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

By

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ABSTRACT

Drinking water continues to be a major source of waterborne diseases and death in the world because many points of water collection remain unsafe. This thesis reports high level of fecal contamination found in rivers and ponds that are major sources of drinking water supply for the local communities in and around Tamale, in the Northern region of Ghana.

Although considerable improvements have been made in the past few decades, greater efforts are still needed to address key issues related to the supply of safe drinking water in Tamale. There is a need to make safe water available, accessible and affordable for the local communities. One such solution is household water treatment and safe storage (HWTS), which is being promoted globally by the World Health Organization, international reference to promote household water treatment and safe storage. HWTS products are sold locally by Pure Home Water (PHW) in Tamale. This work explores the microbial removal and flow rate performance of two of the PHW best sellers: the C.T. Filtron and the Nnsupa filter. These two filters were compared with the Everest Aquaguard, the main competitor of PHW in Tamale.

The C.T. Filtron ceramic filter is the best performer in terms of flow rate efficiency, with a rate of 1.8L/hr for the maximum water head level.

Microbial analysis of the filtered water was performed for total coliform, *Escherichia coli* and hydrogen sulfide (H_2S)-producing bacteria using three simple and low cost methods: membrane filtration (m-ColiBlue24®), 3M Petrifilm, and presence/absence (P/A) H_2S tests. Again, the C.T. Filtron was the most efficient. This ceramic filter was able to remove 99.5% to 100% total coliform when measured by membrane filtration and 3M Petrifilm, respectively. In addition, according to 3M Petrifilm tests, 100% removal efficiency was obtained for *E. coli*. As a result of the better flow rate, microbial removal and filter price for the C.T. Filtron system, PHW decided to stop selling the Nnsupa candle filter.

When the three simple and low cost methods were compared, the P/A H_2S test often gave false positive and false negative results. On the other hand, there is a positive correlation between membrane filtration and 3M Petrifilm results. The author concludes that 3M Petrifilm is a promising approach for the detection of fecal bacteria in the developing world. Its ease of use, cost, ease of interpretation, low level of skill required, accuracy at high bacterial concentrations, user acceptability and low labour requirement to perform the test places it as a good screening approach for low fecal pollution and an alternative to MF (m-ColiBlue24®) at high levels of bacterial contamination.

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"Life is either a daring adventure or nothing". Helen Keller

In fact, the project that PHW team has been committed to was a whole adventure, the people the team met, the wonderful experience we had in Ghana and the hard realities we had to face sometimes with the project challenged us to keep on going beyond our limits.

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LIST OF ABBREVIATIONS

µm	Micrometer
3M-EC	*E. coli* Petrifilm Test
3M-TC	Total coliform Petrifilm Test
CF	Coagulation-Flocculation
CFU	Colony Forming Unit
Chromocult®	Agar for simultaneous detection of Total Coliform and *E. coli*
cm	Centimeter
C.T. Filtron	Ceramica Tamakloe Filtron
CWSA	Community Water and Sanitation Agency
DNA	Deoxyribonucleic Acid
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EC	*Escherichia coli*
EPA	Environmental Protection Agency
FC	Fecal Coliform
GDWQ	Guidelines for Drinking-Water Quality
GPS	Global Positioning System
GWCL	Ghana Water Company Limited
GWSC	Ghana Water and Sewerage Corporation
H_2S	Hydrogen Sulfide
hr	Hour
HWTS	Household Drinking Water Treatment and Safe storage
ID	Infective Dose
IWRM	Integrated Water Resources Management
L	Liter
m-ColiBlue24®	Medium for simultaneous detection of Total Coliform and *E. coli*
m-Endo	Medium for Detection of Total Coliform
M.Eng	Master of Engineering
MF	Membrane Filtration
MF-EC	*E. coli* Membrane Filtration Test
MF-TC	Total Coliform Membrane Filtration Test
MGDs	Millennium Development Goals
MIT	Massachusetts Institute of Technology
mL	Milliliter
mm	Millimeter
MPN	Most Probabe Number
MTF	Multiple Tube Fermentation
NCWSP	National Community Water Supply and Sanitation Policy
NGO	Non-Governmental Organization
NTU	Nephelometric Turbidity Units
P/A	Presence/Absence
P/A- H_2S Test	Hydrogen Sulfide Producing Bacteria Presence/Absence Test
PFP	Potters for Peace
PHW	Pure Home Water
POU	Point-Of-Use
PURC	Public utilities Regulatory Commission
R&D	Research and Development
RNA	Ribonucleic Acid
SHW	Safe Household Water
SODIS	Solar Disinfection

SIP	Strategic Investment Program
TC	Total Coliform
TNTC	Too Numerous To Count
UV	Ultra Violet
USEPA	United States Environmental Protection Agency
VRB	Violet Red Bile
WHO	World Health Organization
WSP	Water Safety Plan
WV	World Vision
X-Glu/BCIG	5-bromo-4-chloro-3-indolyl-β-D-glucuronide

1. INTRODUCTION

1.1 Global Impact of Water–Related Disease

Access to safe drinking water and appropriate sanitation are both essential to life. The lack of safe water supply is one of the world's major causes of preventable morbidity and mortality. World Health Organization (WHO) data on the burden of disease estimates that approximately 1.8 million of deaths per year (3.2%) and 61.9 million of Disability Adjusted life-years[1] (4.2%) worldwide are attributable to unsafe water, sanitation and hygiene. WHO suggests that over 99.8% of the death caused by unsafe water, sanitation and hygiene occur in developing countries, the deaths among children under five years old account for 90% of this number, primarily occurring in developing countries (WHO, 2004).

Considering the effects of the lack of safe water issues on human health, the Millennium Development Goals (MGDs) called for halving the proportion of people without access to a safe drinking water and adequate sanitation by 2015 (WHO/UNICEF, 2004).

While the promotion of universal access to safe water and sanitation to prevent disease burden has been accentuated for decades, 1.1 billion people still lack access to "improved" source of drinking water such as piped connections or protected wells. Even among the remaining 5.2 billion people, in developing and developed countries, using an "improved" source, disease related to unsafe drinking water can occur because of contamination in the distribution system or in the water transport system. The lack of safe water continues to be one of the major causes of diarrhoeal diseases deaths in both developed and developing nations (WHO/UNICEF, 2004).

Although diarrhoeal diseases is a problem worldwide, the gathering of reliable data on the extent of diarrhoeal outbreaks, on the microbial organisms causing the illness and on the link between drinking unsafe water and subsequent diarrhoeal disease remains quite difficult to assess. The International Scientific Forum on Home Hygiene reports that although the extent of mortality due to diarrhoeal disease has decreased in developing nations, there is still no change in morbidity rates (Nath et al., 2006). At the same time, significant improvements in water sanitation and coverage have been accomplished since the 1990s and currently, about 816 million additional people have gained access to improved water sources, which includes piped water connections to households, boreholes, protected dug wells and rainwater, public standpipes, and water access to protected springs. According to WHO/UNICEF (2000, 2004), approximately 714 million people have benefited from improved sanitation facilities such as pour-flush latrines, simple pit latrines, ventilated improvement pit latrines, and piped connections from households to public sewers or septic system.

In 2005, these considerable efforts in the water and sanitation field undertaken mostly by non-governmental organizations (NGOs) or the developing nations themselves together with the water issues following the major natural disasters that struck the industrialized world (e.g., lack of access to safe drinking water in New Orleans, USA, after Hurricane Katrina in September 2005) increased the general public awareness about the importance of safe drinking water quality.

[1] WHO GDWQ 3rd Ed. defines the DALYs as: "means of comparing the different health outcomes for a range of diseases and injuries and allow different hazards to be compared when assessing the importance of their impact on health. DALYs incorporate measures of morbidity and mortality and can differentiate the impacts between vulnerable groups and the general population. They are a population measure, providing estimates across a specified population rather than the impact likely upon an individual."

However, the improvements made still remain just sufficient to cover the World's demographic growth. In total, it is estimated that the absolute number of people still lacking to safe water drinking access are unaltered since the 1990s (Mintz et al., 2001).

The waterborne diseases cases encountered in developed and developing nations, together with the epidemic and endemic diseases caused by unsafe water supply affect health quality, and the economy for individuals or among communities (WHO, 2004). The WHO *Guidelines for Drinking-Water Quality* 3rd edition (GDWQ) describes the need to protect public health through the adoption of a water safety plan (WSP). The GDWQ:

- Establishes general guidelines for drinking water quality, providing a common point of reference for all nations to determine the safe level of drinking water,

- Gives the basis for most national, regional, and agency-level water quality requirement in developing countries as well as in industrialized nations.

The first step of the GDWQ 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 second step in determining GDWQ is developing a system or technology specific 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.

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.

Compared with the GDWQ 3rd edition, one of the short comings of the first two editions of the GDWQ in tackling infectious diseases was to give priority to water access over sanitation and sanitation over hygiene. Hygiene is important because of the most efficient ways of reducing the burden of infectious diseases is be to keep fecal matter away from hands, food and water. Hygiene promotion practices should not be separated from water supply and sanitation programmes. In addition to hygiene behavior, household drinking water treatment and safe storage is relatively new and important intervention. It is suggested that Point-of-Use treatment of water could be the best approach to meet water quality goals in developing countries by increasing effective and quick health benefits to the community (Nath et al., 2006).

New methods and technologies to obtain safe drinking water need to be explored and installed to meet the water and sanitation targets by 2015. As piped connections for water access are always a considerable investment for the governments or private companies in poor and remote communities, meanwhile, the populations of dispersed communities are waiting for safe drinking

water strategies to be implemented. Therefore, there is a need to apply point-of-use treatment as an additional barrier of protection, following a "multiple barrier" approach to safe water.

1.2 Point of Use Treatment

Since the quality of drinking water is hard to control for millions of inhabitants of the developing world, water from unimproved sources is often supplied to communities. Therefore, the implementation of POU water treatments has been proposed as an alternative solution for these people. In contrast to centralized, large capacity systems that treat water for a whole community, POU systems are decentralized and treat water at the household level. These POU technologies offer the advantages of being easily maintained and simple to use.

The POU technologies cover microbiological and/or chemical or physical water treatment including; (*i*) disinfection (safe water system, chlorination, solar disinfection (SODIS), solar pasteurization, UV irradiation with lamps, and boiling), (*ii*) particle filtration (cloth fiber; ceramic filter, biosand and other slow sand filter technologies), (*iii*) adsorption media (granular activated carbon, and activated alumina, clay), (*iv*) combined system (combined flocculation/disinfection, filtration plus disinfection), (*v*) other approaches (plain sedimentation settling, safe storage, coagulation/flocculation with iron or alum salts, membrane processes).
The POU interventions have demonstrated reduced bacterial contamination in water which lead to human health improvements where they have been implemented (Clasen et al., 2004; Sobsey et al., 2002). Chlorination seems to be most effective against bacterial agents since the median reduction in endemic diarrhoeal disease is 46%. Filtration technologies provide a median reduction of 40%, followed by flocculation and combination of flocculation/disinfection with 38% in median reduction. Somewhat less efficient are solar radiation and heating methods accounting for a median reduction of 35% (Clasen and Cairncross, 2004).

If promotion of household water treatment and safe storage is to be successful, it is important that the most adequate method is selected in collaboration with the community in question. The choice of the technique will depend on a range of different factors such as cost, ease of use, microbial efficacy, availability and practicality. The general properties of the household water treatment systems are given in Table 1.1.

Table 1.1. General properties of household water treatment systems.

Treatment	Availability and Practicality	Technical difficulty	Cost[a]	Microbial efficacy[b]
Boiling at 100°C	Varies[c]	Low-moderate	Varies[c]	High
Chemical treatment (chlorine or iodine)	High to moderate	Low-moderate	Moderate	High
Solar disinfection	High	Low-moderate	Low	Moderate
UV lamp treatment	Varies[d]	Low-moderate	Moderate-high[d]	High
Coagulation-Flocculation/ Sedimentation/ Filtration	Varies[e]	Low-moderate	Varies[e]	Varies[f]

Source: Nath et al., 2006. Adapted from Sobsey, 2002

[a] Categories for annual household cost estimates in US dollars are less than US$10 for low, >US$10-100 for moderate and >US$100 for high.

[b] Categories for microbial efficacy are based on estimated order-of-magnitude or log_{10} reductions of waterborne microbes by the treatment technology. The categories are <1 log_{10} (<90%) is low, 1to 2 log_{10} (90-99%) is moderate and >2 log_{10} (>99% is high).

[c] Depends on heating method at a certain location as well as availability and cost of fuels, which range from high to low.

[d] Depends on availability and types of lamps at a certain location, housings, availability and cost of electricity, as well as operation and maintenance needs (pumps and system cleaning methods).
[e] Different types of coagulation, flocculation and filtration are available. For filtration process, practicability, availability, and cost depend on the filter medium and its availability: granular, ceramic, fabric, etc. For FC processes, practicability, availability, and cost depend on the FC prices and availability (alum *vs.* natural plant extracts).
[f] For filtration: depends on pore size and other properties of the filter medium, which may vary widely. For FC: depends on types of FC effectiveness (alum *vs.* natural materials).

1.2.1 Physical Disinfection: Heat and UV

Boiling

Boiling water is a widespread practice despite its cost in both fuel and time. A temperature of 55°C or above over a period of several hours will inactivate most bacteria. Because of monitoring issues raised during the thermal process, householders are usually recommended to heat to a vigorous or rolling boil. In theory, the heat-treated water should be stored in the same container it as boiled in, but in practice, householders should split it into smaller, more convenient buckets. The main drawback of handling large volumes of boiling water is a hazard and time consuming process to cool the water and disperse it into appropriate suitable containers.

Solar Pasteurization

In communities where fuel is scarce, solar pasteurization will be favoured instead of water boiling. Solar pasteurization in vessels painted in black or with non-reflective surfaces are low cost alternatives. Water is put into clear plastic bottles or containers and then they are exposed to sunlight. The thermal effect is increased by exposure to UV light in sunlight. In many regions of the world, solar radiation is sufficient enough for much of the year to obtain temperature of 55°C over several hours inside of the containers. By using this practice, only a small amount of water will be treated at one time, although the use of various containers and capturing more radiation with the addition of solar reflectors can increase the output of a household treatment system (Safapour and Metcalf, 1999; Rijal and Fujioka, 2003).

SODIS

SODIS (Solar Disinfection, see Figure 1.1) - a technique developed by the American University in Beirut, Lebanon and the Swiss institute EAWAG (Swiss Federal Institute of Aquatic Science and Technology) – has improved solar disinfection by adding steps using settlement or filtration to remove turbidity and increasing the effectiveness of UV inactivation by aeration, for instance, by shaking the container to areate the water (Kehoe et al., 2001).

Figure 1.1. SODIS disinfection (Photo: Smith M., 2001).

The best containers are PET plastic bottles because such containers are easier to handle and less likely to release dangerous chemical products into the water that may potentially affect the water taste. The formation of free radical radicals derived from oxygen under the influence of UV radiation may play a significant part in removing pathogens. Wherever SODIS system is implemented, education of communities should be supported in order for the inhabitants to fully understand the limitations of the process, for instance, the minimum amount of solar radiation to give adequate disinfection is around $500 W/m^2$ (Oates et al, 2003).

Sometimes, even with an adequate educational programme, people would not use the technology. This was the case for a successful field study undertaken in Nepal which reduced the fecal coliform count by 90% using SODIS as water treatment but the study revealed that the method was subsequently adopted by only 10% of the households, despite the fact that the implementation was followed by an educational programme (Rainey and Harding, 2005).

UV Lamps

The destruction of water-borne pathogens through the use of UV light has been used for a long time but has received a particular interest since the realisation that organisms protozoal cysts of such as *Cryptosporidium* or *Giardia* presented resistance to chlorination but were sensitive to UV irradiation. Most households UV systems use low pressure mercury lamps which provide UV at 254nm wavelength which is able to cause damage to cellular nucleic acid. These types of lamp consume little power and operate under low temperatures but the main drawback of the system is that the community requires continuous electricity supply although they could be powered by solar or wind turbine generators. Energy costs are smaller than those for boiling water, and for community implementation, it would be as little as US$1 per household per annum (Nath et al., 2006). However, at the household level, the routine maintenance costs and the initial cost of the system are not suitable for the implementation of the system in low income households.

1.2.2 Chemical Disinfection

Chlorine remains the most effective and simplest chemical disinfectant for dinking water at the household level. It is available a broad range of forms (e.g., pills, solution). The chlorine disinfection method is able to kill all forms bacterial and viral water-borne pathogens. However, at low concentrations normally used for water treatment, chlorine lacks activity against protozoal cysts. The production of chlorinated disinfection by-products was for long considered as a threat to human health at high concentrations but according to WHO (2004, pge.5), the "risk to health from these products are extremely small in comparison to the risks associated with inadequate disinfection, therefore, disinfection should not be compromised in attempting to control the disinfection by-products". The reactivity of chlorine with any organic material can reduce its activity, if the correct chemical process is not used.

Iodine is also very effective at killing or inactivating water-borne pathogens and has been widely used for drinking water treatment for short term or emerging situations. It is sold in the form of tablets or as ion-exchange resins. Iodine treatment is not recommended for daily treatments but instead for emergency situations. The reason is that in the long run, this compound can damage health. The major problems with iodine is that it has a short contact time and poor control over the amount of iodine released which is given by the water quality and flow rates. Iodine is also known for giving an unpleasant taste to the water. Enteric viruses are more resistant than bacteria to inactivation by iodine.

1.2.3 Sedimentation, Flocculation and Filtration

Sedimentation is mainly used as a pre-treatment or first stage of treatment of the water to remove large inorganic materials. A few hours is required to settle larger particles whereas several days of settling are necessary for the large clay particles. Pathogens such as helminth ova will settle by gravity but in general, bacteria and protozoal cysts are too small unless settlement is combined with coagulation. The main down sides of this technique are that the vessels that are used need to be frequently cleaned and sediments need to be removed. Microbial films growing on the vessel walls need to be removed by scrubbing or by chemical disinfection. Nath et al. (2006) found that as a pre-treatment process, sedimentation is "very cost effective requiring only a suitable vessel, labour and time".

Coagulation and flocculation processes are important methods for water treatment. In large scale treatment systems, the technique requires technical skills. At the household level, sachets of chemicals which combine coagulation-flocculation (CF) have become available. CF involves adding a coagulant to a vessel of water, mixing rapidly to spread the coagulant, and then slow stirring is required to encourage the formation of large flocs. The flocs are charged positively and attract negatively charged colloidal particles and micro-organisms. The advantage of the method is that it makes significant improvements in terms of turbidity and removes until 90-99% of pathogenic bacteria and viruses under optimum conditions. However, the drawback is that the bacteria accumulated on flocs remain viable and separation is mainly by settlement or filtration to prevent re-contamination of the water. The most common chemical flocculants are alum and iron hydroxides. These are effective and quite inexpensive. Also, other alternatives composed of clay and natural plant extracts have been optimized and are sometimes currently used.

Filtration covers a wide range of technologies from simple removal of large particles (including cloth or plastic gauze) to sophisticated membrane systems operating under high pressure capable of removal of particles down to the nanometer size. For domestic treatment, two general principles are proposed:

- **Straining:** the size of the pores in the filter medium is smaller than the particle being removed. This can occur on the filter surface or within the depth of the filter wherever the water flow channels narrow to a size smaller than the particles. This refers to ceramics and granular media filtration.

- **Depth filtration:** occurring when particles passing through the channels become trapped on the surface of the channel wall by a variety of physical mechanisms. This refers to granular media filtration.

Among the POU processes, filtration is one promising approach because, the main advantage of filters are that they are easy to use and are made of local materials such as sand, gravels and ceramic which are familiar to many communities. Ceramic filters with small pores, often coated with silver for bacteriostasis, have been shown to be effective at removing microbes and other suspended solids (see Chapter 3). In general, filters can be mass-produced or manufactured locally and require low-cost, locally available materials. In Ghana, where the author undertook her field study as part of the MIT Pure Home Water (PHW) Project in January 2006, some of the ceramic filters sold are produced locally to encourage the development of small ceramic filter businesses (see Figure 1.2).

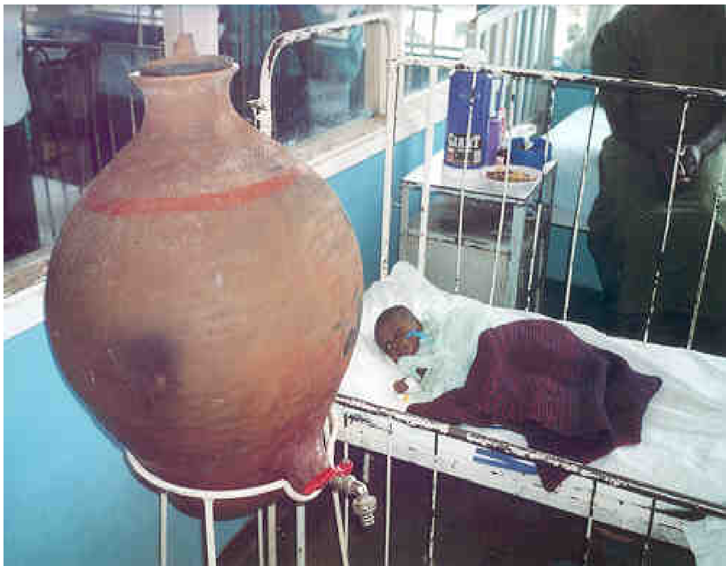

Figure 1.2. Modified clay pot with ceramic lid and brass spigot.

1.3 Background about Ghana

1.3.1 Geographical context

The republic of Ghana is located on the Gulf of Guinea along the west coast of Africa. It is bound by the Ivory Coast to the west, Burkina Faso to the north, Togo to the east and the Gulf of Guinea to the south. Ghana is composed of ten administrative regions. The country has a coastline typified by sand bars and lagoons while the southern part of the country consists of low lying plains that are covered in scrub savannah, including the Accra Plains, the Volta Delta and the Akan Lowlands. To the north lies the Ashanti Highlands, the arid Volta Basin and the forest covered Akwapim-Togo Ranges. The entire country is networked with streams and rivers which include the Volta River with its tributaries as well as the smaller Pra, Ankobra and Tano Rivers (see Figure 1.3).

Figure 1.3. Map of Ghana.

Ghana has a total population of 21.664 million inhabitants and about 52% lives in urban areas (UNICEF, 2004). The population is mainly concentrated in major cities such like Accra, Kumasi, Tamale (in Northern Ghana), and Tema. Life expectancy at birth is 57 years and 46% is below the age of 18. Infant mortality rate (IMR) and under-five mortality rate (U5MR) have steadily declined in Ghana. However, regional disparities between the North and South of the country,

partly due to poverty and to lack of, and poor access to, services, are a cause for concern (UNICEF, 2004).

1.3.2 The Socioeconomic Status

The main sector of economical activity in Ghana is agriculture (small scale peasant framing that represents an average of 60% of the total Ghanaian adult work power). Other sources of income are dominated by mining and a few other industrial activities, while informal sectors such as small-scale businesses, technicians, petty traders, and small artisans are prominant. The gross domestic product (GDP) per capita annual growth rate was 1.9% in 2004 and the annual inflation level was 26%. Table 1.2 shows that population annual growth rate is 2.4 %, 45% of the total population lives below 1 US dollar a day and national literacy is 73.8% (UNICEF, 2004).

Table 1.2. Main indicators for Ghana.

Indicators	Ghana
Annual GDP per capita	1.9%
Life expectancy	57 years
Literacy Rate	73.8%
Annual inflation level	26%
Population annual growth rate	2.4%
Population living below 1 US dollar a day	45%

1.3.3 Water and Health

1.3.3.1 The Main Issues

The predominance of infectious diseases, malnutrition and poor health are serious public health concerns in Ghana. Moreover, new noncommunicable diseases have emerged; neoplasm, diabetes, and cardio-vascular diseases. Most of the diseases causing death in the country are related to poor water and sanitation; malaria and diarrhoea being the most important causes of mortality. Moreover, as a result of the poor water and sanitation conditions, cholera has re-emerged as an endemic disease in the country. Two major epidemics have been recorded in 1991 and in 1999 with case fatality ranging from 2.2 to 3.4%. Seasonal flooding increases the risk of being infected.

It is estimated that overall 60% (92% in urban and 57% in rural regions) of the population has access to health care (UNICEF, 2004). Access is defined as living within one hour travel time (by any available means) from the health facility. Recent surveys have proved that the Ghanaian communities are likely to have their health facilities geographically close to their community. However, in rural areas health care is well below what is expected. This is mainly due to the fact that often the communities live in remote places and it is difficult to retain medical staff in these areas.

In addition, the drilling of boreholes to get groundwater is not easy to do in the Northern region of Ghana. The main problem is that the Northern region's underlying geology is composed by layers of granite, which tend to be drier and poorer, and therefore make access to groundwater difficult (Taylor). "Often you have to drill four or five holes to yield one well, and then it may be contaminated"(…) "It is really a lottery what you get" says Dr. Ernesto Ruiz-Tiben (leader of the Guinea worm eradication program for the Carter Center).

1.3.3.2 Decision-making

Over the past decades, the Ghanaian Government has undertaken initiatives to address some of the issues that limit the sustainable development and management of the nation's water resources. These initiatives are meant to tackle the role, functions, and decision-making processes within the water sector and to strengthen the Water Resources Information and Development Agencies. This effort includes into two major reforms:

- **Rural Water Reform:** Introduced in the early 90's, this reform was mainly applied to accelerate the coverage of the rural population with adequate drinking water and sanitation. By an act of Parliament in 1994, the Rural Department of the Ghana Water and Sewerage Corporation (GWSC) was split and became an autonomous Community Water and Sanitation Agency (CWSA). Through the reform, the main policy change was that supply of water to the rural communities has to be demand driven and the community managed. Since the installation of the reform, the community is required to pay 5% of the capital cost of providing the facility.

- **Urban Water Reform:** The urban water reforms included a Water Sector Rehabilitation Project that started in 1995. The main purpose of the urban reforms was to create an optimal environment for encouraging private sector participation by means of legal, business and regulatory interventions. To favour the private sector to become an active actor of the management and operation of urban water supply systems, GWSC was also split into a smaller company, Ghana Water Company Limited (GWCL).

As a result of these reforms, the regulation of urban water and other services have also become independent and the regulatory Agency known as the Public Utilities Regulatory Commission (PURC). The Commission regulates and oversees the provision of utility services such as the approval of tariff levels and drinking water quality for treated water to consumers. At the same time, its role is to ensure protection of consumer interests and to encourage private sector participation of these services.

- **Protection of Water Resources:** One of the main purposes of the reforms is to protect the water resources and the environment. In 1994, the Environmental Protection Agency (EPA) passed an Act with the Parliament to strengthen the regulations and establish guidelines for water resources. These guidelines were meant to set standards for emissions and release of material into the environment. In addition, the Environmental Protection Agency (EPA) developed an Environmental Impact Assessment procedure that must be followed before project development.

- **Irrigation Development:** The reforms in this sector are to fuel the potential development for the 346,000 hectares of irrigable land in Ghana. The main driving idea was to boost the agricultural sector through the development of water resources for irrigation.

- **Water Resources Management:** The above reforms could are sectorial reforms and therefore they can not achieve an integrated water resources planning, development and management objectives. Therefore, a Water

Resources Commission was created in 1996 to regulate and manage the nation's water resources and co-ordinate government policies related to them. The members of this commission are the main stakeholders dealing with development and use of water resources (Water Supply, Hydrological Services, Environmental Protection, Minerals, Forestry, Water Research, Irrigation Development), some NGO's, traditional rulers and women are also part of the commission. The choice Ghana made to promote an Integrated Water Resources Management (IRMW) approach clearly reflects its objective to move from the unsustainable towards sustainable water resource management. Various educational programs have been launched to create public awareness for stakeholders to participate and profit from the elaboration of IWRM. So far, Ghana experience with IRMW over the last five years is still in the operational phase.

In addition, the Government has adopted a National Community Water Supply and Sanitation Policy (NCWSP) and prepared a Strategic Investment Program (SIP) to promote and improve the supply of water and sanitation conditions in rural and urban areas and reach 85% by 2015. The program aims to meet the Millenium Development Goal of accelerating coverage of water supply and appropriate sanitation. (UN, 2004).

As a result of the reforms, Ghana has improved its water coverage by 46 percent between 1990 and 2002 with a drinking water coverage level being 79 percents in 2002 with urban/rural distribution of 93%/68%, respectively (WHO/UNICEF, 2004). Its progress in water sanitation was reported to have improved by 35% from 1990 to 2002. Total population using adequate sanitation facilities is 58% with urban/rural proportion 74%/46% (see Table 1.3).

Table 1.3. Ghana Estimates on Water and Sanitation (WHO/UNICEF, 2004).

Year	Population			Improved Drinking Water Coverage						Improved Sanitation		
	Total (thousands)	Urban %	Rural %	Total %		Urban %		Rural %		Total %	Urban %	Rural %
				Total	Household Connection[a]	Total	Household Connection	Total	Household Connection			
1990	15,277	36	64	54	14	85	35	36	2	43	54	37
2002	21,667	45	55	79	24	93	50	68	3	58	74	46

[a] Household connections refers to piped water connections to households.

Although largely improved since 1990, these numbers show the large inequalities across geographical areas (urban *versus* rural zones) and socioeconomic groups, the wealthier region situated in urban areas located mostly in central and south of Ghana and the poorest in the rural areas of the Northern part. Table 1.3 shows that the percent of improved drinking water technologies was 50% in urban areas in 2002, representing a 15% increase compared to 1990. The improved drinking water coverage only improved by 1% in rural areas accounting for a total of 2% in 2002. Therefore, there is a need to implement POU water treatment technologies in Ghana especially in the rural areas where the water connection is poor at the household level. The implementation of POU would also retain more medical staff in these areas.

The good news that several improvements have being made in Ghana concerning water and sanitation the last decade mostly in the urban area, is counterbalanced by an increase of disease such as malaria and diarrhoea among the poorest population notably in the rural areas where

poor water and sanitation has been provided. For instance, in 2001, the prevalence of malaria per thousand habitants was 156.76, this number rose to 160.2 in 2004 (George, 2004).

1.4 Tamale, Northern Ghana

In Tamale, where the author undertook her field work, several water-borne outbreaks and diseases were reported to have occurred during the past few years. It is the case for malaria, cholera, diarrhoea epidemics and Guinea worm infections. It is suggested by the author that this increase of diseases is mainly due to the lack of piped connections in Tamale and its surrounding. As a lot of people get their water from dams and rivers located around the city they get sick because of the high level of contamination of these water sources. The rapid growth of Tamale accounts for a part of the malaria. It is considered by rural inhabitants that Tamale usually offers greater economic opportunities and, therefore, attracts them. Unable to afford the higher cost of living in cities, migrants have created squatter settlements on the outskirts but also in the center of Tamale.

These settlements have rapidly grown during the past decade, often overwhelming the available services such as water, health care, sanitation, waste disposal, and electricity supply. The poor conditions in which people are living favour the increase of mosquito population, vectors of malaria disease. Indeed, stagnant water sources found in tires, cans, or plastic buckets will provide shelter for mosquito larvae and therefore will favour the development of malaria.

There is in Tamale various programme campaigns from NGOs and Ghanaian National Health Service dedicated to educate people on how to avoid malaria by empting all potential source of stagnant water. A Guinea worm eradication campaign led by the Carter center targets Guinea worm infections by providing the communities the basic steps to take to avoid the outbreak (e.g., the use of filter cloth to get free Guinea worm water, no swimming recommended in dams or rivers).

1.5 Pure Home Water (PHW) MIT Project, Tamale, Ghana

PHW is a small social business to market and sell household drinking water treatment and safe storage in Ghana. PHW is run by two social entrepreneurs /business coordinators, Hamdiyah Alhassan, a civil and environmental engineer and Wahabu Salifu, a development planner, working in collaboration with MIT and in association with World Vision-Ghana. They have been marketing household drinking water treatment and safe storage products in Ghana through the Safe Household Water (SHW) Implementation Project since 2005. The current SHW is funded by the Conrad N. Hilton Foundation for two years (2005-2007). The purpose of the project is to demonstrate the potential to sell a range of household drinking water treatment and safe storage products to low-income users in urban and rural areas of Ghana.

In January of 2006, a group of three Master of Engineering (M.Eng) students, along with four MIT Sloan Business School students, travelled to Ghana in an effort to understand and study the basic problems linked to water and sanitation in Tamale and to improve the delivery and the use of household water treatment devices. While the Engineering team focused on the implementation of epidemiological surveys, microbial testing and Global Positioning System (GPS) mapping, the business students spent the majority of their time with the two Ghanaian social entrepreneurs of the PHW project, analyzing the market and identifying the best promotion and sales strategies.

The Sloan PHW team, composed of Casey Gordon, Rachel Lawson, Bredan Monhagan and Kenichi Honna, focused on market analysis, product development, accounting and long-term marketing strategy improvement as part of the Global Entrepreneurship Lab (G-Lab) at MIT.

Working with the engineering students on household surveys, the Sloan team gathered information on customer product satisfaction and expansion opportunities. Additionally, the business students served as consultants throughout the selection process of microbiological water testing methods. Throughout their travels, the G-Lab team was also instrumental in obtaining GPS coordinates.

M.Eng teammate Rachel Peletz visited different communities around Tamale and performed an epidemiological survey to collect baseline health data and behavioural patterns in the region as a background against which health-based targets can be measured.

Jenny Vancalcar used GPS mapping to create a GPS tool to aid in the implementation of household drinking water treatment and safe storage (HWTS) systems throughout six districts in the Northern Region of Ghana that are the PHW target areas. The tool is meant to aid the HWTS implementation effort through a variety of services. First, it will provide a database for all relevant information related to the HWTS project (e.g., topography, improved and unimproved water sources, village populations, health data and households utilizing HWTS technologies). As the monitoring and evaluation program progresses, the map can be updated to hopefully show trends and identify future areas where improvement is needed.

Claire Mattelet, the author of this work and the third member of the Engineering team, applied and evaluated a set of simple and low-cost testing methods which can be used during source water quality and HWTS monitoring efforts. She assessed the current microbiological contamination of water sources around Tamale (e.g, dams and rivers).

1.6 PHW Project Ghana

One objective of the PHW project, is to give users choices of a range of simple HWTS products that are locally manufactured and affordable (US$1-US$20), through person-to-person marketing and sale to provide safe water at the household scale. Figures 1.1, 1.2, 1.4, and 1.5 show the range of HWTS products currently sold by the entrepreneurs: SODIS, the modified clay pot, the safe storage container, the Ceramica Tamakloe Filtron (C.T. Filtron) filter.

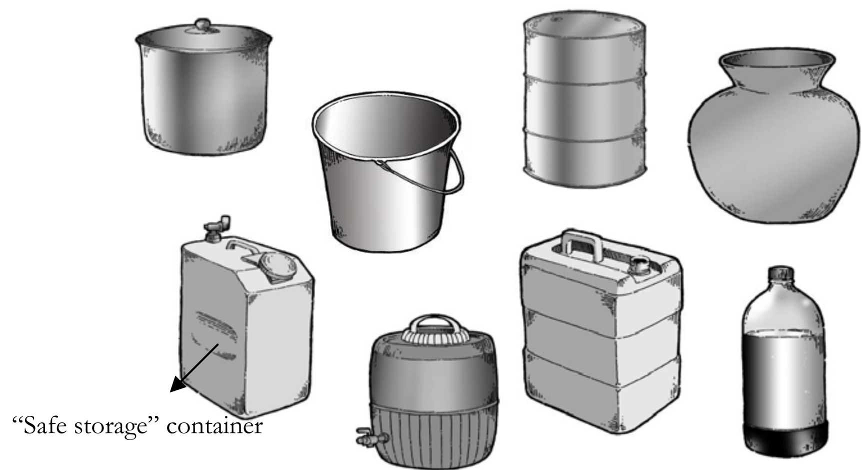

Figure 1.4. Safe storage containers.

Figure 1.5. Ceramica C.T. Filtron Filtron filter.

1.7 Research Goals

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 *Escherichia 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)

2. WATER BORNE DISEASES & INDICATOR ORGANISMS

2.1 Waterborne Pathogens

Waterborne diseases occur in part because of the impurities found in water. The nature of impurities regarding infectious diseases is biological and do not relate to the chemical aspect of water. For instance, the high arsenic concentration sometimes found in water that causes cancers is not infectious. In developing countries, infectious and chemical contaminations exist but in most cases, it is the infectious water-related diseases that are of major importance.

The numerous illnesses occurring with waterborne pathogens that have been reported throughout the world indicate that the transmission of microbes in water remains a significant cause of outbreak. In addition, the evaluation of illness only based on detected diseases might underestimate the issue. For example, the waterborne intestinal outbreaks might not be detected or if detected organisms may not be recognised as water related. Even in developed countries, where the regulations are stricter in terms of water pathogen concentration, the drinking water might still carry pathogenic microorganisms after treatment. These pathogens will cause occasional illness within the community supplied with this drinking water (e.g., diarrhoea).

Four classes of microbial organisms contribute to the spread of diseases with drinking water. These pathogens can infect humans via ingestion, inhalation or contact with skin, wounds, eyes, or mucous membrane (WHO, 2004). These four classes that are described in the next sections include bacteria, viruses, protozoa, and helminths.

Usually, unhygienic practices during the handling of food, utensils and clothing play a major role in the route of transmission of the disease. These pathogens are introduced in water by human or animal waste and can not proliferate in water. The microbial organisms following this route are called enteric because their first niche is the intestines, or enteron, of their host. Once they leave the host, the infectivity[1] and viability of pathogens tend to decrease exponentially (WHO, 2004). The most problematic microbial contaminants for waterborne diseases are the ones that possess a high resistance to decay.

Considering the threat to the health these microorganisms represent for the community, constant vigilance must be paid to the known and potentially unknown waterborne pathogens through the use of appropriate and frequent water tests.

2.1.1 Bacteria

Bacteria are unicellular prokaryotes (lack nucleus) which length varies between 0.3 to 100µm. Among bacteria families, the Enterobacteriaceae are particularly pathogenic humans. The organisms belonging to that family are gram-negative enteric bacilli. Species falling in this category which are notorious waterborne pathogens include *Salmonella typhi*, *Shigella spp.*, EC, and *Yersinia enterocolitca.*

S. typhi is typically present in all kinds of food grown in fecally polluted environments but also in fecally contaminated sources. This bacterium is responsible for Typhoid fever which can be a

[1] The infective dose (ID) of the pathogen determines the number of organisms needed to produce an infection in humans. The ID_{50} is the dose required to produce a clinically detectable infection in 50% of the subjects.

fatal disease. *Shigella spp.* causes dysentery in humans and is usually transmitted through direct contact with infected individuals or consumption of contaminated food and water. Flies can spread the disease after coming into contact with fecally contaminated sources. EC is ubiquitous in nature and part of the intestinal fauna of humans and animals. Usually, it is harmless in the intestines at normal concentrations. Certain virulent strains of the species can cause serious illness, such as urinary tract infections and meningitides. In other cases, some strains of EC can lead to mild to highly bloody diarrhea. Alike *Shigella spp.*, EC spread from contact with infected individual or contaminated food and water. *Y. enterocolitca* infections can lead to gastroenteritis, abdominal pain, fever, enlarged lymph nodes and diarrhea. The main ecological niche for this bacterium is contaminated water and sewage although some harmless strains can be found in nature. Transmission of the bacterium can occur via consumption of contaminated food predominantly but also to a smaller extend, with polluted water or contact with infected individual (WHO, 2004).

2.1.2 Viruses

Viruses are non-cellular organisms which size is much smaller than bacteria, ranging from 0.02 to 0.3μm. They are considered non-cellular because they need a host to reproduce. Viruses are composed nucleic acid (single or double stranded RNA or DNA) which is lodged in a capsid made of proteins and other macro molecules. The pathogenic pathway begins with the attachment of the virus particle (called virion) to a host cell. Subsequently, the virion penetrates the cell and replicates within it, changing the host cell metabolism with its nucleic acid synthesis (Madigan et al., 2003). Usually, viruses are much less easily degraded than bacteria with disinfection and treatment processes because of their resistant capsid protecting their genetic information. The main transmission route of these pathogens is made through contact with contaminated individual or with contaminated food or water.

Likewise bacteria, most of the waterborne viruses are enteric viruses which reproduce in the intestinal tract of human and animals causing infection and subsequently are excreted in feces. One of the most notorious viruses is Hepatitis A virus. This organism causes diarrhea and jaundice resulting in liver damages. Other important classes of viruses include *adenoviruses* (e.g., causing pneumonia, acute respiratory diseases, gastroenteritis and cervicitis), *rotaviruses* (e.g., causing gastroenteritis primarily in children), *enteroviruses* (e.g., source of gastroenteritis), *polioviruses* (e.g., causing polio) and Hepatitis E viruses (WHO, 2004).

2.1.3 Protozoa

Protozoa are unicellular organism possessing nucleus (eukaryotes). They lack cell walls but have a cell membrane around their cytoplasm. Compared to bacteria and viruses, protozoa are larger with a size ranging from a few μm to several mm). These organisms possess flagella, cilia or amoeboid that allows them to move. They usually get their food by phagocytosis (ingesting organisms or particles and further digest them thanks to their enzymatic system). They are responsible for infections and diseases in humans and animals. Large numbers of protozoa can infect humans by staying as parasites in the intestines of humans. The most common diseases are diarrhea and dysentery.

Giardia lamblia is one of the most common protozoa found in water. It causes an acute form of gastroenteritis. It infects individuals by fecal-oral transmission. The cyst form of *G. lamblia* is 8 to 12μm long by 7 to 10μm wide. Germination of the cysts in the gastrointestinal tract leads to the following symptoms of giardiasis: nausea, vomiting, fatigue and diarrhea. The cyst form is extremely resistant to chlorine disinfection treatments, variation of temperatures, pHs, and dehydration by a resistant wall that surround the cyst.

Other protozoan such as *Cryptosporodium* species also source of diarrhea and are waterborne related. This species include *C. parvum* which current reservoirs are humans. An infected individual can excrete up to 10^9 oocysts a day. The oocysts can survive for a long time during non-optimal conditions.

2.1.4 Helminths

Helminths are eukaryotic multi-cellular worms occupying the intestinal tract of vertebrates. They do not multiply in the human host. Rather, they live in the soil and have the potential to infect humans by penetrating their skin. The life cycle of helminths can be direct or indirect. In the direct cycle, helminths have one definitive host and they develop the infective stage during the free living period. In the indirect life cycle, helminths have intermediate hosts and a free-living stage before ending into the final host organism. Helminths include two major waterborne pathogens; *Dracunculus medinensis* and *Fasciola spp.*

In Ghana, there is currently important health issue due to *Dracunculus medinensis* (guinea worm). This worm is found in most West Africa. The symptoms of an infection are inflammatory reactions, giddiness, erythema and vomiting. The worm penetrates the skin of individuals while they are swimming or collecting water. Female worms discharge larvae by putting their end within the skin of the host, forming blisters. When blisters are in contact with water, the worm releases thousands of microscopic larvae. If these larvae are released into surface water and are eaten by cyclopoids (small crustaceans), the crustaceans become infected. The larvae then develop in this host. Because of the small host size, it will be easily consumed with water and then the larvae will develop in the human host. Adult male length can be 25mm long while Adult female ranges in size from 750 up to 1200mm (WHO, 2004).

Fasciola spp. includes *F. hepatica* and *F. gigantica*. *F. hepatica* has snails and vertebrates for hosts. Symptoms developed by the infected host are loss of weight, vomiting, chest pains, fever, abdominal pain, anemia, and potential liver enlargement. The helminth attaches to plants when it is released by snails into the water. When vertebrate eat the plants, they are infected by the helminth. *F. hepatica* will migrate to the bile ducts and liver when they are inside the host. They will release eggs which will be excreted by the feces of the host.

2.2 Microbial Indicators of Waterborne Pathogens in Water

Since the bacteria have been recognized as being agents of disease in the 1800s and thanks to the development of bacteriology, it was possible to use them as a tool to estimate water quality and treatment. The idea is to use non-pathogenic and easy detectable microorganisms as indicators of contamination in drinking water. From their presence or absence, it can be inferred whether or not there is a risk for health. The regularly monitoring and the protection of the water supply are essential to ensure the provision of safe water to the consumer. They are two main approaches to water quality monitoring for pathogen detection.

The first one is to measure directly the concentration of the pathogen agent in water. This method is accurate when specific disease-causing waterborne agents are detected directly for the determination of water quality but on the other hand, there exist some problems concerning this approach. The first objection to rise is that it is practically impossible to take into account the broad range of pathogen organisms present in contaminated water. In addition, this type of method is relatively expensive and therefore difficult to implement in developing countries. And last, the manipulation of such organisms often requires intensive training and is time-consuming.

Instead, the second approach based on "microbial indicators" has several advantages compared to the first method and is most commonly used for the microbial monitoring of water. This method is developed below.

The role of the microbial indicators in drinking water is to use them as an index of fecal pollution and therefore the results are used for the assessment of the health risk. According to WHO GDWQs, a suitable indicator should fulfil the following criteria:

- Safe water does not have to contain the indicator but contaminated water should always carry these organisms.
- The indicator should neither be pathogenic nor multiply in the environment.
- The number of indicators should exceed the number of pathogens.
- The identification, enumeration and isolation of the indicators should be easy.
- The indicators and pathogens should share the same characteristic relative to their common environment and water treatment processes.
- In order to increase the sampling number, the test should be inexpensive.

The indicator method is also largely applied because fecal contamination varies throughout time, usually presenting higher health risk at higher peaks. Therefore by using simple and cheap methods, the sample frequency increases allowing better level of pathogen detection. EC seems to be the best indicator to indicate fecal contamination because it completes all the qualities cited above. Thermotolerant coliforms indicators are often used as an alternative to EC. Most of the microorganisms discussed in the next section are ubiquitous in the environment and can easily contaminate the sampling during the analysis. Therefore, by taking numerous samples, the risk of doing any error in estimating the number of pathogens will be smaller than by analysis the drinking water of a single sample.

2.2.1 The Coliform Group

The coliform group is composed of 2 subgroups of microorganisms that are used to identify pathogens more or less related to fecal pollution. The first subgroup, the TC, includes the bacteria that multiply at 37°C. The second subgroup, the thermotolerant, is composed of bacteria that able to grow at 44.2°C among them, EC, which is the typical indicator of fecal contamination. In case of water contamination by any coliform, whether thermotolerant or not, subsequent water treatment is required to discover the source of the pollution.

2.2.1.1 TC

The basic definition for their characterization is: gram-negative aerobic to facultative anaerobic, non-spore forming, rod shaped bacteria which ferment lactose at 35-37°C in 24-48 hours. A genotypic definition has recently been raised in complementation; it is based on the presence of

β-galactosidase activity that bacteria fermenting lactose possess. By using this principle, TC are defined as members of species within the *Enterobacteriaceae* able to grow at 37°C and possessing β-galactosidase.

TC are not an index of fecal contamination or health risk because they are not necessarily indicative of the presence of pathogens (bacteria, viruses, protozoa). Instead, the microorganisms belonging to the group give information on source water quality. In U.S., the use of coliform organisms as microbial indicator of drinking water quality has been agreed by the EPA Safe Drinking Water Act since 1989 (USEPA, 2001). The main reason is that these bacteria are easy to enumerate and detect. The ability of enteric coliforms to survive for a long period out of the intestine tract in addition to their natural occurrence in unpolluted in tropical countries suggests that the use of these is not recommended as in these areas (Carrillo et al., 1985; Santiago-Mercado and Hazen, 1987; Bermudez and Hazen, 1988; Rivera et al., 1988; Pérez-Rosas and Hazen, 1989).

Included in this group are the genera *Escherichia, Enterobacter, Citrobacter* and *Klebsiella*. The group also includes many lactose fermenting bacteria such as *Citrobacter freundii* and *Enterobacter cloacae*. Members of genera such as *Budvicia* and *Rahnella* fall also in this group. The organisms are mainly distributed in nature and many are native in the gut of warm blooded animals, including human (Gerba et al., 2000). These bacteria are considered to be non-pathogenic under normal conditions and all except *Escherichia* are able to exist as free living saprophytes as well as in the intestinal tract. They are therefore considered of no sanitary significance but if they should not be detectable in water leaving a treatment plant. If these bacteria are detected, treatment remediation should be directly undertaken.

2.2.1.2 Thermotolerant (Fecal) Coliform

The term "fecal coliform organisms" refers to the thermo-tolerant forms of the TC group which ferment lactose at 44.5 ± 0.2°C in 24 hours. Within this group EC and *Klebsiella* species are the organisms of interest since, when present, they indicates that recent fecal contamination has occurred with the possibility of accompanying enteric pathogens. Among these organisms, only EC is considered to come specifically from fecal origins, as it is found in human, other mammals and bird faeces in much larger proportion than it is in water or soil in temperate climates not previously contaminated.

The thermotolerant bacteria other than EC might growth in organically enriched media such as organic materials (plant soil) or industrial effluents. Therefore in tropical and subtropical regions, thermotolerant bacteria can be found in water without having any relation to human waste. When these organisms are found at the end of a treatment process, further investigations must be made based on the assumption that pathogens may be present.

The use of thermotolerant as a fecal index is less reliable than EC in tropical countries but it is well related to EC on surface water in temperate climates. Their use should be required when no other methods are possible. In the best case, both EC and thermotolerant indicators should be used.

2.2.1.3 EC

EC, a 1x3 μm bacterium, belongs to the *Enterobacteriaceae* family and is characterized by the possession of the enzymes β-galactosidase and β-glucoronidase. This organism grows on complex media at an incubation temperature of 44-45°C. It ferments lactose and mannitol with the production of acid and gas, and it produces indole from tryptophan. Nevertheless, some strains do not have the same characteristics; some EC are able to grow at 37°C but not at 44-

45°C, others do not produce gas. Although the complete characterization of the strains requires high-technology methods, routine tests have been developed for a rapid and a reliable identification to a certain degree of accuracy. Some of these routine tests have been standardized and are now internationally and nationally used, other tests are still being developed.

EC is present in human and animal faeces in which it may reach a concentration of 10^9 per gram. It is isolated from soil, natural waters, sewage, and treated effluent that have undergone a recent fecal contamination from human, animal or agricultural activities. It has been proposed that this bacterium may multiply in tropical environments such as waters not subject to fecal contamination. The presence of EC should never been neglected because the assumption remains that the water has been fecally contaminated and that the treatment has been ineffective. EC is the preferred index of fecal contamination, and is also used as an indicator of treatment effectiveness although it is more sensitive to disinfection than many pathogens. The presence of EC indicates the presence of fecal contamination but its absence does not always imply that pathogens have been erased.

This bacterium is isolated by simple and cheap methods including the membrane filtration (MF) test, and 3M Petrifilm test in the requiring basic routine bacteriology laboratory facilities. These two methods were used in the present study and are developed in Chapter 4. In the MF test, a 100mL volume of contaminated water is filtered and the filtrate is incubated for 24Hrs at 35°C. The 3M Petrifilm uses a 1mL of polluted water sample that is spread on the Petrifilm medium and then incubated at 35°C for 24Hrs. The colonies that grew on the MF and 3M can then be counted. However, most of the methods used for the detection of EC require well-trained laboratory workers. In addition, because some strains are pathogenic, it can be an issue for the worker health.

2.2.1.4 Hydrogen Sulfide-Producing Bacteria

The H_2S-producing bacteria include *Citrobacter freundii*, *Salmonella typhimurium*, *Proteus vulgaris*, strains of *Klebsiella*, genuses *Edwardsiella* and *Arizona*. *Desulfovibrio* is also commonly found in aquatic habitat providing sufficient organic material and levels of sulphate. This group has been widely used since the 1980s when they were used as indicator of fecal origin correlation to FC (Manja et al., 1982).

The presence or absence of these bacteria can be indicated by the P/A H_2S test. With this test, broth and water sample are added to test tube. If TC or EC are present in the water sample, the liquid test tube will change colour (this is based on the assumption that TC and EC are likely to be associated to H_2S bacteria).

2.3 Water Quality and Quantity Standards

In the present thesis, the author focussed her efforts on flow rate performance and bacterial removal (TC and EC) of three filters (Nnsupa, C.T. Filtron and Everest Aquaguard). The results of studies will be compared to the current U.S. EPA (EPA, 2005) Standards for Drinking-Water and the WHO GDWQ in order in order to determine filter performances.

2.3.1 U.S. EPA Drinking Water Standards

According to the U.S. EPA, the maximum level goal (MCLG) for TC in a water sample is 0 CFU/100mL. Nevertheless, the maximum contaminant level (MCL) for TC in a water samples requires no more than 5% of total water sampled monthly give positive result for TC (see Table 2.1).

Table 2.1. U.S. EPA, WHO guidelines for drinking water.

Contaminant	MCLG (mg/L)	MCL (mg/L)	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water
TC (including fecal coliform and EC)	0	5.0%[a]	Not a health threat itself. Used to show whether other potentially harmful bacteria may be present	Coliforms are ubiquitous in nature; as well as faeces; fecal coliforms and EC only come from human and animal fecal waste.
Fecal Indicators (TC & EC)	0 [b]			

[a] More than 5.0% samples TC-positive in a month (for water systems that collect fewer than 40 routine samples per month, no more than one sample can be TC-positive per month). Every sample that has TC must be analyzed for either FC or EC if two consecutive TC-positive samples, and one is also EC- or FC-positive, system has an acute MCL violation.
[b] Depending also on the local or national environmental, social, economic and cultural conditions of the country where guidelines are implemented.

2.3.2 WHO GDWQs (WHO, 2004)

The WHO GDWQs provide the background and foundation for the microbiological analysis of this thesis.

The drinking water quality priorities of the GDWQs set the microbiological safety as a first concern. The priorities are given in the following order:

- To ensure an adequate supply of microbiologically safe water and maintain acceptability to discourage consumers from using potentially less microbiologically safe water.
- To manage key chemical contaminants known to cause adverse effects
- To address other chemical contaminants

WHO states that drinking water should contain no indicator organisms such as TC or EC in drinking water (see Table 2.1). Nevertheless, this 3rd of WHO Guidelines states that "neither the minimum safe practices nor the numeric guidelines are mandatory limits". Rather than that, the guidelines limits for the drinking water of the local or national environmental, social, economic and cultural conditions should be taken into account (WHO, 2004).

WHO also support that 7.5L is the minimum necessary volume of water required per person per day for both consumption and food preparation (Howard and Bartram, 2004).

2.3.3 Drinking Water Guidelines in Ghana

Ghana currently follows the 2nd edition of the GDWQ (WHO, 1996). A detailed table of these water quality standards is listed in Appendix 1. However, Ghana is trying to develop its own drinking water standards legislation appropriate to the Ghanaian economy, society and culture, as recommended by the 3rd edition of GDWQ[1]. "Such legislation should be consistent with achievement of the United Nations MDGs and should take into account of levels of acceptable

[1] Personal communication with Dr. Braimah Apambire (World Vision).

access outlined in General Comment 15 on the Right to Water of the UN Committee on Economic, Social, and Cultural Rights[1] and associated documents" (WHO, 2004).

[1] Website: http://www.unhchr.ch/html/menu2/6/cescr.htm

3. Ceramic Water Filtration

3.1 Selling and Manufacturing Water Filters in Ghana

In 1982-1983, a severe drought in Ghana demonstrated the most basic needs of many rural communities-clean water. In 1984, the Ghana Water and Sewerage Corporation and the Water Resources and Research Institute undertook a subsequent survey mainly looking at the water supply in project communities. The results of the survey highlighted the urgent needs of many rural communities to get access to potable drinking water. As a consequence, provision of potable water, sanitary facilities, and intensive health and education were promoted among communities. The result was an overall health and socio-economic life improvements of rural people in Ghana (World Vision-WV, Ghana Rural Water Project). The government also encouraged leadership development programs to build the capacity of many local communities. As a result, various development groups now initiate and manage their own projects. Now, one such small group, PHW, is selling point-of-use drinking water treatment systems in Tamale.

As the majority of inhabitants living in Tamale and in the surrounding rural communities are living in poor conditions, the entrepreneurs decided to sell low-cost filters to people. In an attempt to favour Ghana's business, the initial challenge for the entrepreneurs of PHW has been also to buy the filters from local flourishing filter manufactory businesses to subsequently sell them in Tamale, in its rural surroundings and in other Northern departments of Ghana. Another option PHW has is to buy the parts and assembles household treatment systems themselves.

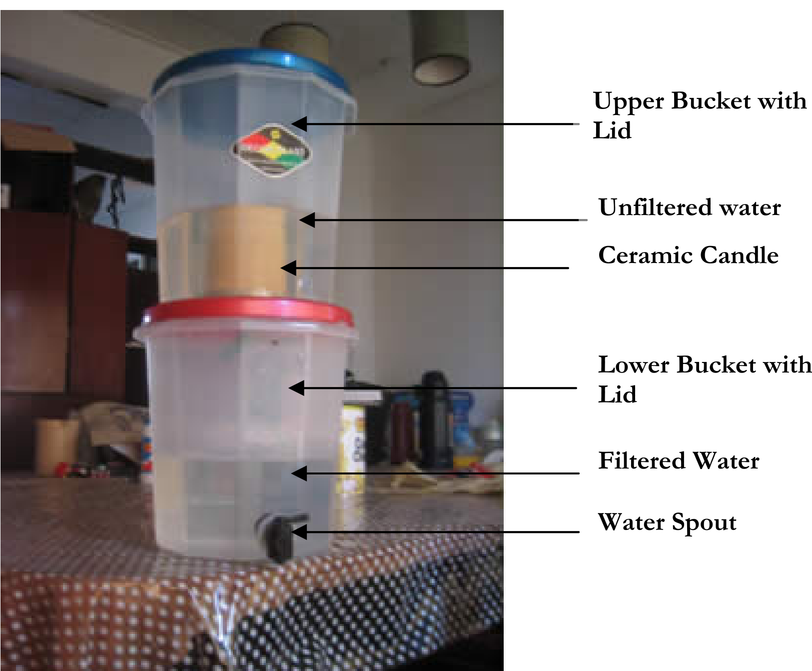

Figure 3.1. Schematic of Nnsupa candle filter.

Among the technologies PHW decided to sell, the author was particularly interested in the C.T. Filtron filter, and the Nnsupa candle filter (see Figure 3.1 above). The author focussed her efforts on the bacterial and flow rate analyses of these two ceramic filters. The two filters were compared to a competitor product in the Tamale market, the Indian candle filter (called Everest Aquaguard), the only such product, apart from PHW, locally available.

3.2 Factor Affecting Filter Performance

As already mentioned in Chapter 1, ceramic water filtration is a popular method of treating contaminated water at the household level. The various sizes and shapes the filters can have include hollow candle filters, disk filters, and pot filters. The materials used in their manufacture are also varied, among them clay is the main material along with a served combustible material such as sawdust or flour. The combination of these components together with the level of technology quality manufacture of the filter will give very different filter performances.

3.2.1 Porosity

Porosity is one of the main determining criterion that impacts filter performance. Total porosity of a solid is characterized as the volume of voids divided by the total volume of the solid. In ceramic filters, porosity will allow water to flow through the device. As porosity is a measure of the volume of empty space in a solid, filters showing a greater porosity will allow more water to pass through the ceramic. The size of the pores is therefore important in controlling the flow rate and the level of contamination removal of the filter. Generally, pore sizes of ceramic filters range between 0.1 to 10μm. Filters showing a large pore size will not be as efficient at removing turbidity and/or bacteria from water as filters having a small pore size. However, as filter flow rate increases with filter pore size, these filters will allow the collection of more water per hour.

3.2.2 Water Turbidity

Water turbidity will also affect the ceramic water filter flow rate. Water containing high organic concentration and/or many suspended particles will slow down the flow rate of water by progressively clogging the ceramic pores. This will affect the volume of filtered water collected.

3.2.3 Filter Thickness

Filter thickness is affecting the ceramic filter flow rate. With a thin ceramic device, flow rate increases but the level of water microbiological and turbidity removal will decrease. By increasing the thickness, the tortuosity[5] of the ceramic element increases, therefore it will retain more particles.

3.2.4 Filter Surface Area

As filter area is directly proportional to flow rate, surface area will have a major impact on the filter efficiency. A larger surface area of the ceramic element will allow more water to flow through the filter. The surface area can be increased by placing more candles in the buckets (usually 2 or 3). Although the efficiency of placing more than one candle was not studied in the present thesis, the Nnsupa filter was sold by PHW Ghana with a bucket containing 2 candles.

3.2.5 Water Pressure

Height of the water above the filter will affect flow rate. Greater fluid pressure which is also known as hydraulic head is a function of height/volume of water in the bucket. The more pressure on the filter element, and thus the more flow through the pores in a given period of time. While the water height decreases with time above the filter, the water pressure becomes smaller and therefore less water will flow through the filter. It is therefore important to maintain a certain level of water head above the filter by filling the upper vessel of the filter with water.

3.2.6 Activated Carbon and Silver Coating

[5] Tortuosity of a porous medium is defined by the ratio between the mean length actually traveled by the fluid passing through the porous medium, and the thickness of the filter in the macroscopic direction of the flow.

Activated carbon and silver coating are two options that can be used to improve the filter efficiency beside flow rate.

Silver coating of the ceramic element is another option for the treatment of water. Filter will be impregnated of silver after being heated. This final phase process coating will prevent bacterial growth as silver has bactericidal properties. This technique is currently used with the C.T. Filtron filter sold by PHW Ghana.

In some cases, activated carbon is added in to the ceramic filter manufacture. This practice is mainly done to improve the performance, taste and/or odour removal. The carbonaceous raw materials the filter is made of will produce an extremely porous and chemically active material when heated slowly in the absence of air. The activated carbon will improve the adsorption of organics and other chemicals. The main drawback of this technique is that carbon is likely to provide a breeding shelter for microorganisms. The activated carbon technique is not currently part of the PHW products.

3.3 Former Investigations Undertaken at MIT on Ceramic Filters

In her thesis, the author referred to various studies already undertaken by previous Master of Engineering students. The ceramic filters have been widely studied in various parts of the world. The previous studies the author refers to are summarized in this section.

3.3.1 Study of Filtration for Point-of-Use Drinking Water in Nepal

In January of 2000, J. Sagara went to Nepal and challenged the Nepalese ceramic candle filter and the Indian ceramic candle filter, among others. Flow rate and turbidity removal performances were compared. The Nepalese ceramic candle filter was found to have a flow rate of 0.24L/hr whereas the Indian ceramic candle filter performed a flow rate of 0.3L/hr. Both filters could remove enough suspended particles from the raw water from values as high as 12 Nephelometric Turbidity Units (NTU)[6] to values below 1 NTU, and gave adequate turbidity results. Sagara used the P/A test for TC and EC and the Most Probable Number (MPN) test for H_2S-producing bacteria to look at the microbial removal efficiencies. The microbial results showed that none of the filters tested were able to meet the WHO drinking water quality standards for EC removal. Sagara concluded that filtration must be combined with a disinfection process. Sagara decided to apply colloidal silver on the filter to try to improve the microbial removal performance. Depending on the colloidal silver dose applied to the candle, results showed that all H_2S-producing bacteria and EC were removed. However, colloidal silver was not able to improve the TC removal (Sagara, 2000).

3.3.2 Investigation of the Potters for Peace Colloidal Silver Impregnated Ceramic Filters

In January of 2001, D. Lantagne conducted experiments on the Potters for Peace (PFP). Colloidal Silver Impregnated Ceramic Filter post-graduation. A survey among households possessing the PFP filter was performed by Lantagne in Nicaragua. The results showed that when used properly, the filters could remove 100% of indicator bacteria. However, according to the survey, due to behavioural issues of receptacle contamination and inadequate water storage, only 4% of the PFP installed in the households removed TC, 53% removing EC and 25% removed H_2S-producing bacteria (Lantagne, 2001).

[6] Nephelometric Turbidity Units (NTU) is a measure of the clarity of water. Turbidity is measured with an instrument called a nephelometer, which measures the intensity of light scatted by suspended matter in the water.

3.3.3 Appropriate Microbial Indicator Tests for Drinking-Water in Developing Countries and Assessment of Ceramic Water Filters

In January of 2002, C.S. Low worked on a project to develop a ceramic disk filter (Thimi filter). The prototype was compared to the TERAFIL Indian terracotta ceramic filter by looking at the turbidity removal, flow rate, and microbial performances. The turbidity could be removed by at least 85% for both types of filters. The flow rate results demonstrated that TERAFIL were faster than the Thimi filters. Low used the P/A H_2S test, and different MF culture media (m-ColiBlue24®, m-FC, m-Endo, Chromocult, and MUG) for various organisms were compared based on cost, ease of result interpretation, and medium preparation. The microbial removal efficiency of the filters showed that in Nepal, the TETRAFIL filter could remove between 80-100% of fecal coliforms and 80-99.89% of EC. The Thimi filter also showed a high rate of TC and EC removal with 89-99.69% and 96-100%, respectively. Low concluded that m-ColiBlue24® be used for TC, m-FC with rosalic acid for FC detection, and either MUG or m-ColiBlue24® for EC detection.

The summary of culture media recommendations for TC and EC detection using MF is shown Table 3.1. Costs were updated by the author to 2006 prices.

Table 3.1. Summary of TC and EC culture media in terms of cost, ease of use interpretation, and medium preparation (Low, 2002).

TC Culture Medium	Medium Cost Per Sample	Total Cost Per Sample	Ease of Interpretation	Ease of Preparation
m-Endo® (pre-packed)	US$1.02 (HACH, 2006)	US$1.81	Difficult	Easy (None)
m-ColiBlue24® (pre-packed)	US$1.58 (HACH, 2006)	US$2.37	Easy	Easy (None)
Chromocult® (self-prepared)	US$1.01 using 500g (Merck, 2006)	US$1.68	Medium	Medium

Prices reviewed by the author for the year 2006.

Low tested the colloidal silver on the filters and a 0.0027% solution of colloidal silver was applied on the filters. It appeared that there was no observable improvement in coliform removal at that concentration. Low suggested using SODIS (see Section 1.2.1) in combination to the filters in order to get 100% bacterial removal efficiency (Low, 2002).

3.3.4 A Performance Study of Ceramic Candle Filters in Kenya including Tests for Coliphage Removal

In January of 2005, A. Franz evaluated the performance of five brands of ceramic candle filters that are locally available in Kenya or brought by her to Kenya: the AquaMaster, Doulton Super Sterasyl, Stefani São João, Pelikan and Pozzani candles. Relevant results for the present thesis included flow rate, TC and EC removal, and cost evaluation made by Franz. Flow rate results showed that the best performance was obtained by the Doulton Super Sterasyl (0.55L/hr). The flow rate of the other brands ranged from 0.14-0.26L/hr. In her research, Franz used m-ColiBlue24® for the detection of TC and EC bacteria. Microbial percent removal ranged between 92-<100%. AquaMaster, Doulton Super Sterasyl, Stefani São João, and Pelikan filters were able to remove significantly more TC and EC than Pozzani filters. The cheapest filters were the Pelikan (retailing US$2 in Nairobi). Franz recommended the use of sedimentation and/or coagulation as a pre-filtration treatment if highly turbid water needs to be filtered. This action is meant to ensure a higher flow rate. In addition, Franz suggested the use of disinfection as a post-filtration process to remove residual bacteria (Franz, 2005).

3.4 Ceramic Filters Studied

3.4.1 Worldwide and Local Production of C.T. Filtron Filter

Potter for Peace-type filters are used at the household level in Africa, Central and South America, and Asia and are particularly pertinent for regions affected by natural disasters (see Figure 3.2). The pot filter technology has been implemented in 9 countries (Murcott, 2006).

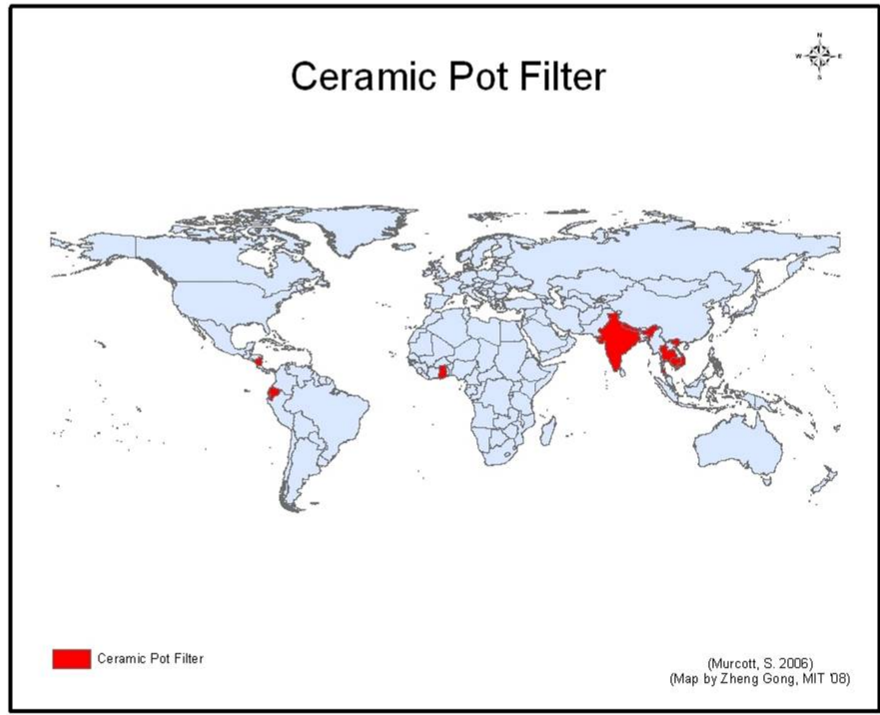

Figure 3.2. Ceramic pot filter worldwide distribution (Murcott, 2006).

The Filtron filter has been locally manufactured in Ghana by Ceramica Tamakloe Ltd. under the name "C.T. Filter". 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 bacterial contamination 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 financing to bring filter ceramist expert Ron Rivera to Ghana to train Peter Tamakloe and his employees. As Mr. Tamakloe, director of Tamakloe Ceramics Ltd. 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.

When the author first travelled to Ghana, she visited the local filter factory located near Accra (see Figure 3.3).

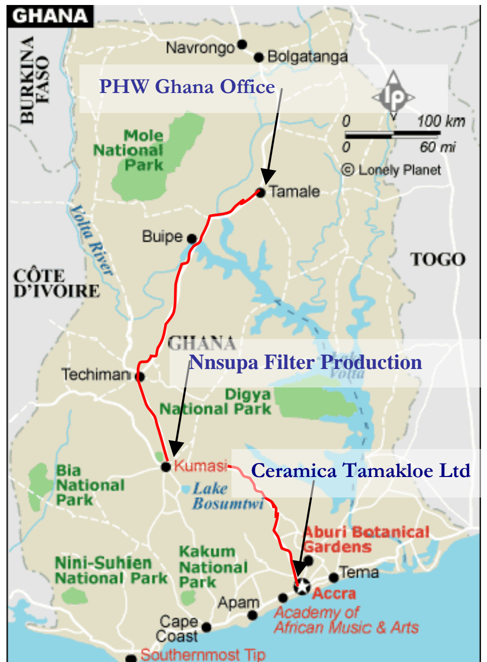

Figure 3.3. Route taken by the PHW team from Accra to Tamale.

After having received training in production, Ceramica Tamakloe Ltd. has produced over 2000 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 (see Appendix 9). Ceramica Tamakloe Ltd. has 35 full-time employees who receive at least twice the minimum wage in Ghana and have benefited from an apprenticeship scheme.

3.4.1.1 Fabrication Process

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[7] 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). 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.

The complete C.T. Filtron system is comprised of the clay pot inserted in a plastic container meant to receive the filtered water. A plastic top is also provided to avoid unwanted contamination or the nesting of insects such as mosquitos in the unfiltered water present on top of the filter. A tap is installed at the bottom of the receptacle bucket to collect the drinking water (see Figure 1.5).

[7] 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.

Ideally, the Filtron technology should remove 99.98% (3 log removal) under laboratory conditions (PFP, 2004). Field studies showed that this level of performance is not consistently achieved mainly because of cracks occurring in the ceramic filter during transportation and/or non-standardization methods. Two principles of the Filtron filter disinfect the water. The main principle of Filtron is filtration through which any harmful microorganism or particle larger than 1μm are removed from the tested water such as most bacteria, all protozoa and helminthes. The process is not likely to trap viruses and some tiny bacteria. The second mechanism is produced by the colloidal silver coating of the ceramic filter inducing a reputed bacteriostatic action. Colloidal silver is composed of silver particles held in suspension in clusters between 10^{-9} and 10^{-6} m wide (Lantagne, 2001). Filter characteristics are reported Table 3.2. Figure 3.4 through Figure 3.8 illustrate the fabrication process.

Table 3.2. 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
C.T. Filtron	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 (10L) 16 (12L) 18 (13.5L)	No	28.4 [b](10L)	20.8 [b](10L)	19.5	5.8	Not Stated	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 these sizes are 10L, 12L and 13.5L for the water collected in the bottom bucket.

Figure 3.4. C.T. Filtron filter promotion during market day in Tamale (S. Murcott and B. Mohagan).

Figure 3.5. Meeting Mr. Tamakloe in his Ceramic company, Accra, Ghana.

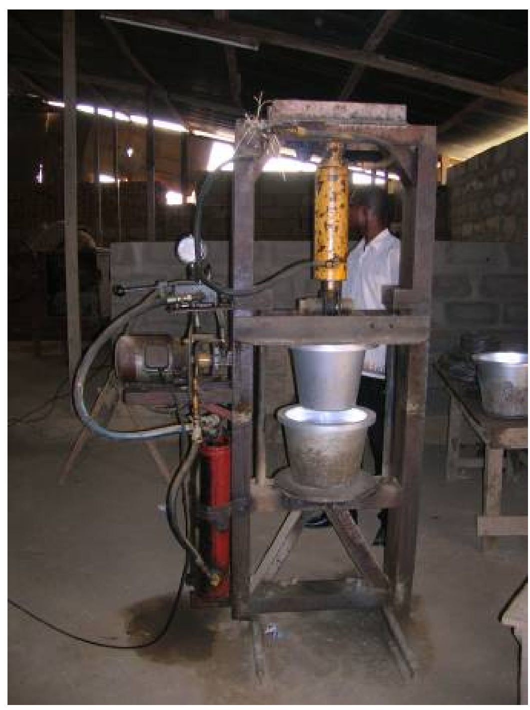

Figure 3.6. Red clay and saw dust pressed in a hydraulic press at Ceramica Tamakloe.

Figure 3.7. Displaying the filter steel mold.

Figure 3.9. Pot filters are dried for several days before firing in the kiln.

Figure 3.8. Pots stacked inside the kiln before firing.

3.4.2 Worldwide and Local Production of Nnsupa Candle Filter

Ceramic candle filters are used at the household level in Africa, Central and South America, North America, and Asia and are particularly pertinent for regions affected by natural disasters (see Figure 3.10). The technology has been implemented in 22 countries (Murcott, 2006).

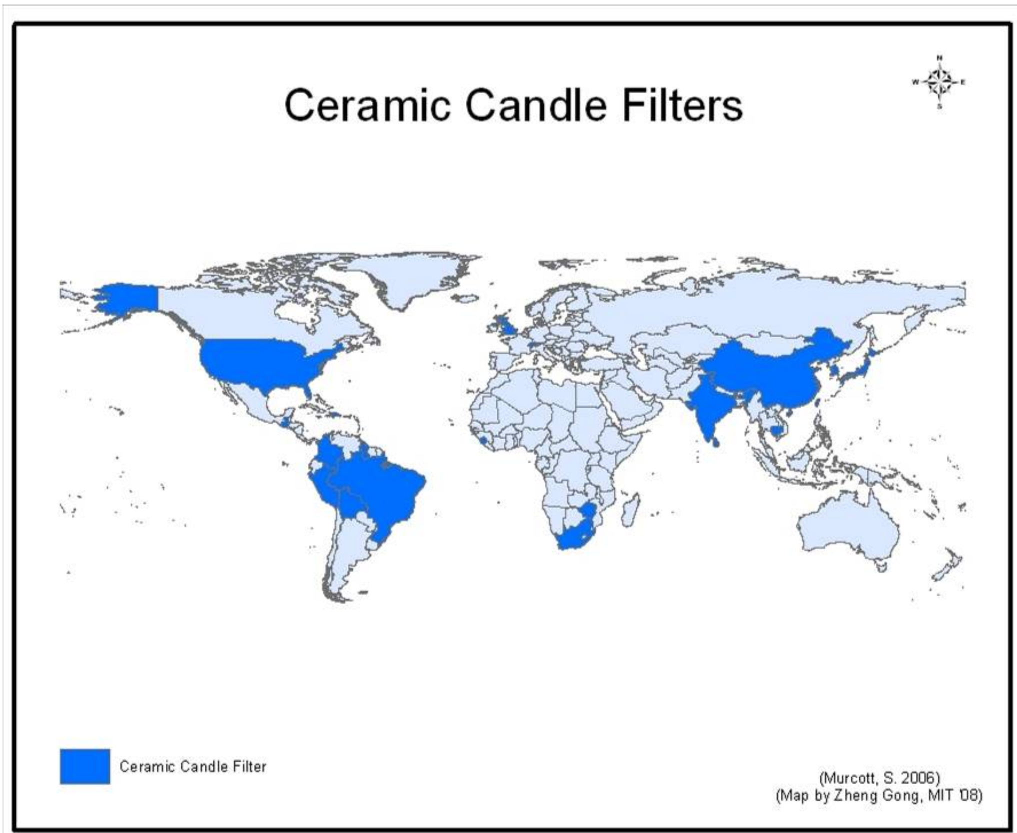

Figure 3.10. Ceramic candle filter worldwide distribution (Murcott, 2006).

The author visited another local production of filter in Kumasi (see Figure 3.3). The manager of the filter production is Mr. Michael Commeh. Michael Commeh's filter system known as the Nnsupa filter[8]. 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 between US$70- US$200). The strategy was to open a local filter production market and to produce cost effective household ceramic filter candles (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 achieve 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 0 EC per 100mL was created. The following full production of the filter candle started in 2004.

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) as shown in Table 3.3.

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

Table 3.3. Nnsupa candle performance (Commeh, 2006).

Reduce to Safety Level	Nnsupa Standard Candle
Bacteria/Pathogens	100%
Cysts	100%
Heavy metals	100%

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.

3.4.2.1 Fabrication Process

The Nnsupa filter is composed of two plastic buckets, one on the top of the product containing the ceramic candle filter and the other plastic bucket receiving the water that has percolated through the candle. A tap is installed in the bottom bucket to access the safe water. The Nnsupa candle fabrication is based on a special particle size distribution which is formed by sintering through temperature manipulation, and through the addition of organic matter to create the desired pore sizes. No specific published data detailing the filter pore size could be found. 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. Each candle is then assembled on an aluminium base (see Figure 3.1 and Figure 3.11 through Figure 3.14). Filter characteristics are reported Table 3.2.

Figure 3.11. Nnsupa Candles.

Figure 3.12. Meeting Mr. Commeh in his candle filter company.

Figure 3.13. Rubber part prevents unfiltered water from leaking in the bottom bucket.

Figure 3.14. Set up of Nnsupa candle filter.

3.4.3 Production of Indian Filter (Everest Aquaguard)

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 3.2. 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 (see Figure 3.15 through Figure 3.18). 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 3.15. Everest Aquaguard kit.

Figure 3.16. Everest Aquaguard filter, displayed in Melcom department store, Tamale, Ghana.

Figure 3.17. Everest Aquaguard candle.

Figure 3.18. Everest Aquaguard top and bottom buckets.

3.5 Methodology of Filter Testing

The performance of the ceramic filters was assessed based on two main criteria

- Flow rate
- Coliform indicator bacteria removal

3.5.1 Flow Rate 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 (see Table 3.4). 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.

Table 3.4. Water filter characteristics observed in Tamale.

Filter	Total Volume of Bucket (L)	Height of Water (cm)	Volume of Water Used (L)
C.T. Filtron	18.1 [a]	20	15.1
Nnsupa	9.7	24	8.2
Aquaguard Everest	9.7	24	8.2

[a] Volume of the ceramic pot.

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))

3.5.2 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 (see Section 4.1 for test procedure and Appendix 3 for Sampling).

The MF and the 3M Petrifilm were also used to quantify the number of TC and EC present in a sample according to the procedure described in Sections 4.2 and 4.3. 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

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

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

4. LOW-COST & SIMPLE METHODS

4.1 Presence/Absence Indicator Test for Coliforms

4.1.1 General Considerations

The presence (P) or absence (A) indicator test for the coliform group is based on the P/A of the coliform indicator in a specified volume of water. The test was first used by J. Clark (Clark, 1968) in an attempt to find a low-cost method for fecal determination. The usual water volume sample for testing fecal contamination in drinking water is 100 mL using fecal indicator with Clark's P/A tests. The test does not provide any estimation of the actual number of coliforms in the sample. Questions were raised concerning the need to count bacteria when experiments showed that coliforms were not uniformly distributed in the municipal water system (Christian and Pipes, 1984) and techniques such as MF were replaced by P/A tests for these specific cases. The P/A tests which estimates the frequency of occurrence of coliform-positive samples was thought to be more representative for the assessment of microbial quality of water (Clark, 1990).

P/A tests influenced both the EPA and the fisrt and second editions of WHO GDQW to adopt regulations and specifications stating that no coliforms should be detected by either P/A or other enumeration methods in 5% of all drinking water samples (see Table 2.1). Two different approaches of testing the water exist using this method. In the first P/A approach, general guidelines expect the fecal indicator to be absent (A) in 95% (5% tolerance) to 100% (0% tolerance) of the 100mL water samples subsequently tested over time. In the second approach, the Most Probabe Number (MPN) methods for fecal water quality testing (e.g., non-P/A), the concentration of the microorganisms is determined using multiple tubes of identical volume, each of which is alternatively noted as positive or negative for the indicator.

4.1.2 Limitations of the P/A methods

Despite the fact that the P/A method is used worldwide, the P/A method has some limitations. One issue using the low-cost P/A technique in developing countries is that, alike any water quality test method, the technique cannot be performed due to the lack of accessibility and lab setting to analyze the water samples. In addition to this limitation, some other problems related to the choice of the indicator to detect the pathogens (mainly thermotolerant and EC indicators) coming from fecal contaminations. Fecal indicators such as enterococci, spores of *Clostridium perfingens* and coliphages, can be detected in drinking water when the usual indicators microorganisms (thermotolerant/TC, EC) are not found in the samples. Waters that are considered microbiologically safe to human beings (0 EC per 100mL according to WHO, 2004) can potentially contain enough pathogen agents (enteric viruses, protozoans) for disease outbreaks to occur (Craun, 1979). It has also been suggested that fecal coliforms and EC have the potential to grow in water under tropical climates (Hazen, 1998; Jimenez et al., 1989). Because of these limitations, there have been some attempts to substitute fecal coliforms and EC by other types of indicators (Sobsey, 2006).

Accessibility to the field study site is often a challenge in developing countries, therefore, one issue is how to conduct water quality testing in the field in developing countries. The standard analysis test kits that have to be done in a sterile environment require materials such as broth, bottle, reagents, pipettes and incubators with controlled temperatures. In many cases, no infrastructure allowing the use of such materials is available, and therefore the standard tests have to be resigned to be as simple and user friendly as possible.

4.1.3 P/A H_2S Test

These challenges in conducting water quality, microbiological, and other tests in developing countries has led to the creation of low-cost, simple and rapid microbial tests. The tests are applicable in low income communities or at the household level where few technical laboratory experts are encountered. The use of P/A H_2S test seems to overcome the main constraints. The H_2S test was created in an attempt to replace the standard MPN test to detect fecal contamination in water.

The H_2S test was developed by Manja et al. in 1982 as a simple technique for the detection of fecal contamination in drinking water in rural and remote areas. It was discovered that the presence of H_2S-producing microorganisms was associated with coliform pathogens in drinking water. Pillai et al. (1999) showed that the P/A H_2S test was able to detect fecal contamination when 1 colony forming unit indicator was present in 100mL water sample (1 CFU/100mL). As a result of the reaction of H_2S with iron, there is the formation of a black precipitate of iron sulfide in the water sample (or on a paper strip). The indicator bacteria if present in the water sample will be screened because of the colored precipitate formed through the reduction of hydrogen sulphur in its sulfide oxidation state as gas (H_2S). Subsequently, the reduced compound will react with the iron to form the black iron sulfide precipitate.

P/A H_2S test has many advantages:

- It is easily portable
- It is simple
- It is rapid to use

Thanks to these advantages, the H_2S tests are therefore interesting tools when field study is to be conducted for drinking water quality testing in developing countries.

However, some problems have to be clarified for the H_2S tests to be performed adequately for the routine detection of fecal pollution in water. This is due to the fact that there are several possibilities of getting a black precipitate suggesting that the test is likely to give positive results when no fecal indicators are present in the water sample:

- Any source of H_2S within the sample can lead to the formation of the black precipitate
- Sulfide can be created by abiotic reactions
- In nature, the existence of a broad range of microorganisms from various different ecological niches are able to release sulfide from proteins, amino acids, and other reduced sulphur compounds by reduction reactions

The types of organisms that have been found to produce H_2S are various and include *Citrobacter freundii*, S*almonella typhimurium*, *Proteus mirabilis*, *Proteus vulgaris*, *Clostrodium perfigerens*, and some species of *Arizona Klebsiella, Edwardsiella* (Manja et al., 1982; Kromoredjo and Fujioka, 1991; Grant and Zeil, 1996; Pillai et al., 1999). Some variant of EC were also detected. In this context, the H_2S test is therefore not specifically meant for the detection of the coliform bacteria. Figure 4.1 shows an illustration of the relationship between the groups of indicators that are used in the author thesis (Low, 2002).

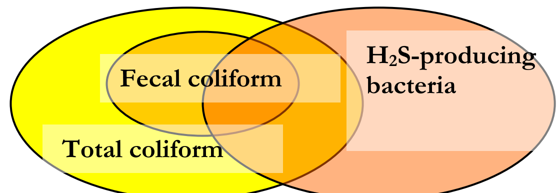

Figure 4.1. Illustration of the relationship between TC, FC, H_2S bacteria (Low, 2002)

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.

However, it is not recommended to use 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).

In general, the required range of temperatures to conduct such P/A H_2S test would vary between 15° to 44°C and the observable results are to be expected within 24 to 48 hours. However, temperatures between 28 to 37°C give faster results (Pillai et al., 1999). If approved incubation temperatures and time are not used, false negative results may appear, so whenever it is possible, the use of incubators is recommended. 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.

4.1.4 Sampling Procedure for P/A H2S Test

4.1.4.1 Instrumentation

- 20mL glass sampling bottle
- Candle

- Lighter
- Alcohol
- HACH PathoScreen Medium for 20mL sample (See Figure 4.2 for the test equipment and supplies used)

Figure 4.2. Presence and absence result with H_2S test after 24 to 48 hr.

4.1.4.2 Procedure (HACH, 2002)

- ❖ Sterilize sampling bottles in a pressure cooker for 10 minutes and allow cooling
- ❖ Pour 20mL sample into bottle
- ❖ Cut PathoScreen sachet and pour into sample bottle. Mix
- ❖ Place sample at 35°C
- ❖ Take H2S Bacteria P/A readings at 24 hours. At this point, if the sample is still yellow, allow an additional 24 hours before taking another reading (see Figure 4.2)

- ❖ - Coloration:
  Black → Positive
  Yellow → Negative

4.2 Membrane Filtration Indicator Test

4.2.1 General Considerations

The MF method was created in order to improve upon the MPN procedure. The MF offers the expert greater precision than expected with the multiple tube fermentation (MTF) whose results are given by MPN method in a shorter period of incubation time (24 hours *versus* 48-96 hours for the standard fermentation tube method). Moreover, the MF technique offers the advantage of allowing much larger volumes of water samples (100mL), resulting in more representative results with very little lab equipment requirements. The MF also gives a direct count of the colonies in the water sample whereas the MPN technique is based on statistical estimates. 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) therefore *Clostrodium perfringens* and coliphages do not interfere with results as they do with MPN evaluations (Grabow and Du Preez, 1979; Rompré et al., 2002).

4.2.2 Classical Metabolic Methods of Coliform Detection using MF

Often, the classification of bacteria based on taxonomic criteria is difficult to determine because gene transfers between bacteria belonging to different species according to taxonomic data have been found to occur in nature. In response to this issue, the classical culture methods using MF is

based on metabolic functions of the coliform bacteria. Organisms producing red colonies with metallic (gold or green) sheen within 24 hours of incubation at 35 ± 0.5°C on an Endo-type medium are considered to belong to the coliform group (Standard Methods, 2005). The sheen area of the colony may vary from partial to total coverage of the colony. The m-Endo broth is a standard culture medium described in the Standard Methods for TC.

4.2.3 Coliform Detection Troubleshooting

Various challenging issues occur related to proper coliform detection including false negatives, false positives, misreading of coliforms, and the bacterial environment.

4.2.4 Colony Misreading

Some variants of the previous described coliform colonies may appear; it has been found that dark red, mucoid or nucleated colonies lacking metallic sheen should also have been counted as coliforms, according to the Standards Methods (Rompré et al., 2002), which could result in a misreading.

4.2.5 False Positives

False positive results may appear on the sample filter. Generally pink, blue, white, or colorless colonies lacking sheen are seen as non-coliform organisms. It has already been seen that MF using the m-Endo culture broths type is not totally TC specific, and other non-TC organisms presenting the same typical coliform description have been detected such as *Aeromonas* which has in common many coliform characteristics (Grabow and Du Preez, 1979; Clark et al., 1982). Reciprocally, the reading of atypical TC colonies can be missed during the bacteria counting. The incubation temperature of the media plays an important role in the detection of bacteria. A deviation from the ideal incubation temperature (44.5°C) as small as 0.2°C might lead to the development of non-fecal organisms such as *Klebsiella* sp. which account for false positive results. Conversely, this temperature difference might inhibit the growth of different kinds of EC strains (Katamay, 1990). Therefore, it is important to take into account the narrower specified range for the growth of bacteria on a specific medium.

4.2.6 Bacterial Environment

Other troubleshooting cases besides false positive results and misreading of coliforms have been described. The bacteriological environment of the coliforms also has an impact on its growth on media. A study demonstrated that a high number of heterotrophic organisms can decrease coliform recovery by MF (Lisle, 1993). The paper reported that non-coliform organisms were able to inhibit the apparition of the sheen area on coliforms but also influenced the growth rate of TC on plates. Therefore, in response to the possibility of an underestimation of the TC count in water sample, Standard Methods were set to report the bacteria as to numerous to count (TNTC) when bacteria counting exceeds 200 colonies per 100mL. Other authors reported that growth interference occurs when 500 colonies or more per 100mL are present (Clark, 1980). Another study explored the effect of four non-coliform bacteria; *Pseudomonas aeruginosa*, *Aeromonas hydrophila*, *Bacillus* sp. and *Flavobacterium* microorganisms injected at different concentrations in water samples containing coliforms (Burlingame et al., 1984). The results showed that *P. aeruginosa* effectively reduced the coliform counts at levels as low as 30 per mL and prevented any coliform detection at levels of about 400 per mL. *A. hydrophila* presented the highest influencing coliform growth pattern with a reduction of coliform count at 2 *A. hydrophila* per mL and no coliform count at 10 *A. hydrophila* per mL. The last two bacteria studied, *Bacillus* sp. and *Flavobacterium*, did not show evidence of affecting coliform counts when added at densities greater than 1000 per mL. The fact that many of these heterotrophic species are not detectable on m-Endo medium

might lead to an error when counting coliform and therefore cause an underestimate of the coliform density without any visual explanation accounting for these low numbers.

In addition to the influence of other non-coliform bacteria, another source of false negative results is the disruption of the growth rate of coliform by the turbidity of water (Lisle, 1993). In general, microorganisms favour solid surfaces to grow on, thus particles of turbid water lying close to one another on the filter are likely to provide adequate support for bacteria to develop. The more turbid the water, the more chance to have the target coliform bacteria, but also unwanted organisms growing on the whole membrane preventing the formation of distinct colonies. In such case, colonies are "joined" and subsequent coliform counting is particularly difficult.

Defects other than false negative results with MF techniques are also an explanation for the underestimation of enumeration of coliforms. The MF method is unlikely to recover the stressed and wounded coliforms (Rompré et al., 2002). The coliform stress during sampling, transportation, and transfer on the counting plates, together with the drinking water treatment and water disinfection processes, are potential sources of coliform injuries. The wounded microorganisms are often likely to die off during the filtration step because they are unable to properly recover and therefore the mother cells do not multiply to form colonies. Furthermore, it is generally believed that only a small part of the whole bacterial population in a water sample can be counted using cultivation-based methods (Amann et al., 1990).

Although no ideal specific coliform broth allowing an optimal counting has been found, other media also respond to the challenges previously described with the MF method, for example, m-Endo in North America (Standard Methods, 2005).

4.2.7 Modified Membrane Filtration Media: m-ColiBlue24® and Chromocult®

As the classical methods of coliform detection presents various limitations, alternative methods such as enzymatic techniques have been developed. They are based on the nutrition of a target organism using vital nutrients. Only the target bacteria are fed, no other types of nutrients are provided to the other organisms. Among the different agar media that are commercially available, the classical agar media is modified with specific chromogenic and/or fluorogenic substrates for the detection of β-D-glucuronidase and/or β-D-galactosidase. These culture media include the Chromocult® Coliform Agar (Merck, Germany) and m-ColiBlue24® broth (HACH, USA).

Whereas the Chromocult® agar requires incubation temperatures varying between 35 to 37°C, the m-ColiBlue24® has a fixed incubation temperature of 35°C ± 0.5°C.

On the one hand, Chromocult® agar possesses the chromogenic Salmon-GAL which is cleaved by β-D-galactosidase produced by coliforms to form salmon to red coloured colonies. For EC, Salmon-GAL and chromogenic X-glucuronide will be cleaved by EC, giving dark-blue to violet colonies (Merck, 2006). The agar media also contains Tergitol®7 molecules which inhibit the growth of Gram positive and some Gram negative unwanted bacteria.

On the other hand, the m-ColiBlue24® (HACH, 1999, 2006) is a lactose-based medium, containing inhibitors to selectively eliminate growth of non-coliform cells. Basically, the TC are highlighted by a non selective dye, 2,3,5-Triphenyltetrazoliumchloride (TTC), which produces red colonies. The EC colonies are shown through the action of a β-glucuronidase enzyme on 5-bromo-4-chloro-3-indolyl-β-D-glucuronide (BCIG or X-Glu).

4.2.8 TC and EC Culture Media Selection

It was demonstrated that the performance of m-ColiBlue24® is better than m-Endo for the detection of TC and more especially for the detection of EC (Sartory and Howard, 1992; Brenner et al., 1993; Cenci et al., 1993). m-ColiBlue24® and Chromocult® agar altogether with m-Endo broth were investigated by Low in 2002. All three media were compared on the basis of three main criteria:

- Ease of result interpretation
- Cost
- Ease of media preparation

In his study, Low concluded that m-ColiBlue24® has a lower false positive than m-Endo medium. It was that concluded that m-ColiBlue24® is a good medium to detect EC and showed an improvement over the traditional m-Endo broth when used for the determination of TC. When using the Chromocult® agar, Low reported that EC showed up as clearly distinct colonies, whereas the TC colonies did not appear as distinct as with the m-ColiBlue24® media. The Chromocult® agar is more time consuming to prepare than m-ColiBlue24® media. The Chromocult® agar preparation is sold in 100g or 500g containers, unlike m-ColiBlue24®, the solution is not prepared. Its advantage is that it is cheaper than the prepared media but it is more labor intensive (see Table 3.1).

Based on the three criteria (Ease of result interpretation, Cost, Ease of media preparation), Low recommended m-ColiBlue24® as the most appropriate medium among the three for the growth of TC because these colonies show more clearly (i.e., "ease of result interpretation"). Although m-ColiBlue24® is a bit more costly than Chromocult® agar, it requires no media preparation. Therefore, for these reasons, it was decided by the author of the present thesis to use m-ColiBlue24® media for the selective growth of TC with MF.

4.2.9 Sampling Procedure of MF Test

Compared to the P/A test, the MF procedure is more complex. More precaution has to be paid to ensure a sterile environment of the MF unit and the samples. The following steps are required.

4.2.9.1 Instrumentation

- Millipore portable MF setup (see Figure 4.3; Millipore, 2006)
- Culture medium
- Absorbent pad
- 0.45µm filter paper
- Candle
- Lighter
- Tweezers
- Magnifying glass
- Incubator (Millipore, xx631K230)

Figure 4.3. Membrane filtration unit and pump.

4.2.9.2 Procedure (Millipore, 1992)

1. Sterilization of the portable Millipore MF stainless steel filter holder

One must sterilize the filter holder between each water sampling. The procedure is to

- ❖ Remove the stainless steel receiver flask from the funnel base assembly
- ❖ Soak the ceramic ring around the holder base with one half capful of methanol and subsequently ignite the methanol with a match
- ❖ Close the filtering cup over the funnel and the burning ceramic ring
- ❖ Leave the filter unit scaled up in place for 15 minutes. Remove cup and rinse funnel thoroughly with approximately 100mL of sterile water

The steps described above are time consuming when a large number of samples have to be tested. Therefore, to save time, when the author used several dilution of the same water sample, the filter holder was not sterilized. To avoid contamination between dilutions of the same sample, the more dilute (in terms of coliform concentration) sample was filtered followed by the less dilute sample. However, sufficient sterile rinse water was used between filtrations to rinse the funnel and flush away potential residues. It is recommended that a sterile blank be inserted after 10 filtrations of 10 samples to check for potential cross-contaminations. Therefore, the author decided to prepare a negative control for each new water sample.

2. Petri dish label and selective growth medium

- ❖ The Petri dish is labelled and absorbent pad is placed aseptically in the dish with the use of sterile tweezers
- ❖ The m-ColiBlue24® culture medium pre-packaged in 2mL plastic ampoules (from Millipore) is poured into the Petri dish and the excess medium remaining in the Petri dish is decanted
- ❖ When medium is poured, special attention is paid to ensure that every surface of the absorbent pad is uniformly soaked and the excess is poured away, leaving behind about one drop at the bottom

3. Sample pouring and filtration

- ❖ 30mL of distilled water is then flushed in the assembled filter
- ❖ 0.45µm filter paper are then flushed on the filter to support base using sterile tweezers
- ❖ A total volume of 100mL water sample is poured in the MF setup
- ❖ Filtration is run, pumping water through the filtration unit

4. Funnel rinsing

- ❖ The interior walls of the funnel are rinsed with about 30mL of distilled water three times to avoid carry-over contamination

5. Filter removing

- ❖ Filter paper is removed carefully with sterilized tweezers and placed into the labelled Petri dish in a rolling motion to prevent trapping of air bubbles. The air bubbles may prevent the absorbing of media on the top of the filter paper, therefore resulting in the uneven growth of colonies

6. Incubation

- ❖ The Petri dishes are placed in the incubator at 35°C for 24 hours. The Petri dishes are inverted to avoid reading trouble shots due steam formation on the filter

7. CFU estimation

- ❖ The number of CFU is counted under magnifying glass and expressed as CFU/100mL

- To be assured of a statistically valid colony count, the number of colonies of TC on plate should be between 20 and 80 CFU for TC, and between 20 and 60 CFU for EC
- The indicator organisms level in water sample are expressed as the number per 100mL
- The number of indicator organisms in the water tested is determined as follows:

$$\frac{\text{No of Indicator Organisms Counted} \times 100}{\text{Milliliters of Sample}} = \text{No. of Indicator Organisms per 100 mL}$$

4.3 3M Petrifilm Methods

4.3.1 General Considerations

The 3M Petrifilm EC/Coliform Count Plate is a sample-ready-culture-medium technique containing Violet Red Bile (VRB) nutrients, a cold-water-soluble gelling agent, an indicator of glucuronidase activity, BCIG, and a tetrazolium indicator which facilitates colony counting. Most EC (about 97%) produce β-glucuronidase which in turn produces a blue precipitate associated with the colony. The top film traps gas produced by the lactose fermenting coliforms and EC. About 95% of EC produce gas, indicated by blue to red-blue colonies associated with entrapped gas on the Petrifilm EC plate (within approximately one colony diameter). Coliforms produce acid and gas from lactose during metabolic fermentation and these colonies growing on EC plates produce acid which causes the pH indicator to make the gel colour darker red. Gas trapped around red coliforms colonies indicates confirmed coliforms.

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 use of the EC Petrifilm plate for water testing analysis seemed therefore reasonable to consider (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 for volunteer-based and educational water quality monitoring applications because of its simplicity of use and storage, its reliability and relatively low cost. 3M Petrifilm would be particularly efficient when used as a preliminary screening method to identify problem sites. Three different categories of 3M Petrifilm are available, as shown by Table 4.1 (3M Petrifilm, 2006).

Table 4.1. Categories of 3M Petrifilm and their relative price.

Number of plates, category number	Price (US$) per Petrifilm
50 plates/box, 6404	1.37
500 plates/case (Price/case), 6144	1.06
500 plates/case (Price/Multi-case)*	1.04

* The Multi-case orders contain any combination of 2 or more cases of Petrifilm Plates and 3M Quick Swabs.

4.3.2 Sampling Procedure of 3M Test

Compared to the P/A test, the 3M procedure is far more complex. More precaution has to be paid to ensure a sterile environment of the 3M plates and samples. Therefore, the following steps are required.

4.3.2.1 Instrumentation (see Figure 4.4)

- Petrifilm plate (3M)
- Spreader
- Pipette
- Incubator

- Magnifying glass

Figure 4.4. 3M Petrifilm.

4.3.2.2 Procedure (3M Petrifilm, 2006)

The use of the 3M Petrifilm EC/coliform count plates is easy. During the procedure, the following steps are required:

1. Storage

- ❖ The unopened packages are stored at ≤8°C. In areas of high humidity, it is recommended to allow packages to reach room temperature before opening to avoid condensation in the package
- ❖ To seal opened package, the end has to be folded over with tape. It is better to keep released package at ≤25°C and avoid refrigeration of the opened package. However, In Ghana, the author refrigerated opened packages because of the high ambient temperatures (20-30°C)

2. Inoculation

- ❖ Petrifilm plates are placed on a level surface
- ❖ Top film is lifted and 1ml of sample is placed onto center of bottom media using a pipette
- ❖ The top film is then rolled down. During this step, air bubbles can be trapped between the top film and the medium, thus it is recommended to carefully manage this operation.
- ❖ With flat side down, the spreader is placed on top film over inoculum
- ❖ Gently pressure is applied to the spreader to distribute the sample uniformly over the media surface area before the gel is formed. During this step, spreader must not be twisted or slid
- ❖ The spreader is removed and the gel is allowed to solidify for one minute

3. Incubation

- ❖ Plates are incubated at 35°C with clear side up in stacks of no more than 20

4. Interpretation

- ❖ Coliform and EC bacteria are counted with a magnified glass
- ❖ Blue to red-blue colonies associated with entrapped gas, regardless of size or intensity of color, are enumerated EC. Blue colonies without gas are not counted as EC
- ❖ Red closely associated (within one colony diameter) with entrapped gas are counted as coliform colonies. Colonies not associated with gas (distance greater than one colony diameter between colony and gas bubble) are not counted as coliforms

- The TC count consists of both the red and blue colonies associated with gas at 24 hours
- When the TC count is greater than 150 colonies, it is recommended by the AOAC Official Methods to estimate the number of colonies by counting the colonies in one or more representative squares of the $20cm^2$ plate and determining the average number per square. The average should then be multiplied by the 20 to get an estimation of the count per plate
- When microorganisms are present in large numbers, Petrifilms EC plates may have one or more of the following characteristics: a deepening of the gel colour with many small, indistinct colonies; and many gas bubbles. High concentration of EC will cause the growth area to turn blue while high concentration of red coliforms will cause the growth area to turn dark red. When this occurs, these results should counted as TNTC and a higher dilution of the sample should be needed to repeat the experience
- The organisms are counted by using the same formula used for estimating the number of coliforms with MF:

$$\frac{\text{No of Indicator Organisms Counted} \times 1}{\text{Milliliters of Sample}} = \text{No. of Indicator Organisms per } 1mL$$

4.4 Low-Cost Methods and Media Choices Conclusion

In her thesis, the author decided to compare three different low-cost and simple indicator methods: the P/A H_2S test, the portable MF unit, and the 3M Petrifilm methods. The media used for the detection of H_2S-producing organisms, EC, and TC colonies, were selected in part because they have the same incubation temperature (35°C) and therefore they could be performed at the same time using the sole incubator the author brought with her in Tamale, Ghana. The low price of each medium (prices reviewed by the author) along with the conclusions made by Low about the performance of m-ColiBlue24® also supported the idea of choosing these methods.

4.5 Method of Comparison for H_2S P/A test, 3M Petrifilm, and MF

4.5.1 *P/A H_2S test* vs. *MF and 3M*

P/A H_2S test was compared to MF and 3M methods. A total of 46 water samples collected at various sources around Tamale were tested for their H_2S-producing bacteria content (see Appendix 5). These P/A H_2S results were challenged with the corresponding TC and EC results of 3M and MF.

Similarly, 46 MF and 3M water sample tests were used for the detection of EC (see Appendix 6). When the colour of the water of a H_2S test turned black after 24 hours or that a black cloud developed at the bottom the bottle after 24 hours, the H_2S organisms were reported present. If after 24 hours no black colour developed or whenever the water sample was turbid, the sample was incubated for another 24 hours. If after 48 hours the sample remained yellow or turbid, the H_2S bacteria were reported as "absent". Each of the H_2S test was then compared to the 3M and MF tests using the same water sample. The corresponding number of CFU/100mL of MF or 3M was then compared to the P/A of bacteria. These data were plotted in a bar graph showing the number of P/A *vs.* CFU/100mL of bacteria in the water samples.

4.5.2 *3M* vs. *MF for TC Enumeration*

A total of 28 water samples that were previously enumerated for TC content (see Appendix 8) were used for the comparison of 3M and MF methods. Most of these TC water samples came

from the same water sources such as the samples considered in Appendix 5. However, some of the samples used in Appendix 5 could not be used for the comparison of 3M and MF because sometimes, no possible count was possible for MF (TNTC) and/or 3M (TNTC). Some other water sources were added in this study.

4.5.3 Statistical Analysis

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 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.

4.6 Fecal Contamination Assessment of Water Sources in Tamale

4.7.1 Water Sources Microbial Analysis and GPS

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 (see Appendix 7). 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 4.5 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 4.5). The photographs of three of the sites are shown in Figure 4.6, Figure 4.7, Figure 4.8, and Figure 4.9 (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. The geographical coordinates of the different sample collection spots were taken with GPS by Jenny Vancalcar (2006) are shown in Table 4.2 and Figure 4.10

Figure 4.5. Samples of water collected (from right to left: St. Mary Dam, Bilpelar Dam, Ghanasco Muali, Kamina River, and dam near the Gillbt Guest House).

Figure 4.6. St. Mary Dam and GPS mapping by J. Vancalcar.
St. Mary Dam and GPS mapping by J. Vancalcar.

Figure 4.7. Bilpelar Dam and collection of water samples by the author.

Figure 4.8. Kamina River water sample collection.

Figure 4.9. Kamina River: evidence of high contamination.

Figure 4.10. Water sample locations for St. Mary Dam, Ghanasco Muali, Bilpelar Dam, Kamina River and the dam near Gillbt shown in blue.

Table 4.2. Geographical coordinates of the different sample collection spots taken with a GPS device.

	Latitude	Longitude
St. Mary Dam	9.38	-0.78
Bilpelar Dam	9.38	-0.84
Ghanasco Muali	9.39	-0.81
Kamina River	9.48	-0.85
Dam near Gillbt	9.47	-0.82
WV[a]	9.60	-0.84

[a] World Vision Office, Savelegu.

4.7.2 Procedure

The fecal contamination (TC and EC contents) of the 6 water sources was analyzed with MF and 3M methods. The standard counts for the colonies on plate (20-80 TC CFU and 20-60 EC CFU) for MF and (15-150 CFU) for 3M, were applied as much as possible. However, sometimes, the colony ranges found on the Petri dish did not fall in the ideal range of colonies on a given plate. In that case, the author paid attention to take the most relevant colony counts and use them for the determination of fecal contamination of the various water sources.

5. RESULTS & DISCUSSION

5.1 Flow Rate

Flow rate tests were performed for the Nnsupa, C.T. Filtron and Everest Aquaguard filters. These tests were repeated three times. Detail of the flow rate tests are given in the Section 5.1.1 through 5.1.2.

5.1.1 Results

In Tamale, the flow rates were performed for three runs of filter testing. The filters were previously immersed for one hour, using the same water, in order to start measuring the flow rate as if the system was run regularly like it would in a household. Final flow rate measurements were made 3 hours after initially adding the water. The three runs were undertaken the same day.

The flow rates range from 0.25L/hr to 0.67L/hr for the candle filters (Nnsupa and Everest Aquaguard) while it varies between 0.48L/hr and 1.91L/hr for the C.T. Filtron filter (see Table 5.1). These results are also shown in Figure 5.1 and Figure 5.2.

Table 5.1. Flow rate testing for Nnsupa, C.T. Filtron and Everest Aquaguard.

	Flow Rate after 1 Hour (L/Hr)				Flow Rate after 2 Hours (L/Hr)				Flow Rate after 3 Hours (L/Hr)					
Filter	Run 1	Run 2	Run 3	**Avg.**	Run 1	Run 2	Run 3	**Avg.**	Run 1	Run 2	Run 3	**Avg.**	**Total Avg.**	St. Dev.
Nnsupa	0.375	0.385	0.480	**0.413**	0.325	0.340	0.330	**0.332**	0.250	0.280	0.300	**0.277**	**0.341**	0.005
C.T. Filtron	1.750	1.855	1.910	**1.838**	0.725	0.870	0.900	**0.832**	0.475	0.540	0.530	**0.515**	**1.062**	0.362
Everest Aquaguard	0.500	0.590	0.650	**0.580**	0.450	0.550	0.670	**0.557**	0.400	0.560	0.550	**0.503**	**0.546**	0.008

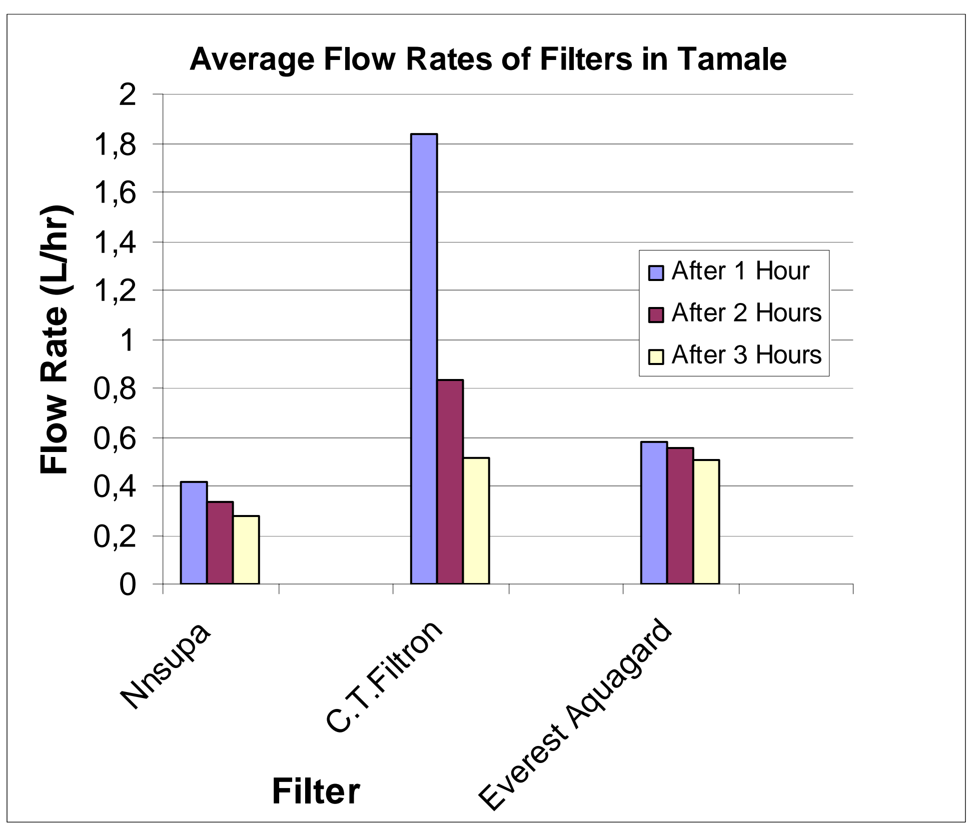

Figure 5.1. One, two and three hour flow rate for Filters in Tamale.

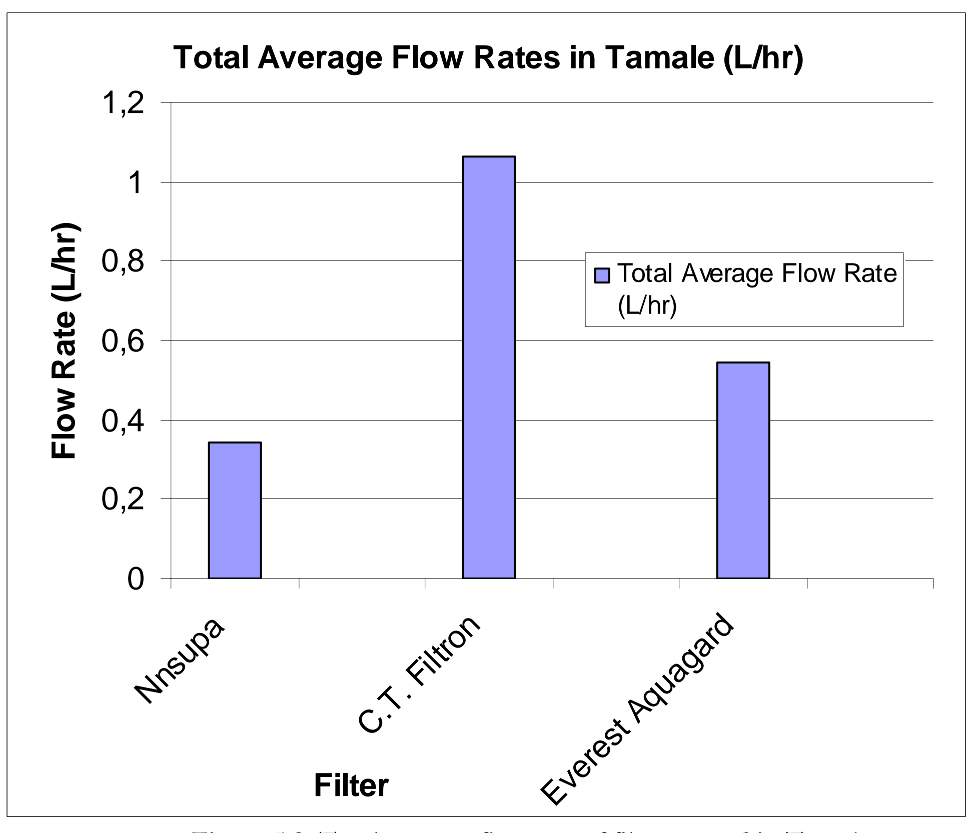

Figure 5.2. Total average flow rate of filters tested in Tamale.

The Nnsupa filter shows the lowest flow rates results with average values of 0.41, 0.33, and 0.28L/hr after 1, 2, and 3 hours respectively. The overall average flow rate of the Nnsupa filter is 0.34±0.01L/hr.

The C.T. Filtron filter shows the highest variability of average flow rates compared with the elapsed time. The average flow rate of the C.T. Filtron filter is 1.84L/hr after an hour, this flow rate decreases to an average of 0.83L/hr and 0.52L/hr after 2 and 3 hours, respectively. However, the overall average flow rate of the C.T. Filtron filter is still the highest among the three filters (1.06±0.36L/hr).

The Everest Aquaguard filter flow rate values range between C.T. Filtron and Nnsupa flow rate values. After an hour of water percolation, it shows an average flow rate of 0.58L/hr, this result is followed by rates averaging 0.56L/hr after 2 hours of filtration and 0.50L/hr after 3 hours. The overall flow rate is 0.55±0.01L/hr for the Everest Aquaguard.

5.1.2 Discussion

The C.T. Filtron filter has the highest total average flow rate performance among the three filters studied. The Nnsupa filter experiences the lowest flow rate while the performance of the Everest Aquaguard filter is in the middle of the C.T. Filtron and the Nnsupa flow rate ranges. Compared to the Nnsupa filter candle (12.8x7.5cm), the candle of the Indian filter is longer (19.5x5.8cm) and presents more surface area (355.3cm^2) compared to the Nnsupa filter (301.6cm^2). A larger surface means a higher number of pore spaces available for water to percolate through. The experiment was performed until the Everest Aquaguard and the Nnsupa filters were approximately 2/3 full of water (height of water was approximately 20cm). Flow rate is also dependent on porosity of the ceramic candle. However, this impact on flow rate is hard to distinguish based on the figures. Results of microbial and turbidity studies should better reflect the effect of pore size.

All three 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. (see Figure 5.1). 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.

Although C.T. Filtron filter performed an initial flow rate value of 1.8L/hr of filtration, it decreased nearly to the average flow rate value of the Everest Aquaguard after 3 hours of water percolation. However, it can be seen that when the filter is filled to the top of the ceramic pot filtering element, the flow rate nearly averages the expected flow rate (2L/hr) given by the manufacturer after fabrication (see Section 3.4.1.1).

The decline of flow rate for candle filters with the increasing elapsed time has already been observed by many other researchers including Franz (2005) in Kenya. In her thesis, Franz studied the microbial efficiency and flow rate of 5 different ceramic candles filters. Franz provided two explanations for the decline in flow rate. The first explanation is due to the high turbidity of the water source. In turbid water, the suspended particles visible in the water are able to clog the pores of the filter as time passes leading to a decline in flow rate. The second explanation Franz gave was that as water flowed out of the filter, less water remained to be filtered. Progressively, as the buckets starts emptying, there is less surface of candle filter available for the water that has to be filtered. In addition, the volume of water (and hydraulic head) was greatest when water was

first added to the filter. The pressure of water decreases as the bucket empties, so there is less water pressure on the filtering element to push water through the candle.

In the present thesis, the author decided to use tap water to test the filter buckets. This selection was made because some households in the Northern region will have relatively clean borehole water passing through their filters and could therefore expect flow rates similar to the author findings. Nevertheless, other households will use dams and other surface water sources and it is expected to see slower flow rates. In the present thesis, the author found a flow rate value of 0.55L/hr for the Everest Aquaguard. Compared to a previous study undertaken by Sagara (2000) with ceramic Indian candles, this value was a little bit higher (0.55L/hr *vs.* 0.30L/hr according to Sagara). This could be due to the fact that Sagara used dirtier water than the author used in her thesis which could have clogged the pores of the candle filter more quickly resulting in lower results for flow rate estimations.

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.

5.2 Coliform Removal

Tests for removal of TC and EC were performed for the C.T. Filtron, Nnsupa, and Everest Aquaguard filters in Tamale. Results obtained from these tests are discussed in sections 5.2.1 through 5.2.2. Data from studies can be found in Appendix 2 and Appendix 3.

5.2.1 Results of Filter Fecal Contamination Removal

The fecal coliform removal tests were performed with a water source collected at St. Mary Dam. The water source was first tested for its fecal contamination content. MF and 3M Petrifilm results of St. Mary Dam are described in Section 5.4. For all filters, MF failed to detect EC in the raw water, therefore no EC removal could be estimated with MF.

The percent and log removal of fecal coliform by Nnsupa, C.T. Filtron and Everest Aquaguard are shown Table 5.2 and Table 5.3. These values are illustrated for Nnsupa and C.T. Filtron in Figure 5.3 and Figure 5.4.

Table 5.2. Percent Removal of TC and EC with the Nnsupa, C.T. Filtron, and Everest Aquaguard filters.

Filter	Percent Coliforms Removed by Filters in Tamale			
	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
C.T. Filtron	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).

Table 5.3. Log Removal of TC with the Nnsupa and C.T. Filtron filters.

Filter	Log Removal of TC by filters in Tamale	
	TC	
	MF[a]	3M[b]
Nnsupa	0.4	1.2
C.T. Filtron	2.3	3.9

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

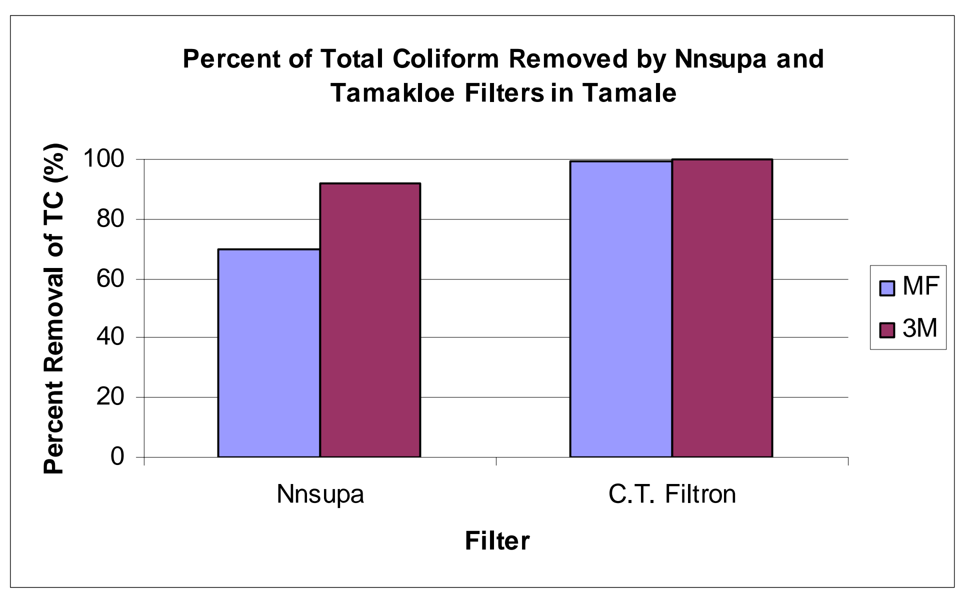

Figure 5.3. Percent of total coliforms removed by Nnsupa and C.T. Filtron filters in Tamale.

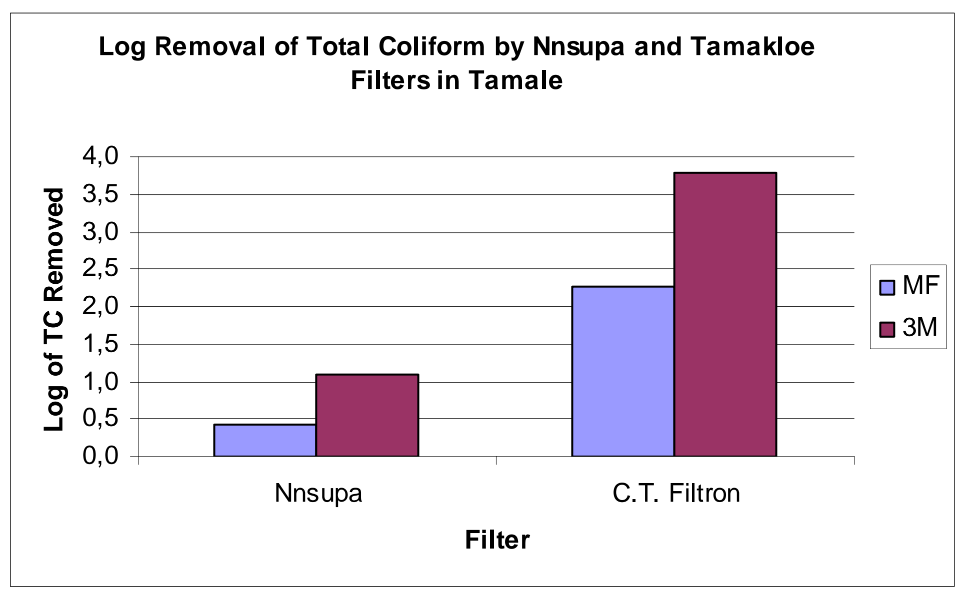

Figure 5.4. Log removal of total coliform by Nnsupa and C.T. Filtron filters in Tamale.

Among the 4 water samples taken from St. Mary Dam, 50% showed the presence of H_2S-producing organisms (see Figure 5.5). The H_2S test results for the polluted water source showed that on January 12, 2006 the raw water of St. Mary Dam water was contaminated at 50x dilution of the water sample. However, at 10x dilution the H_2S result was negative (see Appendix 3).

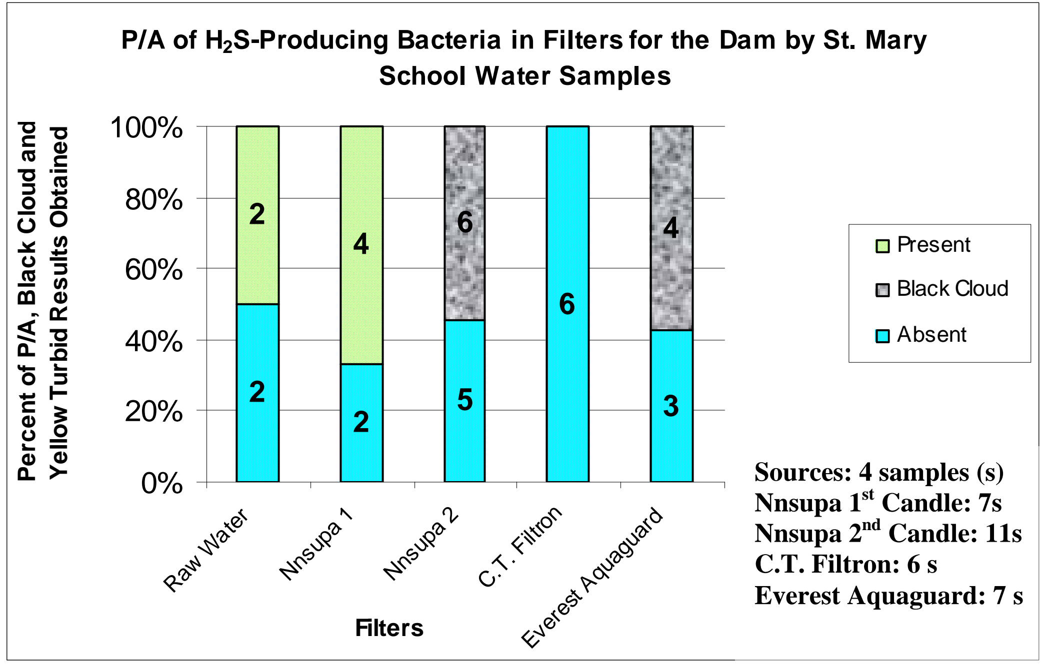

Figure 5.5. P/A H_2S-producing bacteria in filters for the St. Mary Dam water samples.

5.2.1.1 Nnsupa Filter

Two Nnsupa filters that were identical in appearance were tested. The first Nnsupa candle filter shows 62.9% removal for TC with MF whereas the 3M Petrifilm method gave 93.1% TC removal. These values correspond to 0.4 and 1.2 log removal, respectively.

The second Nnsupa candle tested showed contaminations on the MF filter plate so no clear results were obtained. However, Petrifilm showed 69.3% efficiency for TC with the second Nnsupa candle.

Concerning the removal of EC, 100% efficiency was obtained using the 3M Petrifilm method for both the first and the second Nnsupa candles. Because MF failed to detect EC in the raw water, there were no reliable results obtained for EC removal with the Nnsupa filter.

H_2S-producing organisms were not eliminated with the Nnsupa candle. After filtration, 67% of the samples still showed bacterial contamination. With the second Nnsupa candle, 54% of the samples showed H_2S contamination through the development of a black cloud at the bottom of the test flask.

5.2.1.2 C.T. Filtron Filter

The C.T. Filtron filter performed outstanding results with 99.5% efficiency removal for TC using the MF technique and 100% efficiency using 3M Petrifilm method. These values correspond to 2.3 and 3.9 log removal, respectively.

Concerning the removal of EC, 100% efficiency was obtained using the 3M Petrifilm method for the C.T. Filtron filter. Because MF failed to detect EC in the raw water, there were no reliable results obtained for EC removal with the C.T. Filtron.

5.2.1.3 Everest Aquaguard Filter

The TC removal efficiency could not be properly calculated for the Everest Aquaguard. Negative removal efficiencies were observed (-274.7% for MF and -49% for 3M Petrifilm method).

The Everest Aquaguard filter showed a condition where the H_2S test results were situated between negative and positive (presence of black clouds of H_2S-producing bacteria in at the bottom of the test flask). More interestingly, during the first days of analysis the 48 hrs of incubation revealed that the filtration performance was relatively satisfactory (yellow and turbid for the days 01.12.06 and 01.13.06), the following days of water sample analysis revealed the presence of black clouds at the bottom of the sampling flask.

Concerning the removal of EC, 100% efficiency is obtained using the 3M Petrifilm method for the Everest Aquaguard filter. Because MF failed to detect EC in the raw water, there were no reliable results obtained for EC removal with the Everest Aquaguard.

5.2.2 Filter Cost Analysis

Table 5.4 shows the different characteristics of the Nnsupa, C.T. Filtron, and Everest Aquaguard filters which are: flow rate, Bacteria removal, TC and EC % removal, H_2S removal, and the price of the filters.

Table 5.4. 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.

5.2.3 Discussion

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. The comparison of these two methods will be discussed in Section 5.3.4.

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 (see Appendix 9) 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. H_2S test undertaken on this filter did not detect H_2S bacteria at all dilution performed on the two days of sample collection and testing (01.13.06 and 01.14.06).

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 5.4. 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.

5.3 Comparison of 3M Petrifilm, P/A H_2S test and MF Results

5.3.1 P/A H_2S test vs. *MF and 3M Petrifilm Results*

A total of 46 water samples collected at various sources around Tamale were tested for their H_2S-producing bacteria content (see Appendix 5 and Appendix 6). These P/A H_2S results were compared with the corresponding TC and EC results of 3M Petrifilm and MF.

For TC organisms, 6 categories of CFU/100mL (0 to 400, 401 to 1000, 1001 to 5000, 5001 to 15000, 15001 to 75000, TNTC (>75000) CFU/100mL) were made to facilitate analysis. Within each category, the number of presence and absence of H_2S-producing bacteria was reported for 3M Petrifilm and MF (see Figure 5.6).

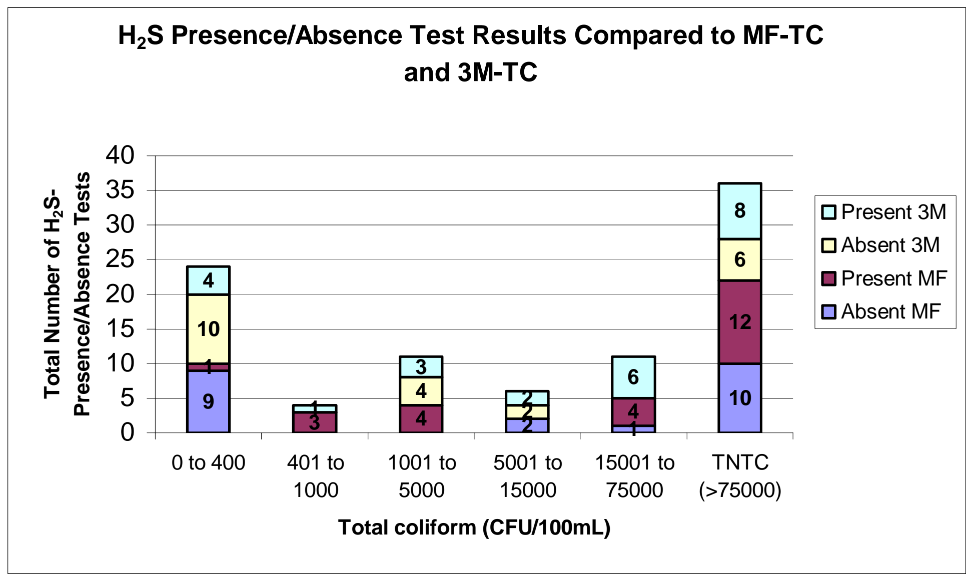

Figure 5.6. Presence/Absence H2S Test Results Compared to MF-TC and 3M-TC.

Results showed that at low CFU/100mL (from 0 to 5000 CFU/100mL), the H_2S-producing bacteria test was more accurate when compared to MF. H_2S tests that were positive seemed to better reflect the TC indicator population with MF. Except for the category ranging from 0 to 400 CFU/100mL, it seemed that 3M Petrifilm method was less sensitive at low TC bacterial concentration to clearly state any tendency between H_2S organisms and TC.

When H_2S tests was compared with TC at higher bacterial concentrations (from 5001 to TNTC CFU/100mL), the tendency shifted and H_2S tests best reflected 3M Petrifilm results. The proportion of H_2S organisms present in the water samples seemed to match better with TC when estimated through 3M Petrifilm method. With MF, there was a higher proportion of absent H_2S organisms at higher CFU/100mL.

Because few EC were reported, it was hard to get significant results for the analysis. However, the author decided to perform the analysis because if no or few EC were reported, the relationship between H_2S test *vs.* Petrifilm and MF was still interesting to study.

Here, it seemed that both Petrifilm and MF behaved the same way when compared to the H_2S test. No particular H_2S test tendency at lower or higher concentration of EC was found to occur with Petrifilm and MF. The Petrifilm proportion of P/A and the MF proportion of P/A were generally equal throughout the 5 concentration categories.

For EC organisms, 5 categories of CFU/100mL (0 to 4, 5 to 100, 101 to 500, 501 to 5000, TNTC (>5000) CFU/100mL) were made to facilitate analysis. Within each category, the number of presence and absence of H_2S-producing bacteria was reported for Petrifilm and MF (see Figure 5.7).

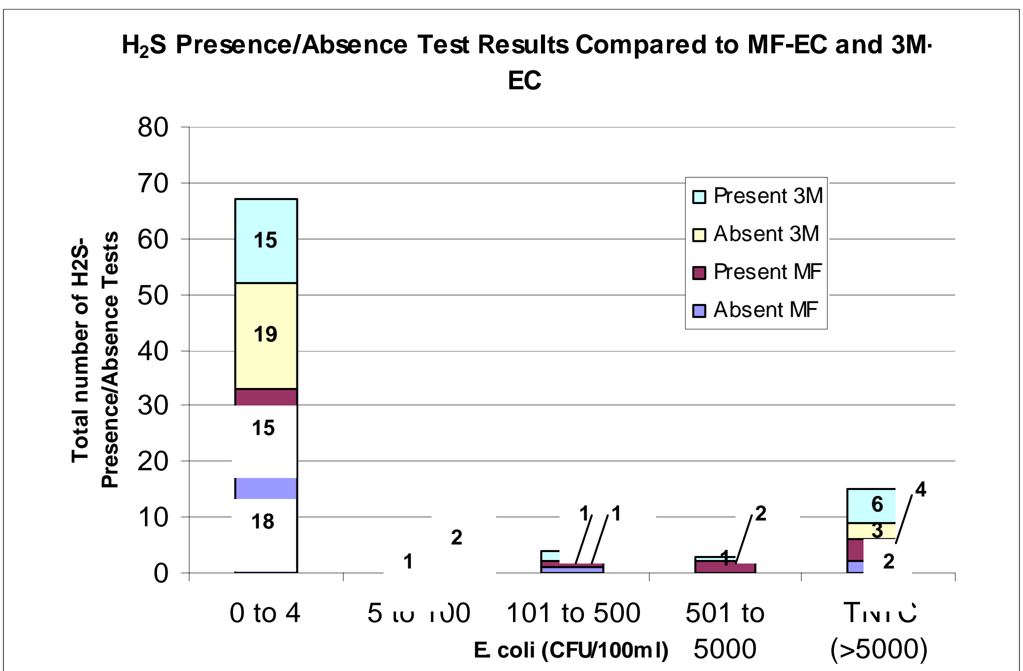

Figure 5.7. Presence/Absence H2S Test Results Compared to MF-EC and 3M-EC.

5.3.2 P/A H_2S test vs. *MF and Petrifilm Discussion*

For TC, H_2S test more closely corresponds to MF at lower CFU/100mL concentrations. At higher concentration, this tendency is reversed and H_2S bacteria more closely correspond to 3M Petrifilm method when analysing TC. This can be explained by the fact that at low concentration, 3M Petrifilm will be less likely to detect organisms since only 1mL is poured on plate. The particles in suspension in the water sample are less easily dispersed in 1mL than with the 100mL MF sample size and therefore this will affect the enumeration of the Petrifilm plate. In this case, MF is recognized as being a better for finding a few coliforms in lots of water. This finding is also discussed in Section 5.3.4. When water samples came from highly contaminated sources, MF was a real bother as more competition between bacteria occurred on

the pertidish. Indeed, the number of organisms is bigger in 100mL than in 1mL. In addition, depending on the degree of turbidity of water, a big volume of sample can easily clog the filter pores and acts as a support for growth for bacteria on the Petri dish[1].

For EC, no clear distinction could be made between 3M Petrifilm and MF. At low CFU/100mL, the proportions of presence and absence of H_2S bacteria were nearly equal for 3M Petrifilm and MF. It seems that H_2S test equally reacts at low and high concentrations with both 3M Petrifilm and MF. However, when high concentrations of fecal organisms were detected by 3M Petrifilm or MF, H_2S test could only detect fecal contamination in 50% of the samples.

In general, false positive and false negative results occurred. When EC was detected by MF or 3M Petrifilm, there was a significant amount of samples showing an "Absence" with the H_2S test when there is at least 5 CFU/100mL. This means that the H_2S test is likely to underestimate the presence of EC with the larger number of false negative results at higher concentrations of EC. 30% gave false negatives results with EC at counts greater than 5 CFU/100mL. When looking at TC, for concentrations greater than 400 CFU/100mL, 37% of false negative results were detected. Therefore, it is suggested that since EC produces the lowest value of false negative results, their presence are more accurately determined by H_2S test. This result was also supported by Low (2002).

5.3.3 3M Petrifilm vs. *MF for TC Enumeration Results*

28 samples coming from different water sources around Tamale were enumerated with Petrifilm and with MF (using m-ColiBlue24®). Results showing the correlation of the counts are shown in Figure 5.8. Counts ranged from 0 CFU/100mL to as high as 200,000 CFU/100mL. Linear regression of counts determined from Petrifilm assays *vs.* enumeration determined with m-ColiBlue24® (MF), after log transform, gave a slope of 1.1, the coefficient of correlation was 0.906.

To test if Petrifilm and MF gave similar enumeration results when they were compared, the mean values obtained by each method for each water sample were compared with a paired *t* test. The overall method means and standard deviations of the log-transformed enumeration were 2.87 ± 0.272 and 3.159 ± 0.331. The mean difference of paired measurements was -0.288 ± 0.143, indicating no significant difference between the results obtained with the two methods ($p=0.054$, paired *t* test, bilateral).

The same analysis could not be performed for EC because, most of the water samples analyzed did not give results for this bacteria with both methods at the same time.

[1] This has already been reported by Pr. R. Metcalf, Professor in Biological Sciences, when doing field experiments.

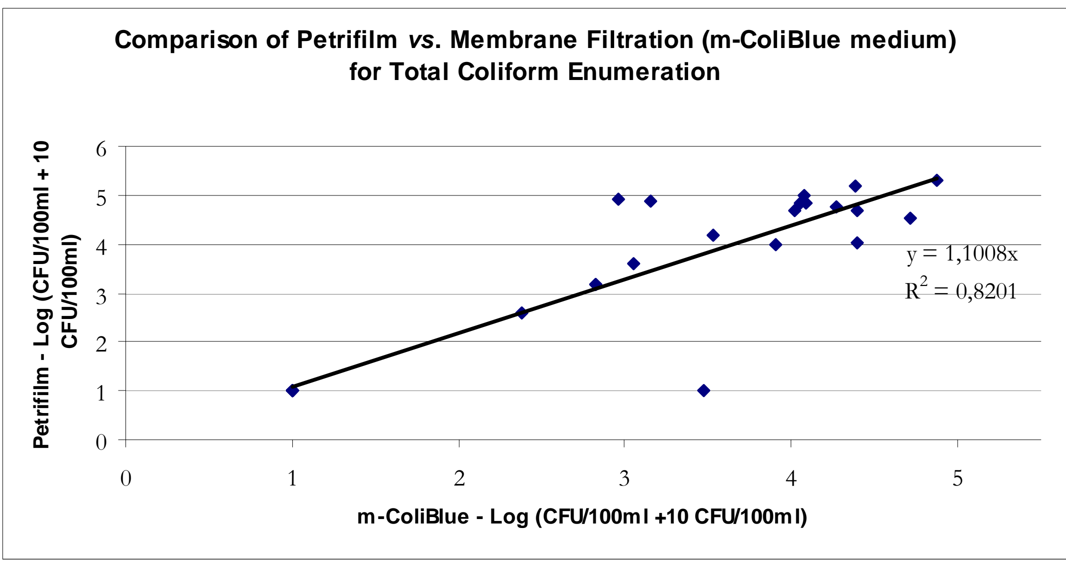

Figure 5.8. Comparison of Petrifilm *vs.* Membrane Filtration (m-ColiBlue24 ® medium) for TC Enumeration.

5.3.4 3M Petrifilm vs. MF for TC Enumeration Discussion

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.

5.4 Fecal Contamination Assessment of Water Sources in Tamale

5.4.1 Results

Different water sources detailed in Section4.7 were tested for their TC and EC content by the 3M Petrifilm and MF methods. The results showed a high degree of TC contamination for St. Mary Dam, Bilpelar Dam, Ghanasco Muali, Kamina River, dam near the Gillbt Guest House, and another water sample that was taken from a dugout close to the World Vision (WV) office of Savelugu (see
Table 5.5).

Table 5.5. Fecal 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

The values shown in Table 5.5 are the average of CFU/100mL of the MF and Petrifilm test samples performed on the water sources (see Appendix 7 for details on water sampling).
[a] World Vision Office, Savlegu.
[b] Too numerous to count.

Kamina shows results for TC ranging between 5.10 10^6 CFU/100mL and for EC 3.45 10^6 CFU/100mL using 3M Petrifilm.

St. Mary Dam showed values of TC of 1.32 10^4 CFU/100mL (MF) and 7.3 10^4 CFU/100mL (Petrifilm). 1,409 CFU/100mL EC colonies were detected with Petrifilm whereas no EC contamination appeared with MF.

Bilpelar Dam showed with MF 4,250 CFU/100mL for TC and 135 CFU/100mL for EC. The 3M Petrifilm results of this source showed 0 CFU/100mL for EC but 5,500 CFU/100mL for TC.

Ghanasco Muali River showed TC colony numbers as high as 25,000 CFU/100mL for MF and 15,500 CFU/100mL for Petrifilm. The EC content of the Ghanasco Muali was lower (250 CFU/100mL for MF and 0 CFU/100mL for Petrifilm).

The dam near Gillbt Guest house MF results showed 1,055 CFU/100mL and 30 CFU/100mL for TC and EC respectively. The 3M Petrifilm results of this source presented higher numbers for TC (2.11 10^4 CFU/100mL). For this source no EC colonies were found using 3M Petrifilm.

The World Vision office dugout water source showed 757 CFU/100mL (TC) and 2,535 CFU/100mL (EC) with MF. The Petrifilm data were higher for TC (1.88 10^4 CFU/100mL) and lower for EC (233 CFU/100mL).

5.4.2 Discussion

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. 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). At usual dilutions (10x, 100x, 500x, 1000x), 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 (see Appendix 7). It was better to use MF when fewer colonies were present in the sample source than Petrifilm. As

mentioned in Section 5.3.4, 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.

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

5.5.1 Results

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 according to Appendix 10 and results are shown Table 5.6

Table 5.6. 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 method is the cheapest among the microbial indicator method tested in terms of cost/test (US$0.25/test *vs.* US$1.04/test and US$2.37/test for 3M Petrifilm and m-ColiBlue24® MF respectively) and net present value over a period of 5 and 10 years (after 5 years: US$1,042.27 *vs.* US$4,336.66 and US$9,882.18 for 3M Petrifilm and m-ColiBlue24® MF respectively, after 10 years:US$1,786.14 *vs.* US$7,430.35 and US$16,932.62 for 3M Petrifilm and m-ColiBlue24® MF respectively). P/A H_2S test is also the fastest, the easiest of use and of interpretation relative to the 2 other methods. P/A H_2S would be the easiest to use for a non expert and according to the WV team of Savelugu, this method is readily used by their microbial experts for the testing of drinking water wells implemented around Tamale.

Among the two other methods 3M Petrifilm appeared to be easier for non-experts and less time-consuming than MF.

5.5.2 Discussion

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 (blue colony for EC and red for TC).

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 Petri dishes 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.

6. CONCLUSIONS & RECOMMENDATIONS

During the month of January 2006, the author compared the efficiency of three different HWTS filter systems marketed in Ghana. Two of the filters, Nnsupa and C.T. Filtron, were sold as HWTS by PHW Ghana team and the third filter, Everest Aquaguard, was the main competitor of the PHW products in the area of Tamale.

The three filters were tested for their flow rate and microbial removal performance using three simple and low-cost microbial indicator methods, P/A H_2S test, MF (m-ColiBlue24®) and 3M Petrifilm. While the P/A test detects the presence of H_2S bacteria, m-ColiBlue24® and 3M Petrifilm identify EC and TC in water samples.

The three microbial indicator methods were also compared according to 6 screening criteria:

- 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

In order to perform the analyses, 6 different water samples were collected in and around Tamale. The range of water samples included rivers, dugouts, and dams waters. Water was collected at Kamina River, Ghanasco Muali River, St. Mary Dam, a dam near Gillbt Guesthouse, and a dugout close to World Vision Office (Savelugu).

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 usability. Results obtained in Ghana showed that all filters were likely to produce adequate 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 (parents and one child).

The C.T. Filtron filter had the fastest flow rate (approximately 1.8L/hr when the pot was full to the top). It was observed that flow rate declined as more and more particles build up and clog the filters.

Flow rate also decreases with the decline of water head with time and this is the reason why filters need to be refilled several times a day to keep enough pressure for a maximum flow rate and also why they need to be regularly cleaned.

Coliform Removal Conclusions

The three filters were studied for their bacterial removal performances. H_2S test was used to determine H_2S-producing bacteria removal whereas 3M Petrifilm and MF (m-ColiBlue24®) were

used to look for the TC and EC content of the source and filtered water. These results were compared with the WHO and EPA guidelines.

Results showed that Nnsupa filter results could only achieve less than 1 log TC removal according to MF results (62.9% efficiency) and only achieved 1.2 log removal according to 3M Petrifilm results (92% efficiency). 3M Petrifilm data showed 100% efficiency in terms of EC removal with this filter. All Nnsupa filters showed positive H_2S results.

C.T. Filtron filter was the best performer using H_2S, 3M Petrifilm and MF (m-ColiBlue24®). No H_2S test showed positive results in the treated water. The 3M Petrifilm results did not detect any TC or EC in filtered water samples and MF showed 99.5% efficiency in removing TC.

Everest Aquaguard was unable to remove TC or EC or H_2S bacteria and that contamination with the candle could have occurred.

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.

Methods Comparison Conclusions

The fecal indicators methods were compared. H_2S results mirrored MF results for TC at low concentrations and more closely mirrored 3M Petrifilm results for TC at high concentrations. When TC and EC results were compared, results showed that EC produced the lowest value of false negative results compared with H_2S tests. False negative and false positive results with H_2S tests were the main factors that led to this author's recommendations 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 the 3M Petrifilm is a promising approach for application in the developing world. 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®). In addition, the 3M Petrifilm's dry gel on the plate sets up quickly with the addition of the water sample. This characteristic is of particular interest in the field when 3M Petriflm samples often have to be transported. Moreover, the 3M Petrifilm plates are compact and thin which allows stocking them easily.

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 perform multiple dilutions as with the MF method. The water sample volumes the MF and 3M Petrifilm methods use are 100mL and 1mL, respectively. Therefore, the number of CFU present on 3M Petrifilms will be smaller and easier to count than the number of organisms present on MF Petri dishes for the same sample.

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. When 3M is compared with MF at low fecal contamination concentrations, MF will more likely collect few organisms on the petri dish, as the

MF water sampling volume is 100mL. Instead, the 3M Petrifilm technology should be viewed as a preliminary method for assessing fecal contamination from a source. It was estimated by the author that zero or one CFU/100mL on 3M Petrifilms would correspond to approximately less than 300 CFU/100mL with MF (using m-ColiBlue24®) method.

The author concludes that 3M Petrifilm needs to be studied more extensively and compared with MF (m-ColiBlue24®) while analysing for EC. Moreover, the 3M Petrifilm has 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 3M Petrifilm method for environmental testing.

Level of Contamination of the Water Sources Analyzed Conclusions

The sources of water analyzed in the present work are point water sources where people routinely get their water. In most cases, water treatment is not 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 (757 to 5.10 10^6 TC CFU/100mL) and EC (0 to 3.45 10^6 EC CFU/100mL) contamination. 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 to local communities needs to be more rigorous and scientific, as well as to move towards anticipating potential risks to ever-present and emerging waterborne pathogens. In terms of drinking water guidelines, less stringent drinking water quality targets than 0 EC CFU/100mL should be given for a developing country such as Ghana. In most cases, these countries do not have the same financial resources to maintain such high standards. As outlined by the 3rd Edition of the GDWQ, the implementation of national drinking water standards should be consistent with achieving the MDGs and should take into account the socio-economy, culture and environment of the nation. Household epidemiological surveys, geographic data and microbial drinking water quality assessments, such as been commenced by our MIT Pure Home Water Team in 2005-2006, will support and pave the way to the establishment of such guidelines. This integrated system approach will help to identify an acceptable risk level which will be protective of the population's health and well-being.

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8. APPENDICES

Appendix 1. Combined WHO and Ghana, Mali and Niger water quality parameters and guideline limits.

	WHO Guideline Limit (mg/liter)	Comments
Complaints	**Levels likely to give rise to consumer complaints[a]**	Reasons for consumer complaints
Physical Parameters		
1. Color	15 TCU[b]	Appearance
2. Taste and Odor		Should be acceptable
3. Temperature		Should be acceptable
4. Turbidity	5 NTU[c]	Appearance; for effective terminal disinfection, median turbidity =1 NTU, single sample =5 NTU
Inorganic Constituents		
1. Aluminum	0.2 mg/l	Depositions, discoloration
2. Ammonia	1.5 mg/l	Odor and taste
3. Chloride	250 mg/l	Taste, corrosion
4. Copper	1 mg/l	Staining of laundry and sanitary ware (health-based provisional guideline value 2mg/litre)
5. Hardness		high hardness: scale deposition, scum formation low hardness: possible corrosion
6. Iron	.3 mg/l	Staining of laundry and sanitary ware
7. Manganese	.1 mg/l	Staining of laundry and sanitary ware (health-based guideline value 0.5 mg/liter)
8. Dissolved Oxygen		Indirect effects
9. Ph		low pH: corrosion high pH: taste, soapy feel preferably <8.0 for effective disinfection with chlorine
10. Sodium	200 mg/l	Taste
11. Sulfate	250 mg/l	Taste, corrosion
12. Total dissolved Solids	1000 mg/l	Taste
13. Zinc	3 mg/l	Appearance, taste
B. Chemicals of Health Significance	**Guideline value (mg/liter)**	**Remarks**
1. Antimony	.005 (P)[a]	
2. Arsenic	.01 (P)	For excess skin cancer risk of 6×10^{-4}
3. Barium	0.7	
4. Beryllium		NAD[c]
5. Boron	0.5 (P)	
6. Cadmium	.003	
7. Chromium	.05 (P)	
8. Copper	2 (P)	Based on acute gastrointestinal effects
9. Fluoride	1.5	Climatic conditions, volume of water consumed, and intake from other sources should be considered when setting national standards
10. Lead	.01	It is recognized that not all water will meet the guideline value immediately; meanwhile, all other recommended measures to reduce the total exposure to lead should be implemented
11. Manganese	0.5	ATO[d]
12. Mercury	.001	
13. Molybdenum	.07	
14. Nickel	.02 (P)	

15. Nitrate (as NO_3^-)	50 (acute)	
16. Nitrate (as NO_2^-)	3 (acute) 0.2 (P) (chronic)	
17. Selenium	.01	
18. Uranium	.002 (P)	
Bacteria[e]	***Guideline Value***	**State**
1. *E. coli* or thermotolerant coliform bacteria[f,g]	Must not be detectable in any 100-ml sample	All water intended for drinking

[a] (P) — Provisional guideline value. This term is used for constituents for which there is some evidence of a potential hazard but where the available information on health effects is limited; or where an uncertainty factor greater than 1000 has been used in the derivation of the tolerable daily intake (TDI). Provisional guideline values are also recommended: (1) for substances for which the calculated guideline value would be below the practical quantification level, or below the level that can be achieved through practical treatment methods; or (2) where disinfection is likely to result in the guideline value being exceeded.

[b] For substances that are considered to be carcinogenic, the guideline value is the concentration in drinking-water associated with an excess lifetime cancer risk of 10^{-5} (one additional cancer per 100 000 of the population ingesting drinking-water containing the substance at the guideline value for 70 years). Concentrations associated with estimated excess lifetime cancer risks of 10^{-4} and 10^{-6} can be calculated by multiplying and dividing, respectively, the guideline value by 10.

In cases in which the concentration associated with an excess lifetime cancer risk of 10^{-5} is not feasible as a result of inadequate analytical or treatment technology, a provisional guideline value is recommended at a practicable level and the estimated associated excess lifetime cancer risk presented.

It should be emphasized that the guideline values for carcinogenic substances have been computed from hypothetical mathematical models that cannot be verified experimentally and that the values should be interpreted differently from TDI-based values because of the lack of precision of the models. At best, these values must be regarded as rough estimates of cancer risk. However, the models used are conservative and probably err on the side of caution. Moderate short-term exposure to levels exceeding the guideline value for carcinogens does not significantly affect the risk.

[e] NAD — No adequate data to permit recommendation of a health-based guideline value.

[d] ATO — Concentrations of the substance at or below the health-based guideline value may affect the appearance, taste, or odour of the water.

[e] Immediate investigative action must be taken if either *E. coli* or total coliform bacteria are detected. The minimal action in the case of total coliform bacteria is repeat sampling; if these bacteria are detected in the repeat sample, the cause must be determined by immediate further investigation.

[f] Although *E. coli* is the more precise indicator of faecal pollution, the count of thermotolerant coliform bacteria is an acceptable alternative. If necessary, proper confirmatory tests must be carried out. Total coliform bacteria are not acceptable indicators of the sanitary quality of rural water supplies, particularly in tropical areas where many bacteria of no sanitary significance occur in almost all untreated supplies.

[g] It is recognized that, in the great majority of rural water supplies in developing countries, faecal contamination is widespread. Under these conditions, the national surveillance agency should set medium-term targets for the progressive improvement of water supplies, as recommended in Volume 3 of *Guidelines for drinking-water quality*.

(WHO, 1996)

Appendix 2. Filters microbial removal 3M Petrifilm and MF (m-ColiBlue24®) testing.

Source: Water sample collected from St Mary School Dam

MF

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
5*	TNTC	TNTC	0	0
10*	TNTC	TNTC	0	0
50*	TNTC	TNTC	0	0
500*	22	11000	0	0
75*	152	11400	0	0
100*	123	12300	0	0
200*	94	18800	0	0
500*	21	10500	0	0
1000*	15	15000	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		13167		0

3M Petrifilm

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
5*	TNTC	TNTC	1	500
5*	131	65500	0	0
10*	TNTC	TNTC	10	10000
50*	5	25000	1	5000
50*	30	150000	0	0
500*	0	0	0	0
75*	9	67500	0	0
100*	7	70000	0	0
200*	3	60000	0	0
500*	-	-	0	0
1000*	-	-	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		73000		1409

Results from Coliform Removal Studies Performed on the Tamakloe filter in Tamale

MF

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	1	1	0	0
1*	92	92	0	0
1*	5	5	0	0
10*	1	10	0	0
50*	1	50	0	0
100*	2	200	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		60		0

% TC Removed	99,5
% E.coli Removed	-
Log removal of TC	2,3

3M Petrifilm

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	0	0	0	0
1*	0	0	0	0
1*	0	0	0	0
10*	0	0	0	0
50*	0	0	0	0
100*	0	0	0	0
1000*	0	0	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		0		0

% TC Removed	100,0
% E.coli Removed	100,0
Log removal of TC	3,9
Log removal of EC	2,2

Results from Coliform Removal Studies Performed on the Nnsupa filter in Tamale
First candle

MF

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	TNTC	TNTC	0	0
1*	TNTC	TNTC	0	0
1*	TNTC	TNTC	0	0
10*	113	1130	0	0
50*	68	3400	0	0
100*	30	3000	0	0
1000*	12	12000	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		4883		0

% TC Removed	62,9
% E.coli Removed	-
Log removal of TC	0,4

3M

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	23	2300	0	0
1*	20	2000	0	0
1*	22	2200	0	0
1*	46	4600	0	0
10*	4	4000	0	0
50*	3	15000	0	0
100*	0	0	0	0
		Avg. TC (CFU/100ml)		Avg. E.coli (CFU/100ml)
		5017		0

% TC Removed	93,1
% E.coli Removed	100,0
Log removal of TC	1,2
Log removal of EC	2,2

Results from Coliform Removal Studies Performed on the Nnsupa filter in Tamale
Second candle

MF

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	C	C	0	0
5*	C	C	0	0
50*	222?	TNTC?	0	0
100*	2	200	0	0
1*	0	0	0	0
20*	0	0	0	0
50*	0	0	0	0
5*	C	C	0	0
50*	C	C	0	0
100*	C	C	0	0
1000*	4/SQUARE	692000?	0	0

3M Petrifilm

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	C	0	0	0
5*	C	0	0	0
50*	1	5000	0	0
100*	5	50000	0	0
1*	TNTC	TNTC	0	0
20*	20/SQUARE	8000	0	0
50*	152	7600	0	0
50*	8/SQUARE	8000	0	0
100*	4/SQUARE	8000	0	0
1000*	27	27000	0	0
		Avg. TC (CFU/100ml)		**Avg. E.coli (CFU/100ml)**
		22400		0
	% TC Removed		69,3	
	% E.coli Removed		100,0	

Results from Coliform Removal Studies Performed on the Everest Aquaguard Filter in Tamale

MF

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	TNTC	TNTC	0	0
1*	TNTC	TNTC	0	0
1*	TNTC	TNTC	0	0
10*	TNTC	TNTC	0	0
50*	TNTC	TNTC	0	0
100*	244	24400	0	0
1000*	74	74000	0	0
		Avg. TC (CFU/100ml)		**Avg. E.coli (CFU/100ml)**
		49200		0
	% TC Removed		-273,7	
	% E.coli Removed		-	

3M Petrifilm

Dilution	Total coliform	CFU/100ml	*E.coli*	CFU/100ml
1*	71	7100	0	0
1*	TNTC	TNTC	0	0
1*	TNTC	TNTC	0	0
10*	128	128000	0	0
50*	28	140000	0	0
100*	16	160000	0	0
1000*	-	-	0	0
		Avg. TC (CFU/100ml)		**Avg. E.coli (CFU/100ml)**
		108775		0
		% TC Removed	-49,0	
		% E.coli Removed	100,0	

Appendix 3. Filter microbial removal H_2S testing using St. Mary Dam water source.

	Source			Nnsupa						Tamakloe			Everest Aquaguard		
				1st[a]			2nd[b]								
Dilution (Test Day)	P[e]	/	A[f]	P[e]	/	A[f]	P[e]	/	A[f]	P[e]	/	A[f]	P[e]	/	A[f]
1*(01.12.06)					x YT[c]							x		x YT[c]	
5*(01.12.06)	x														
10*(01.12.06)			x												
50*(01.12.06)	x														
500*(01.12.06)			x												
1*(01.13.06)					x YT[c]							x		x YT[c]	
1*(01.14.06)				x								x		x YT[c]	
10*(01.14.06)				x								x		x BC[d]	
50*(01.14.06)				x								x		x BC[d]	
100*(01.14.06)				x								x		x BC[d]	
1000*(01.14.06)						x						x		x BC[d]	
1*(01.15.06)								x BC[d]							
5*(01.15.06)								x BC[d]							
50*(01.15.06)								x BC[d]							
100*(01.15.06)								x BC[d]							
1*(01.16.06)								x BC[d]							
20*(01.16.06)								x BC[d]							
50*(01.16.06)									x						
5*(01.18.06)									x						
50*(01.18.06)									x						
100*(01.18.06)									x						
1000*(01.18.06)									x						

[a] H2S test performed on the first Nnsupa candle.

[b] H2S test performed on the second Nnsupa candle.

[c] after 48Hr, the H2S test water sample remains yellow turbid.

[d] After 48Hrs, the H2S test water sample is yellow and includes the formation of black cloud.

[e] Presence of H2S bacteria in the H2S test water sample.

[f] Absence of H2S bacteria in the H2S test water sample.

Appendix 4. 3M Petrifilm and MF (m-Coli-Blue24) samples results for Nnsupa, C.T. Filtron and Everest Aquaguard.

Appendix 5. Water samples used for the H_2S *vs.* MF-TC and 3M-TC analysis.

Water Source, Dilution (Day of Analysis)	H_2S		MF	3M
	P [a]	A [b]	(CFU/100ml)	(CFU/100ml)
St Mary Dam 500*(12.01.06)		1	10500	0
St Mary Dam 5*(12.01.06)	1		TNTC	TNTC
St Mary Dam 10*(12.01.06)		1	TNTC	300000
St Mary Dam 50*(12.01.06)	1		TNTC	25000
Nnuspa St mary Dam [c] 1*(12.01.06)		1	TNTC	2300
Nnuspa St mary Dam 1*(12.01.06)		1	TNTC	2000
Nnuspa St mary Dam 1*(13.01.06)		1	TNTC	2200
Nnuspa St mary Dam 1*(14.01.06)	1		TNTC	4600
Nnuspa St mary Dam 10*(14.01.06)	1		1130	4000
Nnuspa St mary Dam 50*(14.01.06)	1		3400	15000
Nnuspa St mary Dam 100*(14.01.06)	1		3000	0
Nnuspa St mary Dam 1000*(14.01.06)		1	12000	100000
Ev. Aquaguard St Mary Dam [d] 1*(12.01.06)		1	TNTC	7100
Ev. Aquaguard St Mary Dam 1*(12.01.06)		1	TNTC	TNTC
Ev. Aquaguard St Mary Dam 1*(14.01.06)		1	TNTC	TNTC
Ev. Aquaguard St Mary Dam 10*(14.01.06)	1		TNTC	128000
Ev. Aquaguard St Mary Dam 50*(14.01.06)	1		TNTC	140000
Ev. Aquaguard St Mary Dam 100*(14.01.06)	1		24400	160000
Ev. Aquaguard St Mary Dam 1000*(14.01.06)	1		74000	200000
Ev. Aquaguard Dugout close to WV [e] 2*(11.01.06)	1		228	400
Ev. Aquaguard Dugout close to WV 5*(10.01.06)	1		650	1500
Ev. Aquaguard Dugout close to WV 5*(10.01.06)	1		605	0
Ev. Aquaguard Dugout close to WV 50*(10.01.06)	1		1400	75000
Ev. Aquaguard Dugout close to WV 50*(10.01.06)	1		900	80000
Ev. Aquaguard Dugout close to WV 500*(10.01.06)		1	0	0
Ev. Aquaguard Dugout close to WV 500*(10.01.06)		1	0	0
Tamakloe St Mary Dam [f] 1*(12.01.06)		1	0	0
Tamakloe St Mary Dam 1*(13.01.06)		1	0	0
Tamakloe St Mary Dam 1*(14.01.06)		1	0	0
Tamakloe St Mary Dam 10*(14.01.06)		1	0	0
Tamakloe St Mary Dam 50*(14.01.06)		1	0	0
Tamakloe St Mary Dam 100*(14.01.06)		1	0	0
Tamakloe St Mary Dam 1000*(14.01.06)		1	0	0
Ghanesco Muali 500*(12.01.06)		1	25000	10500
Ghanesco Muali 5*(12.01.06)	1		TNTC	11000
Ghanesco Muali 10*(12.01.06)	1		TNTC	25000
Ghanesco Muali 50*(12.01.06)	1		TNTC	0
Kamina River 5*(12.01.06)	1		TNTC	TNTC
Kamina River 10*(12.01.06)	1		TNTC	TNTC
Kamina River 50*(12.01.06)		1	TNTC	TNTC
Kamina River 500*(12.01.06)		1	TNTC	TNTC
Bilpelar Dam 10*(12.01.06)		1	TNTC	2000
Biosand OUT [g] 1*(19.01.06)	1		TNTC	1000
Biosand OUT 5*(19.01.06)	1		TNTC	24500
Biosand OUT 50*(19.01.06)	1		51900	35000
Biosand OUT 100*(19.01.06)	1		25000	50000

[a] TC presence in Water Sample (1 in column = presence of TC for the water source)

[b] TC absence in Water Sample (1 in column = absence of TC for the water source)

[c] St Mary Dam water source flowing out of the Nnsupa

[d] St Mary Dam water source flowing out of the Everest Aquaguard

[e] Dugout close to World Vision water source flowing out of the Everest Aquaguard

[f] St Mary water source flowing out of the Tamakloe

[g] Dugout near Gillbt Guest house water source flowing out of the a Biosand Filter

Appendix 6. Water samples used for the H_2S *vs.* MF-EC and 3M-EC analysis.

Water Source, Dilution (Day of Analysis)	H_2S		MF	3M
	P [a]	A [b]	(CFU/100ml)	(CFU/100ml)
St Mary Dam 500*(12.01.06)		1	0	0
St Mary Dam 5*(12.01.06)	1		0	500
St Mary Dam 10*(12.01.06)		1	0	10000
St Mary Dam 50*(12.01.06)	1		0	5000
Nnuspa St Mary Dam [c] 1*(12.01.06)		1	0	0
Nnuspa St Mary Dam 1*(12.01.06)		1	0	0
Nnuspa St Mary Dam 1*(13.01.06)		1	1	0
Nnuspa St Mary Dam 1*(14.01.06)	1		0	0
Nnuspa St Mary Dam 10*(14.01.06)	1		0	0
Nnuspa St Mary Dam 50*(14.01.06)	1		0	0
Nnuspa St Mary Dam 100*(14.01.06)	1		0	0
Nnuspa St Mary Dam 1000*(14.01.06)		1	0	0
Ev. Aquaguard St Mary Dam [d] 1*(12.01.06)		1	0	0
Ev. Aquaguard St Mary Dam 1*(12.01.06)		1	0	0
Ev. Aquaguard St Mary Dam 1*(14.01.06)		1	0	0
Ev. Aquaguard St Mary Dam 10*(14.01.06)	1		0	0
Ev. Aquaguard St Mary Dam 50*(14.01.06)	1		0	0
Ev. Aquaguard St Mary Dam 100*(14.01.06)	1		0	0
Ev. Aquaguard St Mary Dam 1000*(14.01.06)	1		0	0
Ev. Aquaguard Dugout close to WV [e] 2*(11.01.06)	1		4	0
Ev. Aquaguard Dugout close to WV 5*(10.01.06)	1		0	500
Ev. Aquaguard Dugout close to WV 5*(10.01.06)	1		0	0
Ev. Aquaguard Dugout close to WV 50*(10.01.06)	1		100	0
Ev. Aquaguard Dugout close to WV 50*(10.01.06)	1		0	0
Ev. Aquaguard Dugout close to WV 500*(10.01.06)		1	0	0
Ev. Aquaguard Dugout close to WV 500*(10.01.06)		1	0	0
Tamakloe St Mary Dam [f] 1*(12.01.06)		1	0	0
Tamakloe St Mary Dam 1*(13.01.06)		1	0	0
Tamakloe St Mary Dam 1*(14.01.06)		1	0	0
Tamakloe St Mary Dam 10*(14.01.06)		1	0	0
Tamakloe St Mary Dam 50*(14.01.06)		1	0	0
Tamakloe St Mary Dam 100*(14.01.06)		1	0	0
Tamakloe St Mary Dam 1000*(14.01.06)		1	0	0
Ghanesco Muali 500*(12.01.06)		1	500	0
Ghanesco Muali 5*(12.01.06)	1		100	0
Ghanesco Muali 10*(12.01.06)	1		0	0
Ghanesco Muali 50*(12.01.06)	1		150	0
Kamina River 5*(12.01.06)	1		TNTC	TNTC
Kamina River 10*(12.01.06)	1		TNTC	TNTC
Kamina River 50*(12.01.06)		1	TNTC	TNTC
Kamina River 500*(12.01.06)		1	TNTC	TNTC
Bilpelar Dam 10*(12.01.06)		1	90	0
Biosand OUT [g] 1*(19.01.06)	1		TNTC	18000
Biosand OUT 5*(19.01.06)	1		TNTC	21000
Biosand OUT 50*(19.01.06)	1		3500	20000
Biosand OUT 100*(19.01.06)	1		2600	20000

[a] EC presence in Water Sample (1 in column = presence of EC for the water source)
[b] EC absence in Water Sample (1 in column = absence of EC for the water source)
[c] St Mary Dam water source flowing out of the Nnsupa
[d] St Mary Dam water source flowing out of the Everest Aquaguard
[e] Dugout close to World Vision water source flowing out of the Everest Aquaguard
[f] St Mary water source flowing out of the Tamakloe
[g] Dugout near Gillbt Guest house water source flowing out of the a Biosand Filter

Appendix 7. Water sample used for the fecal contamination assessment of water sources.

Bilpelar Dam	MF	3M	MF	3M
	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
5*(12.01.06)	TNTC	4500	180	0
10*(12.01.06)	TNTC	2000	90	0
50*(12.01.06)	8000	10000	-	0
500*(12.01.06)	500	0	0	0
Average (CFU/100mL)	**4250**	**5500**	**135**	**0**

Ghanesco Muali	MF	3M	MF	3M
	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
5*(13.01.06)	TNTC	10500	100	0
10*(13.01.06)	TNTC	11000	0	0
50*(13.01.06)	TNTC	25000	150	0
500*(13.01.06)	25000	0	500	0
Average (CFU/100mL)	**25000**	**15500**	**250**	**0**

Kamina River	MF	3M	MF	3M
Dilution	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
5*(13.01.06)	TNTC	TNTC	TNTC	TNTC
10*(13.01.06)	TNTC	TNTC	TNTC	TNTC
50*(13.01.06)	TNTC	TNTC	TNTC	TNTC
500*(13.01.06)	TNTC	51000	TNTC	34500
Average (CFU/100mL)	**TNTC**	**5100000**	**TNTC**	**3450000**

St Mary Dam	MF	3M	MF	3M
Dilution	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
5*(12.01.06)	TNTC	TNTC	0	500
10*(12.01.06)	TNTC	TNTC	0	10000
50*(12.01.06)	TNTC	25000	0	5000
500*(16.01.06)	11000	0	0	0
75*(16.01.06)	11400	67500	0	0
100*(16.01.06)	12300	70000	0	0
200*(16.01.06)	18800	60000	0	0
500*(16.01.06)	10500	-	0	0
1000*(16.01.06	15000	-	0	0
5*(18.01.06)	-	65500	-	0
50*(18.01.06)	-	150000	-	0
Average (CFU/100mL)	**13167**	**73000**	**0**	**1409**

Gillbt Guest House Dam				
	MF	3M	MF	3M
Dilution	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
5*(18.01.06)	865	-	30	-
100*(18.01.06)	1300	-	0	-
100*(18.01.06)	1000	-	0	-
1000*(18.01.06)	0	-	0	-
1000*(18.01.06)	0	-	0	-
10000*(18.01.06	0	-	0	-
10000*(18.01.06	0	-	0	-
1*(20.01.06)	-	7200	-	100
5*(20.01.06)	-	16000	-	0
50*(20.01.06)	-	0	-	0
100*(20.01.06)	-	40000	-	0
Average (CFU/100mL)	**1055**	**21067**	**30**	**100**

Dugout close to World Vision				
	MF	3M	MF	3M
Dilution	TC (CFU/100ml)	TC (CFU/100ml)	EC (CFU/100ml)	EC (CFU/100ml)
2*(11.01.06)	228	400	4	0
5*(10.01.06)	650	1500	7500	500
5*(10.01.06)	605	0	0	0
50*(10.01.06)	1400	0	100	0
50*(10.01.06)	900	0	0	0
500*(10.01.06)	0	0	0	0
500*(10.01.06)	0	0	0	0
1*(11.01.06)	-	700	-	100
1*(11.01.06)	-	700	-	100
2*(11.01.06)	-	600	-	0
25*(12.01.06)	-	52500	-	0
75*(12.01.06)	-	75000	-	0
Average (CFU/100mL)	**757**	**18771**	**2535**	**233**

Appendix 8. Water samples used for the comparison of 3M vs. MF (m-ColiBlue24®).

Water Source	MF (CFU/100mL)	3M (CFU/100mL)	Log MF [a]	Log 3M [b]
Dugout WV [c] 2*(11.01.06)	228	400	2,38	2,61
Dugout WV 5*(10.01.06)	650	1500	2,82	3,18
Dugout WV 50*(10.01.06)	1400	75000	3,15	4,88
Dugout WV 50*(10.01.06)	900	80000	2,96	4,90
Dugout WV 500*(10.01.06)	0	0	1,00	1,00
Dugout WV 500*(10.01.06)	0	0	1,00	1,00
Dirty water Tamale 5*(09-01-06)	650	1500	2,82	3,18
Biosand filter out 50*(19.01.06)	51900	35000	4,72	4,54
Biosand filter out 100*(19.01.06)	25000	50000	4,40	4,70
St Mary School Dam 75*(16.01.06)	11400	67500	4,06	4,83
St Mary School Dam 100*(16.01.06)	12300	70000	4,09	4,85
St Mary School Dam 200*(16.01.06)	18800	60000	4,27	4,78
St Mary School Dam 500*(16.01.06)	10500	50000	4,02	4,70
St Mary School Dam Nnsupa [d] 10*(14.01.06)	1130	4000	3,06	3,60
St Mary School Dam Nnsupa 50*(14.01.06)	3400	15000	3,53	4,18
St Mary School Dam Nnsupa 1000*(14.01.06)	12000	100000	4,08	5,00
St Mary School Dam Nnsupa 100*(14.01.06)	3000	0	3,48	1,00
St Mary School Dam Ev. Aquaguard [e] 100*(14.01.06)	24400	160000	4,39	5,20
St Mary School Dam Ev. Aquaguard 1000*(14.01.06)	74000	200000	4,87	5,30
Bilpelar dam 50*(12.01.06)	8000	10000	3,90	4,00
Ghanesco muali 500*(12.01.06)	25000	10500	4,40	4,02
St Mary School Dam Tamakloe [f] 1*(12.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 1*(13.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 1*(14.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 10*(14.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 50*(14.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 100*(14.01.06)	0	0	1,00	1,00
St Mary School Dam Tamakloe 1000*(14.01.06)	0	0	1,00	1,00

[a] Log concentration of TC (CFU/100mL) using MF
[b] Log concentration of TC (CFU/100mL) using 3M
[c] Water coming from a dug out close to World Vision
[d] St Mary Dam water source flowing out of the Nnsupa
[e] St Mary Dam water source flowing out of the Everest Aquaguard
[f] St Mary School Dam water source flowing out of the Tamakloe

Appendix 9. C.T. Filtron microbiological analysis.

GHANA STANDARDS BOARD

P. O. Box MB 245 Accra - Ghana; Tel: (233 - 021) 500065, 500066, 506991 (4 Lines)
Fax: (233 - 021) 500092

EXECUTIVE DIRECTOR: NIMO AHINKORAH

Our Ref: GSB/PSD/101.7/A/VOL. *Your Ref:* ....

Date: 2004-05-07 *Date:* ....

The Managing Director,
Ceramica Tamakloe Ltd.,
P.O. Box NT 99,
New Town, Accra.

Dear Sir,

EVALUATION OF WATER FILTER

We refer to your request for the performance evaluation of the above sample submitted to us on 2004-03-30.

Please find attached our report on the analysis.

Our results indicated that:

1. The filter is able to reduce microbial load in water from $2,0 \times 10^4$ cfu/ml to $<1,0 \times 10^1$ cfu/ml
2. There is no leaching of heavy metals from the filtering element which is made of clay into the filtered medium.

The filter has performed satisfactorily.

Our fee for this work is nine hundred thousand cedis (¢900,000) for which a bill is enclosed for your early settlement.

Yours faithfully,

E. J-L ABLORH (DR).
AG. DIRECTOR, PHYSICAL SCIENCE DIVISION,
For: EXECUTIVE DIRECTOR.

GSB-409-EXD-FM-001-B

GHANA STANDARDS BOARD

Our Ref.: ...GSB/MAT/ Page 1.....of.........2.......Page(s)

Your Ref.: ....

TEST REPORT

TO: THE MANAGING DIRECTOR
CERAMICA TAMAKLOE LTD.
P. O. BOX NT 99
NEWTOWN, ACCRA

LABORATORY CONDUCTING TEST

Materials Science

Codes

Generalised Product Code..................HI........................
Specific Product Code ....WF........................
Officer Responsible for Report............KA........................
Code of Approving Officer ....BG........................
Period of Report ....05/2004......................
Lab. No. (Serial No.)305 Dept MS Source Code 2 Yr 2004

NAME OF SAMPLE:. WATER FILTER .....**SAMPLE SIZE**: ..ONE(1)

DATE RECEIVED: ......2004-03-30..........................**DATE OF REPORT**...2004-05-05........

SOURCE/PURPOSE: Ceramica Tamakloe Ltd – Quality Evaluation......................

TEST CODE	TEST CONDUCTED	UNIT	RESULTS		TEST METHODS	SPECIFICATIONS
			Water before filtration	Water after filtration		
						GS 175:1997 pt. 1
HEM	Heavy Metal :-					
	- Lead as Pb2+	-	Not detected	Not detected	Reinsch Test	0,01(max)
	- Chromium as Cr6+	-	"	"	"	0,05(max)
	- Cadmium as Cd2+	-	"	"	"	0,003(max)
MCB	Microbiological status:				BS 5763 Pt 5 1981	
	-APC/37°C/24h/PCA	cfu/ml	$2,0x10^4$	$< 1,0x10^1$		$<5,0x10^5$
					ISO 7251 1984	
	- Ecoli/37°C/24hr/MB BGBLG/EMBA	"	None detected	None detected		0

GSB-109-EXD-F-001-B

GHANA STANDARDS BOARD

Page 2 of 2 page(s)

REMARKS: The water filter sample is able to reduce the microbial load in water from $1.0x10^4$ to $<1.0x10^1$. Also there is no migration of heavy metals from the burnt clay (filter) into the filtered water. The water filter is therefore of acceptable quality.

REPORTED BY: K. ACHEAMPONG
DATE: 2004-05-05

APPROVED BY: B .K. GOKA
DATE: 2004-05-05

Conditions:

1. Not valid without Ghana Standards Board's Seal.
2. This report does not signify that product tested has been certified.
3. Not to be used for litigation and advertisement without written consent of the Director of Ghana Standards Board.

UNIVERSITY OF GHANA MEDICAL SCHOOL
COLLEGE OF HEALTH SCIENCES
DEPARTMENT OF MICROBIOLOGY

Phone: +233-21-665404
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E-mail: microb@africaonline.com.gh

P O Box 4236
Accra.
Ghana

My Ref. No.
Your Ref. No.

25th Oct 2005

The Manager
Ceramica Tamakloe Ltd
P. O. Box NT 99
Accra.

Dear Sir/Madam

WATER QUALITY ANALYSIS: CT FILTRON

Please find attached a report on the water quality analysis performed at our parasitology research laboratory.

The laboratory carried out macroscopic and microscopic examinations to identify parasitic organisms. The tests were carried out using unfiltered river water fetched from the Densu River at Weija and FILTRON filtered water from the same source. The results are shown in the table attached.

The results indicate that the CT FILTRON is effective for the removal of pathogenic parasitic protozoa, other macroscopic organisms and debris from water. While the unfiltered river water was turbid with lots of contaminants, the filtered water come out clear with just a few particles which are suspected to be part of the ceramic pot.

From our results it could be deduced that the FILTRON has high public health significance and will be useful in areas and communities where water purification procedures are nonexistent or inadequate such as places where people drink directly from streams, rivers and wells.

The FILTRON's ability to remove cyclops and organisms of that size from water is a strong indication that it will be a useful tool for the control of Guineaworm infections.

Thank you.

Yours Sincerely,

Dr. P. F. Ayeh-Kumi
Snr Lecturer and Head of Parasitology Unit

PARAMETER	Number of organisms/artifacts	
	FILTRON Filtered river water	UNFILTERED River water
Cryptosporidium spp. per 100ml	0	0
Cyclospora spp. per 100 ml	0	0
Giardia lamblia per 100 ml	0	0
Entamoeba spp. per 100 ml	0	20
Microsporidia spp per 100 ml	0	108
Sarcocystis spp per 100 ml	0	24
Fungal hyphae per 100 ml	0	32
Free living ciliates (non pathogenic) per 100ml	0	5
Free living rotifiers/cyclpos (non pathogenic) per 100ml	0	20
Artifacts / debris per 100 ml	0	78
Crystals per 100 ml	0	15
Particles per 100 ml	20	≥ 1000
Turbidity	clear	turbid

....

Dr. P. F. Ayeh-Kumi
Snr Lecturer and Head of Parasitology Unit
Department of Microbiology
University of Ghana Medical School
Box 4236, Accra

Our Ref:......................

28th October, 2003

THE DIRECTOR,
CERAMICA TAMAKLOE LIMITED,
P. O. Box NT 99,
Accra.

Tel. 021 – 502219

BACTERIOLOGICAL ANALYSIS ON EFFICACY OF FILTRON, A CERAMIC COLLOIDAL SILVER FILTER, IN REMOVING PATHOGENIC BACTERIA FROM WATER.

ANALYSIS DATE: 22nd – 25th October, 2003

1.0 PREAMBLE:

1.1 Filtron, a ceramic colloidal silver filter, was brought by Ceramica Tamakloe Limited, Accra to be analyzed for their efficiency in removal of pathogenic bacteria from water.
1.2 The FILTRON was able to remove the following pathogens from wastewater; total and faecal coliform bacteria, and specifically *Escherichia coli*, *Salmonella* spp., *Pseudomonas* spp., and *Clostridium* spp..
1.3 The FILTRON qualifies be used as filter to produce potable water.

2 METHOD:

Water from a drain that is heavily polluted from non-point sources as well as from a hospitality industry was filtered using the ceramic colloidal silver filter. The filtration was done aseptically into sterilized beaker. The filtered water sample was analyzed for the presence of total and faecal coliform bacteria, *Escherichia coli, Salmonella, Shigella, Pseudomonas*, and *Vibrio cholerae* using the Membrane Filtration Method. 100ml of the ceramic filtered water was passed through 0.45µm pore size membrane filter (Millipore). To detect the presence of *Clostridium* spp. 0.22 µm pore size membrane filter was used to filter 100 ml of the ceramic filtered water. Each membrane filter was incubated on appropriate media and incubated accordingly (Standard Methods, 2000).

Total Heterotrophic Bacteria count presence in the filtered water sample was determined using Yeast Extract Agar (Oxoid).

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As control the unfiltered water was analyzed alongside the filtered water.

3 **RESULTS:**

Results of the various indicator organisms as determined for the filtered and unfiltered water samples are as follows

Parameter	FILTRON filtered wastewater	Unfiltered wastewater
Total coliform count per 100ml	0	36800
Faecal coliform count per 100ml	0	33400
Escherichia coli count per 100ml	0	26000
Salmonella spp. count per 100ml	0	2180
Pseudomonas spp. count per 100ml	0	1130
Clostridium spp. count per ml	0	590
Vibrio cholerae count per 100ml	0	0
Total heterotrophic bacteria count per 1ml	0	1240

4 **DISCUSSION**:

Total coliform bacteria, faecal coliform bacteria, *Escherichia coli, Salmonella* spp., *Clostridium* spp. and *Pseudomonas* spp. were detected in very high numbers in the wastewater collected from an open drain for this study. There was also very high count of total heterotrophic count in the wastewater.

No bacteria were detected in the filtered water samples using the FILTRON candles provided by Tamakloe Ceramica. Test for the presence of the various pathogenic species detected in the raw wastewater showed total absence of all such species.

Appendix 10. Net present value (5 - 10 years) calcuated for MF (m-ColiBlue24®), 3M Petrifilm and H_2S Tests.

Discount rate: 10%

Test	Price/Test ($US)	Net present value (5 years)	Net present value (10 years)	Capital Cost	Annual O&M (US$)	1	2	3	4	5	6	7	8	9	10
MF (m-ColiBlue24) HACH	$2,37	$9.882,58	$16.932,62	$1.300,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00	$2.370,00
TC/EC 3M Petrifilm	$1,04	$4.336,66	$7.430,35	-	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00	$1.040,00
P/A H2S Pathoscreen HACH	$0,25	$1.042,47	$1.786,14	$200,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00	$250,00

Calculations based on 1.000 tests per year.

P/A H2S Pathoscreen HACH price estimation based on $US200 purchase of glass bottles to perform the tests.