessment of whether the sanitation facility was adequate. Additionally, the time to the sanitation facility was recorded and averaged four minutes; many families practiced "free range," using nearby fields that required travel time. This average is lowered by the participants that had sanitation facilities within the home, where the time to the facility was recorded to be zero minutes. The time to the sanitation facility was not considered in the determination of sanitation access.

- Appropriate hand-washing = $\frac{\text{Number of respondents that always use soap, currently have soap in the home, and wash their hands before cooking, before eating, and after using the toilet}}{\text{Total number of respondents}}$

- Adequate sanitation facility = Number of households with flush toilet or latrine (private/shared) that is always available / Total number of household surveyed

3.4.5 Water Use Practices

The four primary water sources for the surveyed households include the household tap, public standpipe, borehole, and dam (see Figure 3.3). Though households may be using an improved source for their primary or main water source, many households used secondary water sources that were not improved. Sixty-four percent of people were classified as always using an improved drinking water source, defined as a tap, standpipe, or borehole that was always available.

Figure 3.3. Primary Drinking Water Sources for Households Surveyed (from top left to bottom right: household tap, public standpipe, borehole, dam).

The total time to collect the water in the wet and dry season included traveling, waiting at the source (if applicable), filling containers, and returning. This time averaged 26 minutes in the dry season and 10 minutes in the wet season among those surveyed. Participants were also asked about their primary drinking water source while away from home which was found to be sachet and tied water (Figure 3.4). Sachet water costs $0.04 (400 cedis) and tied water costs $0.02 (200 cedis) for a small bag of water, about equal to one cup. Because sachet and tied water were sold by vendors, the source was uncertain and potentially unsafe. This water from vendors could potentially be a source of diarrheal illness, and also indicated that the family is willing to pay for drinking water.

Figure 3.4. Sachet Vendor and Tanker Truck.
Photo (left) courtesy of Susan Murcott

Though not included in Table 3.1, the interview included questions about who collected the water and how many times water was collected each day. It was found that this burden falls unequally on women and children, who travel in groups to the water source as many as eight times a day.

- Always using an improved water source = $\dfrac{\text{Number of households with an improved water source (household tap, public standpipe, or borehole) always available}}{\text{Total number of household surveyed}}$

3.4.6 ***Water Storage***

The most common types of storage containers were found to be ceramic vessels (46%) and plastic bottles (24%). Because many people are using more than one type of container, the total is more than 100% of the type of container used in Table 3.1 Additionally, it was found that 64% of people are practicing proper storage, which was determined as keeping the vessel always covered and by the method used to take water from the container. For proper storage, respondents must pour the water directly (as such with a plastic bottle), use a spigot, or draw the water with a scoop with a handle. Using a scoop without a handle was not considered proper storage because of the possibility of recontamination from dirt on the hands.

Despite the attempt to determine proper storage, it is possible that the water was getting recontaminated through ways not addressed by the questionnaire. During household visits, it was observed that yam reeds were sometimes put into the vessels for carrying water which increased stability during transit, according to the local people. The roots may serve as a pathway for contaminating the drinking water during transit.

3.4.7 ***Water Quality Perception and Household Water Treatment***

Seventy-six percent of the respondents believe that their water is safe to drink without treatment. However, 80% of the households are practicing some type of treatment. This discrepancy may be partially attributed to the ignorance as to germ theory of disease; visible particles and dirt rather than pathogens were found to be the main concern about drinking water. Therefore it is important that the drinking water treatment technology promoted by Pure Home Water is effective in removing visible particles and turbidity in addition to pathogens. The most common type of treatment used was the cloth filter at 54%; this high usage may be partially attributed to the distribution of cloth filters as part of the Guinea Worm Eradication Campaign. Guinea worm is a waterborne illness which has largely been eradicated worldwide but which is still endemic in Ghana. In addition to the products sold by Pure Home Water, one household was practicing boiling, one household was adding alum for coagulation, and five households were settling their water before drinking. Additionally, one household reported adding glucose as a form of water treatment, though the reasoning behind this practice was not fully understood. The summation of the treatment methods is more than the total number of households because some households were practicing more than one treatment method (see Table 3.1).

3.4.8 Pure Home Water (PHW) Technology

Participants were asked questions to determine their interest in the Pure Home Water products. Ninety-four percent of the households reported that they were interested in learning how to produce the Pure Home Water products. This question was added by Hamdiyah Alhassan to determine if consumers would be interested in building their own technology and to identify individuals that could potentially assist the Pure Home Water business in the future. Households with the PHW products were asked additional questions included in Section 5.2 and summarized in Table 3.2.

3.4.9 Family Decision-Maker

The participant was asked who in the family decides what to buy in order to determine the family member(s) to target for Pure Home Water marketing. It was found that 42% of respondents reported that the entire household determines what to buy, and in 24% of households the mother decided what to buy. Sometimes the family debated about who makes the decisions, and both the mother and father claimed to have this responsibility; in this case, the respondent's answer was recorded. Detailed responses to the survey are displayed below in Table 3.1.

3.5 Product Feedback

Households that had purchased a Pure Home Water technology were asked different questions than households without the technology in order to provide user feedback to Pure Home Water. Product feedback survey results are summarized in Table 3.2 Ninety-four percent of households without the technologies were found to be interested in treating their drinking water.

Table 3.2. Pure Home Water Product Feedback Survey Results.

Without Treatment Technology	Interest in Water Treatment	33/35 = 94%
	Willingness to pay	80,000 cedis ($9)
With Treatment Technology	Household with Technology	15/50=30%
	Tamakloe	8/50 = 16%
	Nnsupa	3/50 = 6 %
	Safe Storage	4/50 = 8 %
	Always use technology	13/15 = 87%
	Technology still in use	14/15 = 93%
	Overall changes in water	
	Better	12/15 = 80%
	The Same	3/15 = 20 %
	Worse	0%
	Pleased with technology	13/15 = 87%
	Recommend technology to others	15/15 = 100%
	Noticeable improvements in family health	13/15 = 87%
	Who treats the water	
	Mother	12/15 = 80%
	Female child	1/ 15 = 7%
	Male child	1/ 15 = 7%
	Everyone	1/ 15 = 7%
	Adequate resources to maintain technology	13/15 = 87%
	Willingness to pay if technology breaks	72,000 cedis ($8)
	Why more people haven't bought technology	
	Price	7/15 = 47%
	Don't know about it	3/15 = 20%
	Unknown	5/15 = 33%

The willingness-to-pay for filter technologies was comparable between households with and without the technology, at $8 (72,000 cedis) and $9 (80,000 cedis) respectively. Additionally, the differences between modern and traditional communities for willingness-to-pay were comparable, at $8 (72,000 cedis) for modern communities and $9 (80,000 cedis) for traditional communities. Households without Pure Home Water products (most of which were in traditional communities) were unfamiliar with the technologies and therefore uncertain as to what the products would entail, resulting in a broader range of price responses compared to households with the products.

In general, the feedback was positive from households with the Pure Home Water products. Ninety-three percent of households were still using the technology within six months of purchase. The one household that had discontinued use of the Nnsupa did so because the filter had gotten clogged and the flow rate was unacceptably slow, which was determined to be caused by very turbid water containing many particles that clogged the filter. Eighty-seven percent reported that they always use the technology and 87% reported that they were pleased with the technology. Eighty-percent of the people believe that the water is better aesthetically, 20% have not noticed a difference, and no households reported a negative change in the water aesthetics. Every household reported that they would recommend the technology to others. Eighty-seven percent of households have noticed health improvements in their family, but this response may be partially psychological rather than physical, and no health monitoring was performed to verify this response. In general, the mother is most commonly responsible for treating the water at 80% of the households.

When asked why they purchased the technology, customers reported that the products clean the water, prevent recontamination, and save time since treating water by boiling is no longer necessary. Customers liked the appearance, size, and ease-of-use of the products. Some customers even mentioned that they would like a larger filter or another one in their household. Additionally, customers with the Tamakloe mentioned that they chose the Tamakloe filter over the Nnsupa because of the price ($16 verses $21).

Participants also believed that more people have not bought the technology mostly because of price but also because they are not aware of the products. For the C.T. Filtron filter, additional complaints included that the ceramic was breakable and that clay bits came off of the lip when the lid was opened and closed. Some Tamakloe users also said they would like another one or a bigger unit. One user complained about the price and thought the products should be free since Pure Home Water is working with World Vision, a large and well-established NGO in Ghana.

Using the HWTS Indicators of the WHO Network, the rate of adoption and market penetration can be determined for the PHW technologies (Murcott, 2005). For the rate of adoption, 93% of households were still using the products within six months of purchase. Using the market penetration definition of number of units sold over the total target population, only 152/520,000 or 0.03% of the market in the three districts has been penetrated as of January 2006.

Detailed survey results on product feedback are displayed in Table 4.1.

3.6 Comparison of Survey Data and Ghana Statistical Service Data

The Pure Home Water survey data was compared to data collected by the Ghana Statistical Service (GSS), to compare the population targeted by Pure Home Water to the greater districts of Tamale and Savelugu and to the entire Northern Region. The differences between the survey data and the statistical information can be partially attributed to varying definitions of the factors considered. For example, in the PHW surveys the household size for traditional communities is defined as the circle of dwellings (Figure 3.2), which results in a high number of household members, compared to the GSS data which defines a household as a single dwelling. Since all of the traditional communities were in the Savelugu District, the average size of households surveyed was 24 people compared to the GSS data of 6 people. In the surveys, appropriate hand-washing was defined as respondents washing their hands at appropriate times, and currently having soap in the household. The GSS information on hand-washing is the percentage of households that have hand-washing materials available, which was not confirmed during the household surveys. Additionally, the Pure Home Water survey sampled a small subset of the population, and the small sample size contributes to the difference between the survey results and the GSS data. The diarrheal prevalence for children under five is comparable, at 16% for the entire surveyed population compared to 15.3% for the GSS data. The comparison is displayed below in Table 3.3.

Table 3.3. Comparison of Survey Results and Ghana Statistical Survey Data.

		Tamale		Savelugu		Northern Region
		PHW Survey Data	GSS Data*	PHW Survey Data	GSS Data*	GSS Data *
Communities Surveyed	Traditional/Rural	21%	33%	100%	65%	
	Modern/Urban	79%	67%	0%	35%	
Household Information	Average household size	7 people	6.5 people	24 people	6.1 people	
	Female population with no education	21%	59%	100%	83.3%	
Diarrheal Prevalence	Diarrheal Prevalence for children under 5	13%		17%		15.3%
Hygiene and Sanitation	Appropriate Hand-washing	86%		86%		37.6% **
	Adequate sanitation facility	79%	64.4% have facilities, 13.6% have improved facilities	5%	24.1% have facilities, 4.8% have improved facilities	
Water Use Practices	Tap	79%	33.2%	0%	0.4%	
	Standpipe	21%	45.6%	5%	9.6%	
	Borehole	0%	0.6%	86%	15.4%	
	Dam/surface	0%	14.1%	9%	65.5%	
	Tanker	0%	3.9%	0%	0.6%	
	Well	0%	1.7%	0%	3.7%	
	Spring/rain	0%	0.2%	0%	4.4%	
	Always Using Improved Water Source	64%	79.6%	64%	29.8%	

* Ghana Statistical Service, 2005
**Have hand-washing materials available

3.7 Water Quality Testing Results

To complement the PHW surveys, household drinking water was tested for bacterial contamination. The water quality testing results are summarized in Table 3.4. For the source water, 100% tested positive for total coliform, 71% tested positive for *E. coli*, and 40% tested positive for H_2S bacteria. For the filtered samples, no contamination was detected, though the sample size was small.

3.7.1 H2S Results

Fifty source water samples were analyzed for H_2S bacteria, and 40% (20/50) of the results were positive and 60% (30/50) were negative. Forty-nine of the households supplied fifty samples of source water; at one household two different source water samples were given and one household did not supply a sample since the interview was conducted at her workplace. Additionally, nine households with the Pure Home Water filters were tested for H_2S bacteria after treatment by PHW products (either Nnsupa and C.T. Filtron filters) and all were negative. More extensive field-testing of Pure Home Water products was conducted by teammate Claire Mattelet (Mattelet, 2006).

3.7.2 Membrane Filtration (MF) Results

For the membrane filtration, all of the source water was contaminated with total coliform, with an average of 3000 CFU/100 mL. Seventy-one percent of source water samples were contaminated with *E. coli*, with an average of 50 CFU/100 mL. For the filtered water, only one sample was taken due to time constraints and field feasibility. This sample tested negative for both total coliform and *E. coli*, though the source water going into the filter had minimal contamination as well (see Table 3.4). More extensive field-testing of Pure Home Water products was conducted by teammate Claire Mattelet (Mattelet, 2006).

Table 3.4. Water Testing Results Summary.

	Total Coliform (TC)	***E. coli* (EC)**	**H_2S Bacteria Presence/Absence**
Source Water			
Number of Samples	24 samples	24 samples	50 samples
Results	Average: 3000 CFU/100mL (TNTC) TC present: 24/24 = 100% No TC present: 0/24 = 0%	Average: 50 CFU/100mL EC present 17/24=71% No EC present 7/24=29%	Positive:20/50=40% Negative: 30/50=60%
Filtered Water			
Number of Samples	1 sample	1 sample	9 samples
Results	Nnsupa In: 1 CFU/100mL Nnsupa Out: 0 CFU/100mL	Nnsupa In: 0 CFU/100mL Nnsupa Out: 0 CFU/100mL	Positive: 0/9=0% Negative: 9/9=100%

* P/A= presence/absence

3.8 Epidemiological Study Conclusions

There is a great need for safe water and sanitation in the Northern Region of Ghana, with 36% of the Pure Home Water survey population lacking access to an improved water source and 54% lacking access to an improved sanitation facility. Diarrheal illness prevalence is 5% for the population surveyed and 16% for children under five, underscoring that children under five are more at risk for waterborne illness. Though diarrheal illness is caused by a number of exposure pathways, clean drinking water is one key element that has the potential to improve public health of the Ghanaian communities. The surveyed population was fairly well educated about the importance of hand-washing, with 86% of the cohort practicing appropriate hand-washing. Additionally, there is great need for safe storage in the home, since water testing of improved water sources detected contamination. The cross-section epidemiological surveys were extremely well received within the communities, with 100% participation of the households.

The households were very pleased with the Pure Home Water technologies, with 100% of customers reporting that they would recommend the products to other households. Of the households without Pure Home Water products, 94% responded that they would be interested in treating their drinking water. The presence of filters in the home was found to reduce diarrheal illness by 88% for the household, though significant diarrheal illness reductions were not observed for children under five. These results can be explained by the many other factors of exposure, particularly for children. The public impact from improved drinking water may not be fully realized because of the many other factors for pathogen exposure. In order to substantially reduce diarrheal illness, a complete reform of sanitation and hygiene practices needs to be adopted in addition to improved drinking water. However, the Pure Home Water products are a significant step along the way to reduce waterborne disease.

CHAPTER 3

It was found that the greatest need for clean water was in traditional communities. The traditional communities lacked improved water sources and adequate sanitation facilities more prominently than modern communities. Ninety-five percent of modern communities had access to sanitation facilities, while only 7% of traditional communities had access. Eighty-two percent of modern communities had access to an improved water source, with only 50% having access in traditional communities. Additionally, the traditional communities have a higher diarrheal prevalence for children under five, at 5% for modern communities and 18% for traditional communities. None of the mothers in traditional communities had received education; mothers' education level has been found to be a factor of diarrheal illness for children under five in Ghana (Gyimah, 2003).

Though the greatest need for household drinking water treatment products is in traditional communities, it is difficult for Pure Home Water to sell products to traditional communities because of the generally lower socioeconomic status; price was the most common response when respondents were asked why more households had not bought the Pure Home Water products. After consulting with the business students, it was discovered that it was not feasible to significantly lower the price and still maintain a sustainable business. Therefore, it is recommended that cheaper water treatment technologies be explored, such as solar disinfection or biosand filters, for households that cannot afford the current Pure Home Water products. Additionally, ceramic filter manufacturing closer to Tamale is being investigated as a way to reduce product costs.

CHAPTER 4

CHAPTER 4.HOUSEHOLD CERAMIC WATER FILTER EVALUATION USING THREE SIMPLE LOW-COST METHODS: MEMBRANE FILTRATION, 3M PETRIFILM AND HYDROGEN SULFIDE BACTERIA IN NORTHERN REGION, GHANA

4.1 Objective

The overall objective of the present study is to provide HWTS system assessment and to recommend low-cost methods from among a set of selected technologies that could be used by the PHW Ghana team to check for any potential water quality contamination problem emanating from a HWTS that has been reported by a client.

The microbial study will be done through the assessment of the current *E. coli* (EC) and total coliform (TC) contamination of water sources (e.g., dams and rivers) in Tamale as well as through the microbial removal effectiveness of the household treatment technologies sold by the two PHW entrepreneurs. These results will argue for or against the use of these simple and low-cost methods in Ghana.

The assessment and the comparison of the several microbial indicator methods and their associated labor, equipment and supplies are based on 6 screening criteria which are as follows:

- Cost of the individual test and all supplies needed for the experiments undertaken
- Ease of use of the proposed methods
- Ease of result interpretation of the various tests made
- Labor/ hours required to complete the tests
- Level of skill requirement
- User feedback

The three microbial indicators methods evaluated are as follows:

- Portable Membrane Filtration (MF) using m-ColiBlue24® selective medium (HACH, 2006)
- 3M-Petrifilm (3M Petrifilm, 2006)
- Presence/Absence (P/A) H_2S test (HACH, 2006)

4.2 Introduction

Drinking water provisions continue to be a major source of waterborne diseases and death in the world because many points of water collection remain unsafe. In Ghana, although considerable improvements have been made the past few decades, greater efforts are still needed to address the key issues and questions which relate to the supply of safe drinking water in Tamale. There is a need of making safe water available, accessible and affordable for the local communities. One such solution to safe water for all is household water treatment and safe storage, which is being promoted globally by WHO and which products are sold locally by PHW in Tamale. In addition, low-cost, simple microbial indicator methods are commonly used in developing countries to provide means of assessing drinking-water safety. These methods are implemented so that they require only low-qualified professionals able to self-control and monitor drinking water quality within the community without the need of foreign expert assistance. In the Northern region of Ghana, the poorest of the country, the villages are usually situated far away from each other without any main connection roads. Therefore, the lack of accessibility for any routine water inspection creates a need to implement simple and cheap microbial tests for the assessment of drinking water quality for point-of-use (POU) systems.

4.2.1 ***Presence/Absence H_2S test***

The H_2S test has been evaluated through many studies in various tropic and temperate regions, including Peru, Chile, Nepal and South Africa (Ratto et al., 1997; Castillo et al., 1994; Rijal et al., 2000; Genthe and Franck, 1999). Results were compared to other conventional fecal indicators of water. The method gave comparable results to the test for traditional bacterial indicators of fecal contamination. In some cases, the technique even gave superior results to the conventional indicators of fecal contamination.

Figure 4.1. Presence (black) and absence (yellow) result with H2S test after 24 to 48 hr.

However, it is not recommended to use P/A H_2S test as the only standard method for testing the presence of fecal contamination in water. Too many uncertainties remain in terms of reliability, specificity, and sensitivity of this test.

First, problems concerning false positive and false negative results may occur with H_2S tests. More false positive results are likely to happen rather than false negative results. On the one hand, the fact that there are fewer false negative results means that there is good reliability. 0n the other hand, false positive results might lead to a lower consumption of water, because the analyzed water will be considered contaminated yet it is safe to drink. Such results could increase the cost of delivering safe water.

Second, P/A H_2S method has only been tested indirectly and or in comparison to other conventional indicator of fecal contamination techniques. It has not been evaluated and judged according to the generally accepted characteristic of an indicator for fecal contamination. Some studies focus their efforts on validation and evaluation of the test based on the detection of fecal coliforms and pathogens such as *Salmonella*. The determination of agreement between outcomes for H_2S and fecal indicator bacteria is not always uniform among these studies. Some of the studies support their results by statistical analysis and correlation numbers while other studies do not. Another tendency when comparing results is both to determine sensitivity (lower limit of detection) and specificity (ability to detect bacteria or bacterial groups).

The HACH PathoScreen used by the author cost US$0.25 (20mL sample), which is quite cheap. For the previous reasons; high portability of the test, ease of interpretation of the results, rapid results and fairly good correlation with TC, fecal coliforms, and to a certain extend, EC, the test has been used in field studies by the author of the thesis.

4.2.2 ***Membrane Filtration (MF)***

Compared to the H_2S P/A method which gives a presence or absence result, the MF method quantifies the level of contamination by giving a direct count of the colonies in the water sample (see Figure 4.2). The overall procedure of the MF is based on the detection of some specific metabolic function of coliforms (e.g., the detection and enumeration of coliform organisms from their production of acids during the fermentation of lactose). One of the best MF media that can be used for the detection of TC and EC is m-ColiBlue24® (Sartory and Howard, 1992; Brenner et al., 1993; Cenci et al., 1993; Low, 2002). With m-ColiBlue24®, organisms producing red colonies with metallic sheen within 24 hours of incubation at 35 ± 0.5°C are TC colonies. EC colonies are represented in blue on the petridish.

Figure 4.2. Membrane Filtration Unit and Pump.

Various challenging issues occur related to proper coliform detection including false negatives, false positives, misreading of coliforms, and the bacterial environment. Despite these drawbacks, MF is considered as being one of the most accurate methods for bacteria enumeration when field sampling has to be done.

4.2.3 ***3M Petrifilm***

Petrifilm EC plates were first developed for the detection and enumeration of EC and coliforms in the food and dairy industries (Curiale et al., 1991; AOAC, 2000a,b; Priego et al., 2000; Russell, 2000). The development of the EC Petrifilm plate for water testing analysis seemed therefore reasonable (Vail et al., 2003). Vail et al. concluded in their study that the 3M technique could have great potential for testing drinking water in developing countries because of its simplicity of use and storage, reliability and relatively low cost. 3M would be particularly efficient when used as a preliminary screening method to identify problem sites (see **Error! Reference source not found.**).

Figure 4.3. 3M Petrifilm. TC Colonies are Shown in Red and EC colonies are Shown in Blue

4.2.4 ***PHW Products***

The two main PHW products that were investigated are the C.T. Filtron ceramic filter and the Nnsupa ceramic candle filter. The main competitor of these filters is the Everest Aquaguard, an Indian candle filter, available in the Tamale marketplace. The three filters main characteristics are listed Table 4.1.

Table 4.1. Filter Characteristics.

Filter	Cost (US$)	Silver	Height of Filter Bucket (cm)	Diameter of Filter Bucket (cm)	Candle Height (cm)	Candle Diameter (cm)	Pore Size of Candle (µm)	TC Percent Removal	EC Percent Removal
Tamakloe	18	Yes	24 [a]	31 [a]	-	-	1	99.98	99.98
Nnsupa	25	No	28.4	20.8	12.8	7.5	Not Stated	100	100
Everest Aquaguard	14 (20L) 16 (24L) 18 (27L)	No	28.4 [b]	20.8 [b]	19.5	5.8	20 – 30	Not Stated	Not Stated

[a] Dimensions of the ceramic pot.

[b] The Everest Aquaguard candle was placed in the same bucket as the Nnsupa filter during experiments. Heights and diameters of the Everest Aquaguard bucket commonly marketed are different and the volume ranges between 20L, 24L and 27L.

Local Production of C.T. Filtron Filter

The PFP C.T. Filtron filter has been locally manufactured in Ghana by C.T. Filtron Ltd. under the name "C.T. Filter" (see Figure 4.4). This filter model has won a prize in the World Bank Development Market Place in Ghana in 2005. The filter has been found to be a simple and low-cost technique to reduce water borne diseases in domestic water supply. It is made locally. In Ghana, it has been manufactured since 2004. Specialists from Practica Foundation and PFP Nicaragua provided the necessary training. The Dutch organisation De Oude Beuk foundation provided finance to bring filter ceramist expert Ron Rivera to Ghana to train Peter Tamakloe and his employees. As Mr. Tamakloe, director of Tamakloe Ceramics said: "the next challenge is to create a market for this new filter concept". The prize money is currently being used for awareness creation, publicity, and marketing.

Figure 4.4. C.T. Filtron Filter.

When the author first travelled to Ghana, she visited the local filter cooperative located near Accra. After having received training in production, Tamakloe Ceramics has produced over 1000 filters. Some filters were distributed to villages around Accra and 300 were given for demonstration purposes to other developmental organizations in 2004. The C.T. Filtron filters were tested by the national water lab, confirming that water produced by this filter complies with WHO norms for turbidity and bacteria. The C.T. Filtron filter company has 38 full-time employees who receive at least twice the minimum wage in Ghana and have benefited from an apprenticeship scheme.

The C.T. Filtron filter consists of a flower pot-shaped filter element with a depth of 24cm and a diameter of 31cm. It consists in a combination of red clay and wood saw-dust which gets mixed and pressed in a hydraulic press and fired in a klin. The claypot is burnt at about 900°C and the sawdust is burnt off during the high temperature of firing, this leaves behind small pores in the pot. If the proportion of sawdust[3] is increased in the mixture, the flow rate will increase because of the greater porosity. Once fired, the filters are immersed in a bath of colloidal silver allowing the inside and outside of the pots to be treated with 1cc of 3.2% of colloidal silver in 300mL of water, this will act as a biocide, contribute to the prevention of biofilm inside the filter, and may or may not improve the removal of bacteria (PFP, 2004).

[3] In Nicaragua: One bucket of dry pulverized clay (60%) is mixed with 0.8 buckets of dry sawdust (40%) served between a 35 mesh and 60 mesh screens keeping only what stays between the two screens.

Each pot produced is then tested for its flow rate. The flow rate should be about 2L/hr. In case of abnormal flow rate, the clay pot is destroyed.

Local Production of Nnsupa Filter

Figure 4.5. Nnsupa Filter.

The author visited another local production of filter in Kumassi. The owner of the filter production is Mr. Michael Commeh. The Michael Commeh's Ceramic Candle Filter System known as the Nnsupa filter[4] (see Figure 4.5). The production activities deals with small/medium scale industries/business development. The production was created in response of the expensive cost of imported water purification systems in Ghana (average range situated between US$70- US$200). The strategy was to open a local filter production market and to produce cost effective household ceramic filter candle (US$1.50- US$2.00). The idea started after a ceramic R&D Training workshop, undertaken by M. Commeh in 1995 which showed the possibility of production of household ceramic filters in Ghana, that are expected to meet WHO guidelines (0 EC per 100mL). The project took off thanks to the funding of US$15,256 that came in 2002 from the Swiss government through Swiss embassy in Ghana to complete the R&D and start production. The first trial tests of the complete water filter unit were subsequently undertaken and, in 2003, a full unit of household ceramic filters reputed to meet the WHO guidelines was created. The following full production of the filter candle started in 2004.

The Nnuspa candle is made of white clay. The mould is pre-established and its shape is like the Indian candle except that it is shorter and wider. The Nnsupa candle height is 12.8cm and its diameter is 7.5cm. The white clay is fired at 900°C allowing the shrinkage of the organic matter and the subsequent desired pore size.The Nnsupa filter is simple to use and removes 100% of bacteria contamination, 100% of cysts, and 100% of heavy metals according to Mr. Commeh (Commeh, 2006).

The transparency of the containment vessel allows the user to see the efficiency of the process by seeing the water getting cleaner after treatment. In comparison to the C.T. Filtron filter pot, no colloid silver is applied to the candle and the flow rate of the candles is not tested before selling them. As we learned during our January 2006 trip, a thorough microbiological testing of the candles has not been performed. The price PHW proposed to its clients was US$25. Filter characteristics are reported table 4.1.

Production of Indian Filter (Everest Aquaguard)

[4] Nnsupa means « Safe water » in the local language.

The MIT Sloan team of the PHW project investigated one of the main competitors of PHW products in terms of other locally available HWTS in the Northern region of Ghana. This white clay candle filter finds its origin in India. As no local manufacture could be visited and very few data are available on the internet, it is unclear where the filter comes from and how it is manufactured. Therefore, the characteristics of the Everest Aquaguard ceramic candles that could be reported are the height and the diameter of bucket (28.4x20.8cm), the height and the diameter of candle filter (19.5x5.8cm). Everest Aquaguard characteristics are reported in Table 4.1. The price of the Aquaguard depends on the volume of the stainless steel bucket. The minimum price is US$14 for the 20L bucket capacity. For 24L and 27L bucket volumes the price is US$16 and US$18, respectively. For the experiments the author performed, the candle of the Everest Aquaguard filter was placed in the same type of bucket as the Nnsupa filter. The Indian candle filter is not treated with a colloidal silver coating.

Figure 4.6. Everest Aquaguard Top and Bottom Buckets.

4.3 Methods

*4.3.1 **Filters Testing***

Three flow rate tests were performed on each of the three ceramic filter types. Filters were allowed to be saturated with water before starting the timing. The upper containers were filled so that the water level was flush with the upper containers (different volumes of water were used depending on the container height). The Everest Aquaguard and the Nnsupa filter systems were filled with the same quantity of water as they both have the same bucket height, which was the height of water corresponding to the top of the Everest Aquaguard candle filter for the two buckets. The measured flow rate was calculated by quantifying the volume of water percolating from each filter by hour intervals. The initial flow rate was measured approximately an hour after pouring the water in the top of the filters. Final flow rate measurements were made 3 hours after the first measure.

Flow rate was calculated by dividing the volume of water filtered by the time it took for that volume to be filtered.

Flow rate (L/Hr) = (Volume Filtered (L)) / (Elapsed Time (Hr))

*4.3.2 **Microbial Testing***

The water used for the microbial testing of the Indian, Nnsupa and C.T. Filtron filters came from St. Mary Dam. The different filter systems were initially washed with sterile water to help eliminate bacterial population especially in the bottom bucket. No soap was added to wash the buckets because the soap could provide a potential nutrient source for bacteria. The inflow and outflow waters were tested with the three microbial evaluation technologies.

The inflow and outflow water were tested for microbial removal with P/A H_2S method.

The MF and the 3M Petrifilm were also used to quantify the number of TC and EC present in a sample. The removal efficiencies and log removal of bacteria were then calculated. The formulas were as follows:

%Removal Efficiency= {1- ((Unfiltered-Filtered Sample)/Unfiltered Sample)}*100

$$\text{Log Removal of Coliforms by Filters} = \log10\,(\text{CFU/100mL} + 10\ \text{CFU/100mL})_{\text{source}} / (\text{CFU/100mL} + 10\ \text{CFU/100mL})_{\text{filtered}}$$

Log removal data were adjusted upward by a small constant (10 CFU/100mL) to prevent taking the logarithm of zero.

4.3.3 *Fecal Contamination Assessment of Water Sources in and around Tamale*

This part of the study sought to determine the level of fecal contamination of various water sources in and around Tamale. The raw water samples were collected in Januray 2006 from different dams and rivers. Before the samples were collected, the author made sure that the dams and rivers of interest were used as source of water in households for cooking and drinking. In Ghana, a dam (locally referred to also as a “dugout”) is a closed water area artificially created by humans. The water samples were collected in buckets and transported back to the field lab. Most of the samples were analyzed within 6 hours prior to their collection but if analysis was not possible prior to 6 hours, the samples were refrigerated. The samples were analyzed for their bacteriological content by using the three low-cost and simple methods already described. Some of the samples were used for testing filters as described below.

Figure 4.7 shows the different water samples that were analyzed. The samples came from the St. Mary Dam, the Bilpelar Dam, the Ghanasco Muali, the Kamina River, and the dam near the Gillbt Guest House, another water sample was taken from a dugout close to the WV office of Savlegu (water sample not shown on Figure 4.7). The photographs of three of the sites are shown in Figure 4.8, Figure 4.9, Figure 4.10, and Figure 4.11 (St. Mary Dam, Bilpelar Dam, and Kamina River). The water coming from the St. Mary Dam was used to evaluate the efficiency of the Nnsupa, C.T. Filtron and Everest Aquaguard filters. Locations of the water sources are shown Figure 4.12.

Figure 4.7. Samples of Water Collected at the St. Mary Dam, the Bilpelar Dam, the Ghanasco Muali, the Kamina River, and the Dam near the Gillbt Guest House

Figure 4.8. St. Mary Dam and GPS Mapping by J. Vancalcar.

Figure 4.9. Bilpelar Dam and Collection of Water Samples by the Author.

Figure 4.10. Kamina River Water Sample Collection.

Figure 4.11. Kamina River: Evidence of High Contamination.

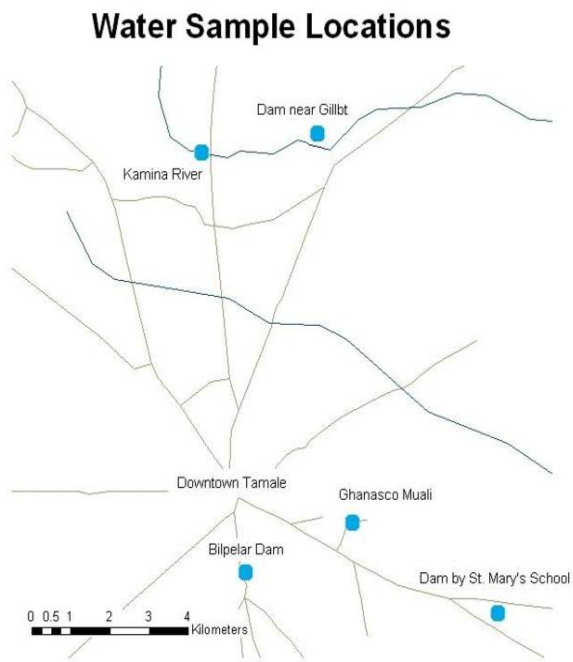

Figure 4.12. Water sample locations for St. Mary Dam, Ghanasco Muali, Bilpelar Dam, Kamina River and the dam near Gillbt shown in blue.

4.3.4 Contamination of 3M Petrifilm and MF

<u>*3M* vs. *MF for TC Enumeration*</u>

A total of 28 water samples that were previously enumerated for TC content were used for the comparison of 3M and MF methods.

Statistical analysis was performed using M. Berthouex and Brown (2002) manual (statistics for Environmental Engineers) was used to perform the statistical tests. Statistical analysis of 3M *vs.* MF for TC Enumeration was undertaken according to Vail et al. (2003) with some changes:

Regression analysis was done on log-transformed data after multiplication by appropriate factors to take into account the amount of dilution, so that counts in 100ml volumes were being compared, and adjusted upward by a small constant to prevent taking the logarithm of zero. The log transformation used for TC organisms was $\log_{10}$(CFU/100mL + 10 CFU/100mL). For 3M Petrifilm in which 1ml was the volume assayed, the log-transform was therefore $\log_{10}$(counts x 100 + 10). Statistical analysis was then computed with Excel for mean, variance and statistical significance with paired *t* test assuming no difference in variances for the two methods. The confidence interval was set at 95%. Therefore if the *t* probability was higher than 5%, no significant difference could be established between the results of 3M and MF. The two-sided *t* probability was used rather than the one-sided. The reasoning is that the 3M results could be higher or lower than the MF results and hence the distribution is two-sided. The log-transformed of 3M *vs.* MF data were plotted in Excel and the linear regression line function adjusted to the 0 coordinates was then selected.

4.4 Results & Discussion

4.4.1 Filters Flow Rate

The C.T. Filtron filter has the highest total average flow rate performance among the three filters studied (1.8L/hr at high water head, see Figure 4.13). However, this flow rate value decreases nearly to the average flow rate value of the Everest Aquaguard after 3 hours of water percolation. The Nnsupa filter experiences the lowest flow rate (0.41 L/hr at high water head) while the performance of the Everest Aquaguard filter is in the middle of the C.T. Filtron and the Nnsupa flow rate ranges (0.58L/hr at high water head). Compared to the Nnsupa filter candle (12.8x7.5cm), the candle of the Everest Aquaguard filter is longer (19.5x5.8cm) and presents more surface area (355.3cm²) compared to the Nnsupa filter (301.6cm²). A larger surface means a higher number of pore spaces available for water to percolate through.

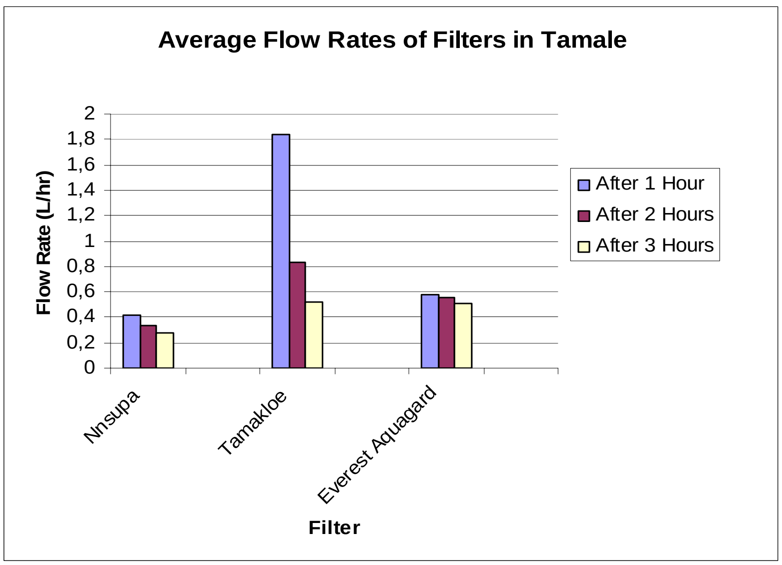

Figure 4.13. One, Two and Three Hour Flow Rate for Filters in Tamale.

The Nnsupa and the Everest Aquaguard filters undergo a decrease of flow rate with time, this flow rate decline is somehow less that the decrease in flow rate observed for the C.T. Filtron filter. This can be due to the mechanism the filters are based on. For the C.T. Filtron filter, the whole ceramic pot acts as the filter whereas for the two candle filters, it is the candle that plays this role. Therefore, it is believed that a decrease in water head will impact the flow rate of the C.T. Filtron filter more than with the candle filters because the available surface area for filtration will decrease more quickly for the C.T. Filtron filter.

The C.T. Filtron filter average flow rate meets WHO minimum necessary volume of water needs at a small household level (three persons could beneficit from it for drinking, food preparation and basic personal hygiene). According to WHO, the minimum necessary volume of water required per person for drinking, food preparation and basic personal hygiene is 7.5L (Howard and Bartram, 2004). If regularly filled, the C.T. Filtron filter would effectively produce 25.5L of potable water per day. The Everest Aquaguard and the Nnsupa filters also fulfil the WHO recommended minimum water need. However, these two POU treatment water will only cover the water needs per day for one person.

As regards the C.T. Filtron filter, the comparatively high flow rate performance is achieved without sacrifice of the microbial removal, as will be described in the next section.

4.4.2 Filters Coliform Removal

3M Petrifilm and Membrane Filtration Removal

The filters studied showed different ranges of bacteria removal (see Figure 4.14, Figure 4.15, Figure 4.16 Table 4.2, and Table 4.3).

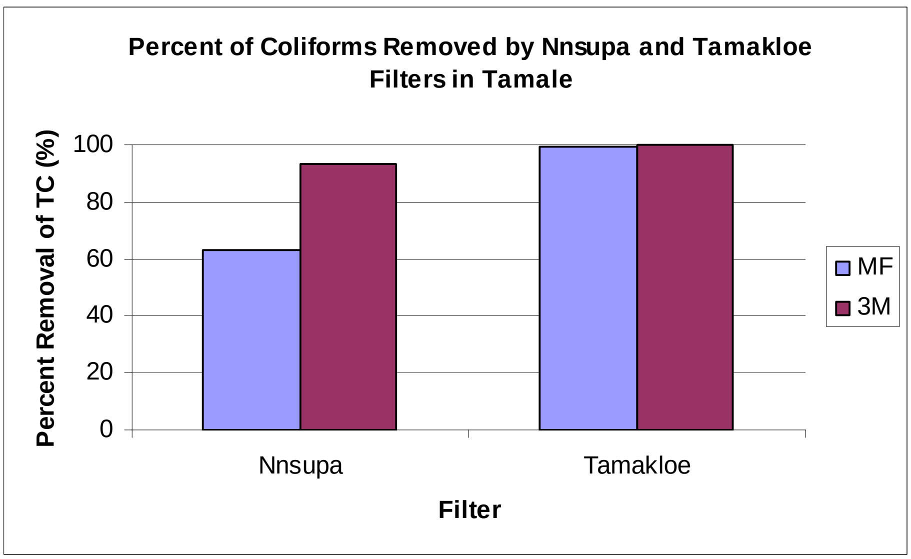

Figure 4.14. Percent of Total Coliforms Removed by Nnsupa and C.T. Filtron Filters in Tamale.

Table 4.2. Percent Removal of TC and EC with the Nnsupa, Tamakloe, and Everest Aquaguard Filters.

	Percent Coliforms Removed by Filters in Tamale			
Filter	**Avg. TC**		**Avg. EC**	
	MF[a]	**3M**[b]	**MF**[a]	**3M**[b]
Nnsupa First Candle	62.9	93.1	-	100
Nnsupa Second Candle	C[c] + CC[d]	69.3 + C[c]	-	100
Tamakloe	99.5	100	-	100
Everest Aquaguard	CC[d]	CC[d]	-	100

[a] Membrane Filtration.
[b] 3M Petrifilm.
[c] Competition between bacteria growth and other red spot colonies.
[d] Suspected candle contamination enhancing the growth of TC bacteria (water flowing out of the filter is more contaminated than the water flowing in the filter).

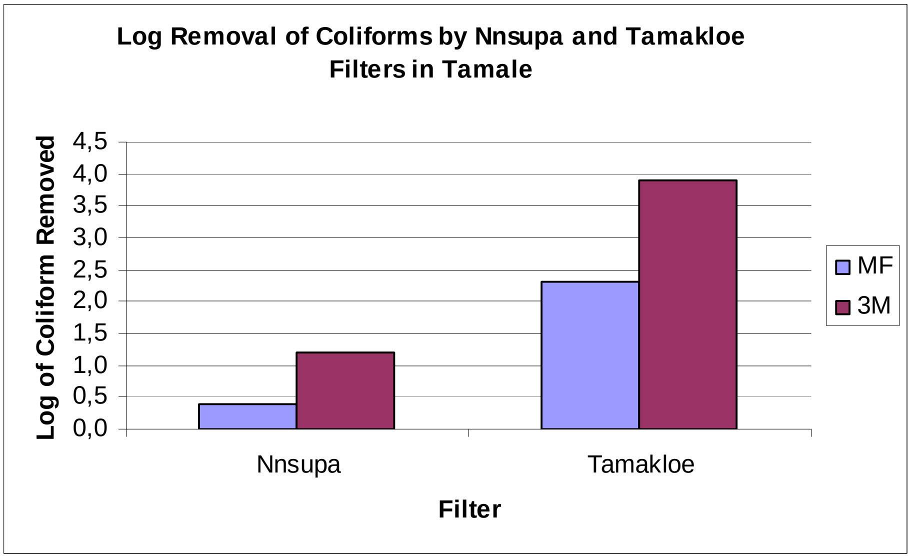

Figure 4.15. Log removal of Total Coliforms by Nnsupa and C.T. Filtron Filters in Tamale.

Table 4.3. Log Removal of TC with the Nnsupa and C.T. Filtron Filters.

	Log Removal of TC by filters in Tamale	
	TC	
	MF[a]	**3M[b]**
Nnsupa	0.4	1.2
Tamakloe	2.3	3.9

[a] Membrane Filtration.
[b] 3M Petrifilm.

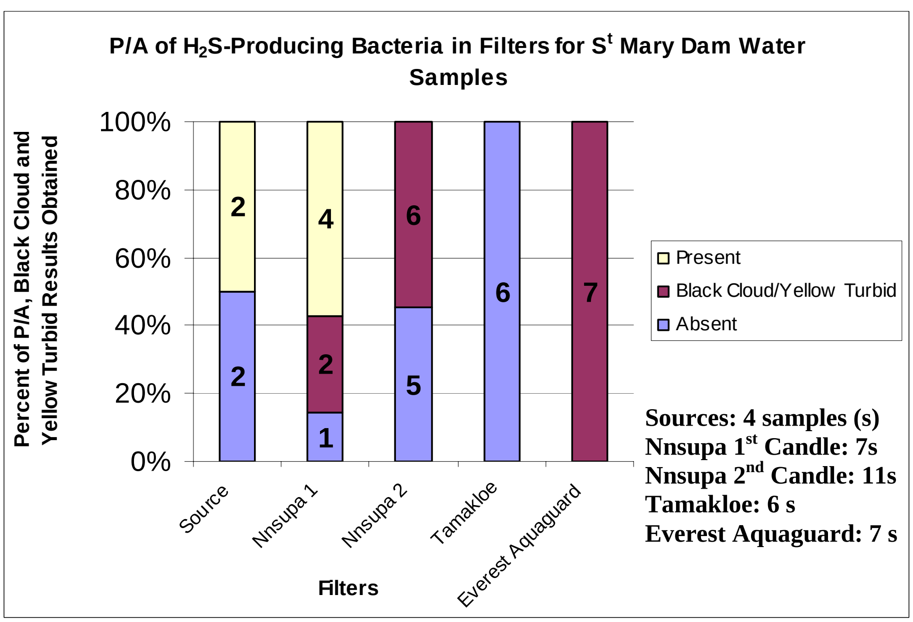

Figure 4.16. P/A H_2S-Producing Bacteria in Filters for the St Mary Dam Water Samples.

CHAPTER 4

The H_2S test of St. Mary Dam polluted water detected the presence of H_2S-producing organisms. The fact that at 10x dilution the result was negative is probably due to inaccuracy caused by the small sample volume. At 20mL sample volume, the test is not as accurate as it is with greater sample volume (100mL). When splitting a great volume into smaller water volume flasks, H_2S organisms are less likely to be uniformly dispersed in the flasks and some of the recipients can lack H_2S bacteria even if they are present in the greater volume.

The Nnsupa filter is not as efficient as the C.T. Filtron and its removal results were significantly different using 3M Petrifilm method or MF method. The difference in efficiency when comparing the removal results obtained by the MF with the results obtained by the 3M Petrifilm (62.9 *vs.* 93.1% for TC removal) can be explained by the fact that the 3M Petrifilm method is more accurate when high levels of contamination are present in the raw water.

When looking at the removal rate of EC, 100% efficiency is obtained on the basis of 3M Petrifilm experiments. Unfortunately, these results could not be supported by MF because MF failed to detect any EC in the raw and outlet water of the filter at the dilutions performed.

As the Nnsupa filter efficiency was low, the author reflected on a problem of fabrication of the candle. This could have been due to some cracks of the candle while it was transported on the dirt road that links Kumasi to Tamale. It was decided to test another Nnuspa candle to confirm or deny the different results found with the Petrifilm and MF data. A new candle that had never been used was tested. The author found bacterial contamination by an organism other than TC on both MF plates and Petrifilms. The alien organism would therefore be able to grow on m-ColiBlue24® selective media and would also show up on the 3M Petrifilm plate. On the 3M Petrifilm plate, the competitor colony appeared red but could be recognized from the TC colonies because they would not produce gas bubbles. Moreover, as the TC colonies were counted on plates in the filtered water, they were more numerous than in the initial source water. Therefore, the water being filtered by the second candle of the Nnsupa filter experienced an in-situ growth of TC.

With the first candle of the Nnsupa filter no improvement of H_2S-prodcuing bacteria is found in the filtered water. The fact that the proportion of H_2S-producing organisms is a little bit higher in the filtered water than in the raw water might be due to some inaccuracy during the P/A H_2S raw water testing as explained before. The second candle filter confirms that no microbiological improvement has been made throughout the filtration process. Moreover, the fact that the proportion of H_2S-producing organisms is high in the filtered samples compared to raw water shows that a possible in situ growth of alien organisms might have occurred.

The C.T. Filtron filter is the most efficient in terms of fecal indicator removal. MF shows 99.5% efficiency for TC. The results obtained from the Water Research Institute analyzed the C.T. Filtron filter and no TC CFU were found in the filtered water Lantagne found that 100% removal efficiency was possible to obtain when Filtron filters are used properly (Lantagne, 2001). Here, the results indicate that these numbers were nearly achieved for MF.

3M Petrifilm results show 100% efficiency in removing EC as predicted by the Water Research Institute. The reason for such efficiency with the C.T. Filtron filter is that the pore sizes of the filter are small, removing particles larger than 1 μm. In addition, its colloidal silver coating will held in suspension particles of 10^{-9} to 10^{-6} m wide (Lantagne, 2001).

The H_2S results obtained for the C.T. Filtron filter all show absence of H_2S bacteria in the treated water. These H_2S results confirm the overall high efficiency of the filter already made with Petrifilm and MF.

The Everest Aquaguard filter was inefficient in removing the TC contamination. This result was also found by Sagara (2000). Sagara did not recommend Indian candle filter as POU treatment sources for TC. This inability of removing TC organisms could be due to a supposed relative great pore size of the candle. When Sagara analyzed another Indian candle filter, she found that the pore size varied between 20 µm to 30µm. Sagara concluded that this could let the TC passing through the candle. Furthermore, results show that the water flowing out of the Everest Aquaguard filter seems subject to bacterial contamination. This contamination includes both a TC and an alien bacterial contamination. The alien bacterial colonies were represented in red on the 3M Petrifilm. They could be recognized from the TC because no gas bubble formation showed up with these alien organisms. On the MF, these unknown organisms looked like pinkish colonies and prevented the growth of TC when they were present in high concentrations. If enough organic matter coming from the polluted water source remains trapped on the surface area of the candle, this can be a nutrient source that can promote bacterial growth on and within the candle. In addition, the high average of temperature promotes this growth. Interestingly, when the tests were undertaken, the candle was new and it seemed that 2 weeks of constant use were enough to contaminate the candle. The contamination could have had the same potential sources as for the Nnuspa filter because the same type of water (St. Mary Dam) was used to fill in the filter.

The high performance for EC removal with the Everest Aquaguard filter was also a result found by Sagara when analysing Indian filters (Sagara, 2000). The EC organisms could have been bigger than the TC or there was no contamination by EC because they were unable to compete with TC and the alien bacteria for a potential deposition of nutrients on the surface of the candle.

The fact that H_2S results with the Everest Aquaguard filter remained mainly yellow seems to agree with the assumption made by Petrifilm, no fecal contamination was detected in the filtered water samples taken the first days of filter launching. However, two days after the first H_2S results, the test also revealed the development of a small black cloud at the bottom of the flask of the 7 samples studied, implying the potential development of fecal bacteria within the filter process.

It is concluded that the C.T. Filtron filter is the best among the 3 systems in terms of the criteria flow rate, bacterial removal performance and price were taken into account on the basis of Table 4.4. It was also decided that the PHW team would stop selling the Nnsupa filter among the range of products they currently propose. The Nnsupa technology was more expensive than the C.T. Filtron filter and all tests (Petrifilm, MF and H_2S) seemed to conclude that C.T. Filtron was the best of the three solutions for bacterial removal.

Table 4.4. Summary of the Data Obtained for Each Brand of Filter Tested.

Filter	Flow Rate (L/Hr)	TC Removal (%)		EC Removal (%)		H_2S (Filtered Water)	Cost (US$)
		MF [a]	3M [b]	MF [a]	3M [b]		
Nnsupa	0.34	62.9	92	-	100	P [d]	25
C.T. Filtron	1.06	99.5	100	-	100	A [e]	18
Everest Aquaguard	0.55	CC[c]	CC[c]	-	100	P [f]	14 (20L) 16 (24L) 18 (27L)

[a] Membrane Filtration.
[b] 3M Petrifilm.
[c] Supposed Candle Contamination enhancing the growth of TC bacteria (water flowing out of the filter is more contaminated than the water flowing in the filter).
[d] The colour of the media within the P/A tube tests was turbid or black for the filtered water for water dilutions until 100x.
[e] All P/A results were negative (remained yellow) for the filtered water.
[f] The colour of the media within the P/A tube tests was turbid and a black cloud formed at the bottom of the tube tests for water dilutions until 1000x.

4.4.3 Fecal Contamination Assessment of Water Sources in Tamale

The water sources that were studied in the present thesis were extremely contaminated with peaks of TC reaching 5.10 10^6 CFU/100mL and for EC 3.45 10^6 CFU/100mL (Kamina River). Both 3M Petrifilm and MF were unable to find 0 CFU/100mL for TC. Some results of 3M Petrifilm or MF showed 0 CFU/100mL for EC but this number was never confirmed by the other method.

The sensitivity of MF was sometimes lower than the sensitivity of 3M Petrifilm at high bacterial concentration. It was even hard to determine the number of organisms at the usual dilutions with MF (St. Mary Dam, Kamina River). The completion of the 15-150 standard count ranges of organisms was easier to obtain with Petrifilm than the standard range of MF (20-80 colonies) at high concentrations for the water sources analyzed. It was better to use MF when fewer colonies were present in the sample source than Petrifillm. This is in part due to the fact that 3M Petrifilm methods only uses 1mL sample whereas MF uses 100mL volume of water sample. It is likely that the organisms are less uniformly distributed in 1mL than in 100mL.

Table 4.5. Faecal Contamination Assessment of Water Sources in Tamale.

Water Source	MF (CFU/100mL)		3M (CFU/100mL)	
	TC	EC	TC	EC
St. Mary Dam	13,167	0	73,000	1,409
Bilpelar Dam	4,250	135	5,500	0
Ghanasco Muali	25,000	250	15,500	0
Kamina River	TNTC[b]	TNTC[b]	5,100,000	3,450,000
Dam near Gillbt	1,055	30	21,067	100
WV[a]	757	2,535	18,771	233

[a] World Vision Office, Savelugu.
[b] Too numerous to count.

4.4.4 3M Petrifilm vs. *MF for TC Enumeration Results*

Results showing the correlation of the counts are shown in Figure 4.17.

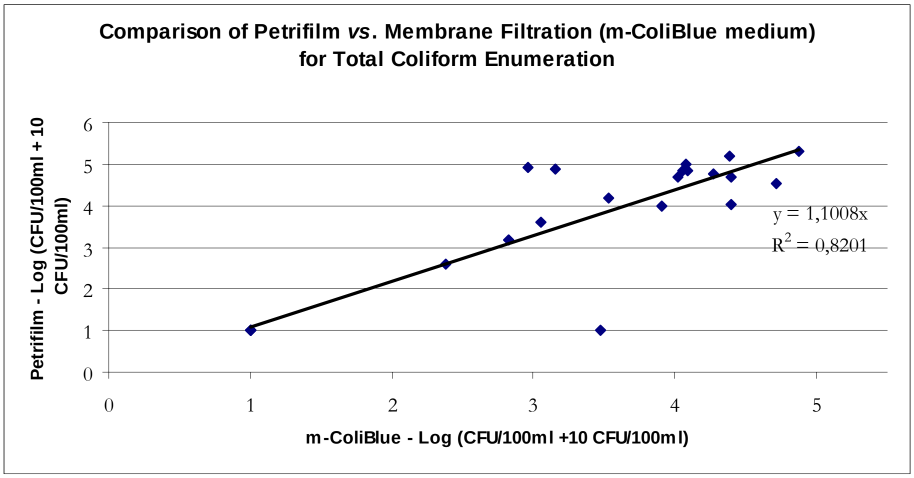

Figure 4.17. Comparison of Petrifilm *vs.* Membrane Filtration (m-ColiBlue24 ® medium) for TC Enumeration.

3M Petrifilm results is highly correlated (R>0.9) and equivalent slope (slope nearly equals to 1.0, no difference on paired t test) to MF m-ColiBlue24® when analysing TC. Interestingly, these results were also found by Vail et al (2003) when they compared 3M and MF based on EC. Vail et al results with EC showed a correlation factor of more than 0.9 and no significant difference on paired *t* test when comparing m-ColiBlue24® to 3M Petrifilm.

3M Petrifilm is less sensitive at low fecal contamination. At low bacteria contamination, few data could be compared because 3M Petrifilm failed to detect the presence of organisms at low contamination concentration or detected only one or two organisms and therefore accurate comparison could not be done. This result was also found by Vail et al. Vail et al. attributed the lack of sensitivity of 3M Petrifilm at low contamination concentration to the fact that MF is more likely to detect few EC organisms in a 100mL water volume than 3M Petrifilm in 1mL.

3M Petrifilm can be used as a preliminary approach to test if the water samples show low level of TC contamination. In the present study, except for the case where no contamination was detected with both 3M Petrifilm and MF, the lower limit of TC at which no comparison seemed to be possible between both methods is around 2.5 log (316 CFU/100mL). This result implies that if zero or one colony is found on the 3M Petrifilm, it is likely that the TC concentration of the water sample is less than 316 CFU/100mL. Remarkably, Vail et al. also found that the tests showing zero or one colony corresponding to 0 to 100CFU/100mL would be good indicators that the actual EC level is less than 300 CFU/100mL.

4.4.5 Assessment and Comparison of the 3 Microbial Indicator Methods based on 6 Screening Criteria Conclusion

The 3 microbial indicator methods were compared in terms of cost (price/test, net present value-5 years, net present value-10 years), and user feedback. The net present value was calculated and results are shown Table 4.6.

Table 4.6. Assessment and comparison of m-ColiBlue24®, 3M Petrifilm and H2S microbial indicator methods based on 6 screening criteria.

Test	Price/Test US$	Net Present Value (5 years) US$	Net Present Value (10 years) US$	Volume of Sample per test (mL)	Ease of Use	Ease of Interpretation	Labour/Hours Required	Level of Skill Required	User Feedback
MF (Millipore) m-ColiBlue24®	2.37	9,882.18	16.932,62	100	LESS EASY	LESS EASY	LONG	HIGH	COMMONLY USED IN GHANA
Petrifilm (3M) EC/Coliform Count Plate	1.04	4,336.66	7.430,35	1	EASY	EASY	QUICK	MIDDLE	NOT KNOWN IN GHANA
Pathoscreen (HACH) P/A H_2S	0.25	1.042,27	1.786,14	20	VERY EASY	VERY EASY	VERY QUICK	NO	COMMONLY USED IN GHANA

P/A H_2S test is the best choice in terms of cost, ease of use, ease of result interpretation, labour/hours requirement, level of skill required. The reading of the test is facilitated by the black coloration of water if H_2S-producing organisms are present. This means that it can be easily used by non-experts people who aim to test the drinking water.

However, the data obtained with the P/A H_2S test indicates the presence of false positive and false negative results. Indeed, the presence of H_2S-producing bacteria does not always imply the presence of fecal contamination in the water tested and *vice versa*. In addition, the P/A H_2S test, by definition, does not quantify the H_2S bacteria present in water. The test will only give a yes/no answer. This suggests that the technique is not reliable enough to be applied for testing drinking water.

Instead, other techniques such as 3M Petrifilm or MF which are more accurate because they allow a quantification of the TC and EC present in the water sample. The 3M Petrifilm is half the price of the MF test performed. Moreover, the net present value of the 3M Petrifilm is less than half that of the MF test because the base price for the whole MF unit is US$1,300. The MF steel unit represents a major cost for communities which can barely afford to buy household drinking water treatment systems. In addition, the water sample analysis with 3M Petrifilm is far more rapid than the analysis with MF because no sterilization time is required for the equipment between each measure taken. The results of the 3M Petrifilm are quite easy to interpret since a different colony colour associated with gas bubbles correspond to the fecal indicators of interest.

3M Petrifilm technique should be used when high bacterial concentration is suspected to be present in the water source (e.g., surface water or other suspected sources) or as a preliminary methods for testing the presence of low fecal contamination (<2.5 log). 3M Petrifilm methods only use water samples of 1mL compared to MF which uses 100mL water samples. Therefore, the number of organisms present on 3M Petrifilm for a certain water sample will be smaller than the number of organisms present on MF petridishes and at high bacterial concentrations, 3M Petrifilm will allow a quick assessment of the bacterial content without having to dilute the sample several times. Although 3M Petrifilm technique is not used as a microbial test in Ghana, the microbial experts to whom the technique was demonstrated during the author's field research looked at the method as a powerful fecal indicator method to be used for a first emergency assessment.

4.5 Conclusion

Flow Rate Conclusions

The three filter flow rates were compared to the minimum daily requirement of water per capita (7.5L) in order to determine filter use ability. Results obtained in Ghana showed that all filters were likely to produce quantity per day. However, whereas the Nnsupa and Everest Aquaguard were barely able to cover the needs for two individuals per day, the C.T. Filtron filter could satisfy the needs of a small family.

Coliform Removal Conclusions

C.T. Filtron filter was the best performer using H_2S, 3M Petrifilm and MF (m-ColiBlue24®). No H_2S test showed positive results with the filtered water. 3M Petrifilm results did not detect any TC or EC in filtered water samples and MF showed 99.5% efficiency in removing TC. Because of its comparatively poor performance and higher price compared with the C.T. Filtron filter, it was decided to stop selling the Nnuspa product until better bacterial removal performances could be achieved. Everest Aquaguard was unable to remove bacteria and that contamination with the candle could have occurred.

Methods Comparison Conclusions

False negative and false positive results with P/A H_2S tests when compared with MF and 3M Petrifilm were the main motivations that drove the author of the thesis to stop using this technique. In addition, P/A H_2S test does not allow bacterial counting.

When 3M Petrifilm and MF (m-ColiBlue24®) were compared, results showed a good correlation between the techniques with TC. Although 3M Petrifilm has been widely used in the food industry, few data are available concerning its use for environmental water sources testing.

The author concludes that 3M Petrifilm is a promising approach for the detection of fecal bacteria in the developing world area. Indeed, the 3M Petrifilm's ease of use, cost, ease of interpretation, low level of skill required, accuracy at high bacterial concentration, user acceptability and low labour/hours required to perform the test makes it as a good alternative to MF (m-ColiBlue24®).

When there is a suspected high level of bacterial concentration for a source, 3M Petrifilm should be used as a method for quickly assessing the bacterial content without having to dilute the sample several times like with the MF method.

At low level of bacterial concentration, the 3M Petrifilm technique lacks accuracy because only 1mL of water sample is used and the method would require performing duplicates or triplicates of the sample to be sure of the number given by 3M Petrifilm.. 3M Petrifilm technology should be viewed as a preliminary method to MF for assessing fecal contamination from a source at low bacterial concentration.

The author concludes that 3M Petrifilm needs to be deeper explored and compared with MF (m-ColiBlue24®) while analysing for EC. Moreover, 3M Petrifilm have not been extensively studied for the occurrence of false positives or false negatives in environmental water samples. Therefore, further work is needed to validate the Petrifilm method for environmental testing purposes.

Level of Contamination of the Water Sources Analyzed Conclusions

The sources of water that were analyzed in the present work are point water sources where people routinely get their water from. In most cases, water treatment is performed by the local communities between collection and consumption and it was therefore striking to see how contaminated the sources of water were before consumption.

The different water sources that were studied showed a high level of TC and EC contaminations. As the drilling of boreholes by the Ghanaian Government and NGOs in the area of Tamale is proceeding, there is a need for the remote communities to get safe drinking water through the use of POU systems such as the products proposed by PHW.

Concentrated efforts in research development and implementation are needed to achieve safe drinking water in Ghana. The author concludes that the overall approach to provide safe drinking water local communities needs to be more rational and scientific, as well as to move towards anticipatory potential risks to ever-present and emerging waterborne pathogens. In terms of drinking water guidelines, less stringent drinking water standards than 0 EC CFU/100mL should be given for countries belonging to the developing worlds. In most cases, these countries do not have the same financial resources to maintain such requiring standards. As outlined by the 3^{rd} Edition of the GDWQ, the implementation of national drinking water standards should be consistent with achievement of the MDGs and should take into account the socio-economic, cultural and environmental fields of the nation. Country household epidemiological surveys, geographic data and microbial drinking water quality assessments will pave the way to the establishment of such guidelines. This integrated system will bring an acceptable risk level which people can get exposed to without falling sick.

CHAPTER 5. FINAL CONCLUSION

Engineering Team Conclusions

Similar to John Snow's pivotal work combining epidemiology, mapping and microbial testing which showed the correlation between cholera infection and certain wells within London in the early 1800s, the MIT Master of Engineering team has to combined these fields of epidemiology, mapping, and microbial testing to gain a better understanding of the drinking water situation in the Northern Region of Ghana. The following are some of our major conclusions:

- In the Northern Region, 56% of the population does not have access to an improved source of drinking water and 92% does not have access to improved sanitation.
- In communities surveyed, the diarrheal prevalence in children under five is only 5% in the modern communities, while it is 18% in the traditional villages. It is the traditional communities that suffer most from diarrheal illness, inadequate sanitation, and unimproved drinking water sources.
- The 3M Petrifilm should be seen as an appropriate water quality testing method for quick diagnostic testing in which there may be a high level of microbial contamination.
- The Nnsupa filter does not perform up the microbial standards of the C.T. Filtron and its sale has thus been discontinued.

The G-Lab Business Team Conclusions

The business team adopted the strategy of the Four Ps: product, price, promotion, and place. The product agenda was to streamline the available products for marketing efficiency. Due to its higher cost and inadequate microbial removal, the Nnsupa product was discontinued and current efforts are focused on promoting the C.T. Filtron filter and safe storage products. After financial analysis, the price of the C.T. Filtron was increased from the equivalent of $16 to $20 out of necessity for Pure Home Water to function as a sustainable business. While in Ghana, the entire Pure Home Water team participated in a market day to promote products awareness, which will be continued by Wahabu and Hamdiyah along with community meetings and other forms of marketing. Concerning place, the Pure Home Water office will be moving to a more central location in Tamale to improve customer accessibility. Though currently produced in Accra, the potential production of the C.T. Filtron filters in the Northern Region of Ghana is also being explored to reduce shipping costs and to offer a lower priced product to those who want it but cannot afford it at the present price.

Recommendations

Because the greatest need for clean water is within the traditional and rural communities, an effort needs to be made to price the treatment systems to meet the needs of these communities. One possible solution is to move the production of the CT Filtron from Accra to Tamale. This would cut down on costs due to transportation, packing materials and breakage. Labor and material costs may also be cheaper within the Northern Region. Another option would be to pursue other treatment technologies besides ceramic filters. One low cost solution would be to evaluate solar disinfection which relies on the UV light coming from the sun as a way to kill pathogenic bacteria. In other countries, this technology has been shown to cost less than a dollar per year since only clear bottles to contain the water are needed.

Another issue throughout the region is that there are more than one million people who lack improved water and these people are spread among many isolated rural communities. A marketing strategy needs to be created that can reach this population and teach them about the availability of household water treatment technologies. One method would be to work through other organizations. Currently the Pure Home Water Team is initiating the distribution of the filters through Shell gas stations in the region. Filters have also been given to a group of midwives for distribution through their patients (Figure 5.1). Other distribution methods could easily be explored including schools, clinics and aid agencies.

The good news is that the C.T. Filtron has been shown by team member Claire Mattelet's thesis work (Mattelet, 2006) to be a highly effective technology in removing fecal bacteria. The household surveys also showed a high level of customer satisfaction and interest in the ceramic product. Hopefully, as the efforts of Pure Home Water continue, this technology can begin to make a significant impact on improving the health within the Northern Region of Ghana.

Figure 5.1. C.T. Filtron Filters Given to Midwives for Distribution to their Patients.
Photo courtesy of Tanja Odijk

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