WATER AND BRICKS CONSULTING

MASSACHUSETTS INSTITUTE OF TECHNOLOGY DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Evaluation and Improvement of WASH and Industry Development Projects in Northern Ghana

Group Report

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Contents

1. Introduction

Ghana is a low-middle income country on the path toward development. However, issues of water quality and supply, sanitation, and sustainable business opportunities are possible hindrances to this development. With this in mind, and in partnership with the NGO Pure Home Water, Water and Bricks Consulting has conducted four studies on these topics.

1.1. Country Overview

The Republic of Ghana is located in West Africa along the Gulf of Guinea (see Figure 1-1). With a population of just over 25 million people, the country comprises an estimated 75 ethnic groups. English is the official language, however many local languages of the Niger-Congo language family are spoken, including 11 government-sponsored languages. The country is divided into ten administrative regions (see Figure 1-2), with the majority of the population centered in the southern part of the country. The population is densest in the Greater Accra Region; the Northern Region is the least densely populated.

Ghana's climate is tropical (although regional variations occur across the country) and is strongly influenced by the West African Monsoon (Lizcano, 2008). The south-western part of the country is distinctly more humid, receiving an average annual rainfall of between 1500 mm to over 2000 mm (Gumma and Pavelic 2013). The northern part of the country is the driest, with pronounced dry and wet seasons and an average annual rainfall between 800 mm and 1500 mm (Gumma and Pavelic 2013).

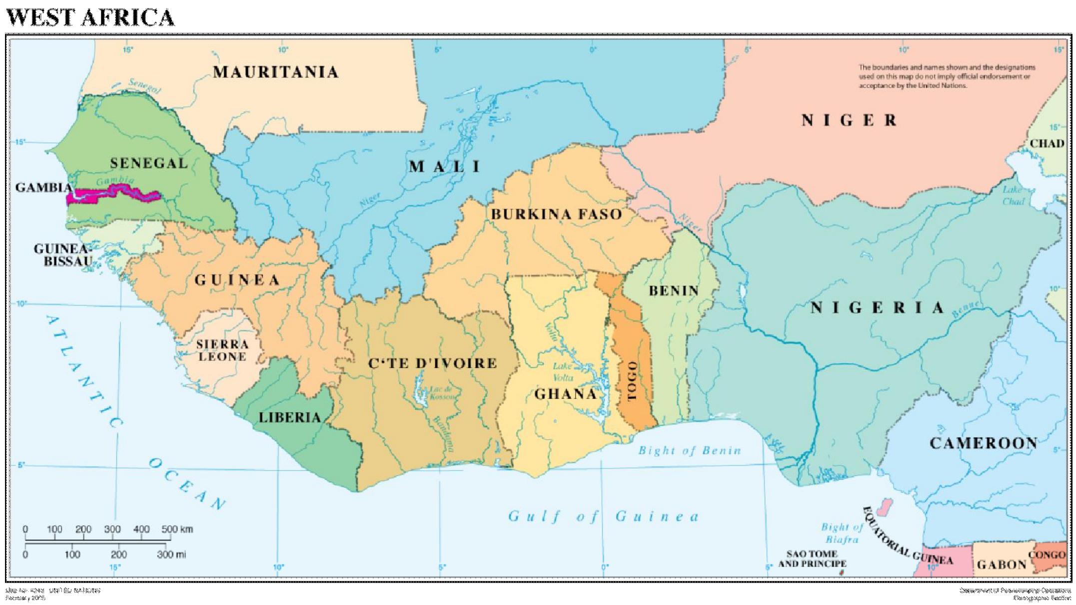


FIGURE 1-1: LOCATION MAP OF GHANA (SOURCE: UNITED NATIONS)

FIGURE 1-2: ADMINISTRATIVE REGIONS OF GHANA (SOURCE: IAEA)

1.2. Water and Sanitation Overview

Although Ghana has experienced increasingly stable democratic governance and has seen considerable economic growth over the past decades, many development challenges persist (Lizcano 2008). Poverty remains endemic in the country as economic growth has been primarily focused in extractive and capital intensive sectors, which do not have a direct poverty reducing effect (Lizcano 2008).

According to the recent UNICEF/WHO Progress Report on Drinking Water and Sanitation, Ghana has performed above the average in Sub-Saharan Africa, and is expected to meet the water Millennium Development Goal (MDG) by 2015 ("Millenium Development Goals" 2014). However, despite significant improvements, it is estimated that approximately 50% of people living in the Northern Region still do not have access to improved water sources (Murcott). Lack of access to improved water supplies increases the risk of contracting waterborne diseases, such as diarrhea, hepatitis A, typhoid, and cholera and contributes to infant mortality rates and loss of income due to illness.

The statistics on sanitation in Ghana are even more sobering. The UNICEF/WHO Progress Report on Drinking Water and Sanitation estimates that only 13% of the Ghanaian population has access to improved sanitation facilities (UNICEF/WHO 2012). This number is even further reduced in rural areas, with only 8% sanitation coverage (Murcott 2013). Open defecation is practiced by an estimated 19% of the Ghanaian population. Recent efforts by global organizations have aimed to provide additional sanitation facilities and improve hygiene practices, however it is predicted that Ghana will not meet its sanitation MDG by 2015 (UNICEF/WHO 2012).

1.3. Pure Home Water

Pure Home Water (PHW) is a registered non-profit organization based in Tamale, Ghana. Founded in 2005, the organization aims to:

1) Provide safe drinking water, sanitation, and hygiene (WASH) in Ghana, with a particular focus on Northern Ghana; and
2) Become locally and finally self-sustaining.

Through the production and distribution of their AfriClay Filter, PHW has reached over 100,000 people in Ghana. Since 2005 the organization has employed more than 20 Ghanaians, has established a training center, a laboratory, an office, a filter production plant, and a tree farm, and is actively involved in ongoing research and development work through collaboration with MIT (Pure Home Water).

1.4. Team Objectives

Water and Bricks Consulting comprises a team of four Masters of Engineering (M.Eng.) students from MIT's Civil and Environmental Engineering Department. The group undertook four projects in Ghana:

1) Water Quality Analysis of the Piped Supply in Tamale, Ghana;
2) Evaluation of Household Water Treatment and Safe Storage (HWTS) Alternatives in Ghana;
3) Evaluation of Innovative Decentralized Sanitation Technologies in Ghana; and
4) Feasibility Evaluation of Fired Brick Technology as a Construction Material and Income-Generating Industry in Northern Ghana.

2. Water Quality Analysis of the Piped Supply in Tamale, Ghana

2.1.Goal and Objectives

In 2000, the United Nations issued a set of Millennium Development Goals which were created to eliminate global poverty. One of these goals, Target 7.C, is to “halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation” (“United Nations Millennium Development Goals” 2014). Although the UN declared the goal for drinking water has been met, further studies have shown that the improved sources used as a metric (see Section 2.3) for determining safe water are not always safe. This begs the question: is the piped water in Tamale, which would be classified as an improved source, actually safe? Finding the answer to this question was the overall goal of this research project.

This goal was achieved by utilizing historical water quality sample data from the Ghana Water Company Ltd. (GWCL), the municipal water supply in Tamale. Previously, this data was only contained in handwritten notebooks and undescriptive Excel spreadsheets. Because of this, the data had not been analyzed in a meaningful way before. For this project, the data from the notebooks was entered into a Microsoft Access database created for future use by the GWCL as well as other computer spreadsheets to analyze the data for spatial and temporal trends, as well as to gain a better understanding of water quality in Tamale.

2.2. Ghana Water Company Ltd.

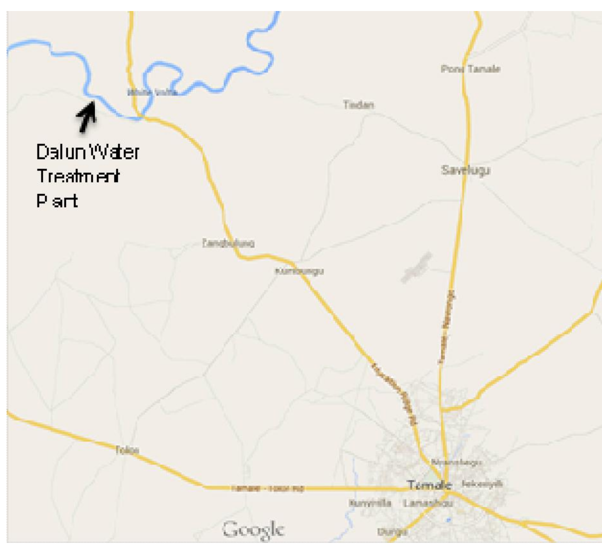


FIGURE 2-1: LOCATION OF TREATMENT PLANT

The GWCL is responsible for providing piped water to Tamale and the surrounding area. The water supplied to Tamale comes from the White Volta River (Figure 2-1). Water is pumped to the treatment plant from an intake point located at the village of Nawuni. The Dalun Water Treatment Plant, 35 kilometers north of Tamale, is responsible for treating the raw water. The treatment process includes: coagulation, flocculation, sedimentation, rapid sand filtration, chlorination, and lime addition. The treatment plant was upgraded in 2008 in collaboration with a UK-based company, Biwater. This upgrade increased the capacity of the treatment plant from 19 to 44 million liters per day.

2.3. Water Quality Standards

Guidelines provided by the World Health Organization (WHO) in *Guidelines for Drinking-water Quality, 4th Edition* (2011) are accepted as standards for water quality parameters in many countries, including the United States. For the parameters measured by the GWCL, the guidelines are:

- pH between 6.5 and 8.5
- Turbidity less than 1 NTU is ideal but less than 5 NTU is acceptable
- Residual free chlorine concentration after 30 minutes of contact time of 0.5 mg/l and greater than 0.2 mg/l at the point of use
- No positive counts of total coliform or *E. coli* in a 100mL sample

The standards for Ghana are hard to obtain, however, it appeared that the GWCL was defining “compliance” based upon slightly less stringent guidelines than the WHO in the case of pH and residual chlorine.

2.4. Water Quality Challenges in Tamale

Maintaining safe water in developing countries faces many challenges, and the water supply in Tamale is no different. The biggest issue is the intermittency of the water. In an intermittent water supply, water is not provided 24 hours a day, seven days a week; it may only be available for a few hours a day. There are many factors that cause this intermittency such as population growth, power outages, lack of maintenance, non-revenue water (water being lost due to leaks, breaks, and illegal connections), and lack of revenue. Because the pipes are not always pressurized, outside contaminants can enter the pipes through any breaks or cracks. Backwashing of pipes can also occur also leading to contamination of water (Lee and Schwab 2005).

Another related problem is the safe storage of water. The intermittency of piped water leads to the necessity of collecting water when pipes are full and then storing it. During storage, water can become contaminated through contact with unclean hands or utensils if the storage container is unsafe. The CDC and USAID define a safe storage container as one in which the opening is too small to easily put hands or objects into, one that dispenses water without requiring contact with water, and one that provides instructions on use and cleaning (CDC and USAID 2009). Last year, M.Eng student Deborah Vacs Renwick conducted user surveys in the Tamale area and found that 53% of households use unsafe storage containers. In addition, she tested water from storage containers and found that 73% tested positive for total coliform and 33% were positive for *E. coli* (Vacs Renwick 2013).

2.5.Results of Analysis

The notebook at the GWCL water quality laboratory in Tamale contained data from 2004 through 2013. Because of the large amount of data and limited amount of time, data entry was simplified. Most sample locations were not measured on a regular basis. Based upon frequency of sampling and geographic spread, eleven sample locations were selected and all water quality parameters were entered for those locations. In addition, to account for all data, sample dates were recorded with the

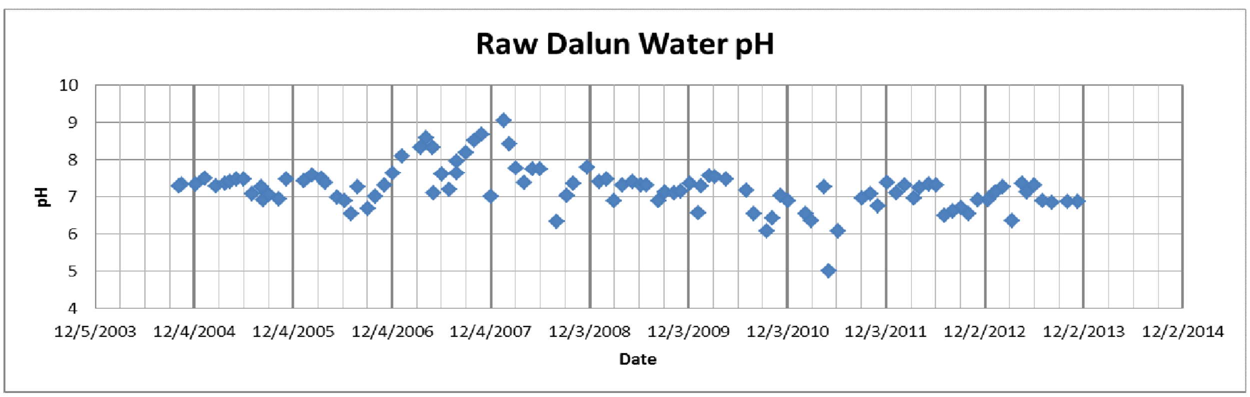


FIGURE 2-2: PLOT OF RAW WATER PH

number of points sampled on that date, the area they were located in, and the number of those points not complying with each of the water quality guidelines. Raw and final treated water for the Dalun Treatment Plant was also included in the notebooks and entered into the spreadsheet.

2.5.1. Dalun Treatment Plant Seasonal Trends

Data for the pH and turbidity of the raw water from the White Volta River entering the treatment plant was plotted using Microsoft Excel. Figure 2-2 shows the pH variation with time and Figure 2-3 shows the

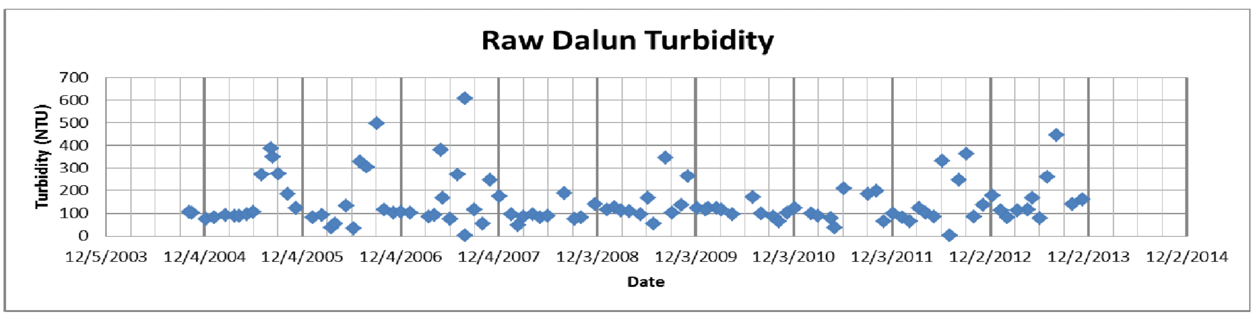
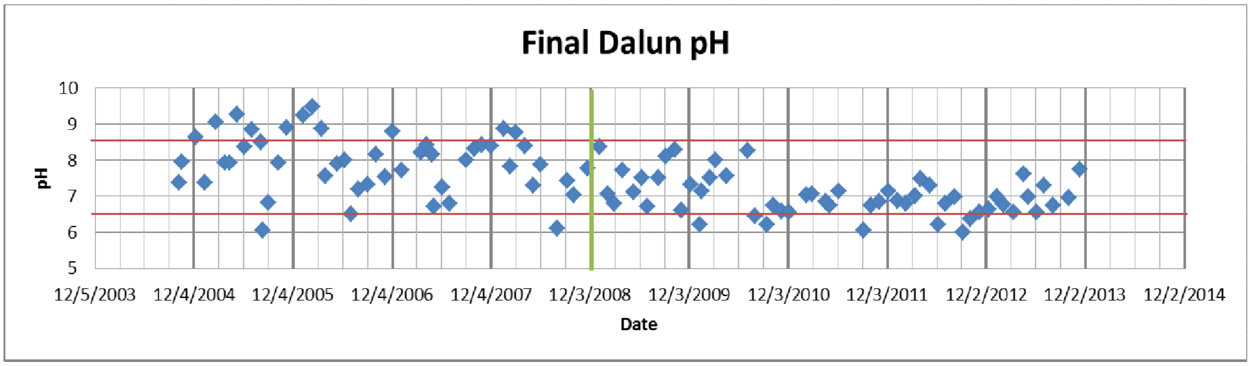


FIGURE 2-3: PLOT OF RAW WATER TURBIDITY

turbidity variation with time.



As seen in these figures, both pH and turbidity show periodic seasonal variations. pH is lower and turbidity is higher during the rainy season, probably due to runoff.

These seasonal trends also show up in the treated water. The pH of treated water is shown in Figure 2-4 and the turbidity of the treated water is shown in Figure 2-5. The residual free chlorine, important for the disinfection of the treated water, is plotted in Figure 2-6.

FIGURE 2-4: PLOT OF TREATED WATER PH

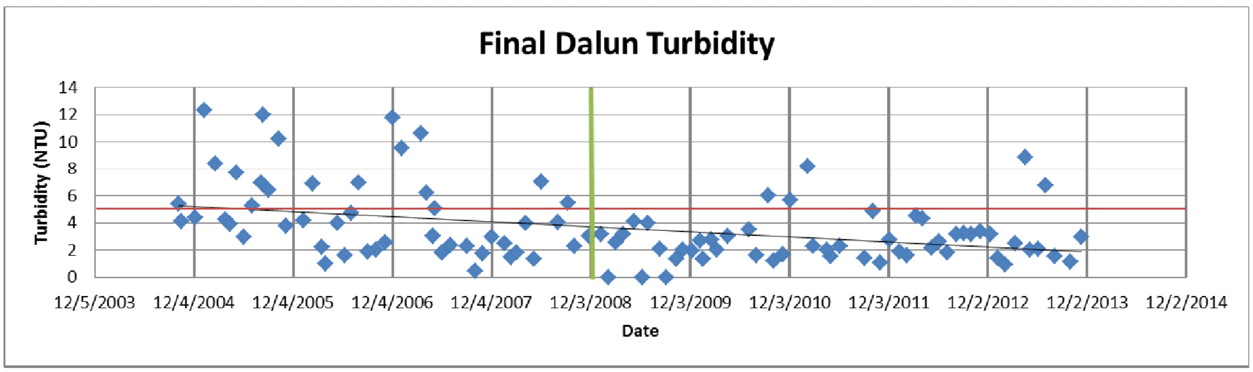


FIGURE 2-5: PLOT OF TREATED WATER TURBIDITY

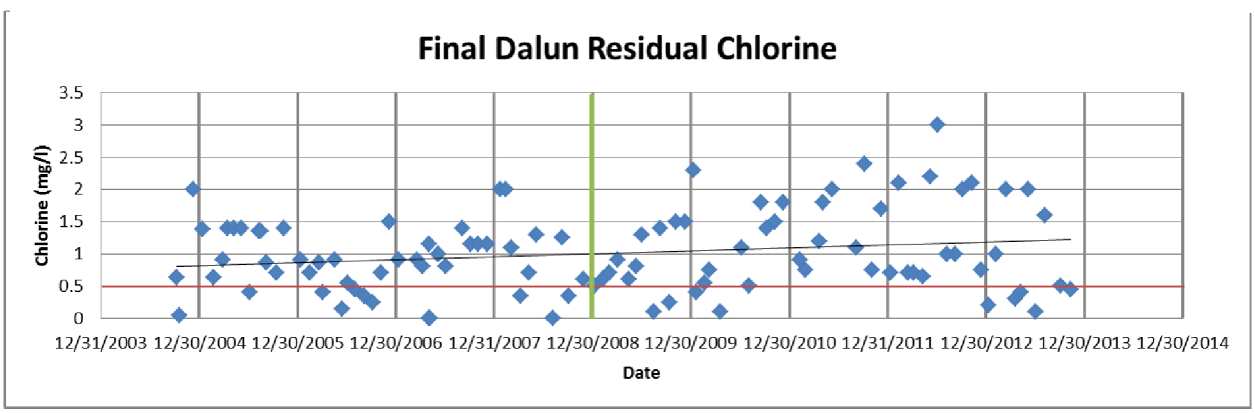


FIGURE 2-6: PLOT OF TREATED WATER RESIDUAL CHLORINE

The vertical green lines in the figures indicate the 2008 upgrade while the horizontal red lines indicate guideline values from the WHO. As seen, values do seem to stay within the guidelines better after the upgrade, however, there are still samples that fall outside of these lines meaning there is still room for improvement.

2.5.2. Spatial Trends

The eleven sample points with higher sampling frequency and good geographic spread were also analyzed. Averages for pH, turbidity, and residual free chlorine were compared between sample points (Table 2-1).

TABLE 2-1: SAMPLE POINT AVERAGES

Averages	Airport	Bagabaga	Dakbopa SHS	Kaafieyili	Kanshegu	Kumbungu SHS	Saakuba	Tamale Int. Sch.	Vittin SHS	Yipelnayili	Zangbalun
pH	7.598	7.328	7.307	7.055	7.279	7.005	7.102	7.218	7.423	7.038	7.024
Turb	2.451	3.853	3.079	3.468	2.774	2.966	4.346	3.285	2.691	3.434	3.418
Resid. Ch.	0.065	0.319	0.305	0.568	0.188	0.388	0.494	0.485	0.343	0.271	0.460
n	46	16	11	46	51	38	75	13	7	42	62

A t-test was used to determine whether the differences between averages were statistically significant which concluded that points further away from each other did have statistically significant differences for residual chlorine concentration but was not conclusive for pH variation. Figure 2-7 shows the sample points mapped using ArcGIS. Color variations correspond to pH values. Similarly, Figure 2-8 indicates chlorine residual concentrations with proportionally sized circles

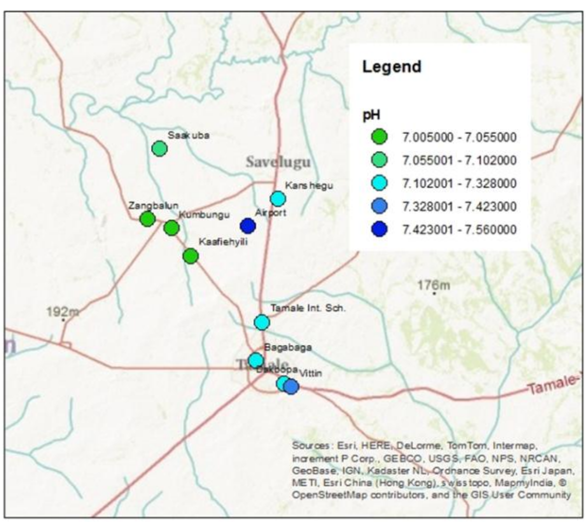


FIGURE 2-7: PH SPATIAL VARIATION

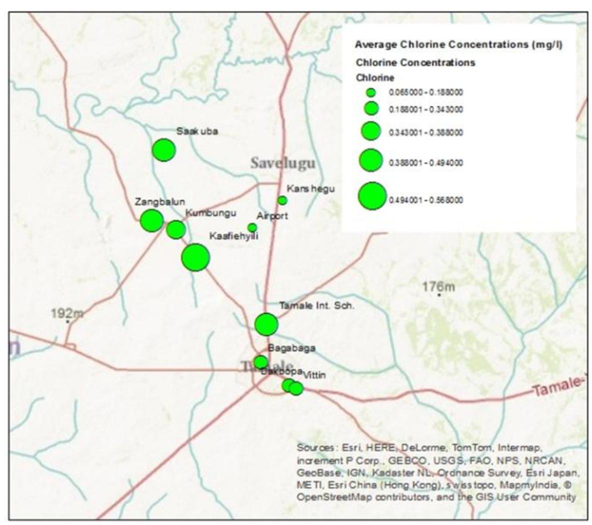


FIGURE 2-8: RESIDUAL CHLORINE SPATIAL VARIATION

These figures show spatial trends. pH increases with further distances from the treatment plant and residual chlorine decreases further away from the treatment plant. It is unclear whether the decay of chlorine is due to first-order reactions related to water age or from increased demand of chlorine for disinfections from outside contamination entering the water.

2.5.3. Overall Water Quality

The overall number of samples not complying with WHO guidelines was used to calculate percentages for how often water quality was not complying and could be unsafe to drink. This analysis found that 10% of samples had a pH that was too low or too high, 24% of samples had high turbidity, 42% of samples had a low chlorine residual, 11% of samples had no chlorine residual, and 2% of samples tested positive for total coliform. Of highest concern is the occurrence of low chlorine residual. If water does not have free chlorine available for disinfection, it can easily become contaminated during storage, especially if storage containers allow for contact with contaminated objects. This may explain the difference between the 2% of samples positive for total coliform found by the GWCL compared to the 73% of samples positive for total coliform collected by Vacs Renwick from storage containers.

2.5.4. Sanitary Survey Results

Observations made of the water supply network during field work in Tamale were used to help answer a sanitary survey from the WHO used in their *Rapid Assessment of Drinking-water Quality*. These observations, such as broken pipes, proximity of water lines to sewers, intermittency, and vandalism, led to a score of five “no” answers which corresponds to a medium risk of environmental contamination. This is a low estimate as observations were not made for some of the survey questions.

2.6. Conclusions and Recommendations

Based upon the data analysis and sanitary survey results, it can be concluded that the “improved” piped water source in Tamale is not consistently safe to drink. This is especially true when water with inadequate residual chlorine is stored in unsafe storage containers causing it to become recontaminated.

The following recommendations are made to the GWCL: the Microsoft Access database should be continuously used and data analyzed, a better sampling methodology should be implemented, water quality standards used by the GWCL should comply with WHO guidelines, seasonal trends should be considered in treatment dosages, and overall maintenance of the system should be done to fix pressure tapping points and prevent vandalism. Unfortunately, these recommendations may prove difficult to be executed due to the lack of available revenue to the GWCL.

Further research in collaboration with the GWCL should be done in order to build upon this project and Vacs Renwick's. These research projects could include: further data analysis, testing for other contaminants such as metals and other chemicals, a more complete sanitary survey, creation of a hydraulic model, determining the exact factors leading to intermittency, and a more current description of the Dalun Treatment Plant (as the last one by an MIT student was prior to the 2008 upgrade).

3. Evaluation of Household Water Treatment and Safe Storage (HWTS) Alternatives in Ghana

3.1. Introduction to Global Water Supply & Household Water Treatment and Safe Storage (HWTS)

Poor drinking water quality remain one of the major threats to human health. According to the World Health Organization (WHO), 1.7 billion people are diagnosed with diarrheal diseases annually, 88 % of which are attributed to unsafe water supply, inadequate sanitation and hygiene. Every one hour about 87 children under five are dying because of diarrhea (WHO; UNICEF, 2013).

In an effect to improve the quality of drinking water in the developing world, a new set of technology known as household water treatment and safe storage (HWTS) or point-of-use (POU) water treatment has been developed and disseminated during the past two decades. HWTS and POU water treatment are commonly referred to as treating water and safely storing it at the household or community level (WHO, 2013). HWTS often uses the same basic approaches of conventional water treatment such as filtration, coagulation, and disinfection (boiling, chlorination, solar) on a smaller decentralized scale.

However, none of them except boiling has been successfully scaled up (Clasen, 2009). There are many challenges to scale-up, including constraints on distribution, user acceptance, and effective use of products, price-economics, training-methods, sustainability, inadequate maintenance, monitoring and evaluation (Arnold, et al., 2009; Mäusezahl, et al., 2009; Brown & Clasen, 2012). One of the main constraints in scale-up of HWTS is the behavior barrier. In some areas where the practice of treating water before drinking itself was never a norm, HWTS is not just a product or technology but a novel idea (Jain, 2010). HWTS thus calls for a behavioral change on the part of the user, which is hard to promote and achieve. It requires collaborative efforts of multiple parties to introduce and educate throughout the community. This has certainly raised the bar to implement HWTS. Furthermore, the demand for HWTS due to low purchasing power of the targeted community is also a dominant factor that holds back the scale-up (Murcott, 2006; PATH, 2009; Jain, 2010). According to report *Implementation, Critical Factors and Challenges to Scale-Up of Household Drinking Water Treatment and Safe Storage Systems*, among a variety of financing approaches of 34 organizations, only 12 percent use commercialization or “for proft model” to implement HWTS product (Murcott, 2006). Despite the fact that there is still a lot of work to get HWTS t breakthrough these barriers, the health benefits it promises to those who lack access to safe drinking water sources is inspiring.

3.2. Background of the Evaluation

According to the recent WHO/UNICEF Progress Report on Drinking Water and Sanitation, 83.8 % of the total population in Ghana has access to improved drinking water. Ghana has performed above the average in Sub-Saharan Africa, and is expected to meet the water Millennium Development Goal by 2015 (WHO; UNICEF, 2012). While these results indicate significant improvement in the Ghana's water supply, disparities in water supply exist between regions within Ghana. It is estimated that approximately 50 % of people living in the Northern Region still do not have access to improved water sources (Murcott, 2013).

One of the goals of Pure Home Water is to provide safe drinking water, sanitation, and hygiene (WASH) in Ghana. To meet this goal, PHW has developed its own HWTS product, a ceramic pot water filter called the AfriClay Classic Filter. This filter has been effective at pathogen removal and treating household drinking water. Through the production and distribution of the AfriClay Filter, PHW has reached to date over 100,000 people in the northern region of Ghana. However, this number is insignificant to the 9 million Ghanaians throughout the country that have no access to safe drinking water (WaterAid, 2005). Although PHW has made some strides towards becoming locally self-sufficient and financially self-sustaining, its ceramic filter Africlay product that is generally meant for humanitarian distribution and low-income community, has limited expansion and the ability to do further good. In order to expand business and improve the conditions of more households in Ghana, a new product which is meant for profit and targeted at middle and upper income families is necessary.

In urban area of Ghana, water service is mainly provided by Ghana Water Company Ltd (GWCL). Despite being a government owned utility whose history can be traced back to the foundation of the country, GWCL had never succeeded to provide water to the whole population of urban Ghana. Reasons for this problem include overwhelming demand for water in over-populated cities and non-revenue water losses due to poor water management (Vacs Renwick, 2013; Van-Rooijen, et al., 2008). As a result, more than half of residents do not have a pipe connection within their yard or compound (Van-Rooijen, et al., 2008). Furthermore, the quality of water delivered is also questionable. Previous study had shown 87 % of residents in Tamale, the Northern capital city of Ghana, suffer intermittent water supply and 73 % of water samples from their drinking water sources showed positive result for total coliforms contamination (Vacs Renwick, 2013). Accra, the capital city suffers similar problem where only 25 % of residents have continuous supply (WaterAid, 2005). This proposes that even with piped water supply;

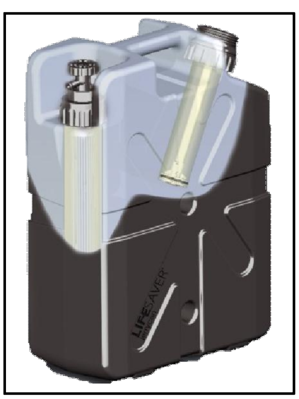
there may be a need and therefore market for household water treatment product. PHW identified this potential market and would like to make profit from this market and use the capital for extension of humanitarian expenditures.

3.3. Purpose and Overview of the Evaluation

In response to the intention of PHW's design of a for-profit HWTS product, an evaluation to access the feasibility of several HWTS products for Ghanaian market was conducted in January 2014. These HWTS products include (1) LifeStraw® Family 1.0, (2) Gravity Driven Membrane (GDM) and (3) Life Saver JerryCan and the deluxe version of PHW's current product, (4) AfriClay Filter (Figure 3-1). As the purpose of the product is to generate revenue, different from PHW's usual practices in its traditional market in the northern region of Ghana, the primary market is thought to be the southern region of Ghana, where most of the middle and high income families reside. Hence, this study is conducted primarily in two different locations: Accra, the capital city and largest city of Ghana and Tamale, the biggest city of northern region Ghana where PHW is stationed.

(1) LifeStraw® Family 1.0

(2) Gravity Driven Membrane (GDM)



(3) Life Saver JerryCan

(3) AfriClay Deluxe

FIGURE 3-1: HWTS ALTERNATIVES FOR MIDDLE AND HIGH-INCOME FAMILIES

The design of the project was primarily based the following three objectives:

- To determine whether there is a need or market for HWTS
- To establish baseline household profiles and consumer segments based on knowledge, preferences, attitudes and motivation for HWTS purchase and use;
- To characterize challenges to HWTS product adoption

For the first purpose, we evaluated the water quality of 42 households using bacteria indicator and conducted household surveys regarding their water practices. We found there is clearly a need for HWTS even in household with access to piped water service, given that Accra and Tamale two of the biggest cities in Ghana suffer severe intermittent piped water supply and water quality degradation. For the second purpose, we conducted 82 housewold surveys in Accra and Tamale and found that there is awareness of the water quality issue but not much knowledge about household water treatment. The survey also shows that Gravity Driven Membrane (GDM) and Ceramic Pot Filter have the potential to do best in the market. For the third purpose, we conducted a field study of two LifeSaver JerryCan units in two households in Accra. The findings show that LifeSaver JerryCan performs perfectly in the setting of urban water of Ghana and the customer-perceived-value changes after the experience.

We concluded that there is definitely a market for HWTS in the in middle and high income families, PHW may either partner with EAWAG and sells GDM as its high-end product, or further develop its own product by taking recommended product features into design.

3.4. Water Practice Surveys & Water Quality Evaluation

This section focuses on findings from the household surveys and water quality evaluation.

Table 3-1 summarizes the results of the water practice surveys and water quality evaluation in Accra and Tamale. The result of Tamale drew largely from Vacs Renwick's study on intermittent water conducted in 2013.

TABLE 3-1: WATER SUPPLY AND QUALITY IN ACCRA AND TAMALE

	Accra (This Study, 2014)	Tamale (Vacs Renwick, 2013)
Rely on piped water supply as main source	26 %	70 %

for drinking water		
Rely on sachet water as main source for drinking water	57 %	30 %
Intermittent Water Supply	77 %	87 %
Practice Water Storage	93 %	100 %
Practice Water Treatment	14 %	25 %
Free Chlorine Residual below 0.2 mg/L	100 %	93 %
Presence of Total Coliform (Detection limit = 10 CFU/100 mL)	74 %	83 %
Presence of *E.coli* (Detection limit = 10 CFU/100 mL)	40 %	33 %

As shown in the Table 3-1, both cities suffer a high degree of intermittent water supply and water quality degradation. Over 70 % of the samples in both cities showed detectable level of total coliform. This number does not meet the U.S. EPA standard that requires 95 % of monthly water distribution system samples test negative for total coliforms (U.S. Environmental Protection Agency 1989). Over 30 % of the samples were found to have at least 10 CFU/100 mL, with 5 % fall into category "very high risk", for which according to the WHO, urgent action is required. Given to these high numbers of contaminated water samples, it is clear that the majority of the population is subjected to degradation of water quality.

Another finding is that these bacterial contamination may begin begins in the distribution system itself as one of the three water samples taken from the tap directly showed positive result for total coliform. There is a high possibility of polluted water infiltrated the pipe supply due to back-pressure condition in an intermittent network. As the number of samples was limited, it is not clear to what degree the water quality is degraded within the distribution network. However, it is clear that there are a number of people who are exposed to this threat of contaminated water supply and in these circumstances, HWTS is certainly a good option to provide additional barrier to contamination.

Only 26% of the respondents in Accra and 70% of the respondents in Tamale uses piped water as their primary drinking source. This suggests that the majority of the population is aware of the degradation of their water quality. However, it is also clear that there is a strong dependency on sachet water for drinking water source in Accra in which 57% of the population relies on sachet water for drinking purpose. This implies that these disposable water products pose strong barrier to the entry of HWTS.

Nevertheless, the intermittent water supply and degradation of water quality issue is universally true in Ghana. In other words, there is a demand for HWTS across the country.

3.5. HWTS preference surveys

This section focuses on findings from the household surveys regarding HWTS products preferences and features preferences in Accra and Tamale.

3.5.1. HWTS Product Awareness

Only two respondents in Accra and one in Tamale had used a Ceramic Pot Filter before and they are satisfied with it performance. These householders who had experience with Ceramic Pot Filter said that they had used it in the village where connection to water distribution were not available, and now that they had come to the city, they think the piped water is good for drinking without further treatment. Given that the majority of the respondents had not seen or used any HWTS products, the lack of awareness of HWTS may pose a major barrier to HWTS adoption. It will require tremendous effort to introduce and promote HWTS in these cities.

3.5.2. Product Preference

Figure 3-2 shows the consumer preference for the four HWTS products. The distribution of product preferences in both cities shows similar trend. A total of 50 out of 82 interviewees picked GDM as their most favorite product. The reasons given were GDM requires the least maintenance; it is easy-to-use and appropriate size for family. Ceramic Pot Filter came in second with 26 votes. Most respondents chose Ceramic Pot because they like frequent cleaning it requires, contradicting reasons given for GDM. This difference of opinions regarding the cleaning frequency showcases the possibility of two different customer segments that could to be targeted. Nevertheless, it is clear that GDM and Ceramic Pot Filter have the potential to do best in the market.

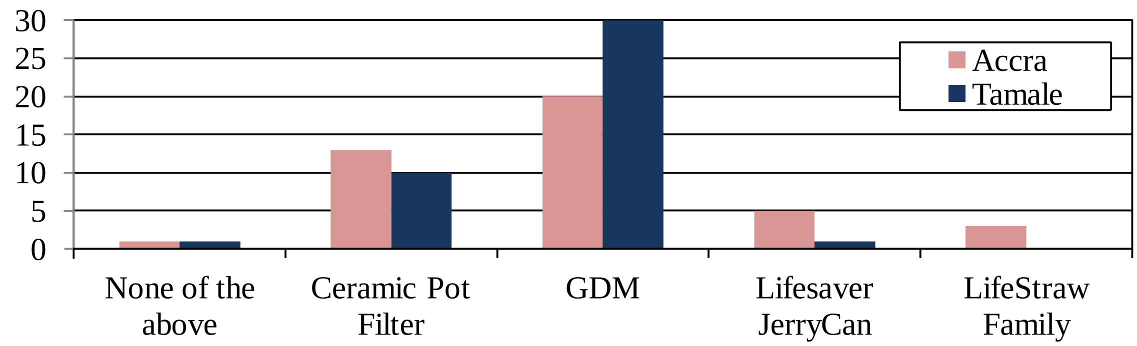


FIGURE 3-2: RESPONSE TO QUESTION "WHICH PRODUCT DO YOU PREFER?"

3.5.3. Feature Preference

Figure 3-3 and Figure 3-4 shows the ideal features preference for a HWTS product. The distribution of each feature preference in two cities is about the same. While the choice of 10 L for ideal size and 10 min for ideal time-to-treat 1 L has the highest votes, the distribution of each choice is not significantly different. This implies that consumers have high tolerance regarding the increment of each feature. In other words, consumers may be willing to accept the size and the time-to-treat 1 L of water as long as it is in range of the choices they made. Based on the distribution and average number, it is suggested to have the ideal product to be set in 5 to 10 L capacity and 10 to 30 min time-to-treat 1 L of water.

Based on the average number of the ideal flow rate which is 3.33 hr/L, it seems like LifeStraw® Family and LifeSaver JerryCan maybe the best option for the consumer, which contradicts the product preference result. This implies that time-to-treat/flow rate is not the first feature consumers would consider. Taking account of the product preference, the importance of HWTS features maybe the easy-to-use element, the size, followed by the time-to-treat. Based on these assumptions, it is important to design a user-friendly product with the appropriate size with less emphasis on time-to-treat.

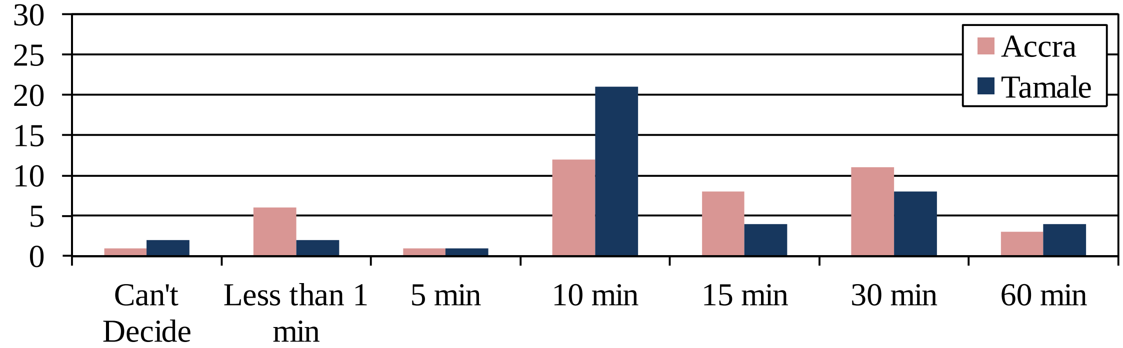


FIGURE 3-3: RESPONSE TO QUESTION "HOW LONG WOULD YOU WAIT TO TREAT 1 L OF WATER?"

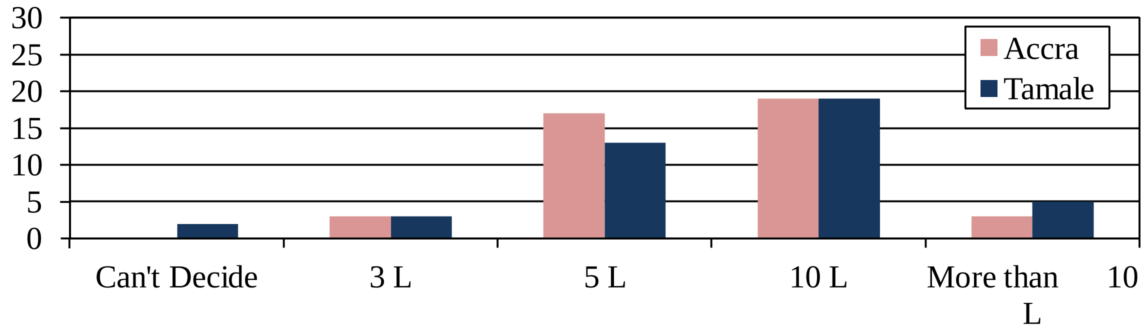


FIGURE 3-4: RESPONSE TO QUESTION "WHAT IS THE SIZE THAT YOU PREFER FOR YOUR HOUSE?"

3.5.4. Willingness to Pay

Figure 3-5 shows the Willingness-to-Pay (WTP) of users for a HWTS product. In order to not influence the decision of the consumer on WTP, the cost of each HWTS products was not included. As many respondents were not familiar with any of the HWTS products introduced or the concept of HWTS, the WTP of the respondent is shockingly low. The average WTP in Accra and Tamale is 62 GHS and 36 GHS respectively. About half of the respondents chose the lowest price point which is 30 GHS. This contradicts the findings of Yang (2013) who found the WTP of a deluxe model of AfriClay Filter to be 40 GHS. The retail price of PHW's current product, AfriClay, is set at 50 GHS. This means that if the price is set in the range of 36 to 62 GHS, it will be difficult to fulfill the purpose of the new product to generate income.

Still, most people in Accra and Tamale are willing to accept or even pay for a HWTS product, believing it will bring health benefits to the family. The major hesitancy on the price is the insufficient knowledge and experience with the product. With enough effort of introducing the HWTS to the public through advertisement or product demonstrations, the WTP may be increased.

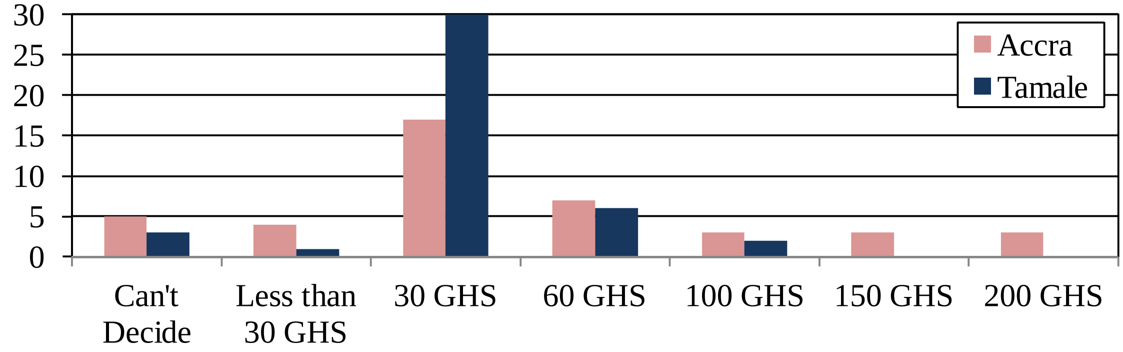


FIGURE 3-5: RESPONSE TO QUESTION "HOW MUCH WOULD YOU PAY FOR A WATER FILTER?"

3.6. Field Study: Products Assessment

This section summarizes the findings from implementation of two units of LifeSaver Jerry Can in Accra.

3.6.1. Bacteriological Results

Table 3-2 shows the bacteriological test result of the LifeSaver JerryCan units given to two household in Accra. Despite the high concentration of total coliform and *E.coli* in the influent, both units perform effectively as no contamination of total coliform or *E.coli* in the effluent was observed.

TABLE 3-2: PERFORMANCE OF LIFESAVER JERRY CAN

Day	Unit 1 (East Legon)				Unit 2 (Legon)			
	Total Coliform (CFU / 100 mL)		*E.Coli* (CFU / 100 mL)		Total Coliform (CFU / 100 mL)		*E.Coli* (CFU / 100 mL)	
	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
01	1700	0	200	0	500	0	200	0
03	1400	0	100	0	300	0	100	0
05	2000	0	0	0	700	0	200	0
07	1300	0	200	0	1000	0	0	0
20	5000	0	0	0	1200	0	0	0
21	4000	0	800	0	800	0	0	0

3.6.2. User Feedback

Table 3-3 summarizes the key information from the interviews of the two users at the end of the study. Both users did not experience any change in the quality of the water. However, one of them claimed that by having it under the shade, the water is cooler and better. Nevertheless, they were pleased with the product, believing it provides clean water that is free of bacteria and dirt. Both users were satisfied with the mechanism and time-to-treat. However, for the size, one of the users claimed that he would prefer a bigger unit.

TABLE 3-3: SUMMARY OF USER FEEDBACK

Key Questions	User 01	User 02
1. How often do you use the filter?	everyday	everyday
2. How much water do you filter a day?	20 cups	half gallon
3. What kind of water do you use as a source?	Piped water inside residence	Public tap
4. Do you clean your filter?	No	Just flush once before use
5. Do you feel there is a change of water quality?	No but it is colder	No
6. Is the filter easy-to-use?	Yes	Yes
7. Do you use the filter for purpose other than drinking?	No, just drinking	No just drinking
8. Do you think the size is enough for your family?	Yes	No
9. Is the time-to-treat good enough for your family?	Yes	Yes
10. How much money would you pay for this product? (Before)	30 GHS	50 GHS
11. How much money would you pay for this product? (After)	100 GHS	100 GHS
12. Is there anything you would like to change about the filter?	No	Size

One of the key findings here is the significant increase of user's WTP after the usage of the product. The WTP of each user was originally 30 GHS and 50 GHS, but after the usage of the product for about three weeks, it increases to 100 GHS. This shows that they can afford for the product at the price of 100 GHS but they were skeptical about the value of the filter prior to actual adoption.

It is not clear if it is the physical appearance of the product or the experience using the product that changed the customer-perceived-value. Although the users reported that they were satisfied with the performance of the product, they cannot really tell the change of the water quality without performing test. The only actual proof of the health benefits was the bacterial test run by the author. This indicates that a demonstration that showcases the effectiveness of the product may replace the whole experience of using the product.

Another feedback given in this section is that the size of the product is a key feature that the user is aware of. This contradicts the findings of Job (2012) in Kenya that showed size of the product is the least important factor in WTP for GDM. This suggests the difference between customers- perceived-value in Kenya versus Ghana. Nevertheless, for the purpose of PHW which focus on the market in Ghana, it is important to give a variety of sizes that are appropriate for different family sizes.

3.7. Conclusion

The goal of this study has been to PHW design a for-profit product targeted at middle and high income families in Ghana. One of the key questions that needed to be answered was if there is a market for HWTS products in the middle and high income customers who largely reside in Accra, the capital city. The findings clearly suggest that there is a market, given that there is a severe issue of water quality degradation within the water distribution system and at the point of consumption. The next question was what HWTS product would be of interest and what kind of HWTS product would prevails in this market. Surveys concluded that products such as GDM and Ceramic Pot Filter that incorporate the following characteristics: separate storage for clean container; easy-to-use; appropriate size, filter time and maintenance will meet most customer need. Findings also imply that the ideal price point of the product is highly influenced by the knowledge and experience of the user with the product.The last question is what challenges HWTS products will meet during usage. The findings show that LifeSaver JerryCan performs perfectly in the setting of urban water of Ghana and the customer-perceived-value changes after the experience.

3.8. Recommendation for PHW

There are two major approaches to sell a HWTS product targeted at middle and high income families. One is to partner with EAWAG and sells GDM as PHW's high-end product; two is to further develop its own product by taking recommended product features including safe storage, one-step treatment, transparent container, filter size between 10 to 15L and flow rate of about 3L/hr. Although GDM did slightly better than Ceramic Pot Filter in the surveys, it is hard to say that Ceramic Pot Filter will do worse than GDM in the market. In a country that has a diverse set of consumer needs, developing different products targeted at different customer segments may not be a bad idea.

The recommended price for the future product is 100 GHS per unit as indicated by the change of the user's WTP during the field study. However, as the initial WTP of most consumers is far lower than 100 GHS, it may be a good idea to incorporate payment via monthly installment with small initial investment of 30 GHS in which the users can experience the benefits of the product gradually and ultimately increase their perceived value of the product.

One of the drawbacks of most HWTS interventions is lack of product awareness. In order to reach out to potential buyers, investment in advertisement is essential. The long existing sachet water and bottled water business are still extensively advertising their products via printed media and television broadcast. In order for HWTS to compete with the strong public perception that cheap and good quality sachet and bottled water have, the same amount of efforts in advertising is necessary. As PHW has limited resources, instead of facing the big players in the market head on, it is possible to propose partnership with one of the water ventures to promote and sells HWTS together.

4. Evaluation of Innovative Decentralized Sanitation Technologies in Ghana

4.1. Background, Purpose, and Overview of the Evaluation

It is estimated that, worldwide, 2.5 billion people lack access to improved sanitation, and 90% of wastewater in developing countries is discharged into the environment without any treatment. Ghana, however, has an even worse record of sanitation, boasting the sixth worst improved sanitation coverage rate, 13%, in the world. Ghana also has a unique cultural practice of using public and shared sanitation, with 59% of the population using shared sanitation facilities. Additionally, 19% of the population practices open defecation (Figure 4-1) (UNICEF/WHO 2013). As a result of this sanitation situation, Ghana loses an estimated US$290 million per year, and 19,000 Ghanaians die from diarrhea, most of which could have been prevented with proper water, sanitation, and hygiene (Water and Sanitation Program 2012).

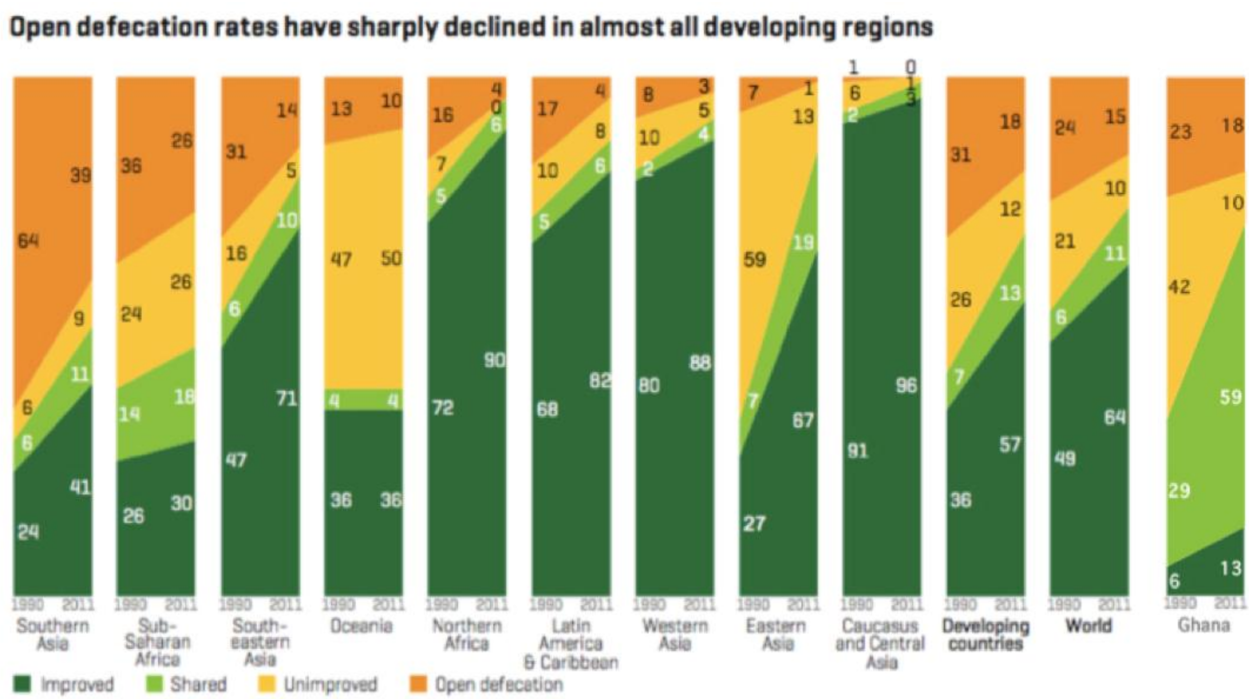


FIGURE 4-1 SANITATION TRENDS IN GHANA AND THE WORLD (UNICEF/WHO JMP 2013)

This is a complicated problem, for the construction of sewerage systems and centralized wastewater treatment plants is neither an affordable nor appropriate solution in Ghana. Therefore, an emphasis has arisen on decentralized sanitation technologies that treat waste on-site and recover resources that can be used to generate economic gains. Using a case study method and an evaluation matrix, this study evaluates the efficacy and scalability of several such innovative sanitation technologies.

The decentralized technologies evaluated include the Clean Team Toilet, Microbial Fuel Cell Latrine, Biofil Toilet, Microflush Toilet, and the more traditional pour-flush toilet. Two semi-centralized technologies, the IMWI Fortifer pellets and Ashesi University's small-scale wastewater treatment system with anaerobic digestion, were studied as well. Case studies of these technologies were conducted in January 2014 in Ghana and involved surveys of users and interviews of service providers and their competition where possible. The evaluations were completed using this information and were guided by criteria on sanitation outcomes, business management, and technology categories.

Using an evaluation matrix, shown in section 4.3, we conclude that the locally sourced Microflush Toilet is currently the most appropriate decentralized sanitation technology for Ghana. The Biofil Toilet is the current gold standard for decentralized sanitation, but it is costly. Therefore, the Microflush Toilet is recommended for middle- and low-income families and small aid projects, for it functions similarly to the Biofil Toilet but is approximately one-fifth the cost. For large projects in densely populated areas, the Clean Team Toilet is recommended if a reuse for waste and safe disposal of biocide can be established. Other technologies require further development before they can be recommended for implementation and use.

4.2. Technology Summaries and Case Studies

4.2.1. Biofil Toilet

The Biofil Toilet, shown in Figure 4-2, features reclamation of composted fecal matter for agriculture as well as a water seal, all while minimizing water consumption. The technology's signature feature is the reuse of 150 mL of greywater from hand washing for the toilet flush. A flush is possible with such a small amount of water because it utilizes a Microflush valve, which is essentially a trap door at the bottom of the toilet bowl (Figure 4-3). Water stands within this trap door until the user steps on a lever, releasing the waste and greywater into a tank below the toilet.

FIGURE 4-2 THE BIOFIL TOILET INTERIOR

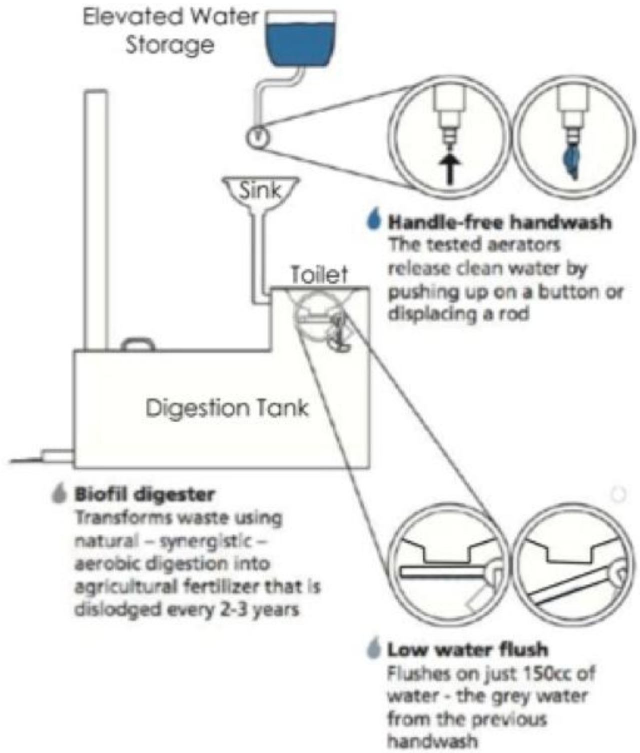


FIGURE 4-3 SCHEMATIC OF BIOFIL AND MICROFLUSH TECHNOLOGIES (MECCA, DAVIS, AND DAVIS 2013)

Within this tank, vermiculture aerobically degrades the waste into humus, which can be used as a nutrient-rich agricultural additive. The Biofil tank features a series of porous concrete filters that effectively separate solid waste from liquid waste. The liquid effluent is allowed to percolate into the ground while the solid waste is degraded by the vermiculture. The Biofil Toilet is manufactured by Biofilcom, led by Kweku Anno in Dzorwulu, Greater Accra (Anno 2014).

The Biofil Toilet performs quite well but its high price makes it unavailable to the majority of Ghanaians. It operates near steady state, so the tank rarely, if ever, needs to be emptied during its life. This allows for it to be installed away from roads. It also does not produce a significant odor due to the water seal, and it promotes hand washing as an integral step in toilet use. However, the design is complex, and removable parts make it problematic for implementation as a public toilet. Users also require education or demonstration before use because of this. Finally, it costs USD 1520 per unit (Anno 2014). This high cost is primarily due to the fact that parts are imported and the units are manufactured at a central location and delivered. Still, if the money is available, the Biofil Toilet appears to be the best decentralized sanitation technology available in Ghana. Where cost is not a significant concern, it is recommended for use in peri-urban areas that lack sewerage connections.

4.2.2. Microflush Toilet

FIGURE 4-4 THE LOCALLY-SOURCED MICROFLUSH TOILET

The Microflush Toilet, shown in Figure 4-4, uses many of the same technologies as the Biofil Toilet, but it is targeted at middle- to low-income consumers. It uses the Microflush valve technology and a digestion tank, but it has eliminated the sink and grey water reuse in order to bring down the cost. As a result, it operates as a pour-flush toilet. Also, it is manufactured onsite by trained local laborers using locally-available materials such as a pie pan for the Microflush valve and reclaimed billboard fabric for the walls of the superstructure (Mecca 2014). The digestion tank of the Microflush Toilet is simpler than the Biofil's tank, utilizing only five layers of wire mesh to separate solids from liquids. It also must be emptied every 2-3 years, forcing the toilet to be decommissioned for 2-3 weeks while the composting finishes. The Microflush Toilet is a product of Dr. Stephen Mecca at Providence College in Rhode Island and GSAP, the Global Sustainable Aid Project. It is important to note that Anno and Mecca originally worked together on a Microflush-Biofil Toilet before separating ways in order to target different consumer bases.

The evaluation matrix in section 4.3 assigns the highest score of seven to GSAP's locally-sourced Microflush Toilet. This technology is fairly well established in Southern Ghana, and costs only US$300 per private unit. It has proven successful as a private unit used by up to four families, but it has shown less promise as a public unit due to its relatively complex design and removable parts. The GSAP Microflush Toilet is therefore the recommended technology for private sanitation projects for low- or middle-income families in peri-urban or rural settings. Ideally, each facility should be used by three or fewer families. NGOs should take advantage of the low price of this technology by constructing many private MFBFs in lieu of a single public facility. In order to foster a sense of ownership of the toilets, recipients of toilets should be involved in the MFBF construction and pay for the MFBF through microloans taken from GSAP. With a GSAP microloan, the toilet costs just USD 10.18 per month for 24 months. User adoption may be further increased by the use of a squatting model of the technology where users indicate that this is more culturally acceptable.

4.2.3. Clean Team Toilets

The Clean Team Toilets project is based in Kumasi, Ghana and provides pre-fabricated, urine-diverting, portable toilets to homes on a subscription fee basis. Upon delivery, these plastic toilets are filled with One Shot Cherry, a solution of biocide and chemicals that reduce odor. Solid waste is deposited into this chemical-filled basin, while urine is diverted outside the home or into a plastic container with the use of a urine-diverting toilet seat. A "Clean Team" regularly seals and collects the buckets of waste from homes, replaces them with new clean buckets, and empties the used ones at a central collection point (Clean Team 2014). This process is depicted in Figure 4-5. CTT has not yet realized a reuse for the waste due to the presence of the biocide.

While the GSAP Microflush Toilet is the highest scoring technology in the evaluation matrix in section 4.3, CTT, with a score of four, is poised to overtake the highest score once it develops an environmentally friendly substitute to its One Shot Cherry biocide, which contains glutaraldehyde and bronopol, and implements profitable recovery of waste as a resource (Gyamfi 2014). Additionally, the financially sustainable subscription basis used by Clean Team Toilets is not assigned value in this evaluation matrix, so the matrix may slightly undervalue CTT. The subscription costs are slightly higher than the Microflush Toilet's loan payments but are still affordable, ranging from USD 11.36 to 20.45 per month (Yeboah 2014). CTT is applicable only in dense urban areas with a large target customer base and requires a permanent, large-scale business to be established. Therefore, it is only advisable to contract CTT for toilets in Kumasi or if a large amount of funding has been secured to implement the model in another city.

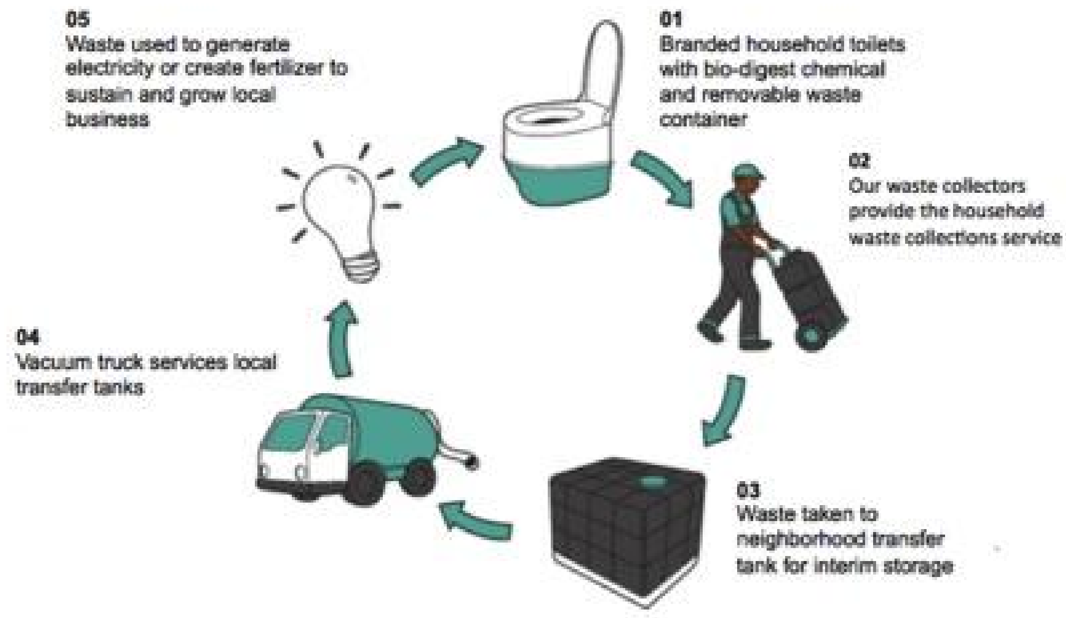


FIGURE 4-5 CLEAN TEAM TOILETS' SERVICE MODEL

4.2.4. Microbial Fuel Cell Latrine

The Microbial Fuel Cell Latrine, located in the small town of Nyakrom outside of Accra, composts waste to be used as a soil additive just as the Microflush/Biofil Toilets do. However, it is unique in that it uses this waste to produce electricity as well. The pit acts as a fuel cell, generating power from the flow of electrons from an anode to a cathode. The fecal organic matter is oxidized at an anode, while the ammonium from the urine is denitrified into nitrates, which are reduced at a cathode. These processes maintain the charges of the anode and cathode, thereby sustaining the flow of electrons and generation of electricity (Logan and Rabaey 2012). The fuel cell is intended to produce electricity to power the facility’s light at night, making it safer to use. However, the facility has never produced enough electricity to power the light during its lifespan. This is likely because male users prefer to urinate outside the latrine rather than in the urinal, eliminating the necessary supply of ammonium. Additionally, only 24% of students surveyed felt comfortable using the toilet, and just 35% preferred it to other available options. Concerns also exist regarding the classification of this facility. It appears to be an unimproved technology by JMP standards because it is an open pit. The Microbial Fuel Cell Latrine, shown in Figure 4-6, was developed by the University of Massachusetts-Amherst and Arizona State University (Castro et al. 2012).

FIGURE 4-6 THE NYASTECH MICROBIAL FUEL CELL LATRINE

The Microbial Fuel Cell Latrine requires further development before it is ready to be produced on a commercial level. Experimentation with a urine-diverting seat, use of low-cost local materials, and more efficient power generation could make this a feasible design. Additionally, the incorporation of some sort of water seal, such as the low-flow flushing mechanism used in the Microflush and Biofil Toilets, would allow this toilet to be classified as an improved facility. This also would significantly reduce the odor and increase the number of users of the facility.

4.2.5. Taha Islamic Kindergarten Pour-Flush Toilets

Pour-flush toilets have a squatting pan with a water seal that separates waste from human contact and a pit or septic tank into which waste is deposited. They require water for flushing to be poured in by the user after each use, and the septic tank becomes full over time and requires vacuum pumping. In Ghana, pour-flush toilet seats are most commonly designed for squatting use, although the technology can be used with seats designed for sitting as well (Anyekase 2014).

The pour-flush toilet is a popular option because the water seal is airtight, so odor and risk of contamination via flies are greatly reduced. The water seal is typically about 50 millimeters thick and is created with the use of a S-trap (or U-bend), which causes a small amount of water to stand in the pipe between the seat and the septic tank. After each use, the user pours a bucket of water into the basin, flushing away the waste and leaving a clean volume of water behind in the pipe as a new water seal. Although they are designed to function with 1-3 liters of water per flush, use of more water is encouraged to prevent blockages in the S-trap. Proper usage should provide an odorless and hygienic experience (WHO 1996).

FIGURE 4-7 TAHA POUR-FLUSH INTERIOR

FIGURE 4-8 TAHA POUR-FLUSH EXTERIOR

Pure Home Water and the MIT Public Service Center donated a sanitation block, shown in Figure 4-7 and 4-8, to the Taha School 5 kilometers east of Tamale, Ghana in June 2013. It was designed and constructed by MIT Master of Architecture student John Maher with collaboration from Pure Home Water and the skills and labor of 4-10 men from Taha over a period of 30 days. This toilet block contains six pour-flush toilets that drain into a septic tank. In the original configuration, three of the seats were for use by males, and three were for use by females. However, a case study revealed problems with adoption of the toilets due to this configuration. As a result, after January 2014, the configuration was modified such that there is now a “school side” and a “community side” to the toilet block, with each side further divided by gender.

The pour-flush facility is widely accepted by Ghanaians, but its dependence upon vacuum truck emptying poses financial and environmental concerns. For these reasons, it is recommended that the industry shift away from such models and toward toilets with on-site treatment, especially for public use. However, it should be noted that the pour-flush model is preferable to KVIP and open pit latrines because its water seal reduces odor and presence of flies.

4.2.6. IWMI Fortifer

IWMI Fortifer is a semi-centralized project that produces sanitary fertilizer pellets out of composted fecal sludge. The pellets are produced from public toilets’ sludge using a five-step process of drying, composting, grinding, enrichment, and pelletizing. The pellets, shown in Figure 4-9, have an N-P-K value of 1.7-0.69-0.36 but are then enriched with synthetic fertilizers, achieving an N-P-K value of 3-0.69-0.69 (Impraim 2014). Other synthetic fertilizers on the market, such as diammonium phosphate, have N-P-K values of 17-45-0 and sell for USD 0.53/kg, or USD 3.12/kg N (Robinson 2005). In order to compete with this, Fortifer will need to be sold for around USD 0.09/kg.

FIGURE 4-9 FORTIFER PELLETS

Centralized recovery of resources from waste sludge holds unique potential in Ghana due to the large amount of public toilets that require emptying. However, there is reason to be skeptical about whether or not composted sludge can compete with inorganic fertilizer on the market. Potential businesses should monitor the success of the Fortifer project as it enters its commercialization phase in 2014. Recovery of diverted urine may provide another avenue for profitable reuse of nutrients from waste, for urea has an N-P-K value of 45-0-0 (Chemical Land21 2013).

4.2.7. Ashesi University's Small-scale Wastewater Treatment System with Anaerobic Digestion

Ashesi University, located in Berekuso, Ghana in the Northern outskirts of Accra, constructed a small-scale, on-site wastewater treatment system in order to prevent their untreated wastewater from running downhill into the pineapple fields and water supply of the village of Berekuso. This wastewater treatment system features an 80 m^3 anaerobic waste digester, primary and secondary clarification tanks, an aeration tank, and two chlorination tanks. The recovered biogas is used to power cooking stoves in the kitchens of the Ashesi canteen, and the treated water is used as irrigation water for the campus gardens (Figure 4-10) (Annie 2014).

The Ashesi model of small-scale treatment and anaerobic digestion is not a cost-effective model but may be applicable for small private communities such as universities or higher-end neighborhoods. However, chemically enhanced primary treatment (CEPT) systems with UV or chlorine disinfection should be used instead in areas where irrigation and fertilization are the top priority. This is because the

Ashesi model was constructed for a capital cost of USD 72,000, and CEPT plants can typically be constructed for 55-60% of the cost of such a system. Also, the CEPT would preserve more of the nutrients in the wastewater, making it more valuable for irrigation (Murcott, Dunn, and Harleman 2009).

FIGURE 4-10 ASHESI'S METHANE COLLECTION BALLOON

4.3.Evaluation Matrix

In order to make recommendations for future sanitation projects and businesses that wish to utilize these innovations, it is important to compare these existing innovative sanitation technology options. This can most easily be done with the use of an evaluation matrix, which evaluates each technology according to a set of criteria and assigns scores to a number of factors within each criteria category for each technology. The Fortifer project and the Ashesi Treatment system were left out of this matrix because, as semi-centralized technologies, they cannot be effectively evaluated with the same criteria used to score decentralized technologies. Through a literature review of similar evaluation tools, criteria that are relevant to the scalability and success of decentralized sanitation technologies in Ghana were selected to be used in the evaluation matrix (Table 4-1).

TABLE 4-2 DECENTRALIZED SANITATION TECHNOLOGY EVALUATION MATRIX

Sanitation Technology Evaluation Matrix

	User Preference	Classification	Conducive to Cleanliness	Maintenance Required	User Satisfaction	Handicap Accessible	Sanitation Outcome Sub-Score
Pour Flush	N/A (apparent popularity amongst Ghanaians)	Yes, Water Seal	Non-Porous, but Squat-Style	Emptying Required	N/A	Squat	2
Biofil (Biofilcom)	47%	Yes, Water & Mech Seal	No Cleaning Chems, but Promotes HW	Removable Parts, Emptying	40	Sitting	1
Microflush (GSAP)	47%	Yes, Water & Mech Seal	No Cleaning Chemicals	Removable Parts, Emptying	40	Sitting	0
Clean Team Toilets	N/A (Apparent Rapid Adoption)	No, Bucket with Biocide	Ownership, Regular Cleaning	Frequent Waste Collection	N/A	Sitting, in-home	2
Microbial Fuel Cell Latrine	35%	No, Open Pit	Porous Surfaces, No Cleaning Chemicals	Emptying and Monitoring Required	46	Sitting	-6

	Single Unit Capital (USD)	Annual Operating Costs	Profitability of Resource Recovery	Durability/ Lifespan	Business/ Management Sub-Score
Pour Flush	1,450	Vacuum Truck Emptying	None	Concrete and Blocks, ~20yr Life	-2
Biofil (Biofilcom)	910	0	Very Small Amount of Compost	Concrete, Tile, and Blocks	1
Microflush (GSAP)	300	Emptying every three years	Small Amount of Compost	Wood, Plastic, and Concrete	3
Clean Team Toilets	200	Labor Costs	Currently None, but in Development	Plastic, Used Indoor	-2
Microbial Fuel Cell Latrine	2,900	Annual Emptying	Electricity Generation Unproven, Compost	Concrete and Blocks	0

	Environmental Impact	Electricity Dependence	Fate of Waste	Water Use On-Site	Technology Sub-Score	Final Score
Pour Flush	Not Recyclable	Except at Night	Emptying Needed	1-3 L	-4	-4
Biofil (Biofilcom)	Not Recyclable, Imported Materials	Except at Night	On-Site Composting	150 mL	1	3
Microflush (GSAP)	Not Recyclable, Local Materials	Except at Night	On-Site Composting	150 mL	4	7
Clean Team Toilets	Recyclable Plastic, but Glutaraldehyde	Except at Night	Biocide Stabilization, Collection Needed, Central Treatment	None	4	4
Microbial Fuel Cell Latrine	Not Recyclable, Local Materials	Independent in Theory, but Unproven	On-Site Composting	None	5	0

Key:						
	2	1	0	-1	-2	N/A

5. Feasibility Evaluation of Fired Brick Technology as a Construction Material and Income-Generating Industry in Northern Ghana

5.1. Project Context and Objective

Although Ghana has experienced increasingly stable democratic governance and is now classified as a lower middle income country by the World Bank, many development challenges persist (UNDP 2013). Poverty remains endemic in the country as economic growth has been primarily focused in extractive and capital intensive sectors, which do not have a direct poverty-reducing effect (UNDP 2013).

Poverty is particularly pronounced in the northern regions, where poverty rates are two to three times higher than the national average (IFAD, 2013). Although the largest of the ten regions of the country by landmass (Government of Ghana, 2013), the Northern Region is much less densely-populated than the southern portion of the country, in part due to a significantly drier climate whose landscape is characterized by grassland and savannah plains. The main economy is agriculture, however due to the dry climate, a lack of irrigation systems, and nutrient-poor soil, the growing season is short and usually limited to one harvest per year (Government of Ghana 2013).

The development of ancillary industries (other than agriculture) in the Northern Region that are less vulnerable to climate variations and seasonal limitations would provide increased stability and security for local communities. One such possible industry that could make use of abundant natural resources and the growth boom in Tamale and vicinity is fired brick manufacturing.

This thesis examines the potential for establishing a fired brick production capacity in the Northern Region of Ghana. Brick making is an industry that has been successful in the southern part of Ghana but no known manufacturing plants exist in the district of Tamale in the Northern Region. Pure Home Water (PHW), a Ghanaian non-profit organization based in Tamale, is keen to explore brick making as a potential extension to their community work and as a potential income-producing activity to support PHW's humanitarian work.

The evaluation of fired brick potential in the Northern Region comprises several components, including:

- Assessment of the quality and quantity of source clay material available;
- Evaluation of best practices for brick production; and
- Preliminary economic assessment.

The ultimate goal of the thesis is to produce a technical recommendation on whether a fired brick production capability at the PHW factory is feasible and sustainable for the local communities and if it can be a source of revenue to support PHW's goal of becoming financially and locally self-supporting.

5.2. Brick Making in Ghana

Several operating brick factories are known to exist in Ghana in the southern part of the country. Five factories were visited during the month of January 2014 and are indicated on Figure 5-1. The plants produce between 30,000 and 70,000 bricks per month using intermittent kiln technology and employ between 20 and 30 full time staff. Firewood is used to fire either clamp or downdraught kilns at four of the five plants; only one factory uses a combination of residual oil and firewood for firing.

FIGURE 5-8 - LOCATIONS OF EXISTING BRICK FACTORIES (MODIFIED FROM CIA, 2007)

5.3. Site Investigation

The surficial geology of Ghana is characterized by two distinct zones as shown in Figure 5-2. The southern part of the country is dominated by Forest Ochrosols and the northern part of the country is dominated by Savannah Ochrosols and Groundwater Laterites. Site investigations completed at the five PHW plots suggest that the soils at the five PHW plots are Savannah Ochrosols. No ironpan was observed in the soils, which is characteristic of the Groundwater Laterite great soil group. The presence of Savannah Ochrosols also suggests that the clay fraction of the soils is dominated by kaolinitic clays (Adjei-Gyapong and Asiamah 2002), which is promising for brick production.

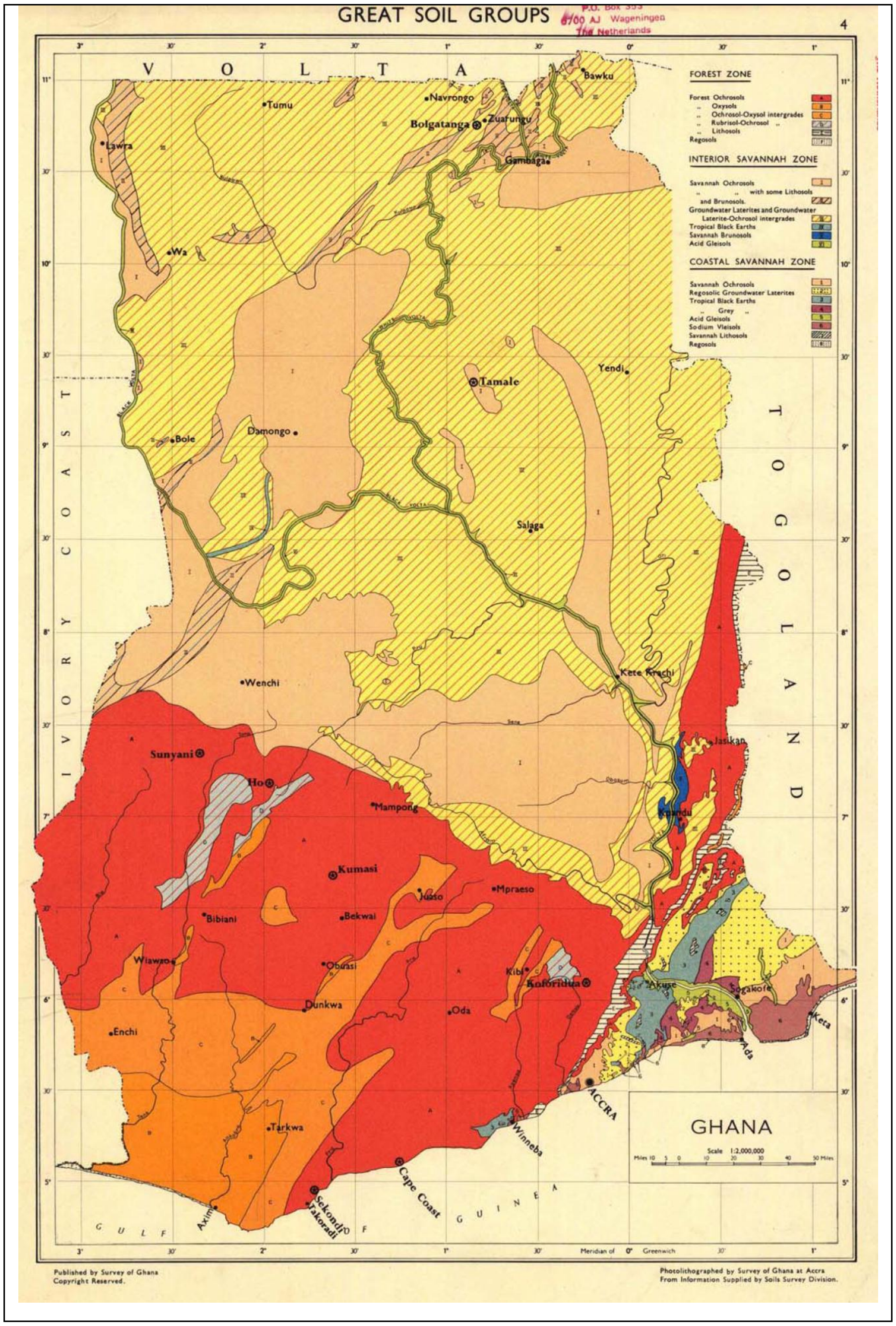


FIGURE 5- 9 - SOIL MAP OF GHANA (SURVEY OF GHANA, YEAR UNKNOWN)

5.4. Laboratory Testing

5.4.1. Moisture Content

Moisture content tests were performed on samples collected from all five PHW plots and three of the brick factories. As seen in Table 5-1, the average moisture contents of the soils at the brick factories are significantly higher than those of the PHW plot soils. This reflects the location of the sites: all of the PHW plots are located in the drier Northern Region and all of the brick factories are in the more tropical climate of southern Ghana. This difference in moisture content will affect how easily the soil is extracted from the ground and how much mechanical effort will be required to mix and temper the soil for brick making. The soils at the PHW plots will require more effort to reach the required consistency for moulding bricks.

TABLE 5-3 - AVERAGE MOISTURE CONTENT AT VARIOUS SITES

	PHW Plots					Brick Factories		
Site	**Gbalahi**	**Kpaumo**	**Wayemba**	**Gburma**	**Taha**	**Adams**	**Obeng 1**	**Obeng 2**
Average Moisture Content (%)	17	22	16	9	7	32	38	30

5.4.2. Atterberg Limits

Atterberg limit tests were completed on samples collected from all five PHW plots and four of the brick factories. As shown on the plasticity chart presented in Figure 5-3, all of the materials tested plot either as low plastic clays or as high plastic clays. The samples from the existing fired brick factories are generally observed to cluster in the centre of the data with liquid limit values between 37% and 58%. The samples from the PHW plots show a larger scatter and span liquid limits between 27% and 69%. The liquid limit and plasticity index values of the Gbalahi clay and Wayemba clay fall within the range of the values for the existing brick plants. This suggests that they display favourable properties for brick making using the technologies practiced in Ghana.

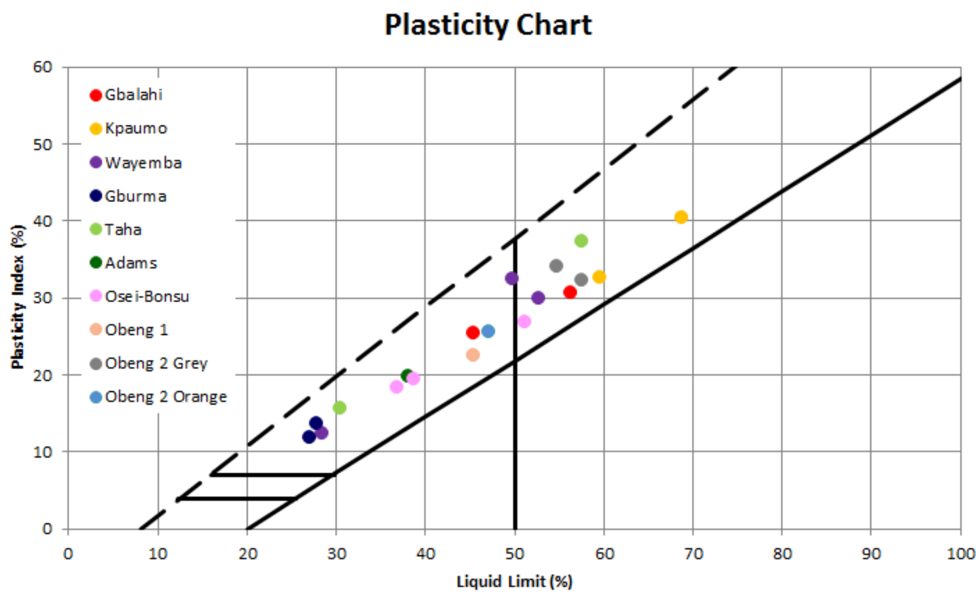


FIGURE 5-3 - PLASTICITY CHART SHOWING TESTED MATERIALS

5.4.3. Simple Sedimentation

Simple sedimentation tests were completed on samples collected from two of the PHW plots and three of the brick factories. Figure 5-4 below shows the grain size distribution curves for the six completed simple sedimentation tests. The six soils show relatively similar grain size distribution curves with clay percentages between 40% and 50%. This indicates that relatively little variation in grain size exists between the southern Ghana and northern Ghana soils.

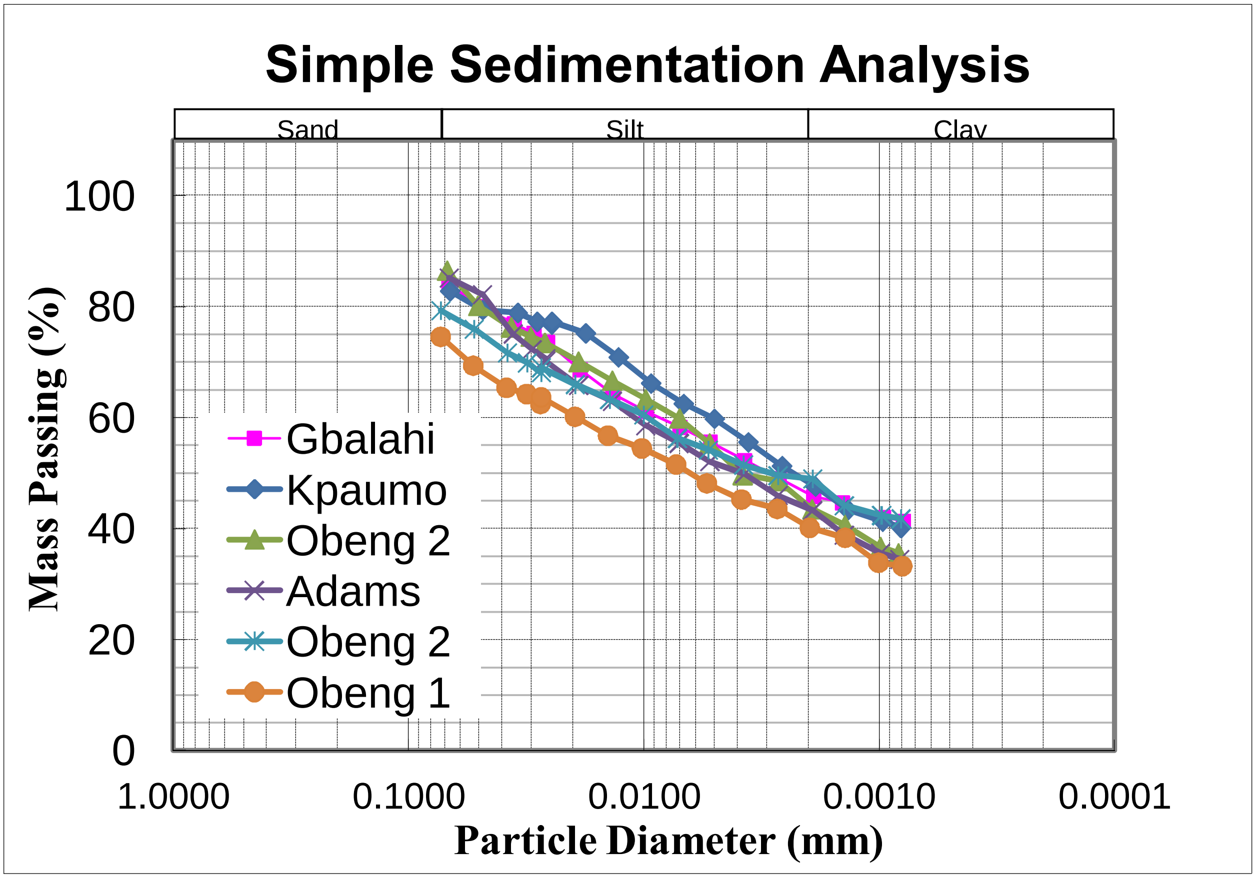


FIGURE 5-10 - GRAIN SIZE DISTRIBUTION CURVES FOR SIMPLE SEDIMENTATION ANALYSES

5.4.4. X-Ray Diffraction Testing

X-Ray diffraction testing to determine the mineralogy of the soils was completed on three samples from the PHW plots and four samples from the brick factories. Results show that all seven samples contain kaolinite and quartz; most also contain illite or muscovite. Smectite clays are also observed in both the PHW plot soils and the brick factory soils. Smectite clays are undesirable for brick production as they exhibit shrinking and swelling behavior due to their interaction with water, which can produce excessive shrinkage or deformation of bricks during drying and firing (Mueller, 2008). However, it is unlikely that the smectites are the major constituent of the soils as the liquid limit and plastic limit values are below the range of smectite-dominated materials. Table 5-2 below presents a summary of the X-Ray diffraction analyses.

TABLE 5-2 - SUMMARY OF RESULTS FROM X-RAY DIFFRACTION ANALYSES

	SITE	QUARTZ	KAOLINITE	ILLITE	MUSCOVITE	SMECTITE
PHW PLOTS	GBALAHI	YES	YES	YES	POSSIBLE	YES
	KPAUMO	YES	YES	YES	YES	YES
	WAYEMBA	YES	YES	LIKELY	YES	NO
BRICK FACTORIES	OSEI-BONSU	YES	YES	YES	POSSIBLE	POSSIBLE
	ADAMS	YES	YES	YES	POSSIBLE	POSSIBLE
	OBENG 1	YES	YES	LIKELY	YES	POSSIBLE
	OBENG 2	YES	YES	NO	NO	YES

5.4.5. Brick Testing

Brick samples were collected from the existing brick factories in Ghana for unconfined compressive strength testing. Test bricks were also made at MIT from soils collected from the PHW plots. Figure 5-5 below shows the results of the unconfined compressive strength testing for the various bricks. The compressive strength of the samples varied considerably from 4 MPa to 35 MPa. The results are difficult to interpret due to several inconsistencies between the samples. The bricks were made using different methods (some were hand moulded and some were mechanically extruded), a variety of kilns were used (clamp, downdraft, and electric), the bricks were dried under different conditions (some in Ghana and some at MIT), the brick geometries varied (some were solid, some had vertical holes, and some had horizontal holes), and the firing temperatures varied (ranging from approximately 830°C to 1200°C – 1300°C). However, some potential conclusions can be drawn from the data.

It is well documented in the literature that a higher firing temperature will produce bricks with a higher strength (Karaman, 2005). This trend is possibly observed in the compressive strength testing as shown in the dark brown and orange boxes in Figure 5-5. Hand moulded bricks tend to be of lower quality than mechanically extruded bricks. This trend is possibly observed in the compressive strength testing as shown in the purple and green boxes in Figure 5-5. The geometry of the bricks in relation to the direction of loading appears to influence the compressive strength. The bricks tested were solid, hollow with horizontal holes, or hollow with vertical holes. The hollow bricks with horizontal holes are outlined in pink in Figure 5-5 and show dramatically lower compressive strengths. Although further testing is required to confirm the above observations, preliminary results show that mechanically extruded bricks, fired at temperatures of approximately 1200°C to 1300°C, that are solid or have vertically aligned holes have the highest compressive strength.

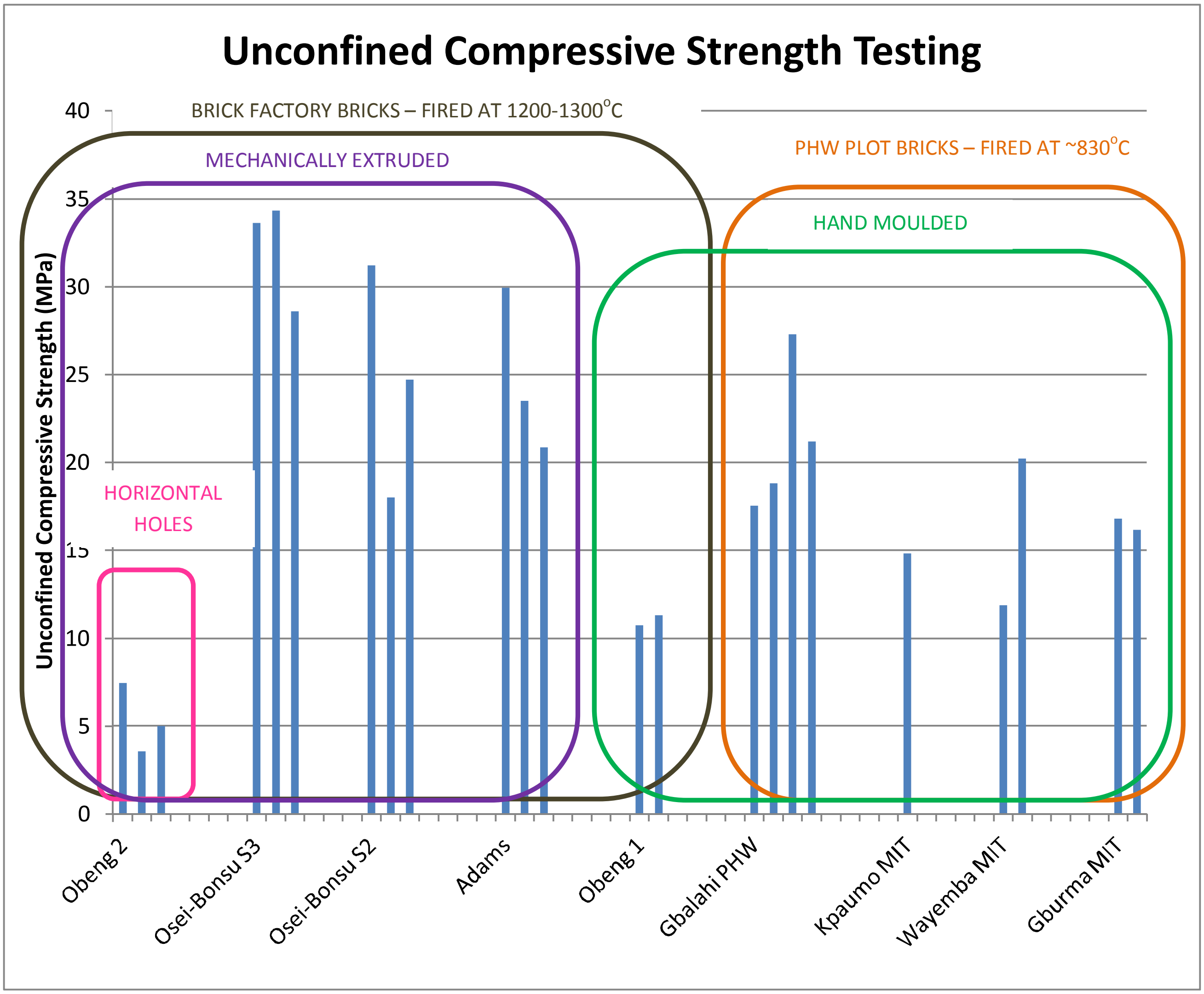


FIGURE 5-11 - RESULTS OF UCS TESTING

5.5. Clay Resource Evaluation

5.5.1. Quantity Estimate

The quantity of clay rich soil available for brick making is an essential consideration in evaluating the feasibility of brick production. Table 5-3 below provides an estimate of the number of years of brick production that could be undertaken at each of the five PHW plots using the following assumptions:

- A production rate of 40,000 bricks per month operating 12 months per year (estimated full operating capacity);
- A solid brick with the following dimensions: 12 cm x 7 cm x 23 cm = 1932 cm^3 = 0.06823 cu. ft; and
- A compaction factor of 0.2 (to account for compaction of the material during moulding) (Mueller, 2008).

TABLE 5-4 - CLAY RESOURCE QUANTITY ESTIMATE FOR PHW PLOTS

	Surface Area	Clay Deposit Thickness	Assumed Coverage	Volume	Years of Brick Production
Gbalahi	30 acres	2 ft.	100%	1,960,000 cu. ft.	47.9 years
Kpaumo	1.5 acre	2 ft.	100%	130,000 cu. ft.	3.2 years
Wayemba	1 acre	2 ft.	50%	45,000 cu. ft.	1.1 years
Gburma	10 acres	3 ft.	100%	1,310,000 cu. ft.	32.0 years
Taha	2.5 acres	1.5 ft.	50%	80,000 cu. ft.	2.0 years

The values presented in Table 5-3 show that the Gbalahi and Gburma plots have the greatest amount of material available due to their larger surface area. They could support brick production for several decades based on the assumptions given above. The Kpaumo, Wayemba, and Taha plots are much smaller and therefore could support only a few years of full brick production.

5.5.2. Evaluation Matrix

The suitability of the five PHW plots for brick production development was evaluated using the matrix provided in Table 5-4 below. Several different criteria were used in the assessment: a score of three was assigned for a favourable assessment; a score of two was assigned for a somewhat favourable assessment; and a score of one was assigned for an unfavourable assessment.

TABLE 5-5 - EVALUATION MATRIX OF PHW PLOTS

SITE	SOIL SUITABILITY	EASE OF BRICK PRODUCTION	APPROPRIATE LAND USE	RESOURCE SIZE	RESOURCE RELIABILITY	TOTAL SCORE	RANK
GBALAHI	3	3	3	3	1	13	1
KPAUMO	2	2	2	1	3	10	2
WAYEMBA	3	2	2	1	1	9	3
GBURMA	1	2	1	3	2	9	3
TAHA	1	2?	1	1	3	8	4
KEY: (1) UNFAVOURABLE (2) SOMEWHAT FAVOURABLE (3) FAVOURABLE							

The Gbalahi Plot scores considerably higher than the other plots and appears to be the most suitable plot for development as a clay borrow source to support brick production. It should be noted that all factors were weighed equally and the score was calculated using the arithmetic sum of the scores in each category. It could be argued that some factors are more important than others and that these should be assigned weightings, but this is difficult to judge. Should PHW consider certain factors more important than others, weightings could be applied and the plots could be reevaluated. No pilot bricks were made from the Taha soil and therefore a score was estimated from the soil characterization and behavior of the other soils during brick production.

5.6. Best Practices Evaluation of Brick Technology

Although there are many potential benefits to establishing a brick production capacity in the Northern Region of Ghana including job creation, industry development, and production of locally-sourced construction material, there are also significant environmental and social concerns associated with brick production. The firing process that imparts strength and durability to bricks is energy-intensive and contributes to global greenhouse gas emissions. Furthermore, small-scale brick production in low income countries tends to be very labour intensive with significant drudgery for workers.

Several improvements to existing brick technology in Ghana can be made to address the issue of high-energy consumption. Firstly, transitioning away from the less-energy efficient intermittent kiln technologies to more energy-efficient continuous kiln technologies can reduce fuel requirements substantially and improve environmental performance (Heierli, 2008). Secondly, hollow bricks contain less clay material than solid bricks, which also reduces the energy requirements for firing. Thirdly, incorporating internal fuel such as powdered coal, boiler ash, rice husk, or saw dust into the bricks improves brick quality, reduces particulate emissions, and decreases the amount of external fuel required (Heierli, 2008). Lastly, optimizing the firing temperature to maintain the required strength characteristics but reduce the maximum firing temperature could be investigated further at PHW to reduce fuel requirements and emissions.

Several of the labour-intensive tasks involved with brick production can be fully or partially mechanized to improve working conditions. The clay-rich soil can be extracted from the borrow source using an excavator or bulldozer; the soil can be mixed and kneaded using hammer mills and pug mills; the soil can be loaded into the mechanical extruder using a conveyor belt; mechanical extruders can be used instead of hand moulding; and certain kiln technologies use carts to load and unload bricks. However mechanization requires investment in equipment and facilities and would mean higher capital investment from PHW for brick production.

5.7. Preliminary Economic Assessment

A preliminary economic assessment completed for average full-scale monthly production shows that if full-scale brick production (40,000 bricks per month) can be achieved, the venture will be profitable with an estimated 35% profit on generated monthly revenue at a production cost of 0.31 Cedis per brick. However, several factors may influence the monthly cash flow. Firstly, the rainy season will likely affect brick production substantially. Access to the clay borrow pit will likely be much more difficult during the rainy season and the green bricks will take significantly longer to dry. Secondly, if a clamp kiln is used, firing will be affected as a clamp kiln is placed outdoors and is exposed to the elements. Thirdly, if full-scale brick production is achieved, the clay-rich soil will be required in large quantities and if the most promising source, the Gbalahi clay is used, it will likely no longer be available at no cost from the Gbalahi Village.

Given the preliminary economic assessment presented above, it appears that brick production is profitable but may be influenced by a number of seasonal and cultural factors that add risk to the business. It is concluded that PHW should be cautiously optimistic about pursuing brick production as a means to support their goal of becoming financially self-sustaining. Further economic evaluation is recommended to determine how different rates of brick production will influence the profitability of the business and how capital expenditures will affect cash flows.

5.8. Conclusions

The work presented in this thesis concludes that in the short-term, brick production using the standard technologies currently available in Ghana is technically feasible and will likely provide revenue to support PHW's goal of becoming locally and financially self-sustaining.

In particular, the Gbalahi Plot appears to be most suitable as a clay borrow source given the properties of the soil and the amount of material available. It is recommended that PHW secure access to the Gbalahi clay deposit to reduce their level of risk should brick production be undertaken.

Given the existing infrastructure available at the PHW filter factory and the rapid growth of Tamale and environs, PHW is well-poised to commence brick production using standard intermittent kiln technology with only minimal capital investment. However, for long-term environmental sustainability and workplace safety, alternative continuous kiln technologies should be considered to minimize energy requirements, emissions, and worker drudgery.

The preliminary economic assessment concludes that brick production is profitable but not extremely lucrative. Furthermore, substantial risks are inherent in the brick industry, including high working capital requirements, increased processing requirements of the source soil due to a lower moisture content than the soils in southern Ghana, substantially reduced production rates during the wet season, and a lack of local familiarity and demand for brick products.

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