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SOCIAL, ECONOMIC, AND TECHNICAL FEASIBILITY OF ABLUTION GRAY
WATER REUSE IN TONG, GHANA

By

Adrienne I. Masterton

A THESIS

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In Civil Engineering

MICHIGAN TECHNOLOGICAL UNIVERSITY

2017

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This thesis has been approved in partial fulfillment of the requirements for the Degree of
MASTER OF SCIENCE in Civil Engineering.

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Definitions

Ablution – the Muslim practice of rinsing the face, mouth, hands, and feet before prayer

Active "fetch" time – the time a user's full attention and energy is required in treating gray water

Active fetch time – the time a user's full attention and energy is required in fetching water from a given source; includes walking or driving to source, would not include waiting in line at a tap or waiting for a hired service to return with the water

AfriClay (AC) – a clay pot filter produced and sold in Tamale

B(ch) – boiling using charcoal

B(fw) – boiling using firewood

Borehole – a mechanically drilled well, typically much deeper than hand dug wells, with a pump device and protective features at the surface; used for both hand pumped and mechanically pumped boreholes

Cedis – the currency in Ghana, equivalent to 100 pesewas and to 0.23 USD in this report

Critical source – used in this report to identify the lowest quality water source that is used by at least half of survey respondents and is available through the entire dry season

Dam – used in this report synonymously with "reservoir," refers to the water contained by an earthen dam, not the dam structure itself

DRAW Chart – a graph providing information on cost, time, and social acceptability of existing dry season water sources for holistic comparison to gray water treatment options

Garawa – the Dagbanli word for a common kind of container that is essentially a large, cylindrical, metal bucket

Gray water – refers to the general definition in section 1 of water that does not contain a heavy amount of fecal matter, refers almost exclusively to ablution wastewater in sections 2-5

Gray water reuse potential – in this report, it is the percent of a household's total daily water consumption that is used for ablution as this amount is theoretically available for reuse

Household – refers to all the individuals, regardless of relation, that spend at least half the year overnighting at a given compound

Kettle – a small plastic container shaped like a tea pot most often used for pouring water into one’s hand during ablution

M(b) – moringa seed treatment using purchased seeds

M(o) – moringa seed treatment using seeds from one’s own tree

Moringa (M) – a tropical tree whose seeds have coagulant properties

Motorking – a three-wheeled vehicle that has a motorcycle front and a flatbed above the two rear wheels

Non-potable – refers to water that will be used for purposes that do not include ingestion, but may include water that meets potable standards

P>M Purifier of Water – also referred to as P>M packets, P>M powder, P>M, or World Vision packets; packaged powder used for quick water treatment including flocculent and disinfectant

Pesewas – unit of currency in Ghana equivalent to 1 Ghana cedi

PetrifilmsTM – portable, pre-prepared plastic films that can be used like petri dishes to incubate bacteria for the purposes of measuring water quality parameters

Polytank – a popular brand name that has become synonymous with large plastic water storage containers in Ghana

Proxy literacy rate – a rough measure of literacy using age groups and education attainment levels

Pure water – basically bottled water placed in a half-liter plastic pouch sold throughout Ghana

Shea – a tree native to Ghana and elsewhere from whose fruit’s pits shea butter is extracted

Wastewater – used synonymously with gray water here

World Vision – a large global charity that has been very active in the study site

List of abbreviations

AGW – Ablution gray water

ANC – Antenatal Clinic

CDC – United States Center for Disease Control and Prevention

Cfu – Colony forming unit

CHPS – Community Health Planning Services

CIA – united States Central Intelligence Agency

CSIR-WRI – Council for Scientific and Industrial Research – Water Research Institute

CWC – Child Welfare Clinic

DA – District Assembly

DRAW – Decision-making for the Reuse of Ablution Wastewater

GEPA – Ghana Environmental Protection Agency

GES – Ghana Education Service

GHG – Greenhouse Gases

GHS – Ghana Health Service

GHS – Ghana Cedi

GMA – Ghana Meteorological Agency

GoG – Government of Ghana

IRB – Institutional Review Board

JHS – Junior High School

JICA – Japan International Cooperation Agency

LPCD – Liters per capita per day, also l/c/d

MTU – Michigan Technological University

MWR – Ministry of Water Resources, Works and Housing

NGO – Non-governmental Organization

NHIS – National Health Insurance Scheme

OIC – Organisation of Islamic Cooperation

P&G – Procter and Gamble

PACA – Participatory Analysis for Community Action

PC – United States Peace Corps

PCV – Peace Corps Volunteer

RAC – Rapid Aerobic Count

SESRIC – Statistical, Economic and Social Research and Training Centre for Islamic Countries

TDS – Total dissolved solids

TSS – Total suspended solids

UN – United Nations

UNAIDS – Joint United Nations Programme on HIV/AIDS

UNEP – United Nations Environment Programme

UNICEF – United Nations Children’s Fund

UN-WWAP – United Nations World Water Assessment Programme

USD – United States Dollar

WHO – World Health Organization

Abstract

Water insecurity is a constant stressor for millions of people around the globe. The potential of gray water as an alternative water source has gained increasing attention in the literature. In water-scarce Muslim communities, the practice of ablution – the rinsing of the face, hands, and feet before prayer – offers a unique opportunity for gray water reuse.

This report investigates the feasibility of treating and reusing ablution gray water (AGW) with respect to religious acceptability, economic measures, and physical parameters in Tong, a rural community of Muslim subsistence farmers in northern Ghana. Investigatory tools included: household water use surveys, opinion leader interviews, wastewater collection prototype design, treatments identification and testing, and comparison to existing water sources. A Ghanaian-made clay pot filter, coagulation and settling using moringa tree seeds, and P&G™ Purifier of Water were the treatments tested. Results were analyzed and compiled into a holistic, visual assessment tool termed a “Decision-making for Reuse of Ablution Wastewater (DRAW) Chart.” DRAW charts are an improved performance measure as they compare water sources based not simply on binary quality and time standards but on a spectrum that includes collection time, monetary investment, social acceptability, and water quality. The DRAW charts developed for Tong, including both current dry season water sources and gray water treatment options, indicate AGW reuse could be socially acceptable, has potential to provide quality water, and would be financially competitive with existing sources. AGW quantities cannot completely alleviate water insecurity but can offer a relatively quick and affordable supplementary water source without external assistance or the risk of failure often associated with other water solutions such as borehole drilling.

The process used in this study and resultant DRAW charts can clarify the multifaceted complexities of water supply in water-insecure, financially disadvantaged communities beyond Tong. The development of DRAW charts for such communities provides community leaders and aid partners a clearer view of all aspects relevant to making water solution decisions and allowing more targeted and appropriate proposals under local budgetary constraints and norms.

1 Introduction

According to the United Nations Water's Water Facts, "Water is at the core of sustainable development and is critical for socio-economic development, healthy ecosystems and for human survival itself" (UN-Water, n.d.). In 2016, the World Economic Forum (WEF) predicted water crises to be the global risk of highest concern for the next 10 years, suggesting that despite the UN's declaration, water needs are not sufficiently addressed in many places around the globe (WEF, 2016).

The UN World Water Assessment Programme's (UN-WWAP) focused on wastewater in their 2017 World Water Development Report (UN-WWAP, 2017). They claim that over 80% of the world's wastewater enters the environment untreated. The associated pollution has implications for public health, ecosystems, industries that depend on natural systems, and affects drinking water sources. They recommend wastewater management policies include wastewater as an alternative water resource, a practice growing in interest but is not yet commonplace or readily accepted (UN-WWAP, 2017).

Figure 1.1 combines a global water scarcity map by Mekonnen and Hoekstra (2016) and statistics on locations of concentrations of Muslim populations provided by the Pew Research Center (2009). India, whose color indicates several months of water insecurity each year, has over 10% of the world's Muslim population. The Middle East and North Africa, experiencing 12 months of water scarcity in places, contain about 20% of the world's Muslim population, with many territories therein having populations that are 95% Muslim. These figures and statistics indicate that millions of Muslim communities suffer from water scarcity throughout the year.

Figure 1.1 Much of the world's Muslim population experiences multiple months of water scarcity. (adapted from (Mekonnen & Hoekstra, 2016), see 6A for full attribution and copyright licensing information)

Motivated by water insecurity in Tong, a rural, Muslim community in Ghana's Northern Region, the present study investigates the potential of a wastewater source unique to practitioners of Islam – ablution wastewater. Ablution is the practice of cleansing one's face, hands, and feet before prayers and typically occurs five times a day. As the following will detail, it is not realistic to attack the water scarcity problems in Tong with complex, expensive, or extensive infrastructure. During her own experiences and observations of Tong during two years of Peace Corps service there, the author began an investigation to estimate the feasibility of ablution gray water (AGW) reuse.

The investigation aimed to predict feasibility with respect to three components – social, economic, and technical. Specifically, the study would:

- Determine the effect of ablution on water quality
- Estimate the volume of water made available by AGW reuse
- Identify locally available treatments and test their ability to treat AGW
- Compare the cost and time involvement of AGW treatment to the cost and time involvement of existing water resources
- Determine whether people in Tong are willing to collect, treat, and reuse AGW given the existing religious and cultural setting

The following subsections describe information relevant to experiment design decisions and interpretations of results. Because the definition and measures of “feasible” are highly local, the context for the current study is extremely important and will be described first. Following that, existing research on gray water reuse will be summarized and gaps identified.

1.1 Ghana, West Africa

Ghana is a country of about 28 million people in sub-Saharan West Africa. As shown in Figure 1.2, it is bordered by Côte d'Ivoire to the west, Burkina Faso to the north, Togo to the east, and the Gulf of Guinea to the south. Once a colony of England, it has been independent and relatively politically and economically stable since its founding in 1957. Its capital is Accra, a city of more than 2 million people on the eastern coast. It is divided into ten regions, which are further divided into districts. Ghana's currency is the Ghana cedi, currency sign GHS, equivalent to 0.23 USD at the time of writing.

Figure 1.2 Map of Ghana showing neighboring countries, major cities, and major bodies of water. (US Department of State, n.d. See Appendix A for full attribution and copyright licensing information.)

Ghana's population is diverse in ethnicity, religion, and language. The Central Intelligence Agency (CIA) lists the most predominant ethnicities as the Akan, Mole-Dagbon, Ewe, and Ga-Dangme (2017). Ghana is about 71% Christian and 18% Muslim; the remaining 11% of Ghanaians practice either traditional religions or no religion (CIA, 2017). Though English is the official language, there are nine government-sponsored languages (meaning they have a formalized written language and are taught in government schools), and a conservative estimate of 40 languages total (Commisceo Global, 2017).

Across all groups in Ghana, the family is hugely important, typically taking precedence over all other obligations (Commisceo Global, 2017). Honor and shame are often associated with an entire family rather than a specific individual. Hierarchies within and external to families are also important. Decisions are often deferred to the person most advanced in age (Commisceo Global, 2017). Ghanaian culture is also very gendered. Women's duties revolve around the children and the home, while men's duties revolve around providing for and protecting the family.

CIA (2017) estimates 73% of Ghanaians have access to electricity, though blackouts are frequent. Ghanaians can travel relatively freely via the ten airports, tens of thousands of miles of roadways, or maritime vessels, especially in the Volta River basin (CIA, 2017).

Education, consisting of primary, junior high, and senior high schools, is free of charge at public schools, but quality varies greatly. All Ghanaians are eligible for free healthcare under the National Health Insurance Scheme (NHIS), but again, depending on location, quality of care varies. Though many other diseases such as hepatitis and meningitis still affect many Ghanaians, Guinea worm was eradicated in 2015 (WHO, 2015) and the HIV/AIDS prevalence rate among adults aged 15-49 years old is much lower in Ghana (1.6%) than the region (9%) (UNAIDS, 2016). Sanitation facilities are nonexistent in many parts of Ghana. Only about 14% of Ghanaians have access to improved sanitation, depending on geographic location and population density (WHO, 2015). As of 2015, over 87% of Ghanaians have access to drinking water from improved sources. Again, there is a rural-urban disparity – of the 13% without access to safe drinking water, almost 70% are rural (WHO, 2015).

1.2 Tong, Northern Region

Tong is a town of about 1,600 people in the Karaga District of Ghana's Northern Region. As shown in Figure 1.3. below, Tong is located about 45 miles northeast of Tamale, the regional capital, and about 3.3 miles west of Karaga, the district capital. The people are primarily Muslim subsistence farmers. The following sections detail characteristics about Tong as personally observed by the author and explained by people in Tong.

Figure 1.3 Map of Ghana showing location of Tong, the study site, northeast of the regional capital Tamale. Inset shows Tong, the district capital Karaga, and main roads. (Map data: Google, 2017, see Appendix A for full attribution and copyright licensing information.)

1.2.1 Culture

Most people in Tong belong to the Dagomba tribe, a sub tribe of the Mole-Dagbon who make up a large portion of the Northern Region's population. A few other tribes are present in small and scattered numbers, usually due to marriage or employment. There are also a few families of a nomadic group of people called the Foolani. These families live in the outskirts of Tong, as their primary occupation is cattle herding and requires more space than the tight cluster of homes in Tong can provide.

Almost everyone speaks Dagbanli, the language of the Dagomba. The author estimates more than 95% of Tong are native speakers. Besides Dagbanli, a handful of residents know other languages, typically depending on occupation. Many businessmen also know Twi, a widely spoken indigenous language in Ghana, or Hausa, a Sub-Saharan lingua franca. Many of the religious leaders speak, read, and/or write Arabic. There are English-speakers of varying levels of fluency with teachers, nurses, the chief, and a few others conversing nearly fluently.

The hierarchy of Tong follows that of the Dagomba tribe. The Dagomba king resides in Yendi, 95 km southeast of Tong. Then there is a regent in Karaga. Tong has its own chief, selected and approved by the king, regent, and local elders. The current chief is Chief Andani, locally called "Naa" (Dagbanli for "chief") or "Selichi" (Hausa for "chief"). He is selected from a certain lineage, and has sub-chiefs in a few of the surrounding communities, and elders, assistants, and warriors in Tong.

The Chief serves as arbiter of all arguments and decides punishment for infractions. He is considered the owner of all the land. Nobody purchases property from each other, rather, if there is unused land, they ask the chief if they can use it. Generally, the wish is granted with some sort of payment to the chief either in gifts like guinea fowl, yams, or labor at his farm.

The chief's word is law, and thus if the chief does not agree to something, one cannot reasonably expect residents to defy him. Community members exhibit a high degree of agency as most day-to-day happenings do not require consultation with the chief. Even more significant community decisions can occur without the chief's approval as he is often called away from Tong. The author consulted with the chief frequently when he was in town, but felt the freedom to move ahead with projects when he was traveling.

The Dagomba, like many cultures, use dancing and drumming in many ceremonies and festivals. Weddings, naming ceremonies, funerals, and other major life moments are marked with drumming and dancing. Meetings are always called with drumming and begin with dancing. Drumming at the chief's palace means the chief is needed there.

Tong's residents are overwhelmingly Muslim, with perhaps only some Foolani and visiting professionals like the nurses practicing a different religion. There are several mosques in town, but the largest one is on the main street in the center of town. For holidays the community will typically go to the school grounds for prayers.

The religion has a hierarchy separate from the Dagomba power structure. The chief imam is the religious leader of the town, but each mosque has its own imam. The muezzins call the prayers. These men are well respected, carry a lot of clout in community decisions, and often hold leadership roles in other community organizations. Informal religious leaders include the Al Hajji, a man respected for his completion of the pilgrimage to Mecca, the karimbanema, tasked with teaching youth the religion and its morals, and other families highly respected for their general devotion and good works. For example, the author's colleague's family is often sought to consult on a variety of issues in the community.

In the Dagomba and Islamic tradition, gender roles are very important and distinct. Women pray in a separate section of the mosque and cannot call the prayers. Clothing and acceptable behavior and expected duties run along gender lines. Women wear head coverings, long skirts, and almost always have a top that covers the shoulders when out in public. Men typically wear long pants and a long shirt, and often times wear a hat, though this is not necessary. The traditional clothing for men also includes leather boots and a large, baggy shirt made of strips of thick, hand-woven cloth called a smock. These traditional garments are mostly utilized in dancing at formal ceremonies.

Like clothing, duties are very different between genders, and fairly strictly adhered to. Women are generally responsible for the domestic sphere – child rearing, cooking, cleaning, fetching water, etc. Petty trading, selling of produce, and shea butter production is dominated by women. Men's duties revolve around providing for the family. They are typically head of household, tasked with making decisions about money, farming, hunting, and income generating activities. Driving of motorized vehicles is almost exclusively done by men.

1.2.2 Economy

According to the Ghana Statistical Service, of all people over the age of 15 almost 94% work in small scale farming, fishing or forestry, about 2% work as trades or crafts people, and less than 0.1% work as professional, clerical associates (Ghana Statistical Service, 2014). From the author's observation, Tong fits its District average. Everyone farms, even teachers and business owners. There are a few tailors, mechanics, carpenters, masons, and storeowners. Some people also do petty trading, walking around town and selling bouillon cubes, gum, and the like from a plate carried atop their head.

Farming occurs in one season as the rainfall pattern and soil type can only sustain one planting a year. The main crops grown are peanuts, maize, yams, millet, soybeans, and hot peppers. Farms surround the concentration of homes; some are fairly close, but many are an hour walk away. Most farmers hire a tractor to till the soil at the beginning of the season, but beyond that most work is done by the farmer, family, and friends. Though fertilizer is expensive, most families will purchase some to fertilize at least a portion of their fields. Many families have gardens near their homes to grow cash crops, like tobacco, or supplemental vegetables like tomatoes. Everything in Tong – religious, cultural, and economic activities – revolves around the agricultural cycle. For example, burials happen according to Muslim custom within 24 hours of death, but almost all funerals occur in January or February when families have sold their crop and have money for a fitting funeral.

Other income is earned from the harvesting of wild plants or animals. Hunters sell a lot of their kill so local food sellers can add meat to their menu. Many people collect shea fruit to eat the fruit and then process the pits to make and sell shea butter (Figure 1.4). Most of the shea butter produced is sold locally or regionally as a cooking oil. Some NGOs and fair trade organizations buy high quality shea butter for export for use in lotions.

Figure 1.4 Shea tree fruits are collected, boiled, dried, roasted, shelled, and then milled into a paste as shown, prior to separation. (Author)

1.2.3 Energy

Tong has electricity, but they experience frequent disruptions. Typically, the power company cuts off the power at least once a week for a few hours to manage the demand/supply gap during what Ghanaians call “Dumsor Dumsor.” In other cases, power is cut off for maintenance or due to late payments. Most homes have at least one light bulb and at least one outlet to run a fan or charge a phone. There are also a few mills throughout town where people can mechanically mill crops into flour or paste.

Off-grid energy includes solar power and organic fuels. Tong’s borehole pump is powered by a large solar array. There is diesel for most motorized vehicles as well as generators for when power is out for extended periods. For cooking, almost all people in Tong use charcoal or wood. Small coal pots are typically used when cooking smaller quantities, such as for tea, or for just keeping a room warm. Firewood is collected from the surrounding bush and carried, usually by women, back to the house to heat food, bath water, and shea fruits during processing.

1.2.4 Transportation

The main road runs east-west through town. There are daily buses going between Karaga and Tamale that pass through Tong. There are also Motorkings that take cargo or passengers. Motorkings are three-wheeled vehicles driven by a motorcycle-like front end that pulls a small flatbed. Some people own motorcycles; only the chief owns a four wheeled vehicle. The majority of people ride a bicycle, walk, or hitch rides pretty much everywhere. Beyond the main road, there are foot paths that pedestrians, cyclists and motorcyclists use to get to more remote destinations.

The main road is a packed dirt road. During rainy season, the rain creates large rivulets. Because Tong is on a hill, the low portions to the east and west fill with very loose sand and silt. Cyclists, motorcyclists, and buses are sometimes forced to walk or ditch their vehicle. In wetter-than-average rainy seasons, the road in Tong floods.

1.2.5 Education

Tong has both a primary school and a junior high school. According to the primary school headmaster, over 300 children are registered at the primary school. Close to one hundred students are registered at the junior high school according to the author’s classroom counts. Subjects covered in the curriculum include English, math, science, information technology, religious morals and ethics, and physical education.

The quality of the education is poor. Teachers are often late or absent altogether. Because most of the teachers and students are Muslim, instruction typically ends by noon or earlier on Fridays, the Islamic holy day. Typically, kids will arrive for the free lunch and snacks and then leave. Many parents are not happy with the teachers or school’s performance, but they fear if they complain the teachers will be reassigned and not replaced.

Oftentimes if children are not sent to school it is because they have household duties. Because these duties fall disproportionately on females, girl children are more likely to be kept out of school. Even for girls go to school, it is often disrupted by having to fetch water for the school hand wash stations or for the teachers' personal use. After school activities offered to a female student often go unutilized as their parents need them to help with household chores that may have gone unfinished while the girl was at school.

1.2.6 Health

Tong has a Community Health Planning and Services (CHPS) clinic. One to three nurses staff the clinic, but not all of them speak Dagbanli. To assist with language issues, there are a couple Tong residents who serve as Community Health Volunteers. The main activities of the clinic, nurses, and volunteers are the weekly Child Welfare Clinic (CWC), where children can get vaccinations and vitamins, and the Antenatal Clinic (ANC), where pregnant women are given presumptive treatments and a checkup. Though these services are free, many women do not come or bring their children for a variety of reasons including too much housework.

According to the nurses, some of the biggest health problems in Tong are ones similar throughout Ghana. Diarrhea among young kids is a very common reason people visit the clinic. Malaria is the most common complaint during rainy season. For the very young children that come to the CWC, malnutrition is sometimes an issue. Because many people do not bring their children to the monthly checkups, though, there is likely a higher incidence of malnutrition than what is seen at CWCs.

1.2.7 Sanitation

Sanitation in Tong, like much of rural Ghana, is insufficient. Charitable organizations, local and regional government agencies, and the author have attempted projects to address the issue, but have had little success. An NGO had provided the town about 20 deep, concrete-lined pits and concrete slabs, the most costly part of a latrine. No one in Tong ever built the above ground portions, and the pits have simply sat and accumulated garbage and dust. As of early 2017, the author estimates perhaps 10% of Tong has access to a household latrine.

There are male and female latrines at the school, but they are in bad shape because maintenance is poor and students do not use them properly. The interiors are filthy as they do not get cleaned. The vault that holds the feces extends beyond the back of the superstructure and thus requires a concrete covering. This covering has crumbled and fallen-in in many places making it unsanitary. Despite their condition, there are some community members who regularly use them since they were taught latrines were more sanitary than going in the bush.

1.2.8 Water Resources

1.2.8.1 Rainwater

Northern Ghana's dry season occurs from November through April. The rainy season begins slowly in May, peaks in August and September, and then begins to drawn down in October. The Ghana Meteorological agency (GMA) states the total seasonal precipitation for the Northern Region averages 740-1230mm (GMA, 2016). Tong water options are largely dependent this precipitation cycle. Monthly rainfall averages are shown Figure 1.5 below. November through January are the coldest months. This season, Harmatan, is cooler due to the amount of dust in the air as prevailing winds change direction.

Figure 1.5 Average monthly rainfall for the grid cell containing Tong based on GMA's gauge and remote sensing data between 1983 and 2014. (Adapted from (GMA, n.d.) See Appendix A for full attribution and copyright licensing information.)

During rainy season, rainwater provides pretty much all water needed. It is collected a bit haphazardly but sufficiently. People rush home from farm or prayer as a storm approaches and then quickly open all water containers and gather all available buckets, basins, and tubs to place under the eaves, as shown in Figure 1.6. All but two homes in Tong have corrugated zinc roofing to efficiently collect rainwater. Homes without zinc collect rainwater from their neighbors during and after a storm. Most households use a manual first flush system meaning rainwater goes uncollected until the roof runoff is clear. In addition to collecting the rainwater for storage, many people perform water-intensive chores such as laundry, washing dishes, or bathing while the rain comes down.

Figure 1.6 Rainwater harvesting at a home in Tong consists of placing containers under the eaves. It typically includes a manual first flush. (Author)

Rainwater harvesting systems, comprised of zinc roofing and gutters and a plastic storage tank on a concrete footing, are present at the two schools. Both systems have failed. One of tank has a puncture, and both tanks are missing the spigot. The gutters have also been damaged and not repaired, decreasing the efficiency of rainwater capture (Figure 1.7).

Figure 1.7 Rainwater harvesting systems were provided for the schools in Tong. However, lack of maintenance has limited their usefulness. (Author)

Rainwater is typically used without any treatment. Many researchers question the quality of rainwater collected from rooftops, stored, and used without treatment (Achadu et al, 2013; Chidamba, 2015). Residents likely notice a difference in quality over time; the author witnessed her host mother emptying containers of water when it was clear the incoming storm would refill them, clearly preferring the fresh rainwater. Most households dedicate certain containers to rainwater such that no mixing with well water occurs, protecting rainwater quality.

Should a household run out of rainwater, they can seek the key holder for the public taps and collect borehole water. This is very rarely done because typically there is enough rainwater and well water during rainy season.

1.2.8.2 Groundwater

The author estimates about 30 hand dug wells are spread throughout town. They are fairly shallow and provide water only from about July through December. As such, they primarily supplement rainwater during the tail end of rainy season. Many are reinforced with timber, but because the surface is open, dust and debris regularly fall in. Typically each household will come with their own rope and bucket to fetch, as shown in Figure 1.8, increasing the risk of contamination.

Figure 1.8 Hand dug wells, a source in rainy season and the beginning of dry season, are often reinforced with timber and packed dirt. People collect water using their own buckets and ropes. (Author)

About 2.25 km north of Tong there is a naturally occurring cistern. During rainy season this fills to the brim, and serves as an additional water source for the people of Tong. As the rains stop and the water level drops, collecting water here can be time consuming and precarious. The low point of the cavern is not directly under the surface opening, so when water levels are low, throwing in a bucket on a string does not work. At this point, people place a large branch with knobs down vertically into the cistern to climb down into it as if on a ladder. This process and incoming surface flow likely contaminate the water. This source is used mostly for laundry by carrying clothes to the site and washing. By January, this source is dry.

There are a couple developed wells in Tong, meaning they have a concrete lining and some kind of structure at the surface to help protect the quality of the water. One is near the southwest edge of town; the other is about 2.3 km from the center of town on the Karaga Road. Visually, the water is clearer than surface sources, but not notably better than the hand dug well water. These wells last until about the end of January. Despite being designed to house a pulley and rope (Figure 1.9), most people bring their own bucket and rope for fetching the water.

Figure 1.9 A protected well located east of town on near the main road. Protection includes concrete lining and surface structure but the collection method no longer functions. (Author)

In 2014, UNICEF drilled a productive well and mechanized the system. The borehole is located about 2 kilometers south of Tong. Its solar-powered submersible pump pushes the water back towards town into two 10,000 L Polytanks approximately 7-8 m high (Figure 1.10). According to UNICEF staff and the pump installation contractor, if the borehole is not providing enough water, then the pump and tank size were based on sustainable yield. They could not provide documentation to support this, but considering the geology of the area, fissures in the rock rather than porosity between soil grains likely feed the borehole. This likely leads to minimal storage size and slow refill. This may explain why past handpump boreholes went dry, too. Being human powered, they were not restricted to a certain daily allotment, and likely overwithdrew from the source.

Figure 1.10 Solar panels near the borehole power the pump (left). Water is pumped up to two 10,000 L tanks set on a metal tube tower in central Tong (right). (Author)

From the tanks, water flows by gravity to four taps in Tong. Users are charged 0.10 GHS, or about \$0.02 USD for a container, typically 20-50 liters. In order to turn on the tap, users must get the key from the “*Kwomlana*,” the woman in charge of that tap. Oftentimes, in rainy season, the key and money collection jar simply sit out at the tap for the few people who require borehole water. During the dry season, the taps are only open when the tanks are filled and run for a few hours until the tanks empty. It is largely first come, first served, although typically a household will not be allowed to collect two days in a row. As such, dry season often sees containers lined up next to a tap (Figure 1.11). Once the tap is opened, the women will come and wait to get water. This can take a very long time and can be quite contentious.

Figure 1.11 Though Tong benefits from a mechanized borehole, water is not available at all hours. Women must mark their place in line with empty containers hours before the taps open. (Author)

From the author's experience the borehole is relatively well managed. A water committee was organized when the borehole was installed. This committee no longer meets, but the rules they established have lasted and helped maintain the borehole to some degree. Fees are regularly collected and accumulate into savings for repairs. For smaller repairs, they use the savings to hire mechanics and purchase minor parts. The savings are often insufficient for larger issues, but are typically enough to provide a community contribution to leverage funds from charities such as UNICEF and World Vision. Such processes still take time, but compared to other communities, Tong exercises fairly successful management. The *Kwomlana* is responsible for maintenance and cleaning, such as daily sweeping and mopping.

Due to the quality of borehole water, Tong's proven ability to maintain a borehole, and Tong's request for additional boreholes, World Vision has drilled several more boreholes. Unfortunately, as of this writing, each attempt has failed with respect to yield or quality.

1.2.8.3 Surface Water

There are two clay-lined reservoirs, dugouts, or dams, as they may be referred to in Ghanaian English. These were built by a charity or possibly the government several years ago, but no one in Tong could clearly recall. Tong's dam was constructed a little more than 2 km south of the town. Tong's neighbor community, Langagu/Gbutugu, or simply "Gbutugu" for the remainder of this report, was given a smaller one east of their town. Both towns and both dams are shown in Figure 1.12 below. Since Gbutugu has received boreholes, they rarely go to their dam and allow Tong residents to use theirs as needed.

Figure 1.12 Map showing communities and their dams. Both dams are more than 2 km from Tong. (Adapted from map data by Google (2017) with image from DigitalGlobe, (2017). See Appendix A for full attribution and copyright licensing information.)

Cattle, donkeys, goats, and other animals walk into the dam daily to drink. Soils in the area are very silty making the water in both dams extremely turbid. The Tong dam seems less turbid than the Gbutugu dam water (Figure 1.13), but both are still nontransparent. Nonetheless, people consume dam water regularly throughout dry season.

Figure 1.13 The visibility of the submerged fingers suggest Tong dam (right) is slightly less turbid than Gbutugu dam (left). (Author)

Though these dams provide a large proportion of water during the dry season, they still get dangerously low. Figure 1.14 **Error! Reference source not found.** shows the Gbutugu dam water level through the year.

Figure 1.14 From upper left moving clockwise, the Gbutugu reservoir in July, February and May. Note the water level with regards to the large tree in the upper left of each image. (Author)

1.2.8.4 Pure Water Sachets

“Pure water sachets” are water drawn from the dam in Karaga that is treated and packaged under hygienic conditions. They are sold in half-liter plastic pouches like the one shown in Figure 1.15. This water is of very good quality, can usually be purchased cold, and costs about 0.15-0.20 GHS depending on the number of sachets purchased.

Figure 1.15 A pure water sachet is a half-liter pouch of filtered and disinfected water commonly sold and consumed cold. (Author)

1.3 Project Motivation

The detailed knowledge of Tong, its culture, infrastructure, and people came heavily from personal observations, conversations, and experiences during everyday life as a Peace Corps volunteer in Tong. These understandings were supplemented by a formal tool employed by Peace Corps volunteers called Participatory Analysis for Community Action (PACA). Through a series of PACA meetings, the residents of Tong listed their assets and resources, mapped their community, described their daily and annual activities, and discussed issues in Tong that people hoped to address. Through priority ranking, in which residents prioritize all issues one-to-one and then see which issue is favored most, the residents unanimously selected water as the highest priority.

Through subsequent meetings, existing water sources and current efforts to address water issues were described as above. The most desired solution was another borehole. Unfortunately, the budget of a Peace Corps Volunteer makes a borehole a very difficult project. Further, the geology in the area makes boreholes very risky, as evidenced by the dozen or so failed attempts of World Vision. Larger scale, long-term rainwater storage was also considered. Following discussions with other aid organizations who have attempted rainwater harvesting projects and considering the length and severity of dry season, this option was eliminated.

Due to the extremely limited physical financial realities in Tong greater efficiency with existing sources was pursued rather than seeking an additional source. Specifically the

author considered gray water, reuse as the most promising option to improve conservation of existing water sources.

1.3.1 Gray Water Literature Review

Literature on gray water was researched to target how Tong may best employ the concept of reuse. The following subsections summarize definitions, quality and quantity of gray water, existing regulations, and treatment options commonly covered by researchers. It then concludes with a discussion of how current research is useful but limited in creating a system for Tong, and thus required the investigation of this report.

1.3.1.1 Definition

Many terms exist for gray water including “gray water,” “grey water,” “greywater,” “recycled water,” and “reclaimed water” just to name a few. This report will use the spelling “gray water,” unless quoting studies that use a different variation on the spelling. Related terms like “recaptured” or “reclaimed” refer to gray water that is intended for or has been put to a second use.

There is also a wide variety of what qualifies as gray water. Most studies agree that gray water is wastewater with none to trace amounts of fecal matter. Some researchers impose additional restrictions because of the expectation of too much fecal matter, perhaps excluding bathing wastewater. Other researchers will restrict the definition based on what is applicable to their area of interest, for example industrial applications may have a very specific wastewater under consideration. For the purposes of providing background to the reader, this section will discuss gray water with respect to the broadest definition.

1.3.1.2 Quality

The composition of gray water can vary greatly. Pollutant types and concentrations depend on the source of wastewater, such as industrial, commercial, and domestic. Household wastewater pollutant levels and types also range a significant degree. Uses like bathing and washing introduce soaps and surfactants. Water uses that involve a significant amount of contact with the human body may contain oils from skin and trace amounts of biological contaminants. Edwin, Gopalsamy, and Muthu (2013) claim that wastewater from washing dishes has a large amount of fats, oils, grease, and food particles making it “less favorable for reuse due to its high concentration of pollutant load” (p. 40).

Gray water quality depends on makeup of the household, as well. “The number, lifestyle, age, presence of children, health status and water usage patterns of the occupants are found to affect the characteristics of [gray water] generated in a household” (Edwin et al., 2013, p. 40). Consumer habits such as types of soaps, detergents, toothpastes, and dyes

purchased will eventually enter household gray water. The household's access to water impacts gray water composition, as higher per capita water consumption will result in more diluted gray water. The degree of contamination in the original source used by occupants affects the quality of gray water (Edwin et al., 2013).

The effects of storage time on gray water quality are widely agreed upon regardless of use. Though many accept the microbiological contamination in gray water from domestic uses is relatively minimal, (Mara and Kramer, 2008, as cited in Edwin et al., 2013), "it favors the growth of microbes and can turn anoxic, emanating foul odor if left untreated for more hours" (Edwin et al., 2013, p. 40). The storage time should be limited, as longer time facilitates the growth of microbial contaminants.

1.3.1.3 Quantity

Understandably, the quantity of gray water also differs greatly between sources. Industrial water consumption and wastewater production volumes are large by nature. At the household level, the specific use and habits of occupants will impact the quantity available. Broader community characteristics play a role as well. More arid regions tend to be more conservative in water use and may have formal management practices in place to ensure conservation of water resources, which may further affect gray water production (Hranova, 2010). Economic status can also affect the gray water quantities produced. Though many estimate higher-income families would consume more water and thus produce more gray water, Haque (2010) found that of the 100 households surveyed, the medium income households produced more gray water than higher income households. The cost, in time and money, likely play a role in water consumption and associated gray water production. In places that get charged for water use, like most municipal service areas as in Haque's 2010 study, income may have different effects on gray water production than in places where water is collected for free. Like the quality of gray water, the quantity of gray water produced is variable and not readily predictable based on a given parameter. Some researchers do provide a range of values, such as Edwin et al., citing a combination of sources who claim that "[Gray water] is considered to be the largest potential source of water reuse option at point source, accounting for around 50–80% of the total water use" (Christova-Boal et al. 1996; Eriksson et al. 2002; Jamrah et al. 2006, as cited in Edwin et al., 2013). Collecting water here can be time consuming and precarious

1.3.1.4 Acceptable Reuse

Another important aspect of gray water reuse is the determination of acceptable second uses. Many jurisdictions have regulations legally restricting the use of gray water, treated or untreated, based on multiple measures. The US Environmental Protection Agency's Guidelines for Water Reuse's Table 4-5 (p.4-18-4-20) provides an excellent summary of American states' regulations (Bastian & Murray, 2012). Most include biological markers

like *E. coli*, metals, suspended solids, and nutrient quantities in their policies. Several organizations also provide guideline values for gray water reuse (Bastian & Murray, 2012; WHO, 2017). Though most regulatory values are primarily based on scientific and statistical predictions of acceptable public health risks, most also account for public perception of what is acceptable, including appearance and odor. The values that delineate acceptable and unacceptable quality also differ depending on the intended second use.

1.3.1.5 Treatment

As viable treatment options depend on the varying quantities, qualities, and intended second uses, they inherently also vary on the location, household incomes, original water source, and occupant lifestyles. Generally, these treatments can be categorized as centralized and decentralized. Most centralized systems are operated by a utility company and wide scale management, such as Namibia's New Goreangab Water Reclamation Plant that was providing 26% of Windhoek consumers' water supply as early as 2004 (Lahnsteiner & Lempert, 2007). Most decentralized systems are designed for individual households, such as those studied by Haque (2012). The specific treatments studied have often included: coagulation, flocculation, chlorination, sand filtration, ultrafiltration, constructed wetlands, and ready-made treatment units. Regardless of use or direct release, many developing countries lack the regulatory and enforcing governance to manage and enforce gray water treatment (UN-WWAP, 2017). In these instances, gray water is likely used or expelled at the owner's discretion without any kind of treatment or second use.

1.3.2 Purpose of This Study

Though these studies provide an immense range of information applicable to a wide variety of scenarios, there are a couple points researchers agree on regardless of specific study context. First, gray water systems show the most potential at the point of use as this reduces storage time and makes the water immediately available to users. Second, to the extent possible, gray water systems work best when they utilize the gray water source with the highest quality. In this way, treatment systems can be kept as simple as possible, typically leading to cost benefits. Considering these two major factors in the success of a gray water reuse system, AGW was identified as the source with greatest potential.

That said, the variety of existing literature still falls short of informing any more specific treatment or collection design decisions. Existing research often looks at developed countries and urban areas of developing countries that are likely to have higher quality water sources, more pre-existing infrastructure, and a wider range of potential second uses. For example, in Tong uses such as watering lawns, industrial cooling, irrigation, and flushing toilets are irrelevant. Some studies focus on AGW, but these have limited usefulness for Tong as they are often based on models rather than field testing (Suratkon, Chan, & Ab Rahman, 2014), focus on physical feasibility in terms of meeting regulatory

standards (Al-Mughalles, Rahman, Suja, Mahmud, & Abdullah, 2012), or, like studies in higher-income areas, focus on other irrelevant uses such as irrigation. Tong needs a study that uses field testing to determine physical, economic, and social feasibility for reuse of AGW in household chores.

The following sections describe the methods used to determine the social, economic, and physical feasibility of reusing treated AGW in Tong, the findings of the investigations, the broader applicability of the findings, and recommendations for further research.

2 Methods

To determine the physical, social, and economic feasibility of AGW reuse in Tong, multiple investigatory tools were employed. This section describes the tools used, the rationale for their use, the specific procedures followed, and data analysis for each and then ends with a description of how the results from each tool will be combined to determine overall feasibility.

2.1 Household Surveys

Household surveys were used to determine the feasibility of the study itself and to shape further investigation by identifying treatments to test and what a AGW collection device might look like. The following subsections describe the procedures used, topics covered, and analysis performed on the survey results.

2.1.1 Procedures

Surveys were done during dry season so that people's answers, reflecting the present, were more likely to represent dry season conditions. If people were asked during rainy season, one does not expect them to be deceitful, but their answers would be based on longer term memory rather than memory of the past few weeks and would thus be susceptible to inaccuracies (Gill, 1991). Due to translator availability and author's schedule, surveys were performed between March 8 and April 3, 2016, during the height of dry season.

Participants were selected randomly using Microsoft® Excel's random number generator within the range 1-120, the numbering of houses as assigned for electric billing purposes. If a house number was selected but no one was home when surveyors arrived, the next randomly-generated house number was selected. Ideally, a woman from the household would be included in surveys. Because women are typically responsible for household water, it was assumed they would be able to give more accurate answers. As others have suggested, those most experienced with a given phenomenon have the greatest ability to describe even complex and inconsistent patterns surprisingly accurately (Gill, 1991). However, if no women were available, men were surveyed. Per best ethical practices, prior to asking any questions, the project and risks were described, and participants had the opportunity to decline. If a household declined, the next randomly-generated house number was selected and visited; otherwise, surveys would commence following verbal consent. Michigan Technological University's (MTU) Institutional Review Board (IRB) approved these sampling procedures.

Surveys were completed using a translator. The translator is fluent in English and respected throughout the community. He did not receive any training in survey procedures, but he had assisted on governmental and academic surveys in Tong

previously. Though deserving of compensation, he was not compensated for his time. In the interest of his and respondents' time, surveys were kept to 30 minutes per household.

The translator agreed to complete 30-60 surveys depending on his availability. Additionally, the author judged the translator's level of detail as an indicator of possible fatigue. The author feared the translator may not feel comfortable admitting to fatigue, and thus she used her ability in the language to determine his level of detail in translation. Based on the author's perceived detail of his translations and the translator's explicit feedback, 30 household surveys were completed.

The author recorded all responses and comments through a written record, as audio recording was not feasible. Complete survey questions and the IRB-approved protocols are available in Appendix B. Survey topics are summarized in the following sections.

2.1.2 Content

A full and verbatim list of questions asked during household surveys is available in Appendix B. The following sub sections summarize topics covered.

2.1.2.1 Demographics

Demographics are commonly asked in household water use surveys and were included in this study's survey for multiple purposes. Because participants were asked about water consumption on a household basis, household size was necessary to calculate per capita water consumption, a quantity which itself would be used in other analyses.

Second, there was concern about the equity of AGW reuse options. To determine whether certain household characteristics made a household more or less capable of adopting AGW reuse, those household characteristics must be known. Thus, in addition to household size, questions were asked to measure age distribution, gender ratio, level of education, and income. These specific characteristics would help determine whether certain households have more potential for gray water reuse and if so which characteristics indicate greater potential.

2.1.2.2 Water

The survey was also designed to get a detailed picture of dry season water conditions in Tong. The survey asked about the volume consumed each day, what sources were used in dry season, how long it takes to fetch from each source, what uses were acceptable for each source, how much each source cost, and what treatments are used.

Combined with the household size, the water consumption questions would indicate the per capita water consumption. The questions on each source allowed each source to be described fully – socially, economically (time and cost), and physically by local standards

– and thus provide information necessary for a whole-picture comparison to gray water reuse options.

2.1.2.3 Ablution

The third category of questions in the household surveys asked about ablution practices. Questions revolved around where and how ablution is done, how much water is required, who performs ablution, and how often one performs ablution. Responses about ablution would determine whether to continue investigating AGW reuse, would be used in designing the collection device, and would be used in calculating the cost of treating AGW – information necessary for full and fair comparison to existing sources.

2.1.3 Analysis

Raw data from the household surveys was tabulated, compiled, and analyzed for more relevant results. The following subsections describe these analyses.

2.1.3.1 Inform Further Study

The information gathered during household surveys was required to decide methods for further research. To measure the worthwhileness of further time, energy, and monetary investment of studying AGW reuse, responses regarding ablution would be compared to the WHO guidelines for hydration – 2 to 4.5 L per person per day (Howard & Bartram, 2003). Further study would be deemed worthwhile if a person could reasonably expect to get at least 2 L of water per day by reusing AGW, assuming 100% efficiency, i.e. if surveys showed an average of 2 L of water are consumed for ablution per day, it would be worth investigating AGW reuse as it could provide someone's daily hydration needs.

Household water use and consumption information garnered from the surveys would be used to select the critical source and treatments. The budget would not allow for testing of all available sources and treatment options. The critical source would have to be one of the sources available during the worst part of dry season as that is the time when AGW reuse would be most needed. Additionally, it would be the source predicted to have the worst quality. In this way, water quality testing results would be conservative. It is hard to say for certain that the visual estimate of a source's quality indicates its objective quality, but this was the assumption. For certain sources, drinking water quality could reasonably be assumed, and thus could very reasonably be assumed to reach higher quality following use and treatment than visibly turbid waters undergoing the same use and treatment. The critical source was that with the lowest visible quality that was also consistently available throughout dry season so test results would reflect the worst case scenario.

To narrow the treatment options, survey results would indicate which treatments are currently used, and thus which ones would more likely be adopted for AGW treatment. That said, potential treatment options would not be limited to those mentioned by respondents in household surveys.

2.1.3.2 Demographics

To determine if any correlation existed between the measured household traits and ablution reuse potential, minor statistical analysis would be performed on survey responses to demographic and water use questions. This analysis would be simple, as only 30 samples were available. Analysis would consist of plotting a regression line between household traits and AGW reuse potential and calculating the coefficient of determination, or R^2 value. If the coefficient of determination suggests the given independent variable (household trait) strongly predicts the dependent variable (AGW reuse potential, defined as the volume of water used for ablution divided by the total household water consumption), more rigorous analysis would be conducted. Ultimately this was not the case and no further statistical analysis was performed.

To estimate literacy levels, respondents were asked about the level of schooling attained by each member. Usually, literacy is measured by asking respondents to read or write a statement and explain what it means to show understanding. Because not all household members would necessarily be present, education level was used to estimate what this report will call a proxy literacy rate.

Based on some common definitions of literacy in other demographic studies and censuses and molded to use the data collected in the study, an equation was formed to calculate a proxy literacy rate (Pessoa, 2008). This calculation likely does not qualify for inclusion under many agencies' data collection methods, but it will serve for the purpose of this report. The literacy rate was taken as the percent of the household over the age of 9 who had completed some junior high school or more. The age 9 was chosen because of the age group breaks selected in the survey. Many censuses and other demographic studies use different ages for the minimum age of literacy, but the Peace Corps' monitoring statistics use age groups split at the 9-10 year old break. One cannot expect children under 9 to be able to read, so they are not included in the assessment. Junior high school (JHS) was chosen as the best estimate of a person knowing how to write and read with comprehension as that is expected of children in JHS. It is also expected of younger children, but in the author's experience reading with comprehension at the levels below JHS is more the exception than the rule.

2.1.3.3 *Water*

Water quantities, time to fetch values, and costs would all be analyzed statistically and would require some sort of verification. This section describes how responses would be statistically analyzed and how a rough confidence level would be estimated.

Because respondents were asked to give volumes in the units with which they are comfortable, conversion to a standard volume unit was necessary. In order to accomplish this, container dimensions would be measured with a tape measure and then converted to liters. Not all existing containers could be measured, but through various verification methods, reasonable volumes would be calculated and then assumed uniform for a given term used by respondents.

In addition to calculating the mean, standard deviation, minimum, and maximum, the per capita water consumption calculated from responses would be compared to two other estimates. First, the author would measure her own water use and compare it to the average from the responses. This comparison would be indirect, as the author's water use, being a single person, with Western hygienic standards, and different water uses was expected to be different. These differences would be accounted for anecdotally and quantitatively to the extent possible. Her water consumption volume adjusted for differences in water habits would still be useful in broadly verifying respondents' estimates.

Second, WHO's level of service quantities (Table 2.1) would be compared to the author's observations of Tong's ability to meet its water needs. Based on participant observation, the author would estimate Tong to be in one of the four categories of "Needs met." From this, a level of service and an average quantity estimate could then be compared to the water consumption calculated from responses. Again, no specific confidence level could be calculated, but a qualitative measure of confidence in volumes given by respondents and converted using the tape measure and assumptions could be estimated.

Table 2.1 WHO's table summarizing what water-consuming necessities are met with a given level of access, described by a category and a per capita daily volume. (Adapted from (Howard & Bartram, 2003))

Service Level	Needs met
No access (quantity collected often below 5 l/c/d)	Consumption – cannot be assured Hygiene – not possible (unless practiced at source)
Basic access (average quantity unlikely to exceed 20 l/c/d)	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/bathing difficult to assure unless carried out at source
Intermediate Access (average quantity about 50 l/c/d)	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing also be assured
Optimal access (average quantity 100 l/c/d and above)	Consumption – all needs met Hygiene – all needs should be met

These two triangulation methods in combination with the statistical description of the range of responses on water consumption could be used to deem the average per capita consumption value calculated from responses reasonable or not. Whether or not the per capita water consumption values were assumed reasonable, the household responses would be used in further comparisons between gray water and existing water sources, but the relative confidence in the data could then be provided.

To fully describe existing water sources, minor statistical analysis would be performed on responses regarding fetching time and cost. First, time and cost would be calculated on a per volume basis, also known as a unit time or unit cost. Only sources with at least half of households reporting use, time, and cost would be used for comparison. The arithmetic mean, standard deviation, minimum value, and maximum value of such sources would be calculated, and the mean would be used for comparison to other sources' and treated gray water unit times and costs.

For confidence in the time and cost values, the range of values would be considered. For example, a range in costs for the same source of free to 5 GHS for a liter would be a large discrepancy and would require explanation. To the extent possible, such discrepancies would be noticed and inquired about during surveys. Where discrepancies are not noted until after surveys, the author would reach out to people in Tong to help explain the

differences. Additionally, the author's own experiences of fetching and paying for water would be used to verify responses.

2.1.3.4 Ablution

Like respondents' estimates on overall household water consumption, consumption of water for ablution would also require some volumetric conversions, statistical description, and verification. For quantities given on ablution water consumption, volume would be determined in the same manner as other per capita water volume quantities – using a tape measure to measure a container's dimensions and then convert to liters. To estimate a standard volume size, the author would complement measurements with further inquiry during interviews and with informal conversations with community members more familiar with the size of a liter and ablution practice. The measurements of containers would be weighted by other information to determine a standardized container volume. With a standard unit – liters – reported volumes can be relatively reliable for use in calculations of unit time and unit cost.

2.2 Qualitative Methods

The short time available and structured design of surveys limit the ability to collect in-depth qualitative information about how households think about water use in all its complexity and how they feel about the possibility of AGW re-use. This section discusses two qualitative methods – interviews and participant observation – that would determine social acceptability of certain practices in greater depth than surveys allowed.

2.2.1 Opinion Leader Interviews

Opinion leader interview questionnaires were developed to elicit deeper understanding of water conditions, ablution practices, and feelings toward AGW reuse. Interviews were designed to gain more information on the social acceptability of AGW reuse, particularly in regards to religion. The following sections describe the procedures followed, topics covered, and analysis methods.

2.2.1.1 Procedures

Like the household surveys, interviews were conducted in dry season to ensure interviewees were in the mindset of dry season and did not have to recall too far back when talking about dry season practices. Dry season runs roughly from November through April; the two interviews were conducted on February 8 and March 3, 2017. The researcher did not impose a time limit on the interviews, but respondents could end the interview at any time.

Ideally, interviews would be conducted with 5-10 Tong leaders and would include men and women, formal and informal leaders, and the leadership role of the interviewees should stem from various sources (i.e. religious, tribal, governmental, etc.). By including various groups, various aspects of AGW reuse would be illuminated. Due to translator and participant availability, two semi-structured interviews were conducted.

Per Michigan Technological University's Institutional Review Board (IRB) approved procedures, participants were given a description of the project and were given the opportunity to decline. Consent was granted in both cases and questions, approved by IRB and available in Appendix B, were asked.

2.2.1.2 Content

Interview topics ranged from how people in Tong distinguish “dirty” water from “clean” water, to the specifics on performing ablution, to in-depth descriptions of treatments available and used. Interviewees were allowed to add comments and details throughout the interview. Perhaps most importantly, the interviewer described AGW treatment and reuse and solicited feedback from them on whether such water could be used in the community. The full list and exact wording of questions asked were developed in coordination with social scientists, approved by Michigan Technological University's IRB, and are available in Appendix B.

2.2.1.3 Analysis

Interview notes were analyzed qualitatively using thematic coding (Braun and Clarke 2006). This process involves reviewing interview notes and coding the text for frequently used terms or concepts important to the social acceptability of AGW reuse. The emerging themes could then be logically analyzed for coherency and consistency to build an initial theory of the social acceptability of the repurposing of treated AGW.

With only two interviews, strong confidence in the discovered themes would not be possible. With a limited amount of text to analyze and no transcription, direct quotes and statistical analysis of a theme's frequency are not possible. Nonetheless, an elementary understanding of the acceptability of the practice in Tong is important in the selection of treatment methods to test and the design of the AGW collection prototype design. The themes can also provide a sense of social criteria that may be applicable in other communities considering the treatment and reuse of AGW.

2.2.2 Participant Observation

The author's personal experience living in Tong as a Peace Corps volunteer from April 21, 2015, to March 10, 2017, would enhance interview note thematic coding. This first-hand experience is more formally termed “participatory observation.” There are several

definitions of “participatory observation.” Kawulich (2005, citing DeWalt & DeWalt, 2002) generally defines participant observation as “the process enabling researchers to learn about the activities of the people under study in the natural setting through observing and participating in those activities” ([2]). Specific observer activities include “active looking, improving memory, informal interviewing, [and] writing detailed field notes” (Kawulich, 2005, [3], citing DeWalt & DeWalt, 2002). Attitudes that benefit useful data collection through participant observation include “having an open nonjudgmental attitude, being interested in learning more about others, being aware of the propensity for feeling culture shock and for making mistakes” by “being a careful observer and a good listener, and being open to the unexpected in what is learned” (ibid). Kawulich (2005) outlines some basic aspects to participant observation. These components and their application in regards to this study are described below.

2.2.2.1 Ethics

Though it is ideal to remain unbiased as an observer, this is never truly attainable. Further, as a member of the community for two years, several personal relationships developed with a finite portion of the population. These relationships heavily informed the work, but likely represent only a portion of perspectives and behaviors present in Tong. The author was not fluent in the local language and thus had most information filtered through a translator, adding a level of bias to the active observation process. Additionally, the author’s outsider status and presence may have influenced behaviors of people in Tong and thus may have affected the voracity of observations and conclusions based upon those observations.

To ensure observations were made ethically, notes were often taken publicly providing community members the opportunity to ask questions about the information collected. Additionally, these notes were often reviewed by the author’s local counterparts. The author is fortunately still in contact with Tong community members, has gained permission for inclusion of names in the report, and will provide Tong with a copy of the final product.

2.2.2.2 Establish Rapport

The study location was assigned to the author by Peace Corps’ site selection process. Permission to enter the site was given by the chief prior to arrival. Also prior to arrival, the author received four weeks of intense language and cultural training from a Dagomba man. Part of this training included a four day workshop, during which the author met with and spoke with her future colleague. He made clear his role would be as a translator, friend, and assistant with cultural and logistical issues.

Upon arrival in Tong, the three month “site integration” period imposed by Peace Corps began. During this time, the author’s assigned task was to learn the language, get to know

the people, and get comfortable in the community without getting into project work. During this period and throughout service, integration and rapport-building activities included farming, housework, celebrating holidays, and participating in communal labor. The language skills provided in pre-service training grew while living in Tong and allowed the author to hang out with a variety of people during a variety of activities. During all activities, local cultural norms were respected to ensure the researcher had the community's respect.

2.2.2.3 Key Informants

The need for key informants present certain disadvantages in participant observation, but in cases where the researcher is not fluent in the local language, such individuals are necessary (Kawulich, 2005). For this study, key informants were primarily the author's colleagues, two educated young men born and raised in Tong. This inherently poses bias or naiveté especially about gender-related issues such as water, the primary focus of this study. Unfortunately no English-speaking women were present in the community. Additional informants include the chief, who though he is the chief, has only lived in Tong for a few years. The nurse was also very helpful in certain respects, particularly health-related topics. He is of the Dagomba tribe, but he was born and raised elsewhere. Other residents who provided a significant amount of information included the author's host mother and one of the muezzins, with whom some conversation occurred in the author's Dagbanli but was typically aided with translation.

2.2.2.4 Procedures

Both descriptive and selective observation were employed. Living in Tong provided impressions and details of big events and everyday minutiae. Everyday activities observed included farm work, collecting firewood, fetching water, going to market, cooking, eating, and living under very similar conditions as other people in Tong.

Selective observation was used primarily in the notetaking process. Only observations deemed relevant at the time were noted in writing. Such observations typically revolved around water use, such as how many buckets were collected at the borehole in a given timeframe, or other health-related activities, such as the number of clients at the CWC event, as that was the author's Peace Corps assignment.

2.2.2.5 Analysis

Observations have been used throughout the report to enhance understanding of social aspects and validate quantitative data. This report includes information from every day observations, experiences, and natural conversations. Some of these anecdotes and examples are described in the field notes. Many references, however, were not recognized as relevant until well after a conversation or event had taken place. The author

has done her best to portray these instances to the best of her recollection and has substantiated with her colleagues via telecommunications when possible.

2.3 AGW Collection Device

Information from the surveys and interviews would inform the design of a AGW collection device. The designed item would be constructed and then used to collect AGW from prototype testing participants. Users would then be asked about the experience and observations would be recorded. The following sections describe the design considerations, testing set up, and user surveys.

2.3.1 Prototype Design

To start, two types of collection approaches were considered – community-wide and individual use. A community-wide system was envisioned to be something like a bench underlain with a basin that leads to a large, likely underground, collection container. Most likely it would be located at the mosque and used by people who pray at that mosque. Individual use collection systems were imagined to be similar, but made small enough for one person to carry to and use wherever they need. Each concept is shown in Figure 2.1.

Figure 2.1 Concept drawing for group AGW collection device allows multiple people to sit on top portion, place feet on lower outer ring and then drains water to basin below (left). Drawing of individual use AGW collection device that rests in front of stool and above basin (right).

Both options offer certain benefits over the other. The community-wide system would provide more volume per system and could possibly be made more affordable by dividing up the costs. The negative aspects would be deciding how water gets divvied up and having to transport back to homes for household use. The individual use option would be more portable and thus could collect the water close to where it would be

treated and used. It would also be held under individual or household ownership and thus would not have the issue of distribution or transport. However, without the economy of scale, it could cost more per user. The household survey responses about how and where people pray, would determine which system to use for prototype testing.

Beyond style of collection device (individual or community) the design was restricted to 100 GHS. This cost was decided based on what was considered affordable on the author's Peace Corps income. This basis meant that the author could afford to construct the prototype for testing without external funding. Additionally, her income was theoretically similar to the income and lifestyle of those in the community and thus has some expectation to reflect what is affordable to the community at large. The ultimate design would also take into consideration survey responses, interview commentary, personal observations of ablution habits, and feedback from the author's host-country colleagues.

This design would be acknowledged as the first iteration in a larger design process. For the purposes of this study, however, it only needed to be usable for the collection of AGW such that the gray water could subsequently be treated and tested for quality. The collection and testing of gray water is described later. No additional design iterations would be attempted, but design recommendations could be made based on the user survey, described in the next section.

2.3.2 User Survey

Though the household surveys asked respondents about ablution practices and interviews asked about hypothetical reuse of AGW, it was important to know how people felt about the reuse process when attempting it and seeing the resulting water first hand. To solicit feedback from the prototype testing participants, a user survey was developed.

2.3.2.1 Procedure

Like household surveys and interviews, prototype user surveys would be performed in the dry season to reflect participants' feelings and opinions during the time period of interest. The timing would necessarily revolve around prayer times when people are performing ablution – roughly 5am, 1pm, 3pm, 6:30pm, and 7:30pm. For efficiency of time and effort, user surveys would be coupled with gray water collection and treatment. This coupling also allowed for a broader range of questions and allowed users to see the treated gray water and comment on its appearance.

Ideally a wide range of people testing the prototype would be represented, including both genders and several age groups. However, out of necessity, participants would simply be chosen by proximity to the treatment equipment and willingness to participate. They would be asked on an individual or small group basis, depending on how the device

would be used (individually or community style). Ultimately, users were the same individuals from trial to trial as the testing occurred at one location and thus was visited by the same mosque-goers. Because there was such significant overlap in participants for each prayer time, the survey was asked only once. Because of the group-tendencies of the participants near the testing location, participants were asked as a group.

As most participants are not literate, questions would be asked and answered orally through a translator and the author would record responses in a written format. The same translator would be used for user surveys as was used for household surveys and opinion leader interviews. Again, he would not be compensated. Additionally, the author would take notes on participants' and passersby's reactions to the AGW collection device, to treatments, and to treated water. Other observations about the process, gray water catchment efficiency and timing of treatment would be written by the author.

2.3.2.2 Content

Questions revolved around the device and its use as well as treatments and the water each produced. Questions about the device aimed to figure out if this particular device is something that people can use with minimal interruption of their normal practices such that the new practice would likely be adopted. The potential obstructions to use considered were physical comfort, upfront costs, and long-term benefits. Suggested improvements were also solicited.

Similar to questions about the collection device, questions about treatment aim to figure out if a particular treatment process is likely to be adopted. The potential obstructions to adoption of a given treatment were physical ability, upfront costs, long-term benefits, and of course their perception of the final water produced. Finally, it also sought recommendations from users to make the treatment process more likely to be used. A full, verbatim list of questions as approved by MTU's IRB are available in Appendix B.

2.3.2.3 Analysis

Ultimately, due to experiment set up and the limited number of unique participants, the results from the survey would not be heavily analyzed. Responses would inform the ultimate recommendations for Tong and further study anecdotally, but do not require rigorous analysis in order to do so.

2.4 Gray Water Quality, Treatment, and Sampling

Water quality analysis was done to see if and how water quality changed throughout the process – from the source, to the AGW, to the treated wastewater. A source was identified for control purposes. Then wastewater, collected using the AGW collection

prototype, was treated and tested. Treatment trials would also be the basis for AGW unit time and unit cost estimates to compare to existing sources.

2.4.1 Control – Critical Source

First, the critical source needed to be identified to serve as the control. This would be decided by analyzing the household survey data. Essentially, the critical source was that with the lowest visible quality that was also available through the entire dry season.

Once this source was identified, a 1 L sample, considered to be representative of the entire source, would be collected during dry season and brought to a testing facility in as timely a manner as possible. Due to locations of testing facilities and travel options, the time between collection and laboratory testing would likely be longer than optimal. To help minimize any changes in water quality, the sample would be stored in a fridge. That said, electricity frequently goes out and thus quality consistency over time could simply not be guaranteed. Specifics on the lab, its testing methods, and parameters tested are described later.

The water quality test results of the critical source would inform further investigation. Due to budget, the results of the critical source water quality tests would determine which parameters to test for in the AGW and in the treated gray water during prototype testing. Any parameters that met standard and had no reasonable expectation of increasing due to use or treatment would not be tested again. On the other hand, any parameter higher than standard to start would require testing following treatment to see if treatment reduced the level, and if so by how much. Given existing knowledge on various treatment methods, the parameters higher than standard would be used to eliminate certain treatment options from testing. For example, high levels of arsenic cannot be reduced by boiling and thus boiling would not be selected for prototype testing and quality analysis if arsenic were detected in the critical source water.

2.4.2 Treatments Tested

Once treatments were decided, a collection device had been constructed, and dry season was reached, prototype and treatment testing could commence. Three trials of AGW collection and treatment were performed for each treatment type. This would provide the greatest likelihood of getting results within a representative range of possible outcomes, but was also within budget. Each trial would include the following steps:

1. People perform ablution using collection device and answer user survey questions.
2. Separate at least 1 L of wastewater into each of four containers – one for testing untreated gray water, then 1 L each for testing treated gray water from each of the three chosen treatment methods.

3. Treat at least 1 L of AGW for each selected method, making sure treatment process is the same for each trial of each given treatment method.
4. Repeat steps 1-3 for two more prayer times
5. Bring samples to Tamale for testing as soon as possible

Throughout the trials, the author would solicit feedback from users and passersby and record any other important observations about the collection device or treatments.

Based on survey results, interviews, and critical water source quality, three treatments were chosen - AfriClay Filter, moringa seeds, and P>M Purifier of Water. The elimination of other possible treatments will be explained in the results, as the reasoning for such eliminations is a results of surveys. The specific procedure for each selected treatment is described below.

2.4.2.1 Pure Home Water's AfriClay Filter

Due to its local availability and ease of use, the AfriClay filter was selected for AGW treatment testing. The AfriClay filter is a hemisphere of clay, with about a foot and a half diameter and a half foot depth. It is formed with local clays at a facility near Tamale, the regional capital. This filter is designed to sit on the upper rim of a large plastic bin. They also come with a top that provides better storage safety than most household water storage containers. A hole is fashioned into the lower part and a spigot is attached for easy, single-hand water retrieval by users. The purchase of the AfriClay filter includes the clay pot filter, the top, the storage container, a sticker with graphic instructions, a spigot, and a brush for cleaning the filter. At the time of testing, it cost 85.00 GHS (USD 19.55), but as of July 2017, it costs 125.00 GHS (USD 28.75) (Pure Home Water, 2017).

The procedure used for the filter during testing was based on recommendations from the manufacturer, Pure Home Water, as described on the stickers distributed along with the filter. Because this treatment method is not currently used in Tong, it was assumed that should this method be adopted, users would receive training in proper use and care. This is a reasonable expectation considering Pure Home Water's emphasis on and provision of this training.

To mimic the more common situation of a previously used rather than brand new filter, the filter would be purchased and used for several weeks prior to use in the trials. Procedures recommended by Pure Home Water would be used during these pretrial weeks. As such, clean water without soap was used to clean the filter, container, and tap following purchase and transport. After cleaning, the filter was used regularly and carefully following instructions. Fortunately, the author's water was not turbid and thus no settling prior to filtering was necessary during this time period. Additional tips were followed; for example, the outside of the ceramic pot was not touched, the container was never overfilled, and the lid was kept on except when filling.

During trials, the following step-by-step procedure was followed. Note that Step 3 is an addition to the recommended procedure since the recommended procedure would require more time than reasonable given the turbidity of influent water.

1. Collect AGW and let settle for 1 hour.
2. Carefully pour wastewater into filter pot.
3. Scrub filter pot as needed to allow extremely turbid water to pass.
4. Wait for at least 1 L of water to pass filter.
5. Collect 1 L of filtered water via tap into clean bottle for transport to lab.

Methodology on laboratory testing performed following the above collection and treatment procedure is described later.

2.4.2.2 Moringa Seed Coagulation

Moringa, *Moringa oleifera*, is a tropical tree with many uses for its various parts and propagates relatively easily. For water treatment, the seeds, which contain a cationic protein, can be used as a coagulant (Beltrán-Heredia & Sánchez-Martín, 2009). The extreme particle charge of these proteins promotes adsorption of other particles in the water, creating larger, heavier particles that fall out of suspension (ibid). Though these properties are fairly well known and described in the literature, results vary greatly depending on initial water quality, specific process, and concentration of moringa seed. Studies have been conducted in Ghana on turbid surface waters and indicate moringa can significantly reduce turbidity and parasite concentrations (Sengupta, et al., 2012). These seeds are currently available in Tong via four trees.

After informal experimentation with varying mix times and moringa seed concentrations, the author roughly optimized the process. The moringa seed treatment process that seemed most effective and was thus used during prototype and treatment testing trials is as follows:

Materials:

- Moringa seeds (at least 2 per liter of water to be treated, but use at least 5 seeds at a time)
- Mortar and pestle
- 250 mL clean water
- Bottle and tight-fitting cap for vigorous shaking (at least 250 mL capacity)
- Stirring utensil (a stick works; make sure it is long enough to reach depth of container)

- Container of wastewater, preferably with smooth, vertical sides (otherwise particles settle on sides of container, making siphoning of clarified water more difficult)

Process:

1. Remove seeds from dried pod and individual husk.
2. Crush seeds in mortar with pestle until they become a fine powder.
3. Add a small amount of clean water to the seed powder and mix into a paste.
4. Add the paste to clean water in the shaking bottle and shake vigorously for about 1 minute.
5. Pour water-paste mixture into wastewater.
6. Stir steadily watching the water closely. Streaks of clearer water in between streaks of dirty water with more visible clumps of particles should become visible; a half inch or so of noticeably clearer water should form at the top (4 minutes).
7. Once the particles start clumping and leaving clearer streaks of water, slow down the stirring action significantly. Continue to gently stir the water until it seems about to become more turbid again (6 minutes).
8. Cover water, let rest at least 30 minutes.
9. Siphon clarified water off the top, holding back floating bits of seed pulp, into a bottle for transport to the lab.

The determination of when to switch from fast stirring to slow stirring is flexible for general purposes, but the timing of each step was precisely timed and performed the same for each trial for testing purposes. The seed concentration is based on informal experiments. During experiments clarifying reservoir water for laundry, 2 seeds per liter seemed the most efficient use of seeds, with higher concentrations having diminishing returns. If treating 1-2 L of water, only 2-4 seeds would be necessary by that measure. Crushing so few seeds means a greater percentage of seed content is lost either by spilling or simply by sticking to the mortar and pestle. Thus, a minimum of five seeds was set to ensure sufficient seed mass was used regardless of the amount of water being treated.

Methodology on laboratory testing following the above collection and treatment procedure is described later in this report.

2.4.2.3 *P>M Purifier of Water*

P>M Purifier of Water is a small packet of powder created by P>M and distributed free of charge in Tong by World Vision, an NGO serving the area. The powder consists of both flocculant in the form of ferric sulphate and disinfectant in the form of calcium hypochlorite (CDC, 2014). Through laboratory and field testing, it has been shown to remove a significant amount of microorganisms, particulate matter, and even some metals (ibid).

The packet comes with instructions on the back, but the locally common application is slightly different. Because these local practices are common and fairly engrained, the local application was used in the trials and is described below. This process was determined from both observations and informal conversations about how people use P>M Purifier of Water.

1. Pour visibly appropriate amount of powder into AGW. (packet instructions direct user to apply entire packet contents to 10 L, but locally the user simply decides by experience, or the “visibly appropriate amount” as noted.)
2. Stir for 90 seconds.
3. Let sit until it looks acceptable (at least 30 minutes).
4. Siphon off 1 L of the clarified water into a clean bottle for transport to the lab.

Again, though the people in Tong would likely not have a consistent number of minutes for stirring or settling, for testing purposes an exact amount of time was consistently used in each trial as stated.

Methodology on laboratory testing following the above collection and treatment procedure is described later in this report.

2.4.3 Water Quality Testing Methods

To aid in comparing treated gray water to untreated gray water, and in comparing treatments to each other, quantitative water quality analysis was conducted on the AGW from 3 trials treated as described in previous sections. This section describes both the 3MTM PetrifilmsTM and the laboratory testing facility, parameters tested for, methods used, and analysis of test results.

2.4.3.1 *3MTM PetrifilmsTM*

3MTM PetrifilmsTM are ready-to-use *E. coli* and coliform counting plates. Like petri dishes, they allow coliforms that are present but too small to see to grow to sizes in the visible range. Once grown and visible, the colonies can be counted.

Initially, these were to be incorporated with the prototype and water sample collection and treatment trials. Unfortunately, during the trials, time was more limited than anticipated. As such, another AGW collection day occurred about a week after the initial trials. At this time, untreated and treated wastewater samples were again collected and applied to the films, although no more samples were collected for laboratory testing, nor were users asked survey questions. The treatment procedures were the same as described in Section 2.4.2. Product documentation from 3M Food Safety (2014) provides the following procedure when using the Petrifilms:

7. Place 3M™ Petrifilm *E. coli*/Coliform Count Plate on level surface. Lift top film.
8. With 3M™ Electronic Pipettor or equivalent held perpendicular to plate, place 1mL of sample or diluted sample onto center of bottom film.
9. Roll top film down onto sample gently to prevent pushing sample off film and to avoid entrapping air bubbles. Do not let top film drop.
10. With flat side down, place 3M™ Petrifilm™ Spreader on top film over inoculum.
11. Gently apply pressure on 3M™ Petrifilm Spreader to distribute inoculum over circular area before gel is formed. Do not twist or slide the spreader.
12. Lift 3M Petrifilm Spreader. Wait a minimum of 1 minute for gel to solidify.
13. Incubate plates with clear side up in stacks of up to 20 at time and temperature listed below. It may be necessary to humidify incubator to minimize moisture loss.
14. 3M Petrifilm *E. coli*/Coliform Count Plates can be counted on a standard colony counter or other illuminated magnifier. Refer to the Interpretation Guide section when reading results. (p. 5-6)

The process provided was adapted to local conditions. Most prominent adaptations include ambient temperature for storage both prior to use and during incubation rather than recommended temperatures, no humidifying during incubation, and counting of colonies using natural light only. Following sample incubation, films would be photographed for colony counting verification and visual comparison of samples.

2.4.3.2 Laboratory Testing Facility

A limited number of testing facilities are available in the vicinity of the test site. Only two labs were within the author's travel budget and a reasonable time frame for travel from the site to the facility. One was built and operated by World Vision in Savelugu to perform testing on all of their West Africa water provision operations. They offer both complete chemical and biological analysis and specific contaminant testing. Though their laboratory is likely of high quality, this facility was not used due to concurrent staff turnover and uncertainty in their workload.

The other facility, the Council for Scientific and Industrial Research Water Institute's (CSIR-WRI) Water Quality Laboratory Tamale, is a government owned and operated facility that hires out their services to non-government clients. Due to their location in Tamale and positive reception of the author, this facility was selected. They also offer complete chemical and biological analyses as well as specific contaminant investigations within budget allowances. These analyses are described in full in the next section.

2.4.3.3 Testing Parameters and Methods

Biological analyses were performed on all samples collected. This analysis tested for quantities of the following parameters:

- Total coliform
- Fecal coliform
- *E. coli*
- Total Heterotrophic bacteria

All biological parameters were tested using American Public Health Association's methods. Total and fecal coliform were tested using the standard method 9222 A and D, respectively. *E. coli* was detected using standard method 9260 F. And the total heterotrophic bacteria were measured using standard method 9215 B, the pour plate method. No other indicator organisms such as enterococci were available.

The complete chemical analysis performed by CSIR WRI Tamale included measuring of the following parameters:

- Conductivity
- Turbidity
- pH
- Total suspended solids (TSS)
- Total Dissolved Solids (TDS)
- Ammonia
- Nitrate
- Phosphate
- Silica Oxide
- Sulphate
- Fluoride
- Total Alkalinity
- Calcium
- Chloride
- Total Hardness
- Magnesium
- Potassium
- Sodium
- Bicarbonate
- Carbonate
- Calcium Hardness
- Mag. Hardness
- Residual Chlorine
- Manganese
- Iron

CSIR-WRI was contacted to discern what methodology was used to determine the chemical parameters. Unfortunately, no response was received. As such, no methodology can be determined with certainty, but it is reasonable to expect the methods used are acceptable under Ghanaian regulations as the laboratory's results are considered proof of compliance. As previously described, a full chemical analysis was only performed on the source water. From those test results, only parameters of concern would be tested during treatment trials.

2.4.4 Analysis

2.4.4.1 Control – Critical Source

The critical water source testing results would be analyzed as-is. With only one sample, no statistical analysis could be performed. Though 1 L is thought to be representative of the whole source, quality does likely change through the season and from year to year. Results of quality testing were assumed to be worst-case scenario, as the sample was

collected during peak dry season when higher concentrations of contaminants and highest use can be expected. The quality parameters would be compared to WHO and MWR guidelines for drinking water, as well as to local determinations of acceptable use.

2.4.4.2 Gray Water – Treated and Untreated

During trials, treated and untreated wastewater was tested, but the water source was different than the critical source tested. The critical source, as determined and explained in the Results section, was reservoir water. From that, the Gbutugu dam water was tested. However, water used for ablution during trials was from the Tong dam and had received alum treatment. Due to timing of testing and discovery of this inconsistency, trials were performed with this second source. As such, direct comparison was not possible. The two sources are quite similar in several ways – both are surface water, they have similar land use in their watersheds, and both are visually similar. Thus, some comparison would be made, albeit with great qualification.

Despite the different water used for testing the critical source and for treatment testing trials, the treatments could still be compared to AGW collected during trials, the other treatments, and MWR's drinking water quality standards. Because only three trials were performed, averages were not considered meaningful. A treatment would be considered to produce potable water only if the treated water was potable by MWR standards for each tested parameter for each trial. MWR standards are used here because they specify requirements for drinking water obtained from 'prepared waters' or 'waters defined by origin' (MWR, 2015) and the lab is assumed to use MWR-approved methods. MWR standards are shown below in Table 2.2. If meeting specification for metals, it will still be considered to produce potable water since biological parameters could be brought to standard via the well-established, commonly known, and readily available method of boiling (WHO, 2015). Costs and timing of boiling would simply need to be estimated for fair comparison to other potable sources. If it met standards for some but not all trials, it could be recommended for further study but would not be considered a potable water source for the purposes of comparison in this study.

Table 2.2 Water quality standards in Ghana. (Adapted from MWR, 2015 Tables 18-20 and WHO guidelines as stated in laboratory reports available in Appendix F)

Parameter	Requirement
Total Suspended Solids/Matter	≤ 0 mg/L for packaged water
Turbidity	≤ 5 NTU
Total dissolved solids	$\leq 1,000$ mg/L
pH	6.5-8.5
Ammonia*	0.00-1.5
Nitrate	≤ 50 mg/L
Potassium*	≤ 30 mg/L
Sodium*	≤ 200 mg/L
Sulphate	≤ 250 mg/L
Fluoride	≤ 1.5 mg/L
Calcium*	≤ 200 mg/L
Residual free Chlorine	≤ 0.2 mg/L
Chloride	≤ 250 mg/L
Manganese	≤ 0.4 mg/L
Total hardness	≤ 500 mg/L
Iron	≤ 0.3 mg/L
Magnesium*	≤ 150 mg/L
Apparent Color	Shall not be objectionable
Odor and taste	Shall not be objectionable
Temperature	Shall not be objectionable
Bacteriological Determinants	
Total viable count, at 37C for 48 h	≤ 500 count/ml
<i>E. coli</i> , count/100ml	Not detected
Total coliform, count/100ml	Not detected

* WHO guidelines for drinking water quality, all else MWR requirements for drinking water from water supply systems or sources defined by source without passing a community water system

Because water is needed for tasks other than drinking, it is also useful to consider the possibility of using AGW for non-ingestive purposes. WHO's "Guidelines for safe recreational water environments" (2003) provides guideline values for measuring the quality of recreational water, but they use enterococci as the indicator organism, which was not measured in this study. In regards to indicator organisms measured in this study, WHO notes that there is "currently insufficient data with which to develop guideline values using [*E. coli*] in fresh water" (ibid, p. 74). In the same document, total coliforms were considered inadequate for measuring the health risks in which WHO was interested,

as the guidelines were designed for fresh or marine waters, not fresh water exclusively (ibid).

In “Monitoring Bathing Waters – A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes,” WHO lists several countries’ recreational water quality standards with total coliform, fecal coliform, and other indicator organisms as the indicator organisms (2000). Table 2.3 below summarizes some of these standards. The UNEP/WHO guideline values for fecal coliform are for the geometric mean of at least five samples. This study has only three samples, but these guideline values are still useful as a cursory comparison to see whether non-ingestive contact with treated gray water would cause great risk to public health. Further, the uses desired by people in Tong – laundry, bathing, and washing dishes – are not exactly the same activities considered in the epidemiological studies on which the guidelines are based. Considering individuals performing these activities are not submerged as they would be when swimming, and because the desired uses all involve the use of soap, it is reasonable to think such uses may be performed with lower quality water without exposing oneself to higher risk of infection. The results in this study would be compared to the UNEP/WHO guideline values for fecal coliform count stated below, but would require further study to form a rigorous recommendation in regards to human health (WHO, 2000).

Table 2.3 Examples of guidelines and regulatory standards for water with which primary contact is recreational. (Adapted from WHO, 2000, Table 9.1)

Organization	Total coliform (cfu/100 mL)	Fecal coliform (cfu/100 mL)	Other	Reference
Europe, EEC - Guide	80% < 500	80% < 100		EEC, 1976
Europe, EEC - Mandatory	95% < 10,000	95% < 2,000		EEC, 1976
Peru	80% < 1,000	80% < 1,000		Environmental Agency, 1981
Poland			<i>E. coli</i> < 1,000	SEDUE, 1983
UNEP/WHO		50% < 100, 90% < 1,000		WHO/UNEP 1977

Additionally, treated water quality could be compared to the quality of the critical source to determine the relative quality of the treated AGW. So, even if determined to not consistently produce potable water, it may still meet recommended guidelines for non-

drinking purposes, or may at least provide better quality than other currently used sources, like the critical source.

The 3M™ Petrifilms present *E. coli* as blue spots with gas bubbles and other coliforms as pink dots. An observer can simply count dots of all colors within the circular growth area for a total coliform count to compare to UNEP/WHO values. Because of sub-optimal conditions, other indicators of improper application, and a collection sample of just 1 mL, these counts will be provided for comparison purposes only but cannot determine potability. The photograph of films with developed coliform colonies would allow a comparison between untreated gray water and gray water treated from the various methods.

The 3M™ Petrifilms would also be used to evaluate lab testing outputs. Because the laboratory samples simply could not be tested in a timely manner, there was concern that lab samples' quality would drastically decrease during transit. Small amounts of coliforms or other bacteria present shortly after treatment would multiply during transit time and thus lab test results would reflect longer term quality rather than immediately after treatment. As such, the films could be compared broadly to lab results. These comparisons would suggest what possible effects extended transport time may have had on lab samples, and thus indicate a level of confidence in lab results or indicate further testing would be required.

2.5 Overall Feasibility – DRAW Charts

The ultimate purpose of all the investigations described throughout this section was to determine the feasibility of using treated AGW for drinking or other household uses. This feasibility is dependent on social, economic, and physical factors. To get a better picture of overall feasibility then, simply comparing water quality testing results to international standards is insufficient. To compare all available dry season sources, a more comprehensive comparison is needed. A chart showing each source and each factor of feasibility will be created using data from the household surveys, opinion leader interviews, participant observation, and water quality testing. An example data set and associated chart are provided in Table 2.4 and Figure 2.2 below. Because these representations are used to aid in the holistic comparison of existing sources and AGW treatment options, they are called Decision-making for the Reuse of Ablution Wastewater (DRAW) charts.

Table 2.4 An example of data used in creating a DRAW chart includes each source, its unit active collection time, its unit cost and a measure of social acceptability.

Source	Active Unit Time (min/volume)	Unit Cost (GHS/volume)	Social Acceptability	
			Descriptive Category	Size of Marker
Source 1	2.1	0.2	Proven, Unlimited	1
Source 2	9.5	0	Unproven, Limited	0.25
Source 3	0.6	1.3	Proven, Limited	0.75

Figure 2.2 An example DRAW chart associated with the data in Table 2.4. Interpretation depends on a household's needs, but generally a larger circle close to the origin is optimal as it indicates low cost, low collection time, and high social acceptability.

On the x-axis of the DRAW chart is the active unit fetch time required to collect from a given source. The “active” time is defined as time required to fetch or treat during which a user cannot do anything else. Thus, walking to fetch water is active time, because walking requires the fetcher’s full involvement. On the other hand, settling time would not be considered active since the user can go elsewhere and do other things while the water settles; she is not *actively* involved in that portion of time required to get the water.

On the DRAW chart’s y-axis will be the unit cost of water from a certain source. This cost, to the extent possible and where relevant, will include all capital and recurring expenses for the user, including fees charged, purchase of treatment supplies, and fuel for

motorized transport. Some of these costs will need to be estimated based on outside literature or online resources, but to the extent possible will be based on responses from household surveys regarding cost and personal experience of the author. Other assumptions will be necessary in determining a cost per volume. For example, the cost of water treated using a filter requires an estimate of how many liters a filter can treat over its lifetime. All assumptions will be made explicit and explained in the results section. Both the x- and y- coordinates for a given source then express the economic component of feasibility, with the origin being ideal.

The social feasibility of a given water source will be expressed on the DRAW chart as the size of the point on the chart. The larger the dot, the greater the social acceptability of that source. More specifically, social acceptability will be represented as one of four point sizes. The largest will represent sources for which water is already proven acceptable for all uses. The next smaller will be for uses with proven acceptability but for a limited number of uses or requiring treatment in order to be acceptable for all uses. The next smaller will be for sources that are not yet proven but promising for acceptability for multiple uses based on user feedback and interview responses. The smallest point will represent sources for which acceptability is not yet proven and not very promising for more than one or two uses based on user feedback during trials and interview responses.

And finally, technical or health-risk-related measures will be represented by the chart on which a given source is shown and the color of its marker. One chart will be specifically for sources that meet Ghanaian regulatory drinking water standards. The second chart will be for all sources, whether they meet potable quality specifications or not, whether they meet bathing water standards or not, and whether or not they are shown to be of better quality than the critical source. On this chart, to distinguish water quality, potable water sources will be shown in a black outline with no fill color, non-potable sources that are minimally turbid will be given a gray fill, and very turbid non-potable sources will be completely black.

In this way, a DRAW chart can show all relevant factors for all sources in a spectral rather than binary way. This will allow the people of Tong to make decisions based on local cultural standards, individual cost and time investment preferences, as well as relative quality standards.

3 Results

As explained in the previous section, several tools were used to investigate the feasibility of AGW treatment and reuse. Unabridged results from each tool (household surveys, opinion leader interviews, user survey, and water quality tests) are available in Appendices C, D, E, and F. The following subsections summarize results and analysis from each tool. The combined analyses will be explained and then presented as two DRAW charts from which recommendations can be made.

3.1 Household Surveys

Household surveys were completed following the aforementioned procedures at 30 households between March 8 and April 3, 2016. All notes and analysis spreadsheets are available in Appendix C.

3.1.1 Demographics

Recall from the Methodology section that questions regarding a household's size and demographics were asked. Table 3.1 below provides the statistical summary of participating households' demographic makeup.

Table 3.1 Geometric mean, standard deviation and range for demographics of households surveyed.

	Average	Standard Deviation	Minimum	Maximum
Household Size	17	9.5	5	42
Gender Distribution (% Female)	50%	18%	0%	83%
0-9 Years Old (%)	31%	13%	0%	57%
10-17 Years Old (%)	12%	9%	0%	30%
18-24 Years Old (%)	15%	12%	0%	50%
≥25 Years Old (%)	41%	14%	10%	68%
Proxy Literacy Rate (%)	24%	16%	0%	53%

Average household size was 16.6. The standard deviation of 9.5 shows that household size is pretty well spread out through the reported range of 5-42 household members. The

age and gender composition of the households surveyed was also collected. For the 30 households, the average household was 50% female with a standard deviation of 18%, a minimum of 0% female, and a maximum of 83% female. Averaging the age distribution for each household, the average percentage of household members under 9 years old, between 10 and 17 years old, between 18 and 24 years old, and over 25 years old was 31%, 12%, 15%, and 41%, respectively, and the standard deviation for each age group was 13%, 9%, 12%, and 14%, respectively. To represent the level of education attained, the level of schooling each member reached was used to calculate a proxy literacy rate. Calculated as described in 2.1.3.2, the average household had a literacy rate of 24% with a 16% standard deviation, a minimum of 0% and maximum of 53%.

Based on household survey responses, the average per capita water consumption and the percent of household water consumption used for ablution – referred to as the potential for gray water reuse – were calculated for each household. These amounts were then used to see if any correlations existed between various household characteristics and water consumption or potential for AGW reuse.

The results actually show very little correlation between any demographic factors and per capita water consumption or between any demographic factors and percentage of used water available for gray water reuse.

The correlation observed was an R^2 value of 0.18 between household size and daily per capita water consumption. That said this correlation is not a strong one. The correlation with AGW available for reuse has an R^2 value of 0.35. Both charts are shown below in Figure 3.1 and Figure 3.2. This suggests weakly that larger households are more efficient with water overall, but the proportion of total household water going to ablution does not also go down with the larger household size. This technology may be slightly more likely to benefit larger households.

Figure 3.1 The effect of household size on daily per capita water consumption is not significant.

Figure 3.2 The effect of household size on the potential for gray water reuse is somewhat significant and suggests a positive correlation.

The R^2 value for a linear correlation between the percentage of a household that is female and the per capita water consumption was just 0.003. The correlation is not as weak

between the percentage of a household that is female and the potential for gray water reuse, which correlate with $R^2 = 0.042$. Both charts regarding the percentage of a household that is female are shown below in Figure 3.3 and Figure 3.4

Figure 3.3 The effect of the proportion of the house who are female on daily per capita water consumption is not significant.

Figure 3.4 The effect of the proportion of the house who are female on gray water reuse potential is not significant.

The proportion of the household that was under nine years old also showed little correlation with water consumption rates or volume available for reuse, each correlation having only an $R^2 = 0.076$ and 0.017 , respectively. The data are shown below in Figure 3.5 and Figure 3.6

Figure 3.5 The effect of the proportion of a household under age nine on daily per capita water consumption is not significant.

Figure 3.6 The effect of the proportion of a household under age nine on gray water reuse potential is not significant.

The educational level was approximated using a “proxy literacy rate.” The correlation between the per capita daily water consumption and the proxy literacy rate was not significant, with an R^2 value of only 0.029. The correlation between the proxy literacy rate and the potential for reuse was 0.004. The charts showing these two weak correlations are shown in Figure 3.7 and Figure 3.8

Figure 3.7 The effect of the proxy literacy rate on daily per capita water consumption is not significant.

Figure 3.8 The effect of the proxy literacy rate on the gray water reuse potential is not significant.

Though respondents were asked about occupations, it was difficult to quantify that in a way to represent income. Directly asking people their income was considered but eliminated from consideration, as most people do not track their income and expenditures. Even an estimate would be heavily colored by time of year, as most income is actually in hand just as crops are sold. As such, it is outside the parameters of this study to investigate any possible relationships between income and water consumption or income and the percent of water consumption used for ablution.

As shown in Figure 3.1 through Figure 3.8, any given household characteristic only contributes in nearly negligible amounts to either the average per capita water consumption or the potential for AGW reuse.

3.1.2 Standardization of Volume Units

Before analyzing the household survey results regarding water volumes and before calculating unit cost and time for each source, the volumetric units used by respondents had to be converted to a standard unit. Most respondents answered in terms of a familiar container, using barrels, “garawa,” or kettles. Though measuring the various containers to obtain the volume seems straight forward, the term for a given container represents a range of volumes. The volume of each container was determined as explained below:

- Barrel – Many homes have a barrel at the house for water storage. Though many of these barrels are the standard 55-gallon drums, there are also many that are welded locally. Because the cutting and welding is all done by hand, volumes are not as consistent as manufactured ones. Many welders will incorporate scrap materials or save on materials in other ways, causing barrels to be noticeably different sizes. Because so many homes have the standard size and measuring the inconsistent, locally made ones would be exhaustive, the 55-gallon size was assumed for all responses in terms of barrels. 55 gallons is equivalent to about 208 L.
- Garawa – Another unit of measurement for volume of water used by respondents was a “garawa,” which is basically a large bucket made from scrap metal. Like the locally welded barrels, garawa are not uniform in size. However, there are general sizes of large and small. A large one at the author’s host family’s house had a 39 cm height and 125 cm circumference. That is equivalent to about 48.5 L. The smaller size is significantly smaller, with only a 32 cm height and 91 cm circumference, or 21.1 L volume. Because most women fetching water prefer the large ones for their greater capacity, the large garawa volume of 48.5 L will be used where respondents used the term “garawa.”
- Kettle – The other unit used, most commonly in regards to ablution, was the kettle. A kettle looks like a teakettle but is made of plastic, often of a very bright

color, and is used for pouring water, especially for ablution. These come in multiple sizes. The larger ones are around 3.5 L, whereas smaller ones are only about 1.4 L. The author's colleague said he could perform ablution with 0.5 L, but that it would not be easy. During the interviews, the nurse said that people should use at least 1 L of water in order to perform ablution properly. The average volume of water used per ablution as reported by survey respondents was 0.7 kettles, equivalent to 2.4 L using the large kettle and 0.98 L using the small kettle. Since 0.98 L is much closer to volumes given by the nurse and the author's colleague, the small kettle seemed more in line with how much water people report to be using than the large kettles. When respondents used the term kettle, 0.98 L was the assumed volume.

3.1.3 Dry Season Water Sources – Collection Times and Costs

Household water survey respondents listed nine different water sources they utilize during dry season to meet their water demands. For a given source, there are a few different modes of transport available to fetch the water. Where possible, modes of transportation were separated as certain modes expectedly have very different transport times and costs. Prices were also recorded, often on a unit basis using local volume units. Using the above volumes and sometimes assumed containers, the unit time and unit price were calculated for each respondent and then averaged. Figure 3.9 below shows the location of all sources listed, and Table 3.2 and Figure 3.10 below summarize the average, standard deviation, and range of unit cost and unit fetch times for each stated source, and, where possible, for the different modes. Additionally, Table 3.2 shows how many households out of the 30 surveyed reported using the given source and transport mode.

Figure 3.9 Map showing dry season water resources used by Tong residents.
(Annotations by author, basemap from DigitalGlobe, 2011; see Appendix A for full attribution and copyright licensing information.)

Table 3.2 All sources listed by respondents, the percentage of respondents reporting its use, the unit fetch time and unit cost for each source, and their associated statistical descriptors.

Source	% of Houses Using	Unit Fetch Time (min/garawa)				Unit Cost (GHS/garawa)			
		Avg.	St. Dev.	Min.	Max.	Avg.	St. Dev.	Min.	Max.
Tong Borehole	100%	196	111	35	462	0.10	0.02	0.02	0.13
Nyensobga Borehole	77%	163	65	28	300	0.10	0.05	0.00	0.20
Gbutugu Borehole	33%	201	73	28	300	0.09	0.03	0.00	0.12
Dams (walk/bike)	77%	92	33	15	120	0.00	0.00	0.00	0.00
Dams (motor/hire)	50%	23	10	7	42	0.91	0.68	0.00	2.59
Karaga Rd. Well	47%	90	35	30	120	0.00	0.00	0.00	0.00
Natural Well	90%	74	39	7	150	0.14	0.75	0.00	3.88
Other Wells	27%	4	3	0.5	10	0.00	0.00	0.00	0.00
Pure Water	80%	314	421	0.8	1455	16.34	2.13	12.93	19.40
Karaga Municipal	7%	61	37	35	87	2.55	1.95	1.17	3.93

Figure 3.10 The average unit fetch time and average unit cost for each dry season water source given by respondents.

The following sections discuss each source, the times, costs, and other comments from survey participants. Additionally, for each source, the author notes whether the results align with her own observations and experiences.

3.1.3.1 Tong Borehole

The borehole in Tong is used ubiquitously, as 100% of households surveyed reported using it. It was assumed that people walk to fetch water from the Tong borehole because each house is within walking distance of a tap, and the author almost never saw anyone using any other means. As such, unless otherwise specified, one was assumed to fetch a garawa with each trip. Despite the relative proximity, the average unit time to fetch was 196 minutes, with a standard deviation of 111 minutes and a range of 35-462 minutes. This range stems from the place in line and associated waiting time, often expressed as a range of times, which for each respondent's given range was averaged in calculating the

average over all respondents. Some also noted there is a risk of waiting but not collecting any water because the tanks often empty before everyone has collected.

The average reported unit cost of water at the Tong borehole was 0.10 GHS per garawa with a standard deviation of 0.02 GHS per garawa and a range of 0.02-0.13 GHS per garawa. All participants reported the same cost except two. One respondent specified fetching a barrel; another specified fetching a jerry can, 25 L, and thus had different unit prices. The list price of the borehole is 0.10 GHS, matching the reported average.

3.1.3.2 Other Communities' Boreholes

The other boreholes used by people from Tong are in Gbutugu and Nyensobga. Recall, Gbutugu is a town about 3.5 km west of Tong. 33% of respondents reported fetching water from Gbutugu boreholes. Nyensobga is another town about 3.7 km north and west of Tong, and 77% of respondents said they use water from the Nyensobga borehole.

For these two sources, respondents did not typically specify which mode of transport they use. Estimating which mode is most common was not possible. Aggregating all modes of transport together then, the average unit fetch time for Gbutugu borehole was 201 minutes per garawa, with a standard deviation of 73 minutes per garawa and a range of 28-300 minutes per garawa. The author has never fetched from the Gbutugu borehole and cannot verify the reported times. Considering the distance, the overall time makes sense. Considering more of the time comes from travel rather than waiting which can be variable, it makes sense that Gbutugu borehole has a smaller standard deviation and range than the Tong borehole.

Respondents require an average 163 minutes to fetch a garawa from the Nyensobga borehole, with a standard deviation of 65 minutes per garawa and a range of 28-300 minute per garawa. The large range of travel times likely stems from the various means of fetching. Most modes are assumed to be walking, but those who specified using a motorcycle are also included and thus decrease the fetch time drastically. Nyensobga is far but has the fewest people. As such, the bulk of the time is spent travelling.

As for cost, the Gbutugu and Nyensobga boreholes are similar in price to water from the Tong borehole. Gbutugu boreholes cost an average 0.09 GHS per garawa with a standard deviation of 0.03 GHS per garawa and a range of 0-0.12 GHS per garawa. This range is a result of one respondent having the social connections to collect the water for free and from one respondent who explicitly stated he collects a barrel and is charged 0.50 GHS. The list price of the borehole is 0.10 GHS, matching the reported average.

The Nyensobga borehole water costs an average of 0.10 GHS per garawa with a standard deviation of 0.05 GHS per garawa and a range of 0-0.20 GHS. Again, these values range based on social connections allowing the collection of water at no charge, others getting overcharged, and one respondent fetching a barrel at a slightly higher unit cost. Like the

Tong and Gbutugu boreholes, the list price of the Nyensobga borehole is 0.10 GHS, matching the reported average.

3.1.3.3 Reservoirs/ Dams

100% of households reported using either the Tong or Gbutugu dam. Though they are two distinct water sources, respondents never distinguished between the two, and thus the times and cost reported here represent both. Respondents often specified how they reach the dam, either by walking, bicycling, riding motorcycles, or hiring a Motorking or donkey cart. Walking and bicycling were averaged together. If bicycle was specified, then two jerry cans, 50 L, were assumed to be collected. Otherwise, walking was assumed and the fetchers presumably fetched one garawa. Walking or cycling was the assumed mode if the cost was zero because the other modes have associated costs (hiring or fuel). By these assumptions, 23 households, or 77% of respondents, reported fetching dam water by cycling or walking. These respondents reported an average unit fetch time of 92 minutes with a standard deviation of 33 minutes and a range of 15-120 minutes. The difference in speed between walking and cycling likely accounts for most of this range. The average unit cost reported by the respondents was 0 GHS per garawa with the same standard deviation and a range. This should be the case as nobody charges for accessing or collecting water at the reservoirs.

Motorized and animal-powered modes were in their own category. 50% of respondents reported using their own motorcycle, hiring a donkey cart, or hiring a Motorking to fetch water at the dams. It was assumed that a motorcycle could carry 50 L based on the author's observations of motorcyclists typically carrying two jerry cans, 25 L each. Hired transporters charge per barrel. Mode was assumed to be motorcycle, Motorking, or donkey if the cost was more than zero, though most people specified. With these assumptions and categorizing, the respondents took an average 23 minutes per garawa to fetch, with a standard deviation of 10 minutes per garawa and a range of 7-42 minutes per garawa. The faster transport is likely motorcycles. Though donkeys and Motorkings can travel faster under most conditions, when carrying a barrel or more and traveling along rutted and sandy footpaths, they are forced to travel slowly. Additionally, they take longer to fill up while at the dam side since they cannot simply dip the barrel in like one can do with a garawa. Rather, they have to fill by fetching a bucket, lifting and dumping it into the barrel about 20 times.

3.1.3.4 Wells

47% of respondents use the Karaga-Pigu Road protected well. Recall this is a well on the road going toward Karaga, about 2.3 km east of the center of Tong. Most respondents did not say which mode was used, but based on the author's observations, walking was assumed. Those using this source report an average unit fetch time of 90 minutes per garawa with a standard deviation of 35 minutes per garawa and a range of 30-120

minutes per garawa. The range likely stems from both differences in estimating ability and in walking to and from the east or west end of town. The average unit cost of fetching was 0 GHS per garawa with the same standard deviation and range.

Another well is the natural well north of town; 90% of respondents, reported using it. Because mode was rarely mentioned, all modes are included in the calculating of averages. From the author's experience it is a pretty good mix of walking, bicycle, and motorcycle as many people will take their bike or motorcycle to farm and then fetch some water at the natural well on the way back. The average unit fetch time across all modes of transport to the natural well was 74 minutes per garawa with a standard deviation of 39 minutes per garawa and a range of 7-150 minutes per garawa. Clearly the low-end fetch times are from motorcycles and the higher end is from walking. The average unit cost of natural well water over all transport methods was 0.14 GHS per garawa with a standard deviation of 0.75 GHS per garawa and a range of 0-3.88 GHS per garawa. This range represents only two values – either free or about 2 GHS of fuel to fetch by motorcycle, as reported by one respondent.

The other wells in Tong include both hand dug and protected wells. 27% of respondents reported using these other wells while they are available, typically from rainy season to the end of December. The average unit fetch time was 4 minutes per garawa with a standard deviation of 3 minutes per garawa and a range of 0.5-10 minutes per garawa. The range in time simply stems from the distance from the house to the well, and perhaps depending on the collection device of a household and its efficiency. The average unit price for water from these wells was 0 GHS per garawa, with the same standard deviation and range as all users reported well water to be free.

3.1.3.5 Pure Water Sachets

The last source listed is pure water sachets, the filtered water sold in half-liter plastic pouches. 80% of respondents reported using pure water sachets. The average unit fetch time was 314 minutes per garawa with a standard deviation of 421 minutes per garawa and a range of 0.8-1,455 minutes per garawa. These values are large because the units used here, garawas, are a significantly larger amount than the amount typically purchased in a trip or even in a day. As such, these values reflect numerous trips of at most six liters at a time. It is possible to purchase a garawa amount in a shorter time, but this is simply not the exhibited behavior. The average unit cost of pure water was 16.34 GHS per garawa with a standard deviation of 2.13 GHS per garawa and a range of 12.93-19.40 GHS per garawa. Again, these amounts represent several small purchases added up. Even at the most cost efficient option, purchasing a 15-L sleeve for 3.50 GHS is still a unit cost of 11.32 GHS per garawa. In the author's experience, the author is the only person in Tong that purchased an entire sleeve at a time.

3.1.3.6 Karaga Municipal Sources

Two households, or 7% of respondents, reported traveling to Karaga for water. Karaga is a large community about 5.3 km east of Tong. They have several public taps and a large dam. The dam is on the east side of Karaga and totals close to 7.5 km from Tong. As these distances suggest, these households fetched with motorized transport, either a motorcycle carrying an assumed 50 L or a Motorking charging by the barrel. Households using sources in Karaga reported an average fetch time of 61 minutes per garawa with a standard deviation of 37 minutes per garawa and a range of 35-87 minutes per garawa. The average cost reported by these two households was 2.55 GHS per garawa with a standard deviation of 1.95 GHS per garawa and a range of 1.17-3.93 GHS per garawa. The author has no experience fetching water in Karaga and thus cannot corroborate these values.

3.1.4 Household Water Treatment Practices

The household surveys also asked respondents about the types of treatments they know and use. Table 3.3 and Table 3.4 below list all treatments reported, their frequency of use, and on which source(s) or task(s) treated water is used. This section describes the two most frequently mentioned treatments – alum and P>M Purifier of Water – and the details provided by respondents.

Table 3.3 Treatments used by the percent of respondents stated and water source(s) on which stated treatment is used.

Treatment	Used By % of Respondents	Used on Source(s)	By % of Treatment Users
Alum	93%	Dam	89%
		All but pure water	4%
		All	4%
		Dam and well	4%
P&G TM Purifier of Water	97%	Dam	86%
		All but pure water	3.4%
		All	3.4%
		Non-borehole	3.4%
		Dam and well	3.4%
Other	6.7%	Dam	50%
		Non-borehole	50%

Table 3.4 Treatments used by the percent of respondents stated and water-consuming task(s) for which treated water is used.

Treatment	Used By % of Respondents	Used on Source(s)	By % of Treatment Users
Alum	93%	All	89%
		All but constr.	3.6%
		All but constr., shea	3.6%
		Laundry and dishes	3.6%
P&G TM Purifier of Water	97%	All	86%
		All but constr.	3.4%
		All but constr., shea	3.4%
		Drink and cook	3.4%
		Laundry and dishes	3.4%
Other	6.7%	All	50.0%
		Drink and cook	50.0%

3.1.4.1 Alum (Aluminum Sulphate)

93% of respondents reported using alum to treat water. Of those reporting use, 89% report using it strictly on water from the reservoirs, the remaining 11% use alum on reservoir water and at least one other source. 89% of households that use alum say they use it for all tasks, whereas others limit its use. Some limitations include using it only for laundry and dishes, others use alum for all purposes except construction and shea butter processing. Additionally, one household estimated that 0.20 GHS worth of alum will treat 2 garawas, or 97 L. Many respondents noted that they use alum “when they have it,” suggesting that many households do not always have the money for alum, but that if they do, the previously described habits are practiced.

3.1.4.2 P>M Purifier of Water

The other frequently used treatment, with 29 households or 97% of respondents, reporting use is P>M Purifier of Water. Recall, P>M powder has both flocculent and disinfectant that users simply stir into the dirty water. In Tong, the NGO World Vision hands out chains of packets free of charge. Of those using it, 86% use it exclusively on dam water. One household also uses P>M powder on well water; another household uses it on any source other than borehole water; and another uses the powder on any water other than pure water sachets. Of those using P>M powder, 86% report to use P>M treated water for any use. Others report using it on water intended for just

cooking and drinking, just laundry and dishes, any use other than construction, or any use other than construction or shea nut processing. One household participant also noted that once water is treated with P&G™ powder, it must be consumed by the end of the day. Although these packets are free, one household said that they use it “when they have it,” suggesting it may not always be available.

3.1.4.3 Other Treatments in Use

Two respondents also reported using treatments other than alum or P&G™ Purifier of Water. One household uses a fine-mesh cloth designed for straining out Guinea worm-carrying vectors that were distributed as part of Guinea worm eradication efforts. This household reports using the cloth for reservoir water prior to any use. As only one household reported using it and the author has not seen such cloths in use at other homes, this treatment was not considered common. Because Guinea worm has been eradicated and distribution of these filters ceased, there is no expectation that others will use this method in the future.

Another respondent also uses a filter provided by the Japan International Cooperation Agency (JICA). Specifics on the JICA filter are unknown as respondents did not show the filter to researchers. This household reports using the JICA filter on any water that did not come from the borehole when they are going to use such water for cooking or drinking. Again, because no other households report using such filters and such filters have not been observed at any other house, they are not considered a commonly used method.

3.1.5 Household Water Consumption

Participants were asked about the volume of water consumed on a daily basis at the house. These questions aimed to determine the average per capita water consumption. Given the aforementioned volume assumptions and all survey responses, the average household size, daily household water consumption and daily per capita water consumption were calculated and are tabulated in Table 3.5.

Table 3.5 The household size, daily household water consumption, and daily per capita water consumption and their associated statistical values.

	Average	Standard Deviation	Minimum	Maximum
Household Size	16.6	9.5	5	42
Daily Household Water Consumption (L)	651	379.6	194	2080
Daily Per Capita Water Consumption (LPCD)	44.2	21.8	9.90	104

As previously stated, the average household size is about 17 people. Over all households, the average household consumption is 651 L with a standard deviation of 380 L and a range of 194-2080 L. This range comes from the size of the household and other factors. To reduce the influence of household size on water consumption values, the water consumption per person was calculated. The average daily per capita water consumption was 44.2 liters per capita per day (LPCD) with a standard deviation of 21.8 LPCD, and a range of 10-104 LPCD. The large range of water use rates may stem from several factors such as estimating ability and different household characteristics.

The author measured her own daily use to compare to water consumption reported by survey respondents. The author found she used about 26 L a day. Additionally, most Ghanaians bathe twice a day, which would add about 7 L of water, and ablution would add 4 L according to survey results. Further, the author only prepared two meals a day from the water sources she was measuring. She estimates the volume of water used by her host mother to prepare her third meal was at least 1.5 L. That total comes to 38.5 LPCD, which is well within the range of reported amounts and fairly close to the average. The difference between the author's use and the reported average is reasonable and suggests the average over all respondents is acceptable.

Additionally, we can consider the lifestyle of the people in Tong and compare it to WHO's increments of water needs (Howard & Bartram, 2003). WHO describes four levels of service and related health risk concern as outlined in Table 2.1. Based on the author's observations in Tong, the author estimates that Tong is pretty close to the "Intermediate Access" category, as people certainly meet their human consumption needs for hydration and food and for the most part are able to complete laundry and bathing and perhaps, to a lesser extent, food hygiene. Hand washing occurs, but often it is without soap and is completed by several people using one bowl in which they dip their hands. As such, they wash, but probably not with the amount of water recommended by WHO for optimal hygiene. Similar for food hygiene, they will rinse obvious dirt off of food, but rarely wash food that does not have noticeable amounts of dirt or grime. Clean clothes are

very important to Ghanaians, and most people in Tong wash their clothes often, but oftentimes this task is performed near the source. Considering the hygiene is close to sufficient but probably slightly less than optimal by WHO's determinations and that laundry is sufficiently done but often at the source, the lower end of the "Intermediate Access" category fits best. This category suggests an average quantity of 50 LPCD. Therefore, the confidence in the household estimate of 44.2 LPCD is fairly high. Again, these comparisons are not accurate enough to allow a calculation of level of confidence, but they do suggest a comfortable degree of accuracy reliability.

3.1.6 Ablution Practices

To determine the potential for AGW reuse, respondents were asked how much water they use for ablution, how many times a day they perform ablution, and how many in the house do ablution. These responses and the assumed volume of a "kettle" provide the quantities needed to calculate the daily volume of water that would be made available for the average ablution-performing individual to collect, treat, and reuse; alternatively they can be used to calculate the proportion of household water use that goes towards ablution. For the relevant questions in the survey, 2 households did not provide responses and were thus not included in analyses regarding ablution. Table 3.6 below and the following describe ablution water consumption results relating to the remaining 28 households.

Table 3.6 Water consumption statistics for ablution.

	Average	Standard Deviation	Minimum	Maximum
% of Household Performing Ablution	63%	26%	17%	117%
Water Consumption from Ablution per Day per Ablution Performer (L)	4.0-4.7 ^a	3.4	2.1	20 ^b
Household Daily Water Consumption from Ablution (L)	34-53 ^a	72	2.8	298
Gray Water Reuse Potential (% of total consumption used on ablution)	6-9% ^a	13%	1%	71% ^c

^a Range is from average for data less two outlier values have been removed to average of all available data.

^b First outlier value. 20 L for ablution in a day is almost triple the amount reported by all others.

^c Second outlier value. Using 71% of household water for ablution is extremely unrealistic and is assumed to be the result of poor estimation.

Among the 28 responding households, an average of 63% of household members perform ablution with a standard deviation of 26% and a range of 17-117%. One household had 17% of household members performing ablution. There are various reasons why some do not perform ablution such as younger children who have not decided to do so yet and women who are pregnant or breastfeeding. One household provided water for several non-household members to perform ablution, resulting in more than 100% of members performing ablution. For those performing ablution, the average ablution consumption in a day was 4.6 L, with a standard deviation of 3.4 L per day. The most efficient ablution-performing people use only 2.1 LPCD on ablution while the least efficient used 20 L. The low range are likely for individuals performing ablution only three times a day. The average percent of total daily household water consumption used for ablution, referred to as the potential for AGW reuse, was 9% with a standard deviation of 13% and a range of 1-71%. Because some of these values seem unrealistic, the average for households with outliers removed was also calculated. One household was considered an outlier because it reported 71% of its household water consumption was used for ablution. A second household was considered an outlier because it reported using almost 20 L of water daily for each ablution performer. When those households' responses are removed, the average ablution performer consumes about 4.0 L a day, the average household consumes 34 L on ablution in a day, equivalent to about 6% of total household consumption.

3.1.7 Data Analysis

From the aforementioned survey results regarding dry season water sources, water treatments currently in use, and the statistical analysis of survey results, some conclusions and a few decisions could be made, which are outlined in this section

3.1.7.1 Justification of Further Study

First and foremost, the surveys were designed to determine whether AGW treatment could even possibly provide enough water to make the investigation worthwhile. Recall the metric was set at 2 L of potential recapture as that is understood to be the minimum requirement for human hydration, and thus recapturing at least 2 L would be meaningful. If the surveys showed that an ablution-performing individual could collect at least 2 L of gray water to treat and then reuse, then further study would be considered useful. The average ablution-performing individual consumes 4.0-4.7 L of water a day for ablution, well above the required 2 L. This is double the desired minimum quantity of 2 L. The minimum reported use was also greater than required at 2.1 L per day per ablution performing individual. Thus, the survey results show that AGW potential meets the minimum for making further investigation worthwhile.

3.1.7.2 Demographics' Correlations

The purpose of the survey's demographics section was to see if any particular household characteristics had any significant correlation with AGW reuse potential so that any future recommendations could be made appropriately and adjustments could be made to ensure equity among beneficiaries. Regression lines were created between each household characteristic and the AGW reuse potential, but no strong correlations were discovered. Likely, the potential for gray water reuse stems from a wide variety of complex and interacting factors and thus no obvious trends emerged. These results suggest AGW reuse is a potentially equitable practice.

3.1.7.3 Critical Water Source

Survey participants described in detail their dry season water sources. From these descriptions, the critical source was determined to be reservoir water, from either Tong or Gbutugu Dam, as respondents never differentiated between the two. Reservoir water became the critical source because it was the poorest quality of the sources available throughout the entire dry season, and it is used by at least half of the responding households. Other turbid water sources, like the wells, were eliminated because most of those go dry by February, well before dry season is over. Other sources, like all sources located in Karaga, were eliminated because they are not used by at least half of responding households. Of the remaining sources, primarily boreholes and reservoirs, reservoirs are the limiting state of gray water treatment potential. Borehole water is very clear to start and would likely be only slightly turbid following ablution, whereas reservoir water is extremely turbid from the start. By testing treatments on reservoir water, the worst-case scenario is tested. If any treatment proves it can provide potable water from used reservoir water, then it can safely be assumed that treatment would also provide potable water if used on other sources. Water quality laboratory testing results of the critical source, reservoir water, is described later in this report.

3.1.7.4 Treatments for Trials

With the author's observations of water treatment and survey responses regarding treatments used in Tong, various treatments available had to be narrowed down for the physical testing. This narrowing of scope was necessary due to time and budget available for testing water samples. In this section, all treatment options considered are described, inclusion or exclusion from the physical testing stated, and rationale for inclusion or exclusion given.

3.1.7.4.1 Boiling

Boiling is a widely promoted treatment method, as it is well proven to deactivate pathogens. Though not mentioned in household surveys, based on participant observation

and conversation, it is a known method in Tong. Many people know they can boil water to make it safe, but many do not boil water before drinking. That said water is boiled for preparing typically warm beverages such as tea, coffee, or “kokoo” (similar to cream of wheat but made from maize flour). One negative aspect of boiling is the burning of resources and production of greenhouse gases (GHG). When using boiling to treat items that will be boiled regardless, these negative impacts are experienced whether the user’s intention is to treat or not. Because these items are regularly consumed, any negative effects of boiling – like greenhouse gas emissions, deforestation, or indoor air pollution – are experienced regardless of water source or necessity of heat for treatment. Because of these factors, boiling as treatment for gray water was considered a beneficial option.

However, because of its well-proven ability to treat water for bacteria and viruses, it was not used in the trials. Because of the well-established effectiveness of boiling against bacteria (WHO, 2015), it would be assumed that boiling was an option for disinfection of treated gray water after other treatments, but was not formally tested in a laboratory setting in this study.

3.1.7.4.2 Solar Disinfection

Solar disinfection is a treatment method that is not used or known in Tong. Ultraviolet (UV) light’s disinfecting properties are well known among professionals and is utilized at countless water and wastewater treatment facilities throughout the world. Though in-situ use of UV via the sun is less tested and not as certain to successfully extinguish contaminants, the author was familiar with its proposed use in low-cost water treatment particularly for developing countries. Because the author frequently observed many things sitting out in the sun as a matter of course (drying laundry, crops, dishes, etc.), she contemplated the option of solar disinfection for gray water, not as a known treatment but as an easily adopted, inexpensive treatment option.

Ultimately, the author excluded solar disinfection from the trials because solar disinfection requires fairly clear water in order to be effective. Dealing with wastewater, it is reasonable to expect the water dealt with in this study would be fairly turbid. As such, solar disinfection would require pre-treatment of AGW. Considering the already tight budget for water testing, the author would investigate other treatments that could potentially clarify water sufficiently to make solar disinfection possible, but would not investigate solar disinfection itself.

3.1.7.4.3 Alum (Aluminum Sulphate)

Alum, or aluminum sulphate, is a water-soluble salt commonly used in water and wastewater treatment worldwide. As explained above, 93% of households surveyed reported they use alum as water treatment.

There are downsides to alum use. First, one has to continually purchase it. Second, people in Tong frequently use it, but often use it ineffectively. It is sold as a large rock that people hold in their hand and then plunge into the water and stir with their arm. Plunging into and stirring wastewater with their arm, would be unacceptable to people in Tong. Further, as witnessed in Tong, alum has very limited ability to clarify water given its local application process. Because of the cost, lack of effectiveness in clarifying water, and the presumably unacceptable process, alum was not included in this study.

3.1.7.4.4 Bleach

Many water treatment facilities use various forms of chlorine to disinfect their water supplies. By extension, many rural locations with household level treatment utilize products that contain chlorine for their household water disinfection. Unfortunately, such supplies are not available in the local markets near Tong. Though some cleaning products that include bleach are available in larger urban centers of Ghana, these are not intended for water disinfection and likely contain other toxic chemicals with unknown health risks. As such, bleach for disinfection was not considered in this study.

3.1.7.4.5 P&G™ Purify Packets

P&G™ Purifier of Water is a popular treatment in Tong, most frequently applied to water from the reservoirs. As mentioned, it is a powder that both settles out and disinfects water, and is provided at no cost by World Vision, a generous but unsustainable system. It has been shown to produce potable water in both lab and field testing (CDC, 2014), but has had dubious results as used by people on reservoir water in Tong. According to the author's local colleague many people do not use it correctly, either by applying one packet to the incorrect amount of water or by not implementing the stirring and settling times correctly. The author also witnessed some people adding the powder to water more like purification tablets, as they allowing the powder to dissolve but never siphon off the clarified water. Despite its dubious long-term sustainability, the frequent acceptance and use of P&G™ Purifier as well as its current cost, P&G™ was included in the treatment testing.

3.1.7.4.6 Moringa Seeds

Moringa, as a tree with many uses for its various parts, quick propagation, and ease of cultivation, is touted by many aid organizations as the "Miracle Tree." As previously described, the seeds contain a cationic protein that can reduce turbidity. The process for utilizing moringa seeds for this purpose was described in the Methodology section, but basically requires one to crush the seeds, mix it in with the turbid water for a while, and then let the particles settle. The author used this process frequently and successfully with

reservoir water to wash clothes. On a number of occasions, other people in the vicinity asked if they could drink the moringa treated water.

Though nobody mentioned using moringa seeds for water treatment in the household surveys, there are four moringa trees in Tong, which prompted the author to speak to people about moringa. From these conversations she learned that people in Tong primarily use moringa for tea, stews, or as medicine. She also discovered that the trees were provided by a charity that taught the owners about many uses for the various parts, but that much of these lessons have since been forgotten.

Unlike alum, moringa seeds offer a free treatment option without the necessity of touching the wastewater. These seeds, obtained from moringa trees already present in Tong, could be sown and brought to maturity with little effort and in relatively little time, as moringa is quick growing and bears seeds at a very young age. There are several other benefits to having moringa, including compostable waste product and nutritional and economic value of the leaves and oil.

Due to the community's familiarity and proven positive reception of moringa, its ease of access, zero cost, and other benefits, moringa was selected for gray water treatment testing in this study.

3.1.7.4.7 AfriClay Filter

Though not commonly used in Tong, filters are a well-known concept and have some prevalence in Tong. Two households surveyed reported using some kind of filter – one was simply a cloth introduced to Tong and many places in Ghana to combat Guinea Worm, and the other was from Japan International Cooperation Agency (JICA). The clinic and schools have received filters from World Vision making them familiar to people in Tong. These are all made available by foreign aid, but there are also locally available filters, such as Pure Home Water's AfriClay Filter.

As previously described, the AfriClay filter is made in nearby Tamale. The purchase includes the filter, a top, a storage container, a spigot, a sticker with graphic instructions, and a brush for cleaning the filter. The cost for all items is 125 GHS (24 USD) as of July 2017. This is expensive for most people in Tong, but not completely out of reach, especially for an entire household or extended family group.

Despite its cost, there are a few reasons the AfriClay filter was ultimately included. First, Pure Home Water is a social enterprise who offers better deals and educational outreach for communities that purchase the items in bulk. They also provide transportation of the filters if enough are purchased at once. Thus, if a group in the community made a large order, they could get a lower price.

Second, metals were a very serious concern. Even before testing the critical source, metals have thwarted many previous water projects in the area. For example, one of the

wells drilled by World Vision in Tong had unsafe levels of fluoride. Arsenic is also frequently discovered in Northern Region groundwater sources (Lutz, Diarra, Apambire, Thomas, & Ayamsegna, 2013). Though P&G™ Purifier of Water has been shown to remove some metals, P&G™ Purifier of Water may not always be available. The AfriClay, though not free, is more sustainable than P&G™ as it reduces the necessity of foreign aid. The AfriClay filter was included in trials due to the familiarity with the mechanism of treatment, possibility of removing metals, and ease of use.

3.1.7.5 Collection Device Type

The household survey data also informed the design of the AGW collection device. Because most people reported performing wherever they are when it is time for prayers, an individual device was selected. Prototype design specifics are provided later in this report.

3.1.7.6 Social Acceptability Determinations

The DRAW charts include cost, time, and social acceptability aspects. Costs and times were directly provided by respondents, but the social acceptability determinations require analysis. Four categories of social acceptability were created:

- Proven Acceptability – at least half of respondents report they already use this source for any use without treatment
- Limited Proven Acceptability – at least half of respondents report they already use this source but for only certain uses or only after a certain treatment
- Unproven Promising Acceptability – Not in current use but feedback and water quality testing suggest it would be acceptable for broad application
- Unproven Limited Acceptability – Not in current use and feedback and water quality testing suggest it may not be readily accepted for more than one or two applications

Because the household surveys only discussed sources already in use, only the first two categories, Proven and Limited Proven Acceptability can be applied to the sources mentioned by respondents. Table 3.7 below shows all the sources that were reported to be available through the end of dry season and were also used by at least half of respondents. Based on the reported acceptable uses and commonness of treatment, each was assigned a category of social acceptability. If the source does not require treatment and is still useable for any application (“N” and “Y” in Table 3.7 columns), it is considered Proven Acceptable. If a source meets only one of those qualities (“N” and “N” or “Y” and “Y” in columns of Table 3.7), then it is considered Limited Proven Acceptable.

Table 3.7 All sources listed by respondents available through entire dry season and used by at least 50% of respondents and their social acceptability determinants and categories.

Source	% of Houses Using	Requires Treatment (Y/N)	Use on Everything (Y/N)	Social Acceptability Category	Symbol
Tong Borehole	100%	N	Y	Proven Acceptable
Nyensobga Borehole	77%	N	Y	Proven Acceptable
Dams (walk/bike)	77%	Y	Y	Limited Proven Acceptable
Dams (motor/hire)	50%	Y	Y	Limited Proven Acceptable
Pure Water	80%	N	N	Limited Proven Acceptable

The Tong borehole, used by 100% of respondents, was categorized as “Proven Acceptable,” due to its potable quality without treatment and the respondents’ current practice of using it for any purpose. The Nyensobga borehole had fewer users with only 77% of respondents reporting use, but just like water from the Tong borehole, people feel free to use it for anything without any treatment. As such, Nyensobga borehole was also categorized as “Proven Acceptable.” The dam water, regardless of transport, had at least half of respondents using it. In both cases they use it for pretty much anything but they strongly prefer to treat dam water prior to use, either with alum or P&G™ Purifier of Water. Because of the treatment preference, the dam water for both transport categories was considered “Limited Proven Acceptable.” Pure water sachets, used by 80% of respondents, does not require further treatment, as it comes from a hygienic treatment facility and is hygienically packaged to prevent further contamination. However, respondents reported only one use for pure water sachets, drinking, because of its high cost. As such, pure water sachets were categorized as “Limited Proven Acceptable.”

The following sections regarding opinion leader interviews, prototype user surveys, and gray water quality testing will be used to apply the same categorization method to gray water treatment options.

3.2 Opinion Leader Interviews

Opinion leader interviews helped determine the social acceptability of AGW reuse. Two interviews were completed – one with a nurse at the Tong clinic on February 28, 2017, and another with an informal religious leader called an Al Hajji on March 3, 2017. The conversations were not recorded and thus no transcripts are available, but notes were taken and are available in Appendix D. Review and coding of interview responses combined with household survey responses and participant observation during two years of service revealed three themes. These are described below and are supported with participant observations and household survey results.

3.2.1 Complexity of “Clean” Water

The first theme gleaned from interview notes was the surprisingly complex combination of facets that play a role in determining whether water is “clean” or “dirty.” When asked directly about how they make such determinations, both interviewees mentioned the water should look clear and smell and taste good. After delving into the topic more deeply, for example considering different sources, uses, and treatments more specifically, determining whether or not certain water was clean enough for a given activity became much more involved and specific. According to Al Hajji, water treated with alum can be good and used on anything, but one can also have too much alum such that it actually makes the user ill. Additionally, he stated that Tong dam water is not clear, but because it is the color of sand, it is clean but Gbutugu reservoir water is not. The nurse, who does not drink reservoir or well water himself, has heard from many community members that though well water is clearer than reservoir water, it is not as satisfying. Another nuance described by Al Hajji is the difference between “clean” water and “good” water. As he explained, reservoir water is not clean, but it is good because one can store kola nuts in reservoir water better than in borehole water. Regarding which water is preferred when performing ablution, Al Hajji stated “with the water crisis you use what you can get.” This likely explains why at the surface, people in Tong judge the cleanliness of water based on appearance, taste, and smell; but because of the limited amount of water meeting that criteria, the decisions become much more complex for available sources.

The aforementioned means of distinguishing clean from dirty water were those of the people of Tong. That said, both interviewees also readily recognized the “geologists” determination methods. Here, “geologists” refers to the trained professionals who perform site investigations, modeling, drilling, and testing of borehole water. Regarding the reuse of treated AGW, the nurse said that if tests prove it is okay to use, then he will use it. Al Hajji mentioned that the geologists have different ways of deciding what qualifies as “clean” water, but that if they say a source is dirty or unsafe, people in Tong accept that. He pointed to the specific example of a borehole drilled about eight months prior. While drilling, people could see this water was clear and very nice looking; some even drank it and said it was sweet. But when geologists said it was unsafe, the people of

Tong respected that. This respect does not mean blind acceptance. For example, during household interviews, a couple people mentioned they do not drink borehole water because it makes their stomach feel bad. Thus, despite the geologists saying it is safe to drink, they still prefer other, likely non-potable, sources. Thus, even if geologists say something is okay, it does not mean people in Tong will feel free to use it for anything.

Overall, this complexity is not easy to navigate, but it does make possible a role for AGW reuse in helping Tong meet their water needs. Appearance, taste, and smell are important and testing can influence how accepting people in Tong are to the collection, treatment, and reuse of AGW.

3.2.2 Religion - Important but Open

As anticipated in this devoutly Muslim community, religion is a major consideration in the social acceptability of any new practice or device, especially when a new practice or device revolves around a religious activity such as ablution. After talking to the interviewees, it was clear that the religion does have many guidelines and rules about ablution. The process of ablution, for example, was described very specifically by Al Hajji, and the nurse listed a couple reasons why one may even have to redo ablution. There is no specific place mentioned by either where a Muslim must perform ablution, as long as it is clean, you are not distracted, and you face the direction from which the sun rises. In addition, the author has often witnessed colleagues correcting the behavior of younger community members based on religious tenets. For example, one colleague told someone he should not pray in his mother's room because Islam does not allow that. If someone were communicating by yelling from the bath, he would explain that by Islam, they should not do that. So it is clear that Islam has plenty of rules and that the people in Tong recognize and do their best to follow these rules.

Nonetheless, there was also a certain openness of interviewees in regards to religion and AGW reuse. As mentioned, if tests showed the water from AGW treatment was safe, both were willing to use it. Both respondents, however had the same qualification – they would not use it for ablution again. When discussing with my colleagues, they said the same thing – that it would be good to have this extra water, but that it could not be used for ablution. Further, the religion can directly support the reuse of AGW, albeit without ablution as a second use. The author's colleague, upon reading an article regarding AGW treatment and reuse in Jordan that included quotes from the Quran, agreed that if the Quran says waste is bad, then Muslim people should do their best to make use of AGW.

Religious aspects are not straightforward. Religion needs to be accounted for in any AGW reuse recommendations, but it should not be assumed that because of Islam's myriad of rules that Muslims would be opposed to AGW treatment and reuse.

3.2.3 Money as Limiting Factor

The final theme emerging from interviews and highly related to the previous two discussed is cost. Based on interviews, household surveys, user surveys, personal conversations, and participant observation, it seems cost is more limiting than water quality or religious rules. The nurse said he would pay 85 GHS (the price at the time of the interview) for an AfriClay filter, but most people in the community would not. During his interview, Al Hajji mentioned cost in several different ways including “free,” “no cost,” and “0 cedis,” when responding to the question about his willingness to adopt such a practice. He had some ideas for making a collection device using found materials, and he noted that moringa and boiling could be essentially free. However, he warned that if there is any cost involved, one cannot expect the people of Tong to employ such a method. He added that if an organization were willing to assist Tong in building or purchasing collection or treatment devices, such assistance must be applied equally to all households; an aid agency should not choose only certain houses. According to interviewees, the exact make up of collecting or the choice of how to treat is fairly flexible, but the cost plays a large role and cost assistance needs to be administered carefully.

Supporting the interviewees comments are a couple other pieces of evidence. The household surveys provided averages of costs and time to fetch. The most popular and widely used sources were the Tong borehole and the reservoirs, both being used by all 30 households. Borehole water is not free, but it is fairly cost effective. For dam water, it can be fetched in much greater quantities and with less time involvement when hiring someone to fetch a barrel, but more households fetch by walking or cycling because they simply cannot afford the 3 GHS for a barrel. More notably, pure water sachets are happily consumed and highly enjoyed by people in Tong, but some people laughed at the question of whether they use it because they never had the income to purchase it for themselves.

Also very telling is the hypothetical situation posed by the author’s counterpart Mohammed. After a borehole was drilled (but before discovering it was not potable), Mohammed was concerned about how far it was – about the same distance as the reservoirs. If the borehole were not mechanized, people would need to walk over 2 km to fetch the borehole water. People would be charged a fee for using the borehole water in order to cover maintenance costs. As he described, if people had to walk the same distance for borehole and reservoir water, but had to pay for borehole water, even though it is of much higher quality, people will still just use the reservoir water because it is free. His hypothesis is supported by the household surveys. People in Tong are more likely to choose the low quality but free reservoir water rather than go to a neighboring community’s borehole, which is potable and takes only slightly more time, but costs money. This suggests that even when people recognize one source as clean, if that is the only advantage over another source, they still choose based on cost, not quality.

3.3 AGW Collection Device Prototype

Recall that a device to collect AGW was required for water quality testing of both the used water as well as treated gray water. Additionally, the device was tested by users who answered questions about the device. The following sections describe the design itself, prototype testing participants' feedback, and the author's observations.

3.3.1 Design

Combined with input from colleagues and craftsmen, the collection device shown in Figure 3.11 was designed. A welder constructed it for 40 GHS. Because the welder is in Karaga, easily reached by bicycle, no transportation costs were associated with the collection device. Often, prices will differ depending on who is buying an item. This study placed a 100 GHS limit, placing the prototype cost well below the maximum, ensuring the cost would be below the limit regardless of purchaser.

The design was based on several factors. The size allows the device to sit easily over basins, a common container in Tong, while simultaneously sitting low enough for users to perform ablution above the drainage plate. The metal construction makes it light enough to be carried around from user to user but sturdy enough to survive repeated use. The top plate has a hole at the center for gray water to drain through to the basin below. As described earlier, this is just a prototype, but it would serve well enough to get both user feedback and collect AGW for treatment and testing.

Figure 3.11 Metal AGW collection device designed for this study and used to collect AGW for treatment application and water quality testing.

3.3.2 User Testing

After designing the above device, prototype and treatment trials were scheduled. Recall, these trials were performed to learn how users feel about the device, the treatment methods, the resulting water, and their overall willingness to put in the requisite monetary and labor inputs.

The prototype and treatment trials were performed on March 6, 2017 at 1:00pm, 3:00pm and 6:30pm prayers. 14, 12, and 19 people performed ablution for Trials 1, 2, and 3, respectively. The participants, all adult males, were largely the same for each trial. The trials were completed at a popular hang out spot, a pavilion across the street from the central mosque.

In designing the trials, the author hoped to have participants do the treatment, but she failed to take into account the time they would be at prayers. If treatment waited until after they returned from prayers it would already be very close to the next prayer time. Considering many of them have other duties – businesses to operate, household responsibilities – it was considered unnecessarily time consuming for participants to also perform the treatments. As such, the author performed the treatment and no feedback was solicited on the treatment process.

3.3.2.1 User Survey Responses

Notes from the prototype testing trials are available in Appendix E. Because there was such significant overlap in participants for each trial, the survey was asked only once. Because of the group setting, they were asked as a group.

Users said they were able to perform ablution comfortably, and they appreciated that they were not wasting water. Further, they would be willing to adopt this method of ablution on a regular basis. They were willing to pay for such a device but would not pay more than 50 GHS. The device used was then in their price range, but they also felt confident they could construct a similar thing on their own.

The author had incorrectly assumed that because they do not perform ablution at the mosque, a large, multi-user device would not be as useful as an individual one. Though the men do not perform ablution at the mosque, they still tend to perform ablution in centralized locations – their sitting spots. As such, they suggested creating a larger device such that many men can perform ablution at once, be done faster, and get to mosque on time. Essentially, they recommend a layout that is somewhere between the individual and community-wide styles initially conceived. They said for women, the device should be located at the house. The men crowded around the device in Figure 3.12 support the need for a multi-user device either at the home for women or at sitting spots for men.

Figure 3.12 Participants perform ablution over the wastewater collection device during trials. The device, made for a single user, is a bit crowded, which may add to the inefficiency in its ability to capture wastewater.

3.3.2.2 Observations

In addition to users' input, observations were noted throughout the trials. Over all three trials, ablution was performed 45 times and consumed a rough estimate of 15.7 L. This means the device captured only an average of 0.35 L per ablution. This is significantly lower than the average of about 1 L per ablution reported in household surveys. Some of this is certainly due to lost wastewater. For example, in Figure 3.12 above, water spillage is visible on the ground around the collection device. Multiple participants using a device designed for a single user likely exacerbates this problem. The device's collection surface was also only slightly sloped and a lot of water never flowed down to the basin. Adjustments in the size and slope should improve efficiency.

Some observations were also made regarding social acceptability of the practice. A positive indicator of religious acceptability of the practice is the participation of the muezzin, the man who calls the prayers at the nearby mosque. Additionally, many users

and passersby noted how nice the water looked following treatment. Without personal experience performing the treatments, it is not possible to say with certainty how people in Tong feel about the treatment methods, but based on commentary from observers watching treatment, there is reason to believe people in Tong would accept it.

3.4 Water Quality Testing

To determine the physical feasibility of AGW treatments, water quality testing was performed to determine if ablution has any significant effect on water quality, if and how any of the treatments improved water quality of gray water, and if any of the treatments brought gray water quality to potable standards. The following subsections describe results from all laboratory testing and explain the significance of the findings.

3.4.1 Control – Critical Source

As described in the Methodology section, a sample of critical source water was tested for all biological and chemical parameters. These results informed decisions on which treatments to test and what parameters were causes for concern.

Based on the household survey results the reservoir water was determined to be the critical source. It was the lowest quality source based on visual assessment of sources available throughout dry season. Due to budget limitations, only one reservoir was sampled. Gbutugu dam was chosen, as visually it is of lower quality. One liter was collected on February 12, 2017. The sample was stored in a fridge at a local store until the following morning at which time it was taken to the lab in Tamale. At the lab it was tested for biological and chemical contaminants. Complete laboratory results are provided in Appendix F; relevant results are summarized in Table 3.8 below.

Table 3.8 Water Quality testing results for Gbutugu reservoir water. Red fill indicates standards were not met; green indicates they were. See Appendix F for full report.

Treatment Type	MWR Standard ($\leq$)	None
Total Coliform (cfu/100ml)	0	2.40E+05
Fecal Coliform (cfu/100ml)	0	0.00
E. Coli (cfu/100ml)	0	0.00
Total Heterotrophic Bacteria (cfu/1ml)	500	166
Manganese (mg/L)	0.4	1.031
Iron (mg/L)	0.3	19.551

As described in the Methodology section, the sample was analyzed for total coliform, fecal coliform, *E. coli*, and total heterotrophic bacteria. Surprisingly, there were 0 fecal coliform and *E. coli* both meeting the MWR standards for drinking water quality. Heterotrophic bacteria was present at 166 cfu/mL, also meeting the MWR standard of less than 500 cfu/mL. Total coliforms were found to be present at 2.4×10^5 cfu/100mL, exceeding the MWR standard of 0 cfu/100mL.

Additionally, it was tested for several chemical components including turbidity, pH, solids, and several minerals and metals. It met standards for all components except turbidity, manganese, and iron. Turbidity was 2,390 NTU, well above the allowable 5 NTU. The water had a manganese concentration of 1.031 mg/L, more than double the allowable level of 0.4 mg/L. The water's iron concentration of 19.551 mg/L greatly exceeded the allowable level of 0.3 mg/L. Because the quantified value of turbidity was not as vital as people's visual assessment of the water's clarity, it would not be tested during trials. Photos would be taken for documentation of visible changes in turbidity. Because manganese and iron were the only remaining components of concern and could not be analyzed by field techniques, these would be tested on treated AGW samples.

Quality of the critical source was unexpectedly good regarding biological parameters, but still did not meet potable standards. Turbidity was high, as expected. Unfortunately, manganese and iron were detected at unsafe levels and would require monitoring during treatment trials.

3.4.2 Gray Water

Once participants had performed ablution and their wastewater was collected, the collection and treatment of gray water was performed following the procedures described in the Methodology section. Table 3.9 below summarizes the laboratory test results and provides MWR's standards for comparison. Red indicates that treatment or source did not meet standard for that parameter; green indicates it did. Black means the parameter was not tested for that source or treatment.

Table 3.9 Summary of relevant laboratory test results for all samples. Red fill indicates standards were not met; green indicates they were. See Appendix F for full report.

Treatment Type	Trial	Total Coliform (cfu/100ml)	Fecal Coliform (cfu/100ml)	E. Coli (cfu/100ml)	Total Heterotrophic Bacteria (cfu/1ml)	Manganese (mg/L)	Iron (mg/L)
MWR		0	0	0	500	0.4	0.3
None	Critical Source	2E+05	0	0	166	1.031	19.551
Untreated	1	7E+07	3E+07	1E+07	1020		
	2	9E+07	8E+07	3E+07	976		
	3	6E+07	2E+07	2E+07	954		
AfriClay Filter	1	7E+07	3E+07	0E+00	860	0.033	0.679
	2	9E+07	8E+07	3E+07	976	0.021	0.287
	3	6E+07	2E+07	2E+07	954	0.023	0.115
Moringa	1	1E+08	0E+00	0E+00	1149	0.527	2.073
	2	9E+08	1E+08	0E+00	969	0.572	4.705
	3	9E+07	8E+07	2E+07	1005	0.543	2.277
P&G™ Purifier of Water	1	8E+07	7E+07	3E+07	885	0.898	86.126
	2	7E+07	6E+07	2E+07	1164	0.802	36.452
	3	9E+07	0E+00	0E+00	852	0.746	47.716

The following subsections describe the findings; original lab reports can be viewed in Appendix F.

3.4.2.1 Untreated AGW

The water used in trials were belatedly recognized to have come from a source than the critical source. As such, quality comparisons to pre-use will be limited. However, the test results for untreated ABW are useful in determining the effectiveness of each treatment.

Table 3.10 Lab results from the critical source (Pre Use) and from untreated AGW. These are informative, not conclusive. Red fill indicates standards were not met; green indicates they were. See Appendix F for full report.

Parameter	Trial	Pre Use	Untreated
Total Coliform MWR (cfu/100ml)= 0	1	2.40E+05	6.72E+07
	2		9.40E+07
	3		5.60E+07
Fecal Coliform MWR (cfu/100ml)= 0	1	0.00	3.00E+07
	2		8.20E+07
	3		1.80E+07
E. Coli MWR (cfu/100ml)= 0	1	0.00	1.00E+07
	2		3.40E+07
	3		1.80E+07
Total Hetero- trophic Bacteria MWR (cfu/1ml) ≤ 500	1	166.00	1020
	2		976
	3		954

Over the three trials, the total coliforms ranged from $5.6\text{--}9.4 \times 10^7$ cfu/100mL, fecal coliform ranged from $1.80\text{--}8.20 \times 10^7$ cfu/100mL, *E. coli* ranged from $1.00\text{--}3.40 \times 10^7$ cfu/100mL, and heterotrophic bacteria ranged from 954-1020 cfu/1mL. For all trials, the untreated AGW's concentration of biological contaminants of each type far exceeded the critical source's concentrations. Unfortunately, it is not clear what portion of these increases is due to ablation or the change in source. These values will serve as a baseline to compare against the water quality of treated gray water.

Ablution was not expected to increase either manganese or iron content significantly, so testing of these parameters was not budgeted. If the discovery of the difference in sources had been discovered, testing would have been performed to determine the level of manganese and iron. Unfortunately this was not realized until after samples had been collected and treated. This means it is impossible to say how much manganese, iron, or any other metal was contained in the untreated AGW.

3.4.3 Treated Gray Water

Following the collection of raw gray water for testing, the remaining gray water was divided into three parts, each part receiving a different treatment. Treated gray water was photographed for a visual comparison. Then 1 mL of treated water was collected for

application to 3M™ Petrifilms™. One liter of treated water was collected following each treatment type. Based on critical source test results, treated gray water was tested at the laboratory for all biological parameters, manganese, and iron. The following describe the test results as well as other observations made while performing the treatments. In the tables used for each, red fill indicates the water did not meet MWR drinking water standards, green indicates it did, and yellow indicates it reduced the concentration of the given contamination but not all the way to MWR standards.

3.4.3.1 Visual Comparisons

AGW samples were photographed for a visual comparison. Figure 3.13 (a), (b), and (c) below are the samples obtained from Trials 1, 2, and 3, respectively. In each picture, the order of samples from left to right is the same: untreated, AfriClay filter treated, moringa treated, and P&G™ Purifier of Water treated.

Figure 3.13 Water samples from Trial 1 (a), Trial 2 (b), and Trial 3 (c). From left, untreated, filtered, moringa treated, and P&G™ treated AGW. (Author)

Visually, each treatment seems to improve turbidity in each trial, some treatments better than others or better in certain trials. In the author's estimate, the best results were found using the AfriClay filter, next best by moringa, and then by P&G™ Purifier of Water.

Comparing samples from all trials for a given treatment is also useful. Figure 3.14 shows the samples from all trials, separated by treatment type.

Figure 3.14 Water samples that received no treatment (a), AfriClay treatment (b), moringa treatment (c), and P&G Purifier of Water treatment (d). In each, from left, is Trial 1, Trial 2, and Trial 3. (Author)

All untreated samples, Figure 3.14(a), look about the same, which is reasonable considering mostly the same people performed ablution for each trial. It is also good to know that the time of the prayer does not seem to have a significant effect on visual water quality. The laboratory test results support this in that all biological parameters were found at levels in the same order of magnitude.

The AfriClay filter treated samples, Figure 3.14(b), are not completely transparent, but overall they look fairly colorless. If anything, the first one looks perhaps slightly yellow. That said, the filter treated samples are aesthetically pleasing.

The moringa treated water, Figure 3.14(c), looked significantly improved over untreated gray water, but did not look as clear as the filtered water. For moringa, the first trial looks to be cleaner, and the lab results support that. For each trial, it looks as if some particulate matter remained after siphoning and continued to settle after collection, as each bottle has settled matter at the base.

The P&G™ Purifier of Water samples, Figure 3.14(d), look better than the untreated water, but they look worse than the filtered and moringa water. Though the Trial 3 sample, all the way to the right, looks obviously more turbid, it is not that drastically worse in terms of measured parameters. In fact, the sample from the first trial has a significant uptick in iron with 86 mg/L as opposed to 36 and 48 mg/L in Trials 2 and 3, respectively.

Overall, the images show that by Tong standards of clean water each treatment provides an upgrade from the wastewater, and even over some currently used sources. The laboratory testing, described next, does not indicate improvements so clearly.

3.4.3.2 AfriClay Filter

Table 3.11 below summarizes the laboratory results for the three samples of AfriClay filtered gray water and compares results to untreated AGW quality.

Table 3.11 Bacteriological test results for AGW treated by AfriClay filter.

Parameter	Trial	Untreated	Treated	% Reduction
Total Coliform MWR (cfu/100ml)= 0	1	6.72E+07	6.50E+07	3%
	2	9.40E+07	9.40E+07	0%
	3	5.60E+07	5.60E+07	0%
Fecal Coliform MWR (cfu/100ml)= 0	1	3.00E+07	2.80E+07	7%
	2	8.20E+07	8.20E+07	0%
	3	1.80E+07	1.80E+07	0%
E. Coli MWR (cfu/100ml)= 0	1	1.00E+07	0.00	100%
	2	3.40E+07	3.40E+07	0%
	3	1.80E+07	1.80E+07	0%
Total Hetero- trophic Bacteria MWR (cfu/1ml) ≤ 500	1	1020	860	16%
	2	976	976	0%
	3	954	954	0%

The AfriClay filter did not increase contamination for any parameter during any trial, but it met standard only once – in Trial 1 in regards to *E. coli*. Following ablation for the 1pm prayers, Trial 1, the wastewater had 1×10^7 cfu/100mL, well above the MWR level of 0 cfu/100mL. The AfriClay filter was reduced that to 0 cfu/100mL in the first trial. Also in Trial 1, the amount of total coliform, fecal coliform, and heterotrophic bacteria reduced by 3%, 7%, and 16%, respectively, as compared to the untreated gray water. In Trials 2 and 3, the filter seems to have made no impact, as the reduction was 0% for all biological

parameters. These test results strongly indicate the AfriClay filter cannot consistently treat AGW sufficiently to provide potable water by MWR standards.

3.4.3.3 Moringa Seed

Table 3.12 below summarizes the laboratory results for the three samples of moringa treated gray water and compares results to untreated AGW quality.

Table 3.12 Bacteriological test results from AGW treated by moringa.

Parameter	Trial	Untreated	Treated	% Reduction
Total Coliform MWR (cfu/100ml)= 0	1	6.72E+07	1.03E+08	-53%
	2	9.40E+07	9.40E+08	-900%
	3	5.60E+07	9.40E+07	-68%
Fecal Coliform MWR (cfu/100ml)= 0	1	3.00E+07	0.00	100%
	2	8.20E+07	1.12E+08	-37%
	3	1.80E+07	8.40E+07	-367%
E. Coli MWR (cfu/100ml)= 0	1	1.00E+07	0.00	100%
	2	3.40E+07	0.00	100%
	3	1.80E+07	2.10E+07	-17%
Total Hetero- trophic Bacteria MWR (cfu/1ml) ≤ 500	1	1020	1149	-13%
	2	976	969	1%
	3	954	1005	-5%

The moringa seed had a wide range of impacts on the treated gray water quality. Overall, it failed to meet all biological parameter standards for any trial. It performed better in Trial 1, where moringa successfully reduced fecal coliform down from 3×10^7 cfu/100mL to 0 cfu/100mL. In the same trial it reduced *E. coli* from 1×10^7 cfu/100mL to 0 cfu/100mL. However, total coliform and total heterotrophic bacteria increased 53% and 13%, respectively, in the same trail. In Trials 2 and 3, all biological parameters increased except for heterotrophic bacteria in Trial 2, which reduced by only 1 %. Failing to meet drinking water quality for all parameters for all trials, the moringa seed treatment cannot be considered to provide drinking water.

3.4.3.4 P&G™ Purifier of Water

Table 3.13 below summarizes the laboratory results for the three samples of P&G™ Purifier of Water treated gray water and compares results to untreated AGW quality.

Table 3.13 Bacteriological test results from AGW treated by P&G™ Purifier of Water.

Parameter	Trial	Untreated	Treated	% Reduction
Total Coliform MWR (cfu/100ml)= 0	1	6.72E+07	7.50E+07	-12%
	2	9.40E+07	7.40E+07	21%
	3	5.60E+07	9.40E+07	-68%
Fecal Coliform MWR (cfu/100ml)= 0	1	3.00E+07	6.50E+07	-117%
	2	8.20E+07	5.60E+07	32%
	3	1.80E+07	0.00	100%
E. Coli MWR (cfu/100ml)= 0	1	1.00E+07	3.30E+07	-230%
	2	3.40E+07	2.10E+07	38%
	3	1.80E+07	0.00	100%
Total Hetero- trophic Bacteria MWR (cfu/1ml) ≤ 500	1	1020	885	13%
	2	976	1164	-19%
	3	954	852	11%

The P&G™ Purifier of Water also had mixed results. During the first two trials, it did not meet any biological parameter standard. Sometimes it reduced the contamination and in others it increased contamination. In Trial 1, total coliform, fecal coliform and *E. coli* contamination increased by 12%, 117%, and 230%, respectively. In Trial 2, P&G™ Purifier of Water reduced total coliform, fecal coliform, and *E. coli* by 21%, 32%, and 38%, respectively. However, the heterotrophic bacteria count increased 19% in the same trial. In Trial 3, P&G™ Purifier of Water reduced the fecal coliform and *E. coli* to 0 cfu/100mL. However, the total heterotrophic bacteria only decreased by 11% and the total coliform actually increased by 68%. Failing to meet drinking water quality for all parameters for all trials, the P&G™ Purifier of Water cannot be considered to provide drinking water.

3.4.3.5 3M™ Petrifilms™

The original experiment design included 3M™ Petrifilms™ testing with lab sample collection. During trials, time between prayers was insufficient to allow for user surveys, three treatments, bottling, labeling, and 3M™ Petrifilms™ application and careful storage. On March 6, 2017, participants allowed the author to again collect AGW. It was at this time that AGW was treated and applied to Petrifilms™. Figure 3.15 below shows the Petrifilms™ of untreated water, AfriClay filter, moringa, moringa and boiling, and P&G™ Purifier of Water treated water. Total coliform colonies, MWR's drinking water

quality standards, and UNEP/WHO's guideline values on recreational water quality standards (stated in Table 2.3) are in Table 3.14 below.

Figure 3.15 3M™ Petrifilms™ from separate trials. Clockwise from upper left: untreated, filtered, moringa treated, moringa and boiled, and P&G™ Purifier of Water. (Author)

Table 3.14 3M™ Petrifilms™ colony counts compared to MWR drinking water standards and UNEP/WHO recreational waters guidelines.

Treatment Type	Time (hrs)	Total Coliform (cfu/mL)	GEPA (0 cfu)	UNEP/WHO 50% < 100 cfu/100mL	UNEP/WHO 90% < 1,000 cfu/100mL
Untreated	16.5	TMC	No	No	No
AfriClay Filter	15.0	46.0	No	No	No
Moringa	18.3	8.0	No	No	Yes
Moringa and Boiling	14.9	102.0	No	No	No
P&G™ Purifier of Water	6.8	0.0	Yes	Yes	Yes

After at least 6.8 hours of incubation time, the untreated, AfriClay filter, moringa, moringa and boil, and P&G™ Purifier of Water treated samples had “too many to count,” 46, 8, 102, and 0 colonies on the Petrifilms™, respectively. Considering 1 mL was placed

on the film, values were multiplied by 100 and then compared to MWR and UNEP/WHO standards. Only P&G™ Purifier of Water met all standards. Moringa met the 90% standard for UNEP/WHO and thus should be investigated further to see if it also meets the 50% requirement with more trials. The AfriClay filter and the moringa plus boiling did not meet any standard. Considering other studies on these two treatments showed much better performance, further study should be done (Cheng, 2013). Nonetheless, all values suggest that there is reason to believe that decreases in coliforms were hampered during trials, either by the length of time between sample collection and testing or possibly contamination of sample bottles. Overall, the Petrifilms™ indicate the treatments were more effective at removing biological contaminants from AGW than laboratory testing suggests and should be researched further to determine if non-ingestive uses like laundry, bathing, or dish washing could be performed with treated AGW without significant risk to human health.

The sample that was boiled causes concern. It had more than 0 cfus, and more than all other treated samples. This may have occurred due to accidental reuse of a pipet or some other cross contamination. From this, the author feared that the P&G™ Purifier of Water may have been cross-contaminated with water treated by moringa or the AfriClay. Since P&G™ is the only treatment with disinfecting abilities, any P&G™ that got into other samples could give falsely positive results. However, based on the times written on the films, the P&G™ sample was collected after the others. Thus no P&G™ Purifier of Water could have gotten into the other samples. As such, cross-contamination may have occurred, but it cannot explain the good performance of the AfriClay filter or the moringa seed. Despite some apparent mishandling, there is still evidence that the treatments tested have potential to successfully remove fecal coliforms. Improved testing is required before determining the performance of the treatments on biological parameters.

3.4.3.6 Manganese and Iron

Because manganese and iron were not tested for in the untreated AGW, it is not possible to determine if or how the treatment methods reduced the levels of manganese and iron. However, it is possible to compare the end product of each treatment method to the others and to potable standards. Table 3.15 below shows the manganese and iron test results for the treated gray water after each treatment. Green indicates MWR's drinking water guidelines were met, red indicates standards were not met, and yellow indicates standards were not met based on taste, but that levels are still within acceptable levels to protect public health.

Table 3.15 Lab test results for manganese and iron. Green indicates MWR standards were met, yellow indicates levels acceptable for human health were met (2 mg/L), and red indicates standards were not met.

Treatment Type	Trial	Manganese (mg/L)	Iron (mg/L)
MWR Standard		0.4	0.3
Filter	1	0.03	0.68
	2	0.02	0.29
	3	0.02	0.12
Moringa	1	0.53	2.07
	2	0.57	4.71
	3	0.54	2.28
P&G TM	1	0.90	86.13
Purifier of	2	0.80	36.45
Water	3	0.75	47.72

For each trial, the wastewater treated with the AfriClay filter had an acceptable amount of manganese. Two of the three trials resulted in an acceptable amount of iron, but the one trial still had more than double the standard set by MWR. It should be noted, however, that according to WHO's "Iron in Drinking Water: Background document for development of WHO *Guidelines for Drinking-Water Quality*" (2003), up to 2 mg/L "does not present a hazard to health" (p. 4). The level of 0.3 mg/L was developed based on what taste is acceptable. People in Tong drink water from Gbutugu dam which testing showed had over 19 mg of iron per liter. As such, the 0.68 mg/L concentration of iron after AfriClay treatment in the last trial has a high likelihood of acceptable taste among the people in Tong. Because of its consistent ability to reduce the levels of manganese and iron in the gray water to acceptable amounts, the AfriClay filter is considered an effective means of removing manganese and iron from AGW.

Moringa treated gray water did not meet MWR standards for manganese or iron. It was close to standard with between 0.53-0.57 mg/L of manganese as compared to MWR's standards of 0.4 mg/L. There was 2.07-4.71 mg/L of iron, more than MWR's drinking water standard 0.3 mg/L for iron. Even relaxing the standard to 2 mg/L, moringa treatment does not provide drinking water quality consistently in any parameter.

P>M Purifier of Water treated water also exceeded MWR's manganese standard with 0.75-0.90 mg/L. The iron levels were far above the MWR standard of 0.3 mg/L and the WHO-determined acceptable health risk of 2 mg/L. The P>M Purifier of Water treated

water had between 36.45-86.13 mg/L. This suggests one of two things. Possibly, the Tong dam water has higher levels of iron than Gbutugu dam water, and the AfriClay filter and moringa seed powder were able to remove a lot and P&G™ Purifier of Water was not. Or it is possible that the coagulant used in P&G™ Purifier of Water, ferric sulphate, introduced excessive levels of iron to the Tong dam AGW. According to WHO's "Iron in Drinking Water: Background document for development of WHO *Guidelines for Drinking-Water Quality*" (2003) daily safe levels are 0.8 mg/kg bodyweight. Based on this, most adults at perhaps 50 kg of bodyweight could take in up to 40 mg a day. One liter of the P&G™ Purifier of Water treated water would put a person over this daily amount. P&G™ Purifier of Water treatment does not provide drinking water quality consistently in any parameter and will not be recommended for drinking purposes due to the extremely high presence of iron.

3.5 Treatments' DRAW Chart Values

Though all the above results are useful, they need to be analyzed for clearer viewing in a DRAW chart. For currently used dry season sources, all these values have been determined using household surveys and opinion leader interviews. For AGW, further analysis is required to determine time, cost, social acceptability, and acceptable uses. This section details the assumptions made, calculations, and values for each treatment or combination thereof.

3.5.1 Potable AGW Options

No gray water treatment met all MWR drinking water biological parameter standards, and iron and manganese were reduced to acceptable levels only with the AfriClay filter. Drinking of AGW would only be possible then with a combination of treatments including at least boiling to successfully remove biological contaminants and the AfriClay filter to remove metals. Boiling in Tong is most often completed using either firewood or charcoal. Though moringa did not treat water to acceptable standards, it could be used as a pretreatment to the AfriClay to speed up filtration, reduce the frequency of cleanings, and increase the life of the filter. Moringa can be obtained by either collecting seeds from one's own tree or by purchasing the seed cake. These options result in several combinations of gray water treatment options and a variety of associated unit costs and fetch times. Table 3.16 below summarizes these quantities as determined by the assumption that the AGW collection device can be constructed using found materials and the additional assumptions and calculations described below.

Table 3.16 All possible treatment components that may be used to treat AGW to potable standards, their abbreviations, unit costs, and unit “fetch” times.

Treatment	Abbreviation	Unit Cost (GHS/garawa)	Unit Active "Fetch" Time (min/garawa)
AfriClay Filter (no pretreatment)	AC	0.92	727
AfriClay Filter (with pretreatment)	+ AC	0.46	0.8
Boiling (with firewood)	B (fw)	0.00	2
Boiling (with charcoal)	B (ch)	8.08	2
Moringa (own seeds)	M (o)	0.00	20
Moringa (bought seeds)	M (b)	0.82	11

3.5.1.1 AfriClay Filter without Pretreatment

The AfriClay filter successfully removed the metals of concern making it a necessary part of any recommendation for treating AGW to MWR standards. Testing directly showed the successful treatment of metals, but some assumptions would have to be made in calculating the unit time and unit cost.

In determining the AfriClay filter’s unit cost, the capital cost would be determined and then spread over the expected lifetime of the filter. The current cost of the clay filter pot is 85 GHS, but if the customer wants the lid, storage container, tap, and brush, it costs 125 GHS (Pure Home Water, 2017). Because the pot is designed to fit the provided container and because the container provides safe storage, the complete set will be considered in this study.

In order to obtain a unit cost then, one must estimate the volume of a water the AfriClay filter is expected to treat. According to Michael Anyekase, a Pure Home Water representative, the AfriClay filter should last 3-4 years depending on the source water, where sooner replacement is expected for more turbid source water (personal communication, September 27, 2017). However, he did not estimate how many liters are expected to be treated in that time. Brown and Sobsey’s study of Potters for Peace’s (PfP) clay pot filters in Cambodia is very useful (2007). The author’s investigated the use of PfP filters up to four years after beneficiaries received them. The study measured how long filters lasted, what health benefits were gained by users, and what affects the likelihood of adoption. The filters studied have smaller pore sizes than the AfriClay and could thus provide a conservative estimate as smaller pores clog faster. Additionally, because the study is based on field observations and not modelling or theoretically

optimized use and maintenance, the study is considered to provide more realistic lifespan estimates. They found that the 10 L-capacity filters were used an average of 1.8 times a day on water with turbidity ranging from 2.8 to 8.4 NTU. With this average use, the filters maintained acceptable filtration rates for an average of two years. This is 13,149 L treated by the average filter (Brown & Sosey, 2007). The water tested in the current study was significantly more turbid and was thus estimated to treat half as many liters of water. It is possible that the filter would not maintain desired filtration rates for even 50% as many liters, but the paper also suggests that users will continue to use the filter beyond typically accepted filtration rates (ibid). Based on participant observation and the limited alternatives for water in Tong, the author estimates a decreased filtration rate would not likely lead to disuse. It is also possible the filter could break or require other replacement parts increasing the price, but again, the two year average from Brown and Sobsey includes about 2% of households who broke the filter in the first few months (2007). Other differences, such as the addition of silver particles to disinfect, were not considered to affect filter lifetime. Thus the author estimates the AfriClay filter without pretreatment would filter 6,574.5 L in its lifetime. The AfriClay filter's unit cost without pretreatment is then 125 GHS per 6,574.5 L, which is 0.02 GHS/L or 0.92 GHS/garawa.

The unit active “fetch” time for treated gray water refers to the time a user must actively participate in the treatment process. The AfriClay filter theoretically has very low active input time, but because of the extreme turbidity, frequent cleaning creates significant unit active fetch time. During prototype testing, the author had to clean the filter three times in the process of obtaining just one liter of filtered gray water. Each cleaning took about 5 minutes using the brush that came with the filter. Thus, the AfriClay filter without pretreatment requires three 5-minute cleanings to produce one liter of filtered water. This equals 15 minutes of active “fetch” time per liter, or 728 min/garawa.

3.5.1.2 AfriClay Filter with Pretreatment

With pretreatment, the unit cost and time are drastically improved. Pretreatment, reduces cleaning, extending the life of the filter. Figure 3.16 shows AGW treated with moringa and siphoned off into a bowl. For comparison a series of samples with known turbidity are also shown. Visually, the author estimates moringa reduces turbidity to less than 100 NTU. Though the pretreated water is possibly more turbid than water treated by the PFP filters in Brown and Sobsey's study, the pore sizes of the filters are also different. The author assumed the greater pore size of the AfriClay would not clog as often, increasing filter lifespan and offsetting the increased turbidity. As such, the values as given by Brown and Sobsey (2007) were used to calculate a lifespan of 13,149 liter filtered by an AfriClay filter with pretreatment. With the same capital cost, 125 GHS, the unit cost for gray water pretreated and then filtered by the AfriClay filter is 0.01 GHS/L or 0.46 GHS/garawa.

Figure 3.16 Top shows water samples with known and labelled turbidity for comparison to lower image showing water following moringa treatment. ((*top*) US Geological Survey, 2016, see Appendix A for full attribution and copyright licensing information; (*bottom*) Author)

The unit active “fetch” time associated with the AfriClay filter is also decreased by pretreatment, as less turbid influent means the filter will clog less frequently and require fewer cleanings. The unit active fetch time for the AfriClay filter is based on the author’s experiences using the AfriClay regularly on a variety of water sources prior to its use in the trials. The author filtered about 13 L per day, would go about 3 months between cleanings, and would require about 20 minutes to clean the filter. This results in 1,170 L treated for every 20 minutes worth of cleaning effort. This results in 0.02 min/L of active fetch time for the AfriClay filter with pretreatment.

3.5.1.3 Boiling with Firewood

In order to meet MWR standards for drinking water, AGW requires boiling of the water following metals removal by the AfriClay filter to sufficiently remove bacteria and other pathogens. Firewood is the primary method of boiling water in Tong. Because firewood is collected for free from the bush, no cost is associated with boiling with firewood. One could argue that the time to collect firewood has monetary value since the time could be

spent performing an income generating activity. However, the monetary value of a person's time in Tong is outside the scope of this study. The cost of boiling using firewood is then assumed to be 0 GHS/garawa when using firewood.

The active time required for boiling is fairly minimal. As observed, most people either keep coals hot throughout the day or will find hot coals at a neighbor's to start a fire. Once a fire is going, there is minimal involvement required of the user. It is true they need to be around to ensure the water doesn't boil over or boil for too long such that it evaporates, but as witnessed at many households, there is almost always somebody around who can take the pot off the fire. Considering people in Tong often cook with a few entire branches, there is also no need to add wood to the fire. Rather, an occasional push of a branch further into the fire may be necessary, nothing more. Typically, a pot is left alone to boil after the fire has been started. Since a person can let the water boil while doing other chores at the house, the active unit fetch time of boiling water with firewood is considered to be just 2 min/garawa, an estimate of the time to get hot coals and to occasionally move the firewood.

3.5.1.4 Boiling with Charcoal

Charcoal is also prevalent in Tong. Of particular interest is its use by men at their sitting spots to boil water for tea. As men do not typically collect firewood and as the income managers of most households, they prefer to purchase charcoal for preparing their daily tea. A male colleague estimated a 0.50 GHS bag of charcoal could treat three liters of water. As such, boiling with purchased charcoal is estimated to have a unit cost of 0.17 GHS/L or 8.08 GHS/garawa.

Charcoal does burn a little hotter than wood and thus can heat water faster. That said, in Tong it takes roughly the same amount of time to get fire started with charcoal as it does with wood since both are started using hot coals. Also, because of the size of charcoal cooking devices in Tong, there is also a small bit of time to add charcoal after the first part has burned off. This does not take long and thus the estimated active unit fetch time for boiling with charcoal is assumed to be 2 min/garawa, just as it is for firewood. Note, the firewood would take longer to boil, but it would require about the same amount of attention from the user as charcoal.

3.5.1.5 Moringa from Own Tree

Moringa cannot be used alone, but when combined with the AfriClay filter and boiling, its cost and time involvement must be included. When somebody owns a moringa tree, as four households in Tong already do, the seeds can then be used for free. Currently, these owners do not use the seeds for anything. For those households that do not currently own a moringa tree, it would be easy to procure and cultivate one. A branch or seed from one

of the existing moringa trees in Tong or one of the nearby communities, can probably be obtained for free or a nominal charge. From this point, the moringa is quite easy to cultivate and requires very few inputs. If planted at the proper time and properly protected by a fence, the tree will grow quickly and seed within a year. Fences in Tong are always produced with found materials and common tools and thus does not cost anything to make. Moringa trees can produce over a thousand seeds each year (Ayerza, 2012). Because the capital cost to obtain and grow a moringa tree is so low and the likelihood of it producing seeds for decades is so great, the unit cost of one's own moringa seeds was considered to be 0 GHS/garawa.

The active time required to treat water with moringa comes from the collection and processing of seeds as well as stirring time. Fortunately, this time is roughly the same regardless of the amount of wastewater receiving treatment. In the author's experience, the ratio of 2 seeds per liter is effective when treating either a bucket or a garawa of water. Deshelling, grinding, and making a paste of the seeds take perhaps 10 minutes while the stirring, fast and then slow, is another 10 minutes. The author is not very experienced grinding by hand; a person from Tong can likely grind seeds better, faster. To keep the time estimate conservative, however, this study will assume a poor grinding ability and a unit active fetch time of 20 min/garawa for moringa treatment when using seeds from one's own tree.

3.5.1.6 Moringa from Market

An alternative to using one's own seeds is purchasing seed cake. The author never purchased seed cake locally, and thus had to rely on prices available online. The best price found online was 20 GHS for 1 kg of seed cake (Ghana Permaculture Institute, n.d.). This product was from Techiman, a town in southern Ghana. The transportation is estimated at 8 GHS by the author, although bargaining skills and personal connections would affect that. It is further assumed that approximately 0.3 g of seed cake is the equivalent of one seed's seedcake. That makes the cost of seed cake 0.84 pesewas per seed, assuming the transport of just one bag at a time. Using the same procedure as described in the Methodology section, two seeds per liter would be used. Additionally, the procedures for treating with moringa call for 250 mL of clean water. This was assumed to come from the borehole, which costs 0.10 GHS/garawa. The cost of seedcake, transport, and clean water inputs comes out to 0.82 GHS/garawa.

The time for market bought moringa seed cake would be similar to the unit fetch time of using one's own seeds, but would decrease slightly by the elimination of the need to crush the seeds. Since seedcake is already deshelled and mostly crushed, the processing time would only take about a minute to make a paste and then 10 minutes to stir. As this time involvement applies to a whole garawa, the unit active fetch time of market bought moringa is 11 min/garawa.

3.5.1.7 Combinations

The aforementioned means of treating AGW to MWR standards for drinking water then need to be combined, in process, time, and cost. Table 3.17 below shows each treatment combination and its associated unit cost and unit active fetch time based on the sums of the previously mentioned values for each treatment component.

Table 3.17 All combinations of treatments expected to produce potable water, their estimated unit price and unit "fetch" time. See Table 3.17 for abbreviations explanations.

Treatment	Unit Cost (GHS/garawa)	Unit Active "Fetch" Time (min/garawa)
AC + B (fw)	1.38	729
AC + B (ch)	9.01	729
M (o) + AC + B (fw)	0.46	23
M (o) + AC + B (ch)	8.54	23
M (b) + AC + B (fw)	1.74	14
M (b) + AC + B (ch)	9.36	14

3.5.2 AGW Treatment Options of All Qualities

Although using water that does not meet MWR standards is not ideal, it may still be necessary and useful in a place like Tong that has such finite sources. It is believed that some of the treated AGW is potentially safer than some currently used sources, such as reservoir water. That said, testing thus far indicates using treated AGW still comes with increased risk as compared to water meeting MWR standards. Nonetheless, comparing gray water treatment options to currently used sources is still useful, as improved testing and treatment procedures may show that certain uses, such as laundry, washing dishes, or bathing would not cause significant risk. For example, the author frequently made use of reservoir water treated with moringa seeds but without boiling. As such, the values in this portion of the report are presented as preliminary that would require further substantiation before people in Tong could use them safely with confidence. Table 3.18 below outlines the treatments that can provide water, albeit water that does not meet national standards for drinking.

Table 3.18 AGW treatment options, their abbreviations, unit costs, and unit active “fetch” times for instances where potable water is not needed. End quality is uncertain but may be consumed at the user's risk.

Treatment	Abbreviation	Unit Cost (GHS/garawa)	Unit Active "Fetch" Time (min/garawa)
AfriClay Filter (no pretreatment)	AC	0.92	727
AfriClay Filter (with pretreatment)	+ AC	0.46	1
Moringa (own seeds)	M (o)	0.00	20
Moringa (bought seeds)	M (b)	0.82	11
P&G™ Purifier of Water	P&G	0.00	24
No Treatment	None	0.00	0

3.5.2.1 P&G™ Purifier of Water

Testing indicated AGW treated with P&G Purifier of Water may contain unsafe levels of iron. One may, however, decide to use this water for something other than drinking. Because the packets are distributed for free, no cost is borne by the user, giving P&G™ Purifier of Water a 0 GHS unit cost.

The unit time is based on common treatment practice in Tong. The active involvement of the user includes opening the packet, pouring it into the AGW, and then stirring for five minutes. Settling is needed but does not require the user's presence. The five minutes of stirring is for a recommended 10 L. For a whole garawa then, 24 minutes of active fetch time is required.

3.5.2.2 No Treatment

The opinion leader interviews revealed that people in Tong already use untreated AGW for construction. For this reason, it was included in the DRAW chart comparisons. For untreated AGW reuse, there is simply no cost and no collection time. Ablution could be performed on site near the construction materials that require wetting. This makes the unit price for untreated gray water 0 GHS/garawa and the unit active fetch time 0 min/garawa.

3.5.3 Social Acceptability Determinations

The social acceptability of treated AGW is also necessary to complete the DRAW charts. To express social acceptability, four categories were created:

- Proven Acceptability – at least half of respondents report they already use this source for any use without treatment
- Limited Proven Acceptability – at least half of respondents report they already use this source but for only certain uses or only after a certain treatment
- Unproven Promising Acceptability – Not in current use but feedback and water quality testing suggest it would be acceptable for broad application
- Unproven Limited Acceptability – Not in current use and feedback and water quality testing suggest it may not be readily accepted for more than one or two applications

As described in the household survey results, all sources described by respondents were placed in the first two categories, as their mention by participants meant they were in current use. Because AGW treatment is not currently in use, these options were placed in either the “Unproven Promising Acceptability” or “Unproven Limited Acceptability” categories. Because gray water reuse is not a current practice, the estimation method was slightly different. Rather than what uses are currently accepted, as was done for existing water sources, gray water treatments were measured based on the potential for use as dictated by the water quality results. Multiple uses does not include drinking but does include most household chores like laundry, washing dishes, and cooking. If a treatment provides water acceptable for only one to two options, it is not considered to provide for “Multiple Uses.” Treatments were also assessed by the feedback received from users and observers during testing and statements from interviewees. Table 3.19 below shows each AGW treatment option, how it did in these assessments, and their categorizations.

Table 3.19 Each gray water treatment, their social acceptability determinants, and their social acceptability and associated symbol for DRAW charts.

Gray Water Treatment Method	Multiple Uses (Y/N)	Positive Feedback (Y/N)	Social Acceptability	Symbol
AfriClay Filter	Y	Y	Unproven Promising
Moringa	Y	Y	Unproven Promising
P&G™ Purifier of Water	Y	N	Unproven Limited
None	N	Y	Unproven Limited

Since the AfriClay filter can remove metals and the Petrifilms™ indicated it could significantly reduce bacteria, it is assumed to be safe for many uses. During prototype testing, users and passersby were very pleased with the water coming from the AfriClay. When combined with boiling, boiling is not assumed to affect social acceptability. These two factors combined to place the AfriClay filter in the “Unproven Promising Acceptable” category.

Similarly, the moringa treatment had fairly good test results. The metals were not brought down to potable levels, but the amount was drastically reduced. And though the lab testing did not look promising, the Petrifilms™ results show that moringa can remove a significant amount of bacteria. As such, moringa would need to be combined with other treatments for drinking, but for other household tasks, moringa alone would be sufficient. As such, moringa was also placed in the “Unproven Promising Acceptable” category.

P&G™ Purifier of Water had similar quality results as moringa – it could be used solely to produce water clean enough for many tasks, albeit not drinking. As such, it was considered to provide water for multiple uses. However, P&G™ did not get any positive feedback from users during prototype testing. Nor did interviewees specify P&G™ as particularly favorable. As such, it was placed in the “Unproven Limited Acceptable” category.

The author did not originally consider untreated gray water to be an accepted source. However, Al Hajji, one of the interviewees, noted that people actually already use this water for construction. Because he says this is already used, it was considered to have positive feedback. That said, Al Hajji said this is strictly done for construction water, and thus it was not considered feasible for multiple uses. As such, untreated AGW (“None”) was placed in the “Unproven Limited Acceptable” category.

3.6 DRAW Chart Comparisons

The results from the household surveys, opinion leader interviews, prototype testing, and water quality testing, reveal a lot of information about Tong, its water crisis, and the viability of AGW reuse options. All this information is unfortunately broad, complex, and does not readily reveal a meaningful solution for Tong. In this section, the results will be combined to form DRAW charts that provide all relevant aspects of each water option – cost, time, and social acceptability – to help decide how AGW reuse might work best for them.

Compiling the results for time, cost, and social acceptability for each potable source and each treatment combination produce expected to produce potable water are shown in Table 3.20 below. Doing the same for all treatments and sources regardless of quality produces Table 3.21.

Table 3.20 All dry season sources used by at least 50% of households and all AGW treatment combinations that provide potable water and all their attributes for plotting on the potable DRAW chart.

Source/Treatment	Abbreviation	Unit Cost (GHS/ garawa)	Unit Active "Fetch" Time (min/garawa)	Social Acceptability
Tong Borehole	-	0.10	15	Proven
Nyensobga Borehole	-	0.10	163	Proven
Pure Water Sachets	Pure Water	16.34	314	Proven Limited
AfriClay and Boil with firewood	AC + B (fw)	1.38	729	Unproven Promising
AfriClay and Boil with Charcoal	AC + B (ch)	9.01	729	Unproven Promising
Own moringa seeds, AfriClay, and Boil with firewood	M (o) + AC + B (fw)	0.46	23	Unproven Promising
Own moringa seeds, AfriClay and Boil with Charcoal	M (o) + AC + B (ch)	8.54	23	Unproven Promising
Buy moringa seeds, AfriClay, and Boil with firewood	M (b) + AC + B (fw)	1.74	14	Unproven Promising
Buy moringa seeds, AfriClay, and Boil with Charcoal	M (b) + AC + B (ch)	9.36	14	Unproven Promising

Table 3.21 All dry season sources used by at least 50% of households and all AGW treatment options that produce water of varying quality and their attributes for plotting on the non-potable DRAW chart.

Source/Treatment	Abbreviation	Unit Cost (GHS/ garawa)	Unit Active "Fetch" Time (min/garawa)	Social Acceptability
Reservoirs (walk/bike)	-	0.00	91.5	Proven Limited
Reservoirs (hire)	-	0.91	4.7	Proven Limited
AfriClay Filter (no pretreatment)	AC	0.92	727	Unproven Promising
AfriClay Filter (with pretreatment)	AC	0.46	0.83	Unproven Promising
Moringa (own seeds)	M (o)	0.00	20.0	Unproven Promising
Moringa (bought seeds)	M (b)	0.82	11.0	Unproven Promising
P&G Purifier of Water	P&G	0.00	24.2	Unproven Limited
No Treatment	None	0.00	1.00	Unproven Limited

3.6.1 DRAW Charts for Potable Options

The options listed in Table 3.20 are the options that meet or are reasonably expected to meet MWR standards for drinking water. When plotted according to procedures described in Section 2.5 the DRAW charts in Figure 3.17 and Figure 3.18 are produced.

Figure 3.17 DRAW chart for all dry season sources that at least 50% of households use and all gray water treatment combinations that provide potable water.

Figure 3.18 The top three choices for potable water in Tong during dry season – Tong borehole, Nyensobga borehole, and gray water treated with moringa, filter, and boiling.

From Figure 3.17 and Figure 3.18, some clear conclusions can be drawn. As expected, the purchasing of pure water sachets is far and away the most expensive. It is frequently purchased however, likely because it is sold cold and is purchased in very small amounts spread over a long period. People in Tong typically buy less than a cedi at a time and thus do not associate such a high expense with pure water sachets.

Comparatively, it is also easy to see why people in Tong use their borehole ubiquitously. The Tong borehole requires minimal active time to fetch and has a relatively low cost. That said, the time spent at the borehole, though considered passive for the purposes of the DRAW chart, is still limited in some ways. However, one can be sitting, braiding hair, or dozing off and thus the waiting time is still preferable to other water sources.

Despite the distance, people use the Nyensobga borehole. If insufficient water is collected from the Tong borehole, the Nyensobga is a good second option. It is farther than the reservoirs, but it provides high-quality water. It is not free like reservoir water, but its price is the same as water from the Tong borehole.

The AGW treatment options have a variety of unit costs and times. The least favorable is clearly the AfriClay filter without pretreatment supplemented by boiling with charcoal. Charcoal is costly unless made by the household. The filter without pretreatment simply takes too long.

For a potable water source, pretreatment with one's own moringa, then filtered with the AfriClay, and then boiled with firewood is a reasonable option. It is more expensive and takes more active involvement than the Tong borehole, but when the borehole runs dry and people start looking for a secondary source of potable water, AGW treatment with this combination is very competitive with existing options. Moringa, AfriClay, and boiling combination is a cost savings of more than thirty fold over pure water sachets. The cost of such treatment is almost five times as much as the Nyensobga borehole, but the treatment saves approximately two and a half hours for each garawa. The upfront cost of the AfriClay filter poses a barrier to adoption at the onset. But if adopted, the regularly observed cost of the user is nothing since all cost is taken care of with the initial purchase.

3.6.1.1 Recommendations for Potable Water

The author recommends that people use the Tong borehole to the extent possible as it provides high quality water at a very affordable price. On days when they cannot collect from the Tong borehole, the author recommends they use their own moringa seeds to pretreat AGW, then run it through the AfriClay filter, and then boil it for safe use. It makes the most sense to use the treated AGW for purposes that involve boiling such as cooking, preparing tea, or even bathing, as people tend to heat bath water in Tong. Families should consider the number of people performing ablution at their household. For the average family of 16.6 people, 63% of members consume 4.0-4.6 liters/day of water for ablution. This results in about 34-53 L/day available for treatment and reuse if collected efficiently. If the collection process is less efficient or too few ablution performers are present, it may be more advantageous to go to the Nyensobga borehole. Further, the purchase of pure water sachets does not make any economic sense, as it is excessively expensive and time consuming compared to other options. Additionally, though regulations suggest the manufacturer complies with hygienic standards, there is some evidence that pure water sachets do not consistently meet standards for drinking water (Dodoo, Quagraine, Okai-Sam, Kambo, & Headly, 2006).

3.6.2 DRAW Charts for All Options

The options listed in Table 3.21 are plotted in DRAW charts in

Figure 3.19 and Figure 3.20 are produced. Because precise potability determinations are not always possible, general quality and associated optimal uses are noted in the legend.

Figure 3.19 DRAW chart for all dry season options regardless of quality (horizontal axis in log scale for improved visibility).

Figure 3.20 Best options for dry season sources for all quality levels.

As seen with the potable sources, the two boreholes offer good prices. The Tong borehole requires less than 15 minutes of active time to fetch a garawa, but the passive, waiting time is restricted as one cannot leave the tap vicinity lest they lose their spot in line. The Nyensobga is also fairly inexpensive, but it requires over two hours of active fetching time for one garawa.

The dams are currently widely used. It takes about an hour and a half, round trip, to fetch a garawa from the reservoir if walking. It is free but it is also of poor quality. Most people in Tong currently treat it with alum, which costs more or without which reduces social acceptability. The other option for fetching water at the reservoir is hiring a donkey or Motorking. This requires minimal active time for the user, but it does cost much more than most options, at almost a cedi for one garawa compared to just 0.82 GHS for the next most expensive option, purchased moringa. Despite the extra cost, the water quality is very low and will likely require the use of alum, adding to the cost.

AGW treatment options for non-ingestive uses can potentially be used on their own. The AfriClay performs better in cost and price, however, when pretreatment is included. The average time investment is less than a minute for a garawa; the price, not including the cost of pretreatment, is almost 50 pesewas for a garawa. For uses that do not involve ingestion, the AfriClay may not be necessary. Though it clarifies water, clarification beyond that done by moringa is not as significant and would come at a relatively high cost. The AfriClay may only be worth the cost if one needs to remove the iron and manganese.

Moringa used on its own is a very cost effective choice. It is free when gathered from one's own tree and requires only about 25 minutes to treat an entire garawa, providing higher quality water faster than by walking to the reservoirs.

P&G™ Purifier of Water did not produce water that looked as good as the water treated with the AfriClay or the moringa. As such, its use would likely be very limited when used to treat AGW. Because it is free, it may still be beneficial for certain uses.

Untreated gray water, labeled as “None” in Figures 3.19 and 3.20, has very limited use, as it is only acceptable for construction, something a household requires only about a few weeks every few years. However, as it is free and does not require any treatment time, it can be very useful for such purposes.

3.6.2.1 Recommendations for Sources of All Quality Levels

Again, most families will likely prefer to use borehole water from the Tong borehole to the extent possible. When this source runs dry, most families fill their remaining water demand using reservoir water, either fetched by walking or by hiring someone. This water is extremely turbid, and most families treat it in some way prior to use. Because time and sometimes money is being spent on this extremely turbid source and often times takes hours away from the women of the house, the author recommends that households replace some of their reservoir water use with treated AGW. The time to treat using moringa is far less than the time required to fetch reservoir water and the household gets less turbid water from the effort. Additionally, a household that hires someone to fetch water can see cost savings of 0.45-0.91 GHS if some of their reservoir water use is replaced by treated AGW. Again, the volumes that a household can replace with treated

AGW is limited by the number of people performing ablution and the efficiency of the collection. Nonetheless, the author recommends collecting AGW, treating it with moringa for free, and then saving fetch time when possible. Moringa does not cost anything and using it for treatment is not very time consuming. The AfriClay may be worth it if the household has the capital and also plans to use the treated AGW for purposes that require the removal of manganese and iron. P>M Purifier can be used for AGW reuse, but it may be better used as it currently is – to treat reservoir water – as it seems to work more successfully on the source rather than the AGW.

4 Discussion

The testing and surveys have resulted in some elucidating DRAW charts and preliminary recommendations for people in Tong. These recommendations did require many assumptions, made use of limited or flawed procedures, and have some nuances that should color how people in Tong use the information provided. Nonetheless, the results generally show AGW can be a viable option to supplement scant water resources. In this section, some of the limitations of the current study are discussed followed by recommendations for further study on the topic.

4.1 Limitations

4.1.1 Household Surveys

The most basic limitation of the household surveys is that all water volumes are based on people's memory and off-the-cuff estimates. Even for things like ages and level of school achieved or even the number of people living at the house likely has some inaccuracies. Most people do not keep track of their children's age and even highly educated people can often only estimate their own age based on elders' description of the year they were born. As for school years, if the respondent had never been to school, they likely were not even familiar with the different levels, let alone know what level each family member had attained. Income was also only asked about indirectly as the author suspected most families would not have an exact number. This study did not attempt to estimate incomes and thus has limited ability to predict what is considered affordable beyond what is currently paid for water. These demographics are simply not important enough for households to keep detailed, precise records, and thus a certain amount of error is expected.

This unfamiliarity also somewhat extends to water consumption, in total household use and especially to ablution. Respondents were asked to estimate in units that were known to them. As such, even with accurate amounts given, conversions to standard units vary from barrel to barrel, kettle to kettle, etc. Some households did not have women responding and likely had lower accuracy of volumes, even if estimating in known units. Then, again, these were generalized and converted likely adding to the error. This error is reflected in the large range of values given for each household. In regards to ablution specifically, most people replied that two people could use a kettle or that one person could use half a kettle. As described in the results, several kettle sizes are available, but all were assumed to be the same. On top of that, it is unclear whether most people fill a kettle to completely full when using it or perhaps fill only partially. This discrepancy adds more uncertainty to the quantitative results and may have important implications in the feasibility of AGW reuse.

4.1.2 Opinion Leader Interviews

Though the opinion leader interviews were very informative and were substantiated by other observations and conversations, the interviews are insufficient to confidently determine social acceptability of AGW reuse. Because the chief's decisions are ultimate rule in Tong, he needs to be interviewed to determine whether such a practice would be permitted. Similarly, the chief imam should be interviewed to determine the official stance of the community's religious leadership. Ultimately, even if deemed acceptable by the community's leadership, it would still come down to how women perceive the practice of AGW reuse in practical terms. Because women are the primary water collectors, the adoption of AGW reuse will ultimately be in their hands. If the time to treat or quality or acceptable uses are insufficient to them for whatever reason, then regardless of the leaders' opinions, it will not be adopted. As the current study does not have input from women, the results are given with the caveat that ultimately women will decide what makes sense for their households.

4.1.3 Collection Method

The design of the AGW collection device was ancillary, required mostly to collect AGW for testing. As witnessed during trials, people likely prefer a larger device for small groups, and the device can and should be made more efficient in capturing the wastewater. Also as an ancillary component, the cost of the device was based on what the author could afford. In constructing the DRAW charts, it was assumed families could create a device using found materials, as the user survey participants and interviewees suggest this is the case. Nonetheless, the device itself would be a key part of a AGW reuse scheme and thus would strongly benefit from further investigation to ensure it is both affordable, efficient, and works with current ablution practices.

4.1.4 Water Quality

The water quality test results were useful, but the results are far from conclusive. The critical source tested was different than the water used for ablution and collected during treatment trials. To represent the critical source, water from the Gbutugu reservoir was tested. This water was collected as close to departure for the lab as possible and was refrigerated during this period. It was not of great quality – it had high turbidity and too much total coliform – but it was better than expected as it had zero *E. coli*, zero fecal coliform, and an acceptable level of heterotrophic bacteria. This set an unexpectedly high bar for AGW treatments.

The water used during treatment trials – alum-treated water from the Tong reservoir – was different than untreated Gbutugu reservoir water, the critical source. As such, it is not possible to determine for certain how the treatments would perform had participants Gbutugu reservoir water been used rather than the alum-treated Tong reservoir water.

On top of this, the AGW was tested, but only for bacterial parameters, not for metals. This makes it impossible to determine to what extent the treatments reduced manganese and iron levels. It is possible that the AfriClay removed a significant amount of iron and manganese, but it is also possible that the alum-treated, Tong reservoir wastewater had acceptable amounts of manganese and iron before treatment that the other treatments added metals to the water. For example, Olagbemide (2014) found that raw seeds had 5.05-5.35mg of iron per 100g of raw seeds. If two seeds, approximately 3g each, are present in one liter of moringa treated water, the seed may be contributing up to 0.32 mg of iron, already above the MWR allowable level of 0.3mg/L. The ingredients in the P&G™ powder, particularly ferric sulphate, suggest the P&G™ treatment may have also increased iron concentrations during treatment. If indeed these treatments added iron to iron-low AGW, then the AfriClay cannot be said to certainly remove iron from AGW.

Additionally, the testing processes themselves were unideal. The samples were collected multiple hours before arrival at the lab and were not refrigerated between collection and testing. The storage in a warmer temperature before and after use likely affected bacterial growth in the samples.

The complete lack of fecal coliforms and *E. coli* in the surface water tested was greatly unexpected. Unlike other coliforms, which may be introduced into the reservoir from the soil or vegetation, fecal coliforms, a class of bacteria that includes *E. coli*, originate primarily from the feces of mammals (Connecticut Department of Health, 2010). It is possible to have high total coliform counts and low fecal and *E. coli* counts, but in a community lacking proper sanitation and a reservoir visited daily by cattle, goats, sheep, and donkeys, it seems highly unlikely no fecal coliforms were present in the Gbutugu reservoir water. This introduces uncertainty in lab results that extends to fecal and *E. coli* measurements found in AGW samples, as they were tested under similar conditions. It is possible that some other water quality parameter induces quick die off of fecal coliforms while other coliforms survive, but further testing is required to validate the discrepancy between fecal and total coliforms in Gbutugu reservoir.

The 3M™ Petrifilms™ results add reason for uncertainty on the water quality lab results. According to the lab results, some treated samples had more bacteria than the untreated wastewater, indicating something about the treatment, specifically moringa and P&G™, aided the growth of worrisome bacteria. Yet in other trials, formal laboratory tests indicated removal of bacteria, results which were supported by the Petrifilms™ results. This further indicates laboratory test results have a high degree of uncertainty in this study and should be verified with further research in which lab methods are known and transport is swift.

4.1.5 Cumulative Comparison Chart

Each data collection method that contributed to the creation of the DRAW charts had its own assumptions and uncertainty, the cumulative effects of which went into the DRAW charts. This requires the chart user to consider the specific characteristics of their household when using the DRAW chart for decision making purposes. For example, all gray water treatment options proposed assume the collection device could be made without paying for any materials or labor in its construction. A household must assess their own ability to obtain a AGW collection device when looking at cost and time values presented in the DRAW chart. The costs were also often estimated roughly. If a household considering boiling for example, is able to make their own charcoal, charcoal may make more sense than firewood, as it boils water faster and at a far lower cost than assumed in the DRAW charts. Alternatively, some households mentioned they can get Nyensobga borehole water for free. In these instances, it may be more practical to take the time walking to fetch free water from the Nyensobga borehole than it does to take time and cost to treat AGW. As such, the charts are informative and indicate what sources and treatments make the most sense generally, but the values and risk are, at this point in the research, still highly uncertain.

Beyond the uncertainty associated with the data represented in the DRAW charts, there are some aspects not represented at all, or are “hidden,” but that may still be important to a household. For example, smaller households may not collect the estimated 34-53 L a day from AGW collection. In these instances, the unit prices may still be accurate, but the payback on the AfriClay filter for example may be longer. Or such a household may not want to have one of their containers sitting, waiting for more AGW when they could fill that container at the dam and have that water available for use sooner than AGW can be produced. As such, a household must consider their own capabilities, assets, and needs in addition to the information directly available via the DRAW charts.

Of particular concern due to its role in recommendations, is the AfriClay filter’s upfront cost hidden within the DRAW charts. Unit costs were calculated to include upfront and recurring costs and then were spread evenly over the lifetime of the filter. Though the unit cost calculated may be accurate, the upfront cost would be a larger hurdle than the unit cost suggests. Families may struggle to afford a large, one time purchase like a filter. At the time of the trials, the AfriClay filter was 85 GHS, but since then it has increased to 125 GHS, both a mathematically and psychologically significant amount. Reliable income information for Tong is not available to determine the precise impact or feasibility of a 125 GHS purchase. Anecdotally this upfront cost would involve serious deliberation for a household considering such a purchase. Price reductions may be available through Pure Home Water’s social enterprise mechanisms but would likely still pose an obstacle to adoption.

In helping convince families of the AfriClay's benefit, the DRAW charts can be helpful. The charts show clearly the cumulative cost of pure water sachets. Calculations could be made to show how much money a family spends on pure water sachets in a month and then compared to the upfront cost of the AfriClay. Additionally, aid agencies considering assisting Tong may be more willing to purchase an AfriClay filter for each household as it has nearly guaranteed quality and quantity improvements at a fraction of the cost of a borehole.

4.2 Recommendations for Further Research

Based on the limitations of this study and potential broader applications, further research is recommended. This section describes what research would be necessary before making confident recommendations to Tong and similar communities as well as suggestions for research to make AGW reuse and DRAW charts applicable and useful in other settings.

4.2.1 In Tong

This paper focused on the potential for AGW reuse in Tong and found promising albeit limited results. The limits of this research should be supplemented with follow up research, especially in regards to water quality testing, affordability of different treatments, and women's perceptions on the practice. Beyond research to address the limitations stated above, research into a few other options could prove useful.

Several treatments were contemplated but were ultimately excluded from investigation in this report, including solar disinfection, which could be of particular interest for Tong. Removing metals was only proven possible with the AfriClay filter, which may be too expensive for some households. However, if the treated AGW is not intended for ingestion, metals are not a concern. Having seen the drastic improvements in turbidity with moringa, solar disinfection could offer a disinfection option to complement moringa's clarifying capabilities. Though boiling was proposed in this report, solar disinfection does not require the collection and burning of firewood and its associated environmental impacts. It is unclear what time involvement would be required of someone using solar disinfection, but at least the energy required would be free in terms of costs. Also, although alum is not free, it is widely used in Tong. The author feels confident that people in Tong would not want to use alum in the local way – by holding the alum salt rock in their hand, plunging it in the water, and then stirring – it is possible that methods such as grinding the rock and stirring in the powder with a utensil would also treat the wastewater without requiring contact with it. Similar in application, cost, and local availability, table salt (NaCl) has been shown to drastically reduce turbidity in water with high concentrations of certain soil particle types (Dawney, Cheng, Winkler, & Pearce, 2014). The treatments could be assessed using the same methods as this study and then added to the DRAW charts to assess their relative feasibility.

Although this report has focused on AGW reuse as a means to supplement water resources in Tong, ultimately, this option would likely still leave Tong with water scarcity issues during dry season. If AGW is collected with perfect efficiency, the potential quantity available on a per capita daily basis is only 4.0-4.6 L. Considering how long people in Tong must wait or travel to get their current water sources, an increase of 4.6 L per person per day improves the situation but does not solve it. As such, the author recommends that research on long-term rainwater storage should be investigated in the area. Many NGOs assume it is not a feasible solution because of the rainfall patterns, but for communities where boreholes have proven unsuccessful multiple times and for whom even successful boreholes have been insufficient, rain water storage may be more reasonable. Rainwater is considered good tasting locally and the concept is clearly well-understood as it is done throughout rainy season. It may be more advantageous to consider treatment of rainwater for safe storage rather than attempt several boreholes with the risk of failure so high.

4.2.2 Ghana's Northern Region

Though the population of Ghana is only 17.6% Muslim (CIA, 2017), in the Northern Region where water access is more severe, 60% of the population is Muslim (Ghana Statistical Service, 2014). In the Karaga District, where Tong is located, 83% of the population is Muslim and only about 55% of the population has an improved source for drinking water (ibid). And in the Northern Region, boreholes have only about a 61% success rate (Anayah & Kaluarchchi, 2009). This sounds decent as a majority of boreholes are successful. However, the success of a borehole is not known until after significant monetary and time investment. Additionally, many boreholes meet yield and quality requirements when first tested but through poor maintenance or over withdrawal many become nonfunctioning within just a few years. The prevalence of Islam and the uncertainty of borehole short term and long term success makes AGW reuse a potentially useful supplement to borehole drilling and other quality control efforts by local governments and foreign aid agencies working in Ghana's Northern Region.

As such, further research on the feasibility of AGW reuse more broadly could benefit more users. Surveys throughout the region would reveal more general trends in acceptability and in quantities the practice could make available. A larger research project could include in-home observations and measurements to obtain more reliable household consumption and ablution water quantities. Better testing of water quality of sources, wastewater, and treated gray water for a variety of sources and treatments should be performed. Again, for a larger research project on the subject, funding should include better transport and storage of samples so that time and temperature do not affect samples' quality. Geographically broader and more scientifically rigorous investigation of AGW reuse would be useful for the entire region as its Muslim population is fairly high and its need for increased and improved water sources is great.

4.2.3 Urban Areas

Though water scarcity issues are greater in rural areas, in Ghana and around the world, AGW reuse can still benefit urban dwellers. In Ghana, the Northern Region is the only region with a majority of the population practicing Islam, but there are also major Islamic concentrations in urban centers such as Accra, Kumasi, Sekondi-Takoradi, Tamale, and Wa (Bureau of Democracy, Human Rights, and Labor, 2015). Most urban populations in Ghana do not have the same water procurement issues as in rural parts of Ghana, but there are serious shortfalls in the sanitation of cities. AGW reuse can be studied in these areas as a way to reduce demand on already failing sewer systems.

Because urban populations are more likely to have access to pipe-borne water, the quality of the source is likely much higher than witnessed in the current study. Further, many urban areas are developed such that the presence of sand and dust is still present but likely does not add as much to AGW as in rural areas where most surfaces are composed of earth. And, as seen in other gray water studies, the uses for treated AGW not meeting drinking standards are broader. In urban parts of Ghana, there are flush toilets, ornamental vegetation, and industry. These applications often do not require as high quality of water and thus can make use of AGW more readily.

The populations in urban areas are different than rural places like Tong. Research on AGW reuse in urban areas would be useful in seeing how income and education, often higher in urban areas, may affect the social acceptability of the practice. Higher incomes may mean better treatments are more affordable and more likely to be adopted. That said, higher incomes may also mean that people would rather pay for piped water than for wastewater reuse.

As such, the author recommends that existing research on urban gray water reuse be supplemented with research specifically on the reuse of AGW in urban centers with high Muslim concentrations. AGW is likely easier to treat given the low risk of fecal or chemical contaminants, can decrease demand on municipal sewer systems, and can be applied more broadly as most household water needs are already met but high quality piped water is wasted on industrial, sanitation, and ornamental purposes.

4.2.4 Developed Areas

The acceptability of AGW reuse estimated in Tong is likely higher than in most developed communities where water scarcity is not an issue. However, in developed areas where environmental concerns such as water conservation may be more prominent, it is possible that Muslims in developed countries may also be interested in conserving water by treating and reusing their AGW. Like urban populations in Ghana, Muslims in developed countries can likely afford better treatments and can apply treated wastewater to uses that have less human interaction such as flushing toilets or watering flowers. Further, in developed countries, Muslims likely use more water per ablution than in

Tong. When water scarcity is not an issue, people tend to be less efficient with it. As such, AGW treatment and reuse may offer greater quantities of water.

The Organization of Islamic Cooperation's Statistical Economic and Social Research and Training Centre for Islamic Countries (OIC SESRIC), a nongovernmental organization composed of 61 member countries, produced a water report in 2015 claiming "one of the major challenges facing OIC countries is limited water availability" (p. vii). Many of their member countries depend on non-renewable groundwater sources which face increasing stress as consumer habits change and populations grow. For these countries, the reuse of AGW may be a potential source for renewable water as they have significant Muslim populations to provide the AGW and the motivation for reuse from water scarcity issues. Another fear pointed out by the OIC SESRIC report is the diversion of scarce water resources to industrial and municipal use away from food production (SESRIC, 2015). In these instances, it may make sense to use treated AGW for agricultural purposes, which does not require potable water. With proper research on the topic, AGW could be a resource that plays a role in water scarcity and food security nexus issues.

4.2.5 DRAW Chart Process

Beyond other geographic locations to which AGW reuse may readily apply, the process of interviews, surveys, treatments identification and testing, and DRAW chart comparisons can be helpful in general assessments of water demand and supply in communities hoping to address water scarcity. The process can be conducted by water committees, government workers, university students, or motivated leaders from other segments of the community. Alternatively aid agencies, who often perform a variety of outreach activities prior to deciding on and executing a particular intervention, can conduct the interviews, surveys, and analysis in a community. This process and the results presented as a DRAW chart can help clarify complex, tangled water scenarios in their entirety and readily compare existing water supply options to proposed solutions, AGW treatment or otherwise. For struggling communities, the visuals and holistic comparison can help them identify options within their budget. It may illuminate sources in current use that do not justify their costs or it may indicate the most promising solutions out of several possible options. Charities hoping to assist water-insecure communities can use the DRAW charts to aid in decision-making for their limited funding and can justify their choices to donors using DRAW chart results. In these instances, one DRAW chart can be made to represent time and cost to beneficiaries and another to represent time and cost to the NGO. These dual charts can help identify options that best suite both the community's context and the NGO's budget. For example, in Tong and similar communities in the Northern Region, the cost of the borehole and an AfriClay filter may be fairly comparable. From the NGO's perspective, providing each household an AfriClay filter at 125 GHS a piece may cost a fraction of the tens of

thousands of dollars they may spend on boreholes that prove to be contaminated, insufficient, or unsustainably managed.

5 Conclusion

Though further study is recommended to confirm findings, this study showed that AGW treatment and reuse in Tong is socially, economically, and physically feasible. Each tool used and analysis performed provided information critical to the creation of the DRAW chart assessment tools and the process offers insights for other communities considering AGW reuse or other water resource solutions.

5.1 Household Surveys

The household surveys provided important information on household water use, ablution practices, and water sources in Tong, from which broader lessons can be learned. First, the household surveys suggest that the quantities of water available through AGW reuse are potentially significant. The specific value depends on the community and household, but in Tong, approximately 40 L per day could be recaptured at the average household through AGW reuse. Second, the collection of demographic information suggests that AGW reuse is likely to be equitable in terms of household size, gender ratio, age distribution, and education level. This study did not determine, however, how income may affect equitability.

5.2 Conditional Acceptability

From participant observation, user surveys, observers during trials, and opinion leader interviews, this study suggests that Muslims may be open to the reuse of treated AGW. This openness is likely contingent upon:

- Not using the treated gray water for ablution again,
- Other culturally-imposed restrictions to the use of treated AGW, likely based on its appearance, and
- The severity of water scarcity

Overall, aid organizations, government agencies, or local community groups else attempting to improve a community's water situation in a Muslim community should not assume Muslims would be opposed to AGW reuse. It is worth the effort of asking about ablution practices, perceptions on water use, and "clean" water definitions to determine whether AGW treatment is worth further investigation. This is particularly true in locations that traditional water solutions such as boreholes have had limited success and high costs.

5.2.1 Tong Gray Water Recommendations

For the average household, approximately 40 L of AGW is available daily through collection, treatment, and reuse. As such, gray water reuse will not replace any of the current sources. The borehole in Tong is well used and liked and should remain so as it is not far from any house, it is relatively inexpensive, and it is of high quality. That said, the borehole's yield is insufficient to meet all of Tong's water demands and thus requires a secondary source. AGW treatment and reuse provides a source comparable to several currently used sources in terms of costs and time.

The AfriClay is necessary if reservoir water is used for ablution and the household wants potable water. The AfriClay will likely last longer when paired with pretreatment or if borehole water is used for ablution. When calculating the cost of the AfriClay filter over time, it is very competitive with other sources such as pure water sachets and hired reservoir fetching services. However, the capital cost of the AfriClay is fairly high. For households that cannot purchase the AfriClay filter, the moringa is still an excellent choice. Though it cannot be used to produce potable water on its own, it can significantly clarify AGW, shows signs of bacteria reduction capabilities, had a positive impression on people in Tong, and is a familiar treatment method. Moringa-treated AGW can likely be used for laundry, washing dishes, feeding animals, watering gardens, or construction with less time and monetary investment than hiring someone to fetch reservoir water and with higher quality than reservoir water. As it can be readily grown and maintained for almost no cost, moringa is a useful choice to supplement borehole water supplies for families of all incomes. The AfriClay filter and moringa can also be used on sources other than AGW for improvements in quality. P&G™ Purifier of Water has been shown in other studies to treat water to potable standards, but this study failed to support such findings. It did not show great reduction in turbidity and may have introduced unsafe levels of iron. As such, it may be used to treat AGW but would require further experimentation. Additionally, a household should endeavor not to depend on the P&G Purifier of Water, as it is currently free from an NGO but can become costly or simply unavailable if that NGO changes its focus.

5.2.2 Process for Other Communities

Though the DRAW charts developed in this study are specific to Tong, other communities can develop similar charts to aid in their water solution decisions. Inclusion of AGW treatment and reuse is encouraged, but in non-Muslim communities, other gray water sources can be substituted. The basic process in developing a DRAW chart is:

1. Determine whether the community has a significant population and whether the community prioritizes water scarcity as an issue. Many aid organizations have developed tools for identifying and prioritizing issues in a community. For

example, the Peace Corps encourages the use of Participatory Analysis for Community Action (Peace Corps, 2007).

2. Conduct household surveys to estimate current water consumption values and what proportion of that is used in ablution. The survey questions and procedures used in this report provide a starting point for survey development. WHO and UNICEF have jointly developed and published a brochure on some key questions to include in their “Core questions on drinking-water and sanitation for household surveys” (2006). Choose a threshold amount for which the community believes it is worth continuing to study. This can be set based on minimum human requirements, as done in this study. Alternatively, a threshold value can be established by adding the topic to household surveys or through interviews with key individuals in the community.
3. In the same or a follow up survey, determine the existing dry season sources, their costs, and their fetch times. These values will provide comparison to see whether AGW provides comparable cost and time options. Further, the current uses will determine socially-acceptable uses of the sources.
4. Based on the dry season sources in use, determine the critical source, meaning the dry season source that most people rely on and is of the lowest quality. Test this water for bacteriological and chemical components to help decide which treatment options would be most feasible. If quality testing shows the water is not likely treatable with any currently available treatment technologies, you may decide to test a new treatment, or you may consider a different critical source and base gray water reuse recommendations on the use of the specific source during ablution.
5. Create a collection device. This does not need to be state-of-the-art or even efficient. It simply needs to collect enough AGW to treat and test without causing great disruption to ablution practices. Consult people in the community, formally or informally, to decide what characteristics to incorporate in your design.
6. Have people perform ablution using the wastewater collection device and solicit feedback. Have them perform the treatments or treat the water yourself. If community members perform the treatment, solicit feedback from them on how they feel about the treatment process and the treated water product.
7. Test the treated water, ideally in a timely fashion. Analyze the results to determine whether any treatments or combinations of treatments may provide potable water. Ask users how they would feel comfortable using this treated water considering the laboratory testing results.
8. From the testing, costs of treatments, and time required to treat during trials, estimate some unit costs and collection times for the treatments. These estimates can be very approximate, as at this point it is very difficult to estimate any treatment’s life cycle costs given the AGW characteristics are not well-defined and user practices are unknown.

9. Estimate social acceptability for each treatment based on discussions with AGW collection and treatment participants, and use the household surveys to determine the social acceptability of sources already in use. The categories from this study can be used, or ones more appropriate for the community at hand can be created.
10. Plot each source and treatment's unit active fetch time, unit price, and social acceptability levels to see what options make the most sense for the community at hand. Try to use units that make sense to the community. For example, a cost per liter may not be well understood by a community that typically purchases water in 25 L jugs.
11. Share the charts with community members for interpretation and to decide the optimal solution.

The interpretation of the DRAW chart is community and even household dependent. For example, other communities may find they have plenty of potable water, but they are hoping to place gardens closer to their homes. In this case, the potable DRAW chart may not be as relevant as the chart of sources and treatments for non-potable uses. In Tong, any additional amount of water is needed, but for a household with income other than farm income, such as a teacher's salary, perhaps the cost is not as limiting as it may be at other households.

For Muslim communities who are not meeting their water demands and who are struggling to find success with traditional methods of water supply improvements, AGW reuse can offer affordable and easily adopted options for supplementing current water supply. In non-Muslim communities, the same process can be applied while considering gray water producing activities other than ablution. For these communities, list all activities for which water is used, and predict which would have the highest quality or most easily treated contaminants.

This report hoped to determine the feasibility of AGW treatment and reuse in regards to religious acceptability, economic measures of time and cost, and in physical parameters to protect health in Tong, Ghana. The qualitative and quantitative results combined in to a DRAW demonstrates that the practice is promising, albeit requires further testing for confirmation. It more broadly suggests that water assistance interventions should incorporate atypical approaches as traditional solutions do not work in every cultural and physical context. Alternative water-related interventions would benefit from more spectral and localized standards like those described in a DRAW chart rather than in strict binary standards of water quality. The option of AGW reuse may not produce the quantity of water that a borehole has the potential to, but AGW reuse is viable without external assistance and thus can be implemented quicker by the people who need it.

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B IRB-approved Protocols

B.1 Household Surveys

Adrienne Masterton

IRBNet New Project Package

Technical and Social Feasibility of Ablution Wastewater Reuse in Tong, Ghana

Household Water Use Survey

Sampling

I will get a list of Tong's house numbers from the electricity company and then use Excel's random number generator to select:

- 5-10 homes for pretesting the survey
- 30-60 homes for the actual survey (I chose 30 for the minimum because it is the minimum for statistically significant results, assuming 100% response rate. I chose 60 for the maximum because the translator said that is the most he thinks is reasonable to do, and quite frankly that's more than I think I could do.)

Consent

The following is the script the translator will translate for potential survey participants to decide whether they will consent:

This is Adrienne, or you may know her by her local name Lahiri. She is a Peace Corps volunteer from America and she is also a graduate student at Michigan Technological University. She is conducting a study to complete her Master's degree. The study is about water use, wastewater treatment and the potential to reuse wastewater. When finished, she will write a paper and present to several people at her school about her findings. Today, she would like to talk to you about your household and family, your household water use and your wastewater. As we talk, she would also like to take notes to help her remember what was said.

You are not required to talk to her or answer her questions. If, for any reason at all, you do not wish to participate in this study, that is absolutely okay. She will not be upset; it will not affect her studies; she will still respect you and your family. We will not tell anyone that you have declined. Even if you decide to talk to her at first and change your mind later, we can stop at any point. Again, this would be with no ill will. Nothing bad will happen to you, me, or her if you decide to not answer her questions about your household, your water use and your wastewater.

If you decide to participate, there are a few things she wants you to know. During our conversation, you can ask her questions at any time. You should also feel free to speak about things she did not directly ask about but you want her to know. It is also okay if you interrupt her to ask such questions. Should there be certain questions you prefer not to answer, you can decline to answer and we will move to the next question. And throughout, please know that we are not judging your answers; there is not a particular answer we are looking for. There are no "good" answers or "bad" answers. We are just looking for honest information. If you feel uncomfortable giving honest answers, then you can simply decline to answer.

Lahiri nor I will reveal anything that you say to anyone outside of those helping on the project. This includes professors and other students and staff. These individuals also know not to tell anyone outside the project what you have said. Lahiri and myself, and all others on the project will do everything we can to protect your privacy, but there is always a slight chance that someone could find out about our conversation.

Considering all that, she is asking if you would agree to participate in this study and talk to her about your household, your household water use, and your wastewater. Do you agree to participate?

Questions

If I received oral consent I will document it and then ask the following questions.

Demographics:

1. How many people are in this household, meaning people who regularly sleep overnight at the compound?
2. How many are female? How many are male?
3. How many people are between 0 and 9 years old? 10 and 17 years old? 18 and 24 years old? Older than 25 years old? It is okay to estimate if you do not know everyone's exact age.
4. What is the educational level of each member, select from the following: nil, in primary, completed primary, in junior high school, completed junior high school, in senior high school, completed senior high school, received formal education beyond senior high school
5. What are the occupations of household members?

Water Use:

1. On an average dry season day, how much water does your household use? Please use whatever unit makes the most sense to you. I will also measure these containers just so I can convert it to liters. I will do this at all houses I visit.
2. What water sources are available in the dry season? Which sources does this household use?
3. For each source, how long does it take to fetch a given container? Choose from 0-30 minutes, 30-60 minutes, more than an hour. Include wait time for the taps.
4. How much does a given container cost?
5. List the different activities you use water for and for each, tell us where you perform the activity and what water sources you are willing to use for that activity.
6. Answer the same question but for other members of the household to the extent you can.
7. If ablution was not volunteered, provide the same information as asked in 5 and 6 but for ablution water.
8. Do you ever treat water? If so, how and when? Is it for certain uses or certain sources?
9. How does your household deal with wastewater?

Explain they may be contacted later for a personal interview. Whether they are chosen does not reflect on them or their answers, it is simply based on attempting to get a good representation of Tong. Thank them for participating.

B.2 Opinion Leader Interviews

Adrienne Masterton
IRBNet New Project Package
Technical and Social Feasibility of Ablution Wastewater Reuse in Tong, Ghana
Water Reuse Interview

Sampling

I will interview the chief imam, the village chief, and the nurses at the clinic and 4-10 community members including men and women, younger and older, large households and small households, etc. These community members will be selected from a representative selection of the surveyed households. Then the male and female heads of household will be interviewed. Knowing whether the opinion leaders support the use of treated wastewater helps me know if they would allow it. Knowing the “regular folks” reaction will help me to know that if given the opinion leaders’ assent, whether they would actually be willing to do it.

Consent

The following is the script the translator will translate for potential interview participants to decide whether they will consent:

This is Adrienne, or you may know her by her local name Lahiri. She is a Peace Corps volunteer from America and she is also a graduate student at Michigan Technological University. She is conducting a study to complete her Master’s degree. The study is about water use, wastewater treatment and the potential to reuse wastewater. When finished, she will write a paper and present to several people at her school about her findings. Today, she would like to talk to you about your water use, ablution practices and your perceptions about clean and dirty water, particularly your opinions about treating and reusing wastewater. As we talk, she would also like to take notes to help her remember what was said.

You are not required to talk to her or answer her questions. If, for any reason at all, you do not wish to participate in this study, that is absolutely okay. She will not be upset; it will not affect her studies; she will still respect you and your family. We will not tell anyone that you have declined. Even if you decide to talk to her at first and change your mind later, we can stop at any point. Again, this would be with no ill will. Nothing bad will happen to you, me or her if you decide to not answer her questions about your water use, ablution practices and your perceptions about clean and dirty water, particularly your opinions about treating and reusing wastewater.

If you decide to participate, there are a few things she wants you to know. During our conversation, you can ask her questions at any time. You should also feel free to speak about things she did not directly ask about but you want her to know. It is also okay if you interrupt her to ask such questions. Should there be certain questions you prefer not to answer, you can decline to answer and we will move to the next question. And throughout, please know that we are not judging your answers; there is not a particular answer we are looking for. There are no “good” answers or “bad” answers. We are just looking for honest information. If you feel uncomfortable giving honest answers, then you can simply decline to answer.

Lahiri nor I will reveal anything that you say to anyone outside of those helping on the project. This includes professors and other students and staff. These individuals also know not to tell anyone outside the project what you have said. Lahiri and myself, and all others on the project will do everything we can to protect your privacy, but there is always a slight chance that someone could find out about our conversation.

She is asking if you would agree to participate in this study, and talk to her about your water use, ablution practices and your perceptions about clean and dirty water, particularly your opinions about treating and reusing wastewater. Do you agree to participate?

Questions

After receiving oral consent, I will ask the following questions and allow for discussion regarding the research subject.

1. How do you/people in this community distinguish between clean and dirty water? How do you/people in this community decide safe uses for water from a given source?
2. Do you limit the use of water from certain sources to certain activities? Describe.
3. How and where do you perform ablution? Would you/people in this community be willing to change that? Or are you/people in this community fairly strict about where and how ablution is performed?
4. How much water do you use for ablution? How often do you perform ablution per day? How many others in the household do ablution? How often do they do it? How much water do they use? You can just estimate if you're not exactly sure, or if you cannot guess well, then just say you do not know. Would you guess that is a fairly typical amount? Which water do you use for ablution during dry season?
5. What do you do with the wastewater? With ablution wastewater?
6. Do you treat your water? Before drinking or any other uses? For water from certain sources? If so, how?
7. If (treatment method from number 6) were used on the wastewater from ablution, would you consider that treated water safe to use? For what purposes? Or, why is it not safe?
8. Have you heard of the following treatment methods? If so, explain what you know about them: Boiling, SODIS/ UV, moringa coagulant, clay filters, other filters.
9. If ablution wastewater were treated using one of the methods from question 8, would you/people here consider it okay to use? Why or why not? If yes, for what uses?
10. When NGOs like Unicef or World Vision come to provide a borehole, they collect samples of the water and perform various tests on it to determine whether it is safe for the community to use. For example, the borehole in town was tested by Unicef and found to be safe, so they proceeded with the construction of the system, the one we use today. On the other hand World Vision found water and tested it, but found it was not good for drinking. If you collected ablution wastewater, treated it (using any of the methods) and then tested it in the same way Unicef and World Vision do and the tests showed it was safe, would you use it? Why or why not? How would you use it?
11. Would you find it worth the following efforts and/or money to get an additional XX liters (determined from survey responses) of safe water each day at the house?

- a. Purchase or build a household collection system
 - b. Only perform ablution at the house
 - c. Grow moringa to then collect seeds, crush seeds and stir into water then wait to clarify before use
 - d. Boil water before use
 - e. Purchase shallow, clear container and allow to sit for minimum 6 hours for SODIS treatment before use
 - f. Purchase a filter and filter before use? Models vary in cost, one available in Tamale is ~60GHC
12. Would you find it worth the following effort and/or money to get an additional XX liters per day (determined from survey responses combined with estimates of total mosque users) water source in the community (with water for community purposes or for sale like at the borehole)
- a. Contribute cash to help purchase/build the collection system. How much would you be willing to contribute per household?
 - b. Contribute labor for building the collection system
 - c. Perform ablution at mosque as much as possible

B.3 Prototype User Surveys

Adrienne Masterton

IRBNet New Project Package

Technical and Social Feasibility of Ablution Wastewater Reuse in Tong, Ghana
Collection and Treatment User Acceptability Survey

Sampling

Due to the likely timing of these surveys, I will simply select available individuals. These surveys are likely to happen during farming season and thus people often work up to 16 hours a day. I do not wish to take people from farm, as it is typically the core source of food and income. As such, the participants are likely to be older or somehow unable to work at farm, such as pregnant women. I recognize this is not a representative sample, but it will still provide useful initial feedback about the prototype collection and treatment options.

Consent

The translator will translate the following script to potential participants for them to decide whether to participate:

This is Adrienne, or you may know her by her local name Lahiri. She is a Peace Corps volunteer from America and she is also a graduate student at Michigan Technological University. She is conducting a study to complete her Master's degree. The study is about water use, wastewater treatment and the potential to reuse wastewater. When finished, she will write a paper and present to several people at her school about her findings. Today, she would like you to try some prototypes she made. These prototypes allow you to collect ablution wastewater and then treat it. After using the different methods, she would like to discuss them with you.

You are not required to try these prototypes or answer her questions. If, for any reason at all, you do not wish to participate in this study, that is absolutely okay. She will not be upset; it will not affect her studies; she will still respect you and your family. We will not tell anyone that you have declined. Even if you decide to participate at first and change your mind later, we can stop at any point. Again, this would be with no ill will. Nothing bad will happen to you, her, or me if you decide to not test the prototypes and discuss it with her.

If you decide to participate, there are a few things she wants you to know. During our time, you can ask her questions at any time. You should also feel free to speak about things she did not directly ask about but you want her to know. It is also okay if you interrupt her to ask such questions. Should there be certain questions you prefer not to answer, you can decline to answer and we will move to the next question. And throughout, please know that we are not judging your answers; there is not a particular answer we are looking for. There are no "good" answers or "bad" answers. We are just looking for honest information to help us make better collection and treatment methods. If you feel uncomfortable giving honest answers, then you can simply decline to answer.

Lahiri nor I will reveal anything that you say to anyone outside of those helping on the project. This includes professors and other students and staff. These individuals also know not to tell anyone outside the project what you have said. Lahiri and myself, and all others on the project will do everything we can to protect your privacy, but there is always a slight chance that someone could find out about our conversation. There is also a slight chance of injuring yourself while using these devices, though it is extremely unlikely as you will more or less be performing ablution as you usually do.

Considering all that, she is asking if you would agree to participate in this study by testing the prototypes and telling us what you think. Do you agree to participate?

Questions

Have the participant perform ablution using the wastewater collection system. It is not possible to say for certain what this collection system will look like, but currently, the idea is to have a place to sit, either a chair, bench or small stool similar to what they already use that has some type of catchment area below the person, likely made out of concrete or metal, that drains into a small container either above or below ground. Once finished, have the translator ask them the following questions:

1. Were you able to satisfactorily perform ablution? Yes or No
2. Would you be willing to adopt this method of ablution on a regular basis? Yes or No
3. Would you be willing to pay for this system if it provided you with XX liters (determined from surveys and measurements of daily ablution wastewater) of additional water each day? No, not at all – No, only if it were free – Yes, up to 10GHC – Yes, more than 10GHC
4. Would you be willing to construct such a system yourself? Yes or No
5. What changes do you suggest to make the system better?

Have the participant conduct the treatment process on the wastewater that was collected by the collection system above. Time how long it takes them to do it. Treatment methods will include: boiling, filtration, moringa seed coagulation, and/or UV disinfection. Boiling is simply taking the collected water and boiling it over a fire. Filtration is simply taking the water and pouring it into the AfriClay ceramic filter. Moringa coagulation is grinding moringa seeds and stirring it into the collected water. The oil from the seeds causes solids in the water to bunch up. Then you stop stirring and let it sit for some time and allow the solids to settle to the bottom. UV disinfection is taking the water after filtration and/or coagulation and placing it in a clear container and allowing it to sit in direct sunlight for a few hours. The UV rays deactivate viruses left in the water. Collect a sample of the wastewater for testing and then ask the participant the following questions:

1. How easy or difficult was this process? Very easy – somewhat easy – not easy – difficult – very difficult
2. Would you be willing to do this process daily if it provided you with XX liters (determined from surveys and measurements of daily ablution wastewater) of additional

water each day? No, not at all – Yes, if it were free – Yes, as long as it costs less than 10GHC– Yes, even if it costs more than 10GHC

3. Do you consider this water clean enough to use? If yes, for what uses? If no, why not?

Any other suggestions or comments you have about either the collection or treatment methods you tried today?

C Household Survey Results

This section includes scans of the hard copy responses and spreadsheets used to log the data digitally for analysis.

C.1 Household Survey Notes Scans

Demographics

1-3. Household members

Male	Female	Total	
14	20	34	
0-9	10-17	18-24	25+
8	2	1	23

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
17	14	—	1	—	1
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	34	Butcher	1
Business (shea selling)	5	Tailor	1
Bike repair	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
6	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	Y	2 hrs.	free / 30HC barrel
Borehole	Y	depends 10min - 3hrs.	0.104HC/garawa
Natural Well	Y	2 hrs.	free
Karaga Rd. Well	Y	1hr. 30m.	free
Pure Water	Y	1min.	2 cedi / 15 sachets.

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms		ALL	
Bathe ✓	bathrooms in house & individ.	rooms	ALL but pure water	
Cooking ✓	court yard		dam, ALL borehole	but pure water
Wash dishes ✓	outside yard		ALL but pure water	
Laundry ✓	dam side or outside yard		dam water	
Home industries (i.e. shea) ✓	outside yard		dam	
Construction ✓ (not every year)	House		wells in town	
Ablution ✓	bathing room & court yard		borehole dam	

8. Water treatment

Methods	Alum	P&G Purify
Uses	ALL	ALL
Source	dam,	dam,

9. Wastewater

pour in outside yard.
 ablution water sit in courtyard & dry in sun.

Comments:

34 ppl do ablution
 (6 breast feeding row not perform)
 1 is single /kettle per ablution

Demographics

1-3. Household members

Male	Female	Total	
8	13	21	
0-9	10-17	18-24	25+
11	—	4	6

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
12	6	2	—	—	—
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	21	Tailor	1
Business	2	Butcher	1
Bike Repair	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
3	Barnels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam walking donkey	✓	2hrs.	Free
Borehole	✓	45min.	3GHC/Korael
Wells	✓	5hrs	0.10/ganna wa
Natural well	✓	5mins	free
Pure water	✓	2h 30m	Free
Kanaga Rd Well	✓	3mins	0.20 for 1 0.30 for 2
		1h30m	Free

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms		ALL	
Bathe ✓	bathrooms		ALL but PW	
Cooking ✓	court yard		ALL but PW	
Wash dishes ✓	court yard		ALL but PW	
Laundry ✓	court yard / dam		ALL but PW	
Home industries (i.e. Shea) ✓	outside yard		ALL but PW	
Construction ✓	House		well, dam	
Ablution ✓	courtyard		ALL but PW	

8. Water treatment

Methods	Alum	P&G Purify
Uses	any	any
Source	dam	dam

9. Wastewater

take & throw away

Comments:

ablution: 6 per household
1 juglet per 2 person

Demographics

1-3. Household members

Male	Female	Total	
10	7	17	
0-9	10-17	18-24	25+
6	3	2	5

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
7	5	2	1	—	1
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	17	Business (petty trade)	1
Tailor	4		
Barber	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borchole	✓	4hrs.	0.100 IC
Dam (motos)	✓	30mins	4GHC
Natural Well (women walk)	when has water	1h 30m	free
Pure Water	✓	1min.	1 for 0.2 GHC 2 for 0.3 GHC
Karago Rd. Well	✓	1hr 30m	free
Nyansobga Borchole (walk)	✓	2hr	free

for 3 jerry cans

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms		ALL	
Bathe ✓	bath rooms		ALL but pure	
Cooking ✓	court yard		ALL but PW	
Wash dishes ✓	court yard		ALL but PW	
Laundry ✓	outside/dam/near yard/site/boothole		ALL but PW	
Home Industries (i.e. Shea)				
Construction ✓ ^{not every year}	House		Wells if water there or dam	
Ablution ✓	women: court yard	men: outside yard	ALL but PW	

8. Water treatment

Methods	Alum	
Uses	before anything —————	
Source	Dam	Dam

9. Wastewater

take it & pour it in outside yard.

Comments:

// do ablution
2-3 people per kettle

Demographics

1-3. Household members

Male	Female	Total	
2	3	5	
0-9	10-17	18-24	25+
1	0	1	3

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
5	—	—	—	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	5		
Business	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
1	Barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	Y	1h 30m	Free
Borehole	Y	3hrs.	0.10GHC/girawa
Karaga Rd well	Y	2 hrs.	Free
Natural well	Y	1h 30m	Free
Nyensobga Borehole	Y	3h 30m	0.10 GHC/girawa
Pure water	Y	3-4m	1GHC/6sachets

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	house	ALL
Bathe ✓	bath room	ALL but pure water
Cooking ✓	court yard	ALL but pure water
Wash dishes ✓	court yard	ALL but pure
Laundry ✓	outside yard	ALL but pure
Home industries (i.e. shea)		
Construction ✓ (not every year)	House	dam
Ablution ✓	outside yard	borehole ALL but pure

depends
whats
avail.

8. Water treatment

Methods	P&G Purify	Alum
Uses	ALL	ALL
Source	dam	dam

9. Wastewater

pour ~~in~~ it in outside yard.

Comments:

2 ppl do ablution
half jingla/kettle per ablution

Demographics

1-3. Household members

Male	Female	Total	
5	10	15	
0-9	10-17	18-24	25+
4	3	4	4

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
8	4	—	1	1	—
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	15		
Business	3		
Butcher	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	Y	1hr. 30m.	free) / 20GHC donkey
Borchole	Y	2hrs.	0.10GHC/ garawa
Natural well	Y	1 hr.	free
Nyensobga borchole	Y	3hrs.	0.10GHC/ garawa
Karaga Rd. Well	Y	2hrs.	free
Pure water	Y	0-30m.	.20GHC

11-05-17:
Since circled,
assume this house
only get
dam H₂O
on own.

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	ALL
Bathe ✓	bath room	ALL but Pure water
Cooking ✓	court yard	borehole dam
Wash dishes ✓	court yard	borehole
Laundry ✓	house	borehole
Home industries (i.e. shea) ✓	outside yard	ALL but pure water
Construction ✓ (not every year)	House	dam (motor king)
Ablution ✓	court yard	borehole

8. Water treatment

Methods	Alum	P&G Purify
Uses	everything	everything
Source	dam	dam

9. Wastewater

pour wastewater in outside yard.
 ablution waste stays in courtyard & evaporates.

Comments:

12 ppl do ablution
 1 jingla / kettle per person

Demographics

1-3. Household members

Male	Female	Total	
10	8	18	
0-9	10-17	18-24	25+
8	1	2	7

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
6	8	—	—	1	—
SHS done	Beyond SHS				
2	1				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Shea Butter	1	Teacher	1
Farming	18		
Tailor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam (walk)	Yes	1h 30m - 2hrs.	free
Borehole	Yes	4hrs.	0.10 GHC
Natural ne	Yes	2hrs 30m	fr e
Karogo Rd. 1 1	Yes	2hrs.	free
PW	Yes	15min	3 for 0.50 GHC 2 for 1 GHC
Nyensobga d	Yes	3h 30m	0.10 GHC

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	Room	Dam, ALL
Bathe ✓	Room	Borehole
Cooking ✓	court yard	Borehole
Wash dishes ✓	court yard	Borehole, dam
Laundry ✓	outside yard	dam, Borehole
Home industries (i.e. shea) ✓	outside yard	dam
Construction ✓	House	well or dam
Ablution ✓	court yard	borehole
Wash hands	court yard	borehole

8. Water treatment

Methods	Alum	P&G Purify	Filter (guinea worm) <i>after Alum</i>
Uses	ALL	ALL	ALL
Source	dam	dam	dam water

9. Wastewater

pour it outside yard
ablution water evaporates in courtyard
bath drain

Comments:

12 ppl do ablution
dry season 2 ppl / jingla

Demographics

1-3. Household members

Male	Female	Total	
3	7	10	
0-9	10-17	18-24	25+
3	3	3	1

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
5	2	—	—	2	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	10		
Business	2		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	Yes	4 hrs	0.10GHC/garawa
Dam	Yes	2 hrs.	free
Nuensobga borehole	Y	2h 30m	0.10GHC/garawa
Natural well	Y	1h 30m	free
Karaga Rd. well	Y	2 hrs.	free
Pure water	rarely		only if someone

5-7. Domestic water activities

most of daily use not include ell rice, construction

Activity	Location	Source
Drink ✓	rooms	borehole, dam, all
Bathe ✓	rooms	borehole
Cooking ✓✓ self & sell	court yard	ALL
Wash dishes ✓	court yard	borehole, ALL
Laundry ✓	outside yard	ALL
Home industries (i.e. Shea)	outside yard	dam, water
Construction ✓ (not even year)	House	dam
Ablution ✓	court yard	borehole

8. Water treatment

Methods	Alum	PdG Purify
Uses	ALL	ALL
Source	dam	dam

9. Wastewater

pour it in outside yard.

Comments:

5 ppl do ablution
2 ablutions / jingla

Demographics

1-3. Household members

Male	Female	Total	
7	0	7	
0-9	10-17	18-24	25+
0	2	3	2

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
2	2	1	1	1	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	7		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borchole	✓	4hrs.	0.10GHC/garawa
Dam (walking)	✓	2hrs.	3GHC if donkey but usually walk → free
Natural well	✓	30min.	free
PW	✓	5min.	2 for 0.3GHC.
Karaga Rd. Well	✓	2hrs.	free
Nyensobga	✓	2h30m	0.10GHC/garawa

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	room	.	ALL	
Bathe ✓	bathroom		ALL but	PW
Cooking ✓	courtyard		ALL but	PW
Wash dishes ✓	courtyard		ALL but	PW
Laundry ✓	outside yard		ALL but	PW
Home Industries (i.e. shea)				
Construction ✓	house		Dam	
Ablution ✓	outside yard		ALL but	PW

8. Water treatment

Methods	Alum	P&G Purify
Uses	any	any
Source	dam	dam

9. Wastewater

Throw it out in yard

Comments:

7 ppl do ablution
1 jugla per person per ablution
1

Demographics

1-3. Household members

Total members			
Male	Female	Total	
9	7	16	
0-9	10-17	18-24	25+
3	1	2	10

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
10	3	1	—	1	—
SHS done	Beyond SHS				
1	1				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	16	Food seller	1
Tailor	1	Drug seller	1
Butcher	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Moto King (dam)	Y	3hrs.	4GHC/Barrel
Borehole	Y	4 hrs.	0.10 GHC/garawa
Wells (rainy season)	Y	1 min.	free
Natural well	Y	45 min.	free
Karaga Rd. Well	Y	50 min.	free (end in Dec.)
Pure water	Y	2 min	4GHC/30 sachet

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	room	not borehole ALL
Bathe ✓	bath room	ALL but pure
Cooking ✓	court yard	ALL but pure
Wash dishes ✓	court yard	ALL but pure
Laundry ✓	outside yard	borehole
Home industries (i.e. shea) ✓ rice	outside yard	dam
Construction ✓ flooring yes rooms not	House	well
Ablution ✓	outside yard	borehole

8. Water treatment

Methods	Alum	PdG Purify
Uses	ALL but construction	
Source	Dam, all but pure	Dam all but pure

9. Wastewater

pour it away in outside yard.

Comments:

13 do ablution
1 person / jingla

Demographics

1-3. Household members

Male	Female	Total	
3	4	7	
0-9	10-17	18-24	25+
4	—	—	3

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
3	4	—	—	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	7		
Business	1		
Tailor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Garawa	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	Y	20m (moto)	2.50GHC
Borehole	Y	1 hr.	0.10GHC
Natural well	Y	30m (moto)	4.00GHC
Pure water	Y	2 min.	2 for 0.30GHC
Karaga City	Y	1hr 30min	Dam-free Taps - 0.10GHC Petrol - 4GHC.

for petrol

garawa

for petrol

will buy 2GHC/day more if strangers
8 not sure how much women kids

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	room	borehole ALL
Bathe ✓	bath rooms	ALL but pure
Cooking ✓✓✓	court yard	ALL but pure
Wash dishes ✓	court yard	ALL but pure
Laundry ✓	dam site	dam
Home industries (i.e. shea) ✓	outside yard	ALL but pure
Construction ✓	House	dam
Ablution ✓	court or outside yard	borehole
Wash Moto	outside yard	ALL but pure
Animals	court yard	Dam

8. Water treatment

Methods	P&G Purify	Alum
Uses	ALL	ALL
Source	dam	dam

9. Wastewater

pour it outside yard

Comments:

5 ppl do ablution

1 kettle per person per ablution

Demographics

1-3. Household members

Male	Female	Total	
6	2	8	
0-9	10-17	18-24	25+
2	1	1	4

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
3	3	—	2	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	8		
Butcher	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
3	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam (walk)	✓	1hr. 30m.	free
Borchole	✓	5hr 50m.	0.10GHC / garawa or jerry can.
Nyensobga Bore hole	✓	3hrs.	0.10GHC
Natural Well	✓	1hr 30m	free
Pure Water	✓	3min.	2 for .30GHC
Karaga Rd Well	✓	2 hrs.	free

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	ALL
Bathe ✓	bath rooms	ALL but PW
Cooking ✓	court yard	ALL but PW
Wash dishes ✓	court yard	ALL but PW
Laundry ✓	court yard	ALL but PW
Home industries (i.e. shea)	—	—
Construction ✓ every other yr.	House	Dam
Ablution ✓	court yard but flows to bath	Prefer borehole or Alum treated dam water
Animals	court yard	ALL but PW

8. Water treatment

Methods	Alum	P&G Purify
Uses	before any uses	—
Source	dam,	dam

9. Wastewater

pour it outside

Comments:

5 do ablution
2 people per ablution

Demographics

1-3. Household members

Male	Female	Total	
14	7	21	
0-9	10-17	18-24	25+
4	3	3	11

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
8	4	—	7	—	1
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	21		
Shea Butter	2		
Carpenter	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam ^{1 walk} 2 donkeys	✓	2hrs.	free
Borehole	✓	2hrs. 30m	3GHC / barrel
Nyensobga Borehole	✓	4hrs.	0.10GHC / ganawa
Natural well	✓	3hrs.	0.10GHC / ganawa
PW	✓	1hr. 30m	free
	✓	2 mins.	2 for 30 p 1 for 20 p

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	courtyard		ALL	
Bathe ✓	bathroom		ALL but PW	
Cooking ✓	Courtyard		All but PW	
Wash dishes ✓	courtyard		All but PW	
Laundry ✓	dam site courtyard		dam borehole	
Home industries (i.e. shea) ✓	courtyard		ALL but PW	
Construction ✓	house		dam	
Ablution ✓	our in the wall	outside men	All but PW	

8. Water treatment

Methods	PO	alum
Uses	all	
Source	dam	dam

9. Wastewater

outside the yard

Comments:

4 do ablution
2 people per jugla
~

Demographics

1-3. Household members

Male	Female	Total	
16	17	33	
0-9	10-17	18-24	25+
14	0	2	17

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
25	3	4	—	—	—
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	33		
Mason	2		
Business	4		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
5	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	✓	2 hrs	free
Borehole	✓	3-4hrs.	0.10 GHC/garawa
Bush-dig holes	✓	3 hrs.	free
Pure water	✓	5 min	0.20 GHC/one
Natural well	✓	1.5 hours	free
Karaga Rd. Well	✓	2 hours	free

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	dam BH
Bathe ✓	bath room	dam BH
Cooking ✓✓✓	House	dam BH
Wash dishes ✓	House	dam BH
Laundry ✓	dam site	dam
Home industries (l.e. shea) ✓	Yard	dam
Construction ✓	House	dam
Ablution ✓	bath room & courtyard	dam BH
Look food to sell	House	BH

not
part of
HH water
use est.

8. Water treatment

Methods	Alum	PdCl Purify
Uses	not const. / shea ———	
Source	ALL	ALL

9. Wastewater

pour it outside
bath's have holes

Comments:

15 do ablution
1 barrel/day.

Demographics

1-3. Household members

Male	Female	Total	
12	10	22	
0-9	10-17	18-24	25+
8	2	3	8

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
11	7	0	3	0	1
SHS done	Beyond SHS				
0	0				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	22		
Carpenter	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
10+	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	✓	30mins+	free; buy motor king barrel 30HC
Borehole	✓	3hrs	0.10GHC
Wells	✓	~5mins	—
Pure Water	✓	10mins	0.20/500mL
Natural Well	✓	60mins	free
Karaga Rd. Well	✓	40mins	free

— finish Dec.

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	dam borehole
Bathe ✓✓	bath room	borehole dam
Cooking ✓	house	borehole
Wash dishes ✓	Yard	borehole
Laundry ✓	Yard	dam
Home Industries (i.e. shea) ✓	Yard	dam
Construction ✓ ^{not every year}	House	dam
Ablution ✓	Yard	borehole dam

not
included
in 10
barrels

8. Water treatment

Methods	PG Purify	Alum
Uses	all	all
Source	dam	dam

9. Wastewater

toss it on ground outside
bath room has drain.

Comments:

11 pray
3 tea pots per person / day for ablution
5 showers a day

Demographics

1-3. Household members

Male	Female	Total	
1	5	6	
0-9	10-17	18-24	25+
1	1	1	3

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
2	2	—	—	—	1
SHS done	Beyond SHS				
—	1				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	6		
Food seller	2		
Tailor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
3	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam (Motoking)	Yes	2hr 30m.	3 GHC/Barrel
Borehole	Yes	4hrs.	0.10GHC/Barrel
Dam (Donkey)	Yes	3hrs.	3GHC/Barrel
Natural Well	Yes	2hrs. (walk)	free
Langogu Borehole	Yes	3h 30m (walk)	0.10GHC
Pure water	Yes	5min	1.50/10 sachets.

* PW = pure water

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	borehole PW only
Bathe ✓	bath rooms	dam
Cooking ✓	court yard	ALL but PW
Wash dishes ✓	outside yard	dam, prefer borehole
Laundry ✓	outside yard	dam
Home industries (i.e. shea) ✓	outside yard	dam
Construction ✓ not every year	House	dam
Ablution ✓	outside yard	dam

for drinking

8. Water treatment

Methods	Alum	if have Ps G Purify
Uses	ALL	ALL
Source	dam	dam

9. Wastewater

pour it outside except bath water

Comments:

- 3 do ablution
+ neighbors (4)

Demographics

1-3. Household members

Male	Female	Total	
4	5	9	
0-9	10-17	18-24	25+
3	1	—	5

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
7	1	1	—	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	9		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
6	garawa	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	5hrs.	0.10GHC
Dam	✓	2hrs.	free
Nyensobga	✓	2hrs.	free
Natural Well	✓	45m.	free
PW (rare)	✓	1min.	30pes.

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	ALL
Bathe ✓	bath rooms	Both
Cooking ✓	court yard	dam - TZ borehole - soup
Wash dishes ✓	court yard	Both
Laundry ✓	outside yard	Both
Home industries (i.e. Shea) ✓	inside yard	dam or well
Construction ✓	House	Dam
Ablution ✓	court yard	Both

8. Water treatment

Methods	P&G Purify.	NO ALUM
Uses	before anything	
Source	dam	

9. Wastewater

pour outside yard.

Comments:

6 do ablution
2 people per kettle

Demographics

1-3. Household members

Male	Female	Total	
3	7	10	
0-9	10-17	18-24	25+
4	3	—	3

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
5	3	1	—	1	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	10		
Business	2		
Butcher	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
3	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam <small>walking</small>	✓	2hr	free
<small>donkey/moto</small>	✓	1hr	3GHC
Karaga Dam	✓	2h 30m	5GHC / barrel
Borehole	✓	5hr 50m	0.10GHC
PW	✓	2min	1 for 20 p 2 for 30 p
Nyensolga borehole	✓	2 hrs.	0.10GHC.
Natural well	✓	2 hrs.	free

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	sta room	ALL
Bathe ✓	bathroom	ALL but pure
Cooking ✓✓✓	courtyard	All but PV
Wash dishes ✓	courtyard	All but PV
Laundry ✓	courtyard	All but PV
Home industries (i.e. shea) ✓	courtyard	All but PV
Construction ✓	House	well, dam
Ablution ✓	courtyard	ALL but PV

8. Water treatment

Methods	PSG Purify	Hum
Uses	before any use	starting after Dec.
Source	dam	dam

9. Wastewater

outside the yard.

Comments:

7 do ablation
1 person / jungle

Demographics

1-3. Household members

Male	Female	Total	
7	6	13	
0-9	10-17	18-24	25+
4	2	1	6

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
7	4	—	2	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	13		
Business	2		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
3	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
DAM	Y	2hrs.	free/(3GHC)
BOREHOLE	Y	6 hrs.	0.10GHC
Pure water	Y	1min.	0.20GHC
Natural Well	Y	1hr. 30m ^{-2hrs.}	free
Wells	Y	1min.	free, or other's bng
Other comm's	Y	3hrs.	0.10GHC

donkey barrel

one sachet; 0.50GHC for 3

for free

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms		ALL	
Bathe ✓	bath room		ALL but pure	
Cooking ✓	court yard		ALL but pure	
Wash dishes ✓	court yard		ALL but pure	
Laundry ✓	outside yard dam site		ALL but pure	
Home industries (i.e. shea) ✓	outside yard		ALL but pure	
Construction ✓	House		wells or dam	
Ablution ✓	bath	outside yard	borehole	

8. Water treatment

Methods	P&G Purified	Alum
Uses	ALL	ALL
Source	dam	dam

9. Wastewater

pour it away outside

Comments:

8 do ablution
2 jingla / 2 people

Demographics

1-3. Household members

Male	Female	Total	
8	7	15	
0-9	10-17	18-24	25+
5	2	4	4

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
9	6	—	—	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	15		
Shea Butler Sell	3		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barnels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam (walking)	✓	2hrs.	free
Borehole	✓	6hrs ^{some}	0.10 GHC/garawa
Wells	✓	10mins.	free (if have rope (20HC) & contain
Nyensobgo borehole	✓	3h 30m	0.10 GHC/garawa (5GHC) = 7GHC)
Langogu borehole	✓	6hrs - crowded 3hrs - not crowd	0.10 GHC/garawa
PW (don't buy, min. if given)		1 min.	2 for 30 1 for 20

sometimes wait & still not get

free (if have rope (20HC) & contain (5GHC) = 7GHC)

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	ALL
Bathe ✓	bathrooms	ALL but PW
Cooking ✓✓✓	courtyard	ALL but PW
Wash dishes ✓	courtyard	ALL but PW
Laundry ✓	outside yard	ALL but PW
Home industries ✓ (l.e. shea)	outside yard	ALL but PW
Construction ✓	house	dam
Ablution ✓	courtyard	borehole → prefer dam → only if not have borehole
Fetch for birds ✓	courtyard	ALL but PW

8. Water treatment

→ 2 gana wa (7 gawawa = barrel)

Methods	Alum (20 pesos)	P&G Purify
Uses	any use	any use
Source	dam	dam

9. Wastewater

pour it away outside yard

Comments:

9 ppl perform ablution in HH
2 people per jingla per ablution

Demographics

1-3. Household members

Male	Female	Total	
6	11	17	
0-9	10-17	18-24	25+
5	3	1	8

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
9	7	—	1	—	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	17	Mat maker	1
Food Seller	5		
Sheo Butter	4		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	2h 30m	0.10 GHC
Dam Motosking	✓	1h 30m	3 GHC
Dam Donkey	✓	2hr.	3 GHC
Natural Well	✓	1hr.	free
PW	✓		2 GHC / 12 sachets
Lanc 1		3h 30m	0.10 GHC

5-7. Domestic water activities

ayg
soaking
shea
ocess &
sundry
st part
b est.

Activity	Location		Source	
Drink ✓	room		PN, borehole	
Bathe ✓	bath room		dam	
← Cooking ✓	court yard		borehole	
Wash dishes ✓	court yard		borehole	
Laundry ✓	court yard		borehole	
Home industries (i.e. shea) ✓	court yard		dam	
Construction ✓	House		dam	
Ablution ✓	court yard		borehole	

water looks okay

8. Water treatment

Methods	P&G Purify (finish water in same day)	Alum
Uses	ALL	ALL
Source	dam	dam

→ prefer alum

Dr. fetch dam
→ don't treat
Jan going there treat

9. Wastewater

pour it away in outside water
court yard - evap for ablution
baths drain out

Comments:

9 do ablution
2 ppl per jungle

Demographics

1-3. Household members

Male	Female	Total	
6	6	12	
0-9	10-17	18-24	25+
4	2	1	4

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
7	2	—	1	2	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	12	Water Fetching	2
Business	2		
Tailor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	2hrs +	0.10GHC
Dam (Donkey own)	✓	1hr	free
Natural well	✓	1hr women or donkey	free
Wells	✓	3mins.	free
Langogu bore hole donkey	✓	2hrs.	0.50GHC
Nyensobga borehole donkey	✓	"	"

barrel / garawa

/barrel

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms		Borehole Dam	
Bathe ✓	both room		"	
Cooking ✓✓	court yard		"	
Wash dishes ✓	"		"	
Laundry ✓	"		"	
Home industries (i.e. shea)	House		"	
Construction ✓	House		Wells or dam	
Ablution ✓	outside yard	court yard	borehole or dam	
Animals	outside yard		dam	

8. Water treatment

Methods	PdG Purify	Alum
Uses	—————	ALL
Source	—————	Dam

9. Wastewater

dig hole outside yard & pour it in
bath rooms have drain

Comments:

6 people do ablution
2 ppl / jungle or 1 person / small jungle

Demographics

1-3. Household members

Male	Female	Total	
6	9	15	
0-9	10-17	18-24	25+
6	1	2	6

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
7	5	—	2	1	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	15	Hus & mats maker	1
Business	2		
Carpenter	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam (walking)	✓	45m.	free
Borchole	✓	1hr 30m	0.10GHC
Natural well	No		
PW	No		
Karaga Well 1	No		

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	drinking room	ALL
Bathe ✓	bath room	ALL
Cooking ✓✓✓	court yard	ALL
Wash dishes ✓	"	ALL
Laundry ✓	outside yard	ALL
Home Industries (i.e. rice shea) ✓	court yard	ALL
Construction ✓ not every year	House	dam
Ablution ✓	outside yard	ALL

8. Water treatment

Methods	Pd G purify	Alum
Uses	ALL	ALL
Source	Dam	Dam

9. Wastewater

pour it away

Comments:

7 people do ablution
2 people per jingla

Demographics

1-3. Household members

Male	Female	Total	
11	19	30	
0-9	10-17	18-24	25+
3	5	5	17

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
8	7	3	7	—	2
SHS done	Beyond SHS				
2	1				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	30	Food Seller	3
Driver	1		
Garbage Man	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	Yes	2hrs.	free
Borehole	Yes	3hrs.	0.10GHC
PW	Yes	seconds	0.20GHC/1 sachet 8GHC per day = 2 sleeves = 60 sachet
Nyensobga bore	Yes.	4hrs.	free
Langogu holes	Yes	4hrs.	free
Natural Well	Yes.	40min.	free

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	rooms,		ALL	
Bathe ✓	bath room	outside yard for some	DAM & Borehole	
Cooking ✓	court yard		"	
Wash dishes ✓	court yard		"	
Laundry ✓	outside yard		"	
Home industries (i.e. Shea) ✓	court yard		"	
Construction ✓ <small>not every year</small>	House		dam	
Ablution ✓	outside yard		borehole or dam	
Horse ✓ <small>2garawa per day.</small>	inside room		"	

8. Water treatment

Methods	Alum	PdG Purify
Uses	Any use	
Source	Dam	

9. Wastewater

take it & pour it outside

Comments: 27 people do ablution
2 people / jingla
4 times a day.

Demographics

1-3. Household members

Male	Female	Total	
13	5	18	
0-9	10-17	18-24	25+
7	2	1	8

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
9	5	1	1	1	—
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	18		
Business (petty trading)	1		
Driver tractor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	Y	1 hr.	0.106HC
Dam	Y	1 hr.	free
Natural well	Y	40 min.	free
Pure water	Y	<1min	1GHC/6 sachets

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms.	ALL
Bathe ✓✓	bath rooms	ALL but pure
Cooking ✓✓✓	court yard	ALL but pure
Wash dishes ✓	court yard	ALL but pure
Laundry ✓	outside yard	ALL but pure
Home industries (i.e. shea) ✓	outside yard	ALL but pure
Construction ✓	House	dam
Ablution ✓	outside yard	ALL but pure

8. Water treatment

Methods	Alum	PdG Purify
Uses	ALL	ALL
Source	dam	dam

what ever amount
they can use in a
day is what they
treat.

9. Wastewater

pour it in outside yard.

Comments:

7 do ablution
2 people per jingla per ablution

Demographics

1-3. Household members

Male	Female	Total	
5	1	6	
0-9	10-17	18-24	25+
2	4	3	1

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
3	1	1	—	—	—
SHS done	Beyond SHS				
1	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	6		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
1	Barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	10mins - 1hr.	0.10GHC/garawa
Dam (bicycle)	✓	15m.	free
Nyen. Borehole	✓	45mins	0.10GHC/garawa
Natural well	✓	7mins	free
PW	✓	10mins	20p for 1

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	ALL
Bathe ✓	bathroom	All but PW
Cooking ✓	courtyard	All but PW
Wash dishes ✓	courtyard	All but PW
Laundry ✓	outside or courtyard	Any
Home industries (i.e. shea)		
Construction ✓	House	dam
Ablution ✓	outside yard	all but PW

8. Water treatment

Methods	P&G Purify	Alum
Uses	for all uses —	—
Source	dam	dam

9. Wastewater

outside the yard.

Comments:

1 person does ablution
2 ablution / jingla
3 person do

Demographics

1-3. Household members

Male	Female	Total	
8	9	17	
0-9	10-17	18-24	25+
9	2	1	5

4. Education

NII	Some primary	Primary done	Some JHS	JHS done	Some SHS
11	6	—	—	—	1
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farming	17		
Business	3		
Tailor	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	5hrs.	0.10GHC/garawa
Dam (walking)	✓	1hr. 50m.	free
Nyensobga borehole	✓	4hrs.	0.20GHC/garawa
Pw	✓	2mins.	0.20P/ore
Natural Well	✓	2hrs.	free

5-7. Domestic water activities

Activity	Location	Source
Drink ✓	rooms	borehole, PW
Bathe ✓	bathroom (w/ soak pit)	borehole
Cooking ✓	courtyard	borehole or dam
Wash dishes ✓	courtyard	borehole
Laundry ✓	courtyard	borehole or dam
Home industries (i.e. shea) ✓	court or outside yard	dam
Construction ✓	House	dam
Ablution ✓	courtyard	borehole
Animals ✓	courtyard	dam

8. Water treatment

Methods	P&G Purify	Alum
Uses	any use	any use
Source	dam	dam

9. Wastewater

pour it outside.

Comments:

8 do ablution
2 people per jingla, young kids 1 per person
-

Demographics

1-3. Household members

Male	Female	Total	
3	4	7	
0-9	10-17	18-24	25+
1	1	2	3

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
3	1	1	1	1	—
SHS done	Beyond SHS				
—	—				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	7	Butcher	1
Mason	1		
Barber	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2 1/2	barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Borehole	✓	1h 30m - 2h	0.10 GHC / garawa
Dam	✓	1hr	free
Nyensobga borehole	✓	1hr 40m	0.10 GHC / garawa
Natural Well	✓	50m	free
PW	✓	4sec.	0.20 GHC per l

5-7. Domestic water activities

Activity	Location	Source
Drink ✓ 10 times a day	rooms	All
Bathe ✓✓✓	bathrooms	All but PW
Cooking ✓✓✓	courtyard (room for rainy season)	borehole
Wash dishes ✓	courtyard	All but PW
Laundry ✓	courtyard	All but PW
Home industries (i.e. shea)		
Construction ✓	House	dam or borehole
Ablution ✓		
Animals ✓	courtyard	ALL

8. Water treatment

Methods	Filter	Filter
Uses	before drinking	
Source	dam	dam

9. Wastewater

throw it outside

Comments:

7 do ablution
1 people per jungle

Demographics

1-3. Household members

Male	Female	Total	
12	30	42	
0-9	10-17	18-24	25+
8	12	6	16

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
19	11	2	1	2	3
SHS done	Beyond SHS				
2	2				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmer	39		
Students	3		
Business	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
2	Barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dug outs (dams)	✓	1 hour	3cd / barrel for donkey
Borehole	✓	30-60min	0.10¢ per garawa
Natural well	✓	30-60min	3GHC (donkey) free if women
Pure water	✓	0-30min	0.20 / one 0.30 / two
Other communities'		3hr	also GHC.

boreholes

or free if women do

finish by end April
women pay
not enough daily

finish by end Dec.

5-7. Domestic water activities

Activity	Location	Source	
		respondent	other HH members
Drink ✓	rooms	dam or borehole or hand water	
Bathe ✓	bathing room	natural well then dam	
Cooking ✓	kitchen	dam	III
Wash dishes ✓	yard	dam	III
Laundry ✓	yard	dam or borehole	Σ
Home industries (i.e. shea)	yard	dam	Σ
Construction ✓ (not every year, maybe every other)	house	dam	Σ
Ablution ✓	bathing room	borehole or dam	Σ
Animals ✓	near house	dam	

8. Water treatment

Methods	Filter (JICA)	World Vision Rocket
Uses	drinking & cooking	→
Source	non-borehole sources	→

9. Wastewater

dig a hole & pour the water in

Comments:

42 ppl do ablution
1 person /jingle

Demographics

1-3. Household members

Male	Female	Total	
14	18	32	
0-9	10-17	18-24	25+
13	0	2	15

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
19	8	3	1	1	0
SHS done	Beyond SHS				
0	0				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	29		
Shea Butter	1		
Carpentry	3		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
4	Barrels	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	✓	2 hours	free - (3GHC/barrel)
Borehole	✓	up to 4hrs	0.10GHC
Neighbor Communities Boreholes	✓	3 hrs.	0.10GHC
Karago Rd. Well	✓	1 hr.	free
House wells	✓	none	free

- dry in Dec.

5-7. Domestic water activities

Activity	Location		Source	
Drink ✓	House	— —	borehole	
Bathe ✓	bath area		dam	
Cooking ✓✓	house		dam	
Wash dishes ✓	Yard		dam	
Laundry ✓	Yard or at source		dam	
Home industries (i.e. Shea) ✓	house		dam from donkeys	
Construction ✓	house		dam	
Ablution ✓	bath st court house yard		dam & borehole	

not every year

8. Water treatment

Methods	WV PG Purify	Alum
Uses	all	all
Source	dam & well	dam & well

9. Wastewater

carry bowl or something outside

bath rooms have drains

Comments: —

Demographics

1-3. Household members

Male	Female	Total	
10	5	15	
0-9	10-17	18-24	25+
5	1	2	7

4. Education

Nil	Some primary	Primary done	Some JHS	JHS done	Some SHS
6	4	0	0	3	0
SHS done	Beyond SHS				
2	0				

5. Occupation(s)

Occupation	# of members	Occupation	# of members
Farmers	15		
Business	2		
Bike repair	1		

Water Use

1. Water consumption

Quantity	Container	Container dimensions
1	Barrel	

2-4. Dry season water sources

Available	This HH use?	Fetch time	Cost
Dam	✓	1 hour	∅ unless donkey sometimes
Natural Well	✓	30-60min	∅ unless hire donkey/not
Karaga Rd Well	✓	30min	∅
Borehole	✓	0min depends 3hr if still not get	0.10GHC/garawa
Pure water	✓ some	0-30min	0.20GHC/one 0.30GHC/two

too low

dry be March but has some water as rain come by end Dec.

5-7. Domestic water activities

not included
n 1
arrell
est.

Activity	Location	Source
Drink ✓	Rooms	borehole borehole pure water
Bathe ✓	Rooms	borehole dam
Cooking ✓	kitchen	" "
Wash dishes ✓	Yard	dam borehole dam
Laundry ✓	Yard Natural Well	borehole Natural Well
Home Industries (i.e. shea) ✓	Yard	dam
Construction ✓	Home	dam
Ablution ✓	bathing area	borehole dam

8. Water treatment

Methods	GP Purify (from World Vision)	Alum
Uses	laundry, dishes	→
Source	Dam	Dam

(not for some
container)

9. Wastewater

carry in pot / bucket / bowl & ~~can~~ dump outside
bath has drain to outside

Comments:

C.2 Data Input to Excel for Analysis

Serial No.	Male	Female	Replier female	Household Size	% Female
1	14	20	1	34	59%
2	8	13	1	21	62%
3	10	7	0	17	41%
4	2	3	1	5	60%
5	5	10	1	15	67%
6	10	8	NULL	18	44%
7	3	7	NULL	10	70%
8	7	0	0	7	0%
9	9	7	NULL	16	44%
10	3	4	0	7	57%
11	6	2	1	8	25%
12	14	7	1	21	33%
13	16	17	1	33	52%
14	12	10	1	22	45%
15	1	5	NULL	6	83%
16	4	5	NULL	9	56%
17	3	7	NULL	10	70%
18	7	6	NULL	13	46%
19	8	7	1	15	47%
20	6	11	NULL	17	65%
21	6	6	0	12	50%
22	6	9	0	15	60%
23	11	19	0	30	63%
24	13	5	0	18	28%
25	5	1	NULL	6	17%
26	8	9	NULL	17	53%
27	3	4	0	7	57%
28	12	30	NULL	42	71%
29	14	18	1	32	56%
30	10	5	1	15	33%

Serial No.	0-9 YO (No.)	10-17 YO (No.)	18-24 YO (No.)	≥25 YO (No.)	0-9 YO (%)	10-17 YO (%)	18-24 YO (%)	≥25 YO (%)
1	8	2	1	23	24%	6%	3%	68%
2	11	0	4	6	52%	0%	19%	29%
3	6	3	2	5	35%	18%	12%	29%
4	1	0	1	3	20%	0%	20%	60%
5	4	3	4	4	27%	20%	27%	27%
6	8	1	2	7	44%	6%	11%	39%
7	3	3	3	1	30%	30%	30%	10%
8	0	2	3	2	0%	29%	43%	29%
9	3	1	2	10	19%	6%	13%	63%
10	4	0	0	3	57%	0%	0%	43%
11	2	1	1	4	25%	13%	13%	50%
12	4	3	3	11	19%	14%	14%	52%
13	14	0	2	17	42%	0%	6%	52%
14	8	2	3	8	36%	9%	14%	36%
15	1	1	1	3	17%	17%	17%	50%
16	3	1	0	5	33%	11%	0%	56%
17	4	3	0	3	40%	30%	0%	30%
18	4	2	1	6	31%	15%	8%	46%
19	5	2	4	4	33%	13%	27%	27%
20	5	3	1	8	29%	18%	6%	47%
21	4	2	1	4	33%	17%	8%	33%
22	6	1	2	6	40%	7%	13%	40%
23	3	5	5	17	10%	17%	17%	57%
24	7	2	1	8	39%	11%	6%	44%
25	2	0	3	1	33%	0%	50%	17%
26	9	2	1	5	53%	12%	6%	29%
27	1	1	2	3	14%	14%	29%	43%
28	8	12	6	16	19%	29%	14%	38%
29	13	0	2	15	41%	0%	6%	47%
30	5	1	2	7	33%	7%	13%	47%

Seri al No.	Nil	Some pri	Pri done	Some JHS	JHS done	Some SHS	SHS done	Beyon d SHS	Proxy Literac y Rate (%)
1	17	14	0	1	0	1	1	0	12%
2	12	6	2	0	0	0	1	0	10%
3	7	5	2	1	0	1	1	0	27%
4	5	0	0	0	0	0	0	0	0%
5	8	4	0	1	1	0	1	0	27%
6	6	8	0	0	1	0	2	1	40%
7	5	2	0	0	2	1	0	0	43%
8	2	2	1	1	1	0	0	0	29%
9	10	3	1	0	1	0	1	0	15%
10	3	4	0	0	0	0	0	0	0%
11	3	3	0	2	0	0	0	0	33%
12	8	4	0	7	0	1	1	0	53%
13	25	3	4	0	0	0	1	0	5%
14	11	7	0	3	0	1	0	0	29%
15	2	2	0	0	0	1	0	1	40%
16	7	1	1	0	0	0	0	0	0%
17	5	3	1	0	1	0	0	0	17%
18	7	4	0	2	0	0	0	0	22%
19	9	6	0	0	0	0	0	0	0%
20	9	7	0	1	0	0	0	0	8%
21	7	2	0	1	2	0	0	0	38%
22	7	5	0	2	1	0	0	0	33%
23	8	7	3	7	0	2	2	1	44%
24	9	5	1	1	1	0	1	0	27%
25	3	1	1	0	0	0	1	0	25%
26	11	6	0	0	0	1	0	0	13%
27	3	1	1	1	1	0	0	0	33%
28	19	11	2	1	2	3	2	2	29%
29	19	8	3	1	1	0	0	0	11%
30	6	4	0	0	3	0	2	0	50%

Serial No.	Quantity	Unit Volume	Total Daily HH Consump (L)	Daily per Capita Consump (L)
1	6	Barrels	1248	36.7
2	3	Barrels	624	29.7
3	4	Barrels	832	48.9
4	1	Barrels	208	41.6
5	4	Barrels	832	55.5
6	4	Barrels	832	46.2
7	2	Barrels	416	41.6
8	2	Barrels	416	59.4
9	4	Barrels	832	52.0
10	4	Garawa	194	27.7
11	3	Barrels	624	78.0
12	4	Barrels	832	39.6
13	5	Barrels	1040	31.5
14	10	Barrels	2080	94.5
15	3	Barrels	624	104.0
16	6	Garawa	291	32.3
17	3	Barrels	624	62.4
18	3	Barrels	624	48.0
19	2	Barrels	416	27.7
20	4	Barrels	832	48.9
21	2	Barrels	416	34.7
22	2	Barrels	416	27.7
23	4	Barrels	832	27.7
24	2	Barrels	416	23.1
25	1	Barrels	208	34.7
26	4	Barrels	832	48.9
27	2.5	Barrels	520	74.3
28	2	Barrels	416	9.9
29	4	Barrels	832	26.0
30	1	Barrels	208	13.9

Serial No.	Tong Borehole	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	95	0.1	48.5	95	0.10
2	1	300	0.1	48.5	300	0.10
3	1	240	0.1	48.5	240	0.10
4	1	180	0.1	48.5	180	0.10
5	1	120	0.1	48.5	120	0.10
6	1	240	0.1	48.5	240	0.10
7	1	240	0.1	48.5	240	0.10
8	1	240	0.1	48.5	240	0.10
9	1	240	0.1	48.5	240	0.10
10	1	60	0.1	48.5	60	0.10
11	1	350	0.1	36.75	462	0.13
12	1	240	0.1	48.5	240	0.10
13	1	210	0.1	48.5	210	0.10
14	1	180	0.1	48.5	180	0.10
15	1	240	0.1	208	56	0.02
16	1	300	0.1	48.5	300	0.10
17	1	350	0.1	48.5	350	0.10
18	1	360	0.1	48.5	360	0.10
19	1	360	0.1	48.5	360	0.10
20	1	150	0.1	48.5	150	0.10
21	1	120	0.1	48.5	120	0.10
22	1	90	0.1	48.5	90	0.10
23	1	180	0.1	48.5	180	0.10
24	1	60	0.1	48.5	60	0.10
25	1	35	0.1	48.5	35	0.10
26	1	300	0.1	48.5	300	0.10
27	1	105	0.1	48.5	105	0.10
28	1	45	0.1	48.5	45	0.10
29	1	240	0.1	48.5	240	0.10
30	1	90	0.1	48.5	90	0.10

Serial No.	Nyen Borehole	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	0				NULL	NULL
2	1	300	0.1	48.5	300	0.10
3	1	90	0	61.75	70.68825911	0.00
4	1	210	0.1	48.5	210	0.10
5	1	180	0.1	48.5	180	0.10
6	1	210	0.1	48.5	210	0.10
7	1	150	0.1	48.5	150	0.10
8	1	150	0.1	48.5	150	0.10
9	1	150	0.1	50	145.5	0.10
10	0	NULL	NULL	NULL	NULL	NULL
11	1	180	0.1	48.5	180	0.10
12	1	180	0.1	48.5	180	0.10
13	1	120	0.2	48.5	120	0.20
14	0	NULL	NULL	NULL	NULL	NULL
15	0	NULL	NULL	NULL	NULL	NULL
16	1	120	0	48.5	120	0.00
17	1	120	0.1	48.5	120	0.10
18	1	180	0.1	48.5	180	0.10
19	1	210	0.1	48.5	210	0.10
20	1	210	0.1	48.5	210	0.10
21	1	120	0.5	208	27.98076923	0.12
22	0	NULL	NULL	NULL	NULL	NULL
23	1	240	0	48.5	240	0.00
24	0	NULL	NULL	NULL	NULL	NULL
25	1	45	0.1	48.5	45	0.10
26	1	240	0.2	48.5	240	0.20
27	1	100	0.1	48.5	100	0.10
28	1	180	0.1	48.5	180	0.10
29	1	180	0.1	48.5	180	0.10
30	0	NULL	NULL	NULL	NULL	NULL

Serial No.	Langagu Borehole	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	0	NULL	NULL	NULL	NULL	NULL
2	1	300	0.1	48.5	300	0.10
3	0	NULL	NULL	NULL	NULL	NULL
4	0	NULL	NULL	NULL	NULL	NULL
5	0	NULL	NULL	NULL	NULL	NULL
6	1	210	0.1	48.5	210	0.10
7	0	NULL	NULL	NULL	NULL	NULL
8	0	NULL	NULL	NULL	NULL	NULL
9	0	NULL	NULL	NULL	NULL	NULL
10	0	NULL	NULL	NULL	NULL	NULL
11	0	NULL	NULL	NULL	NULL	NULL
12	0	NULL	NULL	NULL	NULL	NULL
13	0	NULL	NULL	NULL	NULL	NULL
14	0	NULL	NULL	NULL	NULL	NULL
15	1	210	0.1	48.5	210	0.10
16	0	NULL	NULL	NULL	NULL	NULL
17	0	NULL	NULL	NULL	NULL	NULL
18	1	180	0.1	48.5	180	0.10
19	1	270	0.1	48.5	270	0.10
20	1	210	0.1	48.5	210	0.10
21	1	120	0.5	208	27.98076923	0.12
22	0	NULL	NULL	NULL	NULL	NULL
23	1	240	0	48.5	240	0.00
24	0	NULL	NULL	NULL	NULL	NULL
25	0	NULL	NULL	NULL	NULL	NULL
26	0	NULL	NULL	NULL	NULL	NULL
27	0	NULL	NULL	NULL	NULL	NULL
28	1	180	0.1	48.5	180	0.10
29	1	180	0.1	48.5	180	0.10
30	0	NULL	NULL	NULL	NULL	NULL

Serial No.	Dams (walk/ bike)	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	120	0	48.5	120	0.00
2	1	120	0	48.5	120	0.00
3	1	90	0	48.5	90	0.00
4	1	90	0	48.5	90	0.00
5	1	90	0	48.5	90	0.00
6	1	105	0	48.5	105	0.00
7	1	120	0	48.5	120	0.00
8	1	120	0	48.5	120	0.00
9	0	NULL	NULL	NULL	NULL	NULL
10	0	NULL	NULL	NULL	NULL	NULL
11	1	90	0	48.5	90	0.00
12	1	120	0	48.5	120	0.00
13	1	120	0	48.5	120	0.00
14	1	30	0	48.5	30	0.00
15	0	NULL	NULL	NULL	NULL	NULL
16	1	120	0	48.5	120	0.00
17	1	120	0	48.5	120	0.00
18	0	NULL	NULL	NULL	NULL	NULL
19	1	120	0	48.5	120	0.00
20	0	NULL	NULL	NULL	NULL	NULL
21	0	NULL	NULL	NULL	NULL	NULL
22	1	45	0	48.5	45	0.00
23	1	120	0	48.5	120	0.00
24	1	60	0	48.5	60	0.00
25	1	15	0	50	14.55	0.00
26	1	110	0	48.5	110	0.00
27	1	60	0	48.5	60	0.00
28	1	60	0	48.5	60	0.00
29	0	NULL	NULL	NULL	NULL	NULL
30	1	60	0	48.5	60	0.00

Serial No.	Dams (motor, hire)	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	120	3	208	27.98076923	0.70
2	1	45	3	208	10.49278846	0.70
3	1	30	4	75	19.4	2.59
4	0	NULL	NULL	NULL	NULL	NULL
5	0	NULL	NULL	NULL	NULL	NULL
6	0	NULL	NULL	NULL	NULL	NULL
7	0	NULL	NULL	NULL	NULL	NULL
8	1	120	3	208	27.98076923	0.70
9	1	180	4	208	41.97115385	0.93
10	1	20	2.5	50	19.4	2.43
11	0	NULL	NULL	NULL	NULL	NULL
12	1	150	3	208	34.97596154	0.70
13	0	NULL	NULL	NULL	NULL	NULL
14	1	30	3	208	6.995192308	0.70
15	1	165	3	208	38.47355769	0.70
16	0	NULL	NULL	NULL	NULL	NULL
17	1	60	3	208	13.99038462	0.70
18	1	120	3	208	27.98076923	0.70
19	0	NULL	NULL	NULL	NULL	NULL
20	1	105	3	208	24.48317308	0.70
21	1	60	0	208	13.99038462	0.00
22	0	NULL	NULL	NULL	NULL	NULL
23	0	NULL	NULL	NULL	NULL	NULL
24	0	NULL	NULL	NULL	NULL	NULL
25	0	NULL	NULL	NULL	NULL	NULL
26	0	NULL	NULL	NULL	NULL	NULL
27	0	NULL	NULL	NULL	NULL	NULL
28	1	60	3	208	13.99038462	0.70
29	1	120	3	208	27.98076923	0.70
30	0	NULL	NULL	NULL	NULL	NULL

Serial No.	Karaga Rd. Well	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	90	0	48.5	90	0.00
2	1	90	0	48.5	90	0.00
3	1	90	0	75	58.2	0.00
4	1	120	0	48.5	120	0.00
5	1	120	0	48.5	120	0.00
6	1	120	0	48.5	120	0.00
7	1	120	0	48.5	120	0.00
8	1	120	0	48.5	120	0.00
9	1	50	0	48.5	50	0.00
10	0	NULL	NULL	NULL	NULL	NULL
11	1	120	0	48.5	120	0.00
12	0	NULL	NULL	NULL	NULL	NULL
13	1	120	0	48.5	120	0.00
14	1	40	0	48.5	40	0.00
15	0	NULL	NULL	NULL	NULL	NULL
16	0	NULL	NULL	NULL	NULL	NULL
17	0	NULL	NULL	NULL	NULL	NULL
18	0	NULL	NULL	NULL	NULL	NULL
19	0	NULL	NULL	NULL	NULL	NULL
20	0	NULL	NULL	NULL	NULL	NULL
21	0	NULL	NULL	NULL	NULL	NULL
22	0	NULL	NULL	NULL	NULL	NULL
23	0	NULL	NULL	NULL	NULL	NULL
24	0	NULL	NULL	NULL	NULL	NULL
25	0	NULL	NULL	NULL	NULL	NULL
26	0	NULL	NULL	NULL	NULL	NULL
27	0	NULL	NULL	NULL	NULL	NULL
28	0	NULL	NULL	NULL	NULL	NULL
29	1	60	0	48.5	60	0.00
30	1	30	0	48.5	30	0.00

Serial No.	Natural Well	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	120	0	48.5	120	0.00
2	1	150	0	48.5	150	0.00
3	1	90	0	48.5	90	0.00
4	1	90	0	48.5	90	0.00
5	1	60	0	48.5	60	0.00
6	1	150	0	48.5	150	0.00
7	1	90	0	48.5	90	0.00
8	1	30	0	48.5	30	0.00
9	1	45	0	48.5	45	0.00
10	1	30	4	50	29.1	3.88
11	1	90	0	48.5	90	0.00
12	1	90	0	48.5	90	0.00
13	1	90	0	48.5	90	0.00
14	1	60	0	48.5	60	0.00
15	1	120	0	48.5	120	0.00
16	1	45	0	48.5	45	0.00
17	1	120	0	48.5	120	0.00
18	1	105	0	48.5	105	0.00
19	0	NULL	NULL	NULL	NULL	NULL
20	1	60	0	48.5	60	0.00
21	1	60	0	128.25	22.69005848	0.00
22	0	NULL	NULL	NULL	NULL	NULL
23	1	40	0	48.5	40	0.00
24	1	40	0	48.5	40	0.00
25	1	7	0	48.5	7	0.00
26	1	120	0	48.5	120	0.00
27	1	50	0	48.5	50	0.00
28	1	45	0	48.5	45	0.00
29	0	NULL	NULL	NULL	NULL	NULL
30	1	45	0	48.5	45	0.00

Serial No.	Other Wells	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	0	NULL	NULL	NULL	NULL	NULL
2	1	5	0	48.5	5	0.00
3	0	NULL	NULL	NULL	NULL	NULL
4	0	NULL	NULL	NULL	NULL	NULL
5	1	3	0	48.5	3	0.00
6	0	NULL	NULL	NULL	NULL	NULL
7	0	NULL	NULL	NULL	NULL	NULL
8	0	NULL	NULL	NULL	NULL	NULL
9	1	1	0	48.5	1	0.00
10	0	NULL	NULL	NULL	NULL	NULL
11	0	NULL	NULL	NULL	NULL	NULL
12	0	NULL	NULL	NULL	NULL	NULL
13	0				NULL	NULL
14	1	5	0	48.5	5	0.00
15	0	NULL	NULL	NULL	NULL	NULL
16	0	NULL	NULL	NULL	NULL	NULL
17	0	NULL	NULL	NULL	NULL	NULL
18	1	1	0	48.5	1	0.00
19	1	10	0	48.5	10	0.00
20	0	NULL	NULL	NULL	NULL	NULL
21	1	3	0	48.5	3	0.00
22	0	NULL	NULL	NULL	NULL	NULL
23	0	NULL	NULL	NULL	NULL	NULL
24	0	NULL	NULL	NULL	NULL	NULL
25	0	NULL	NULL	NULL	NULL	NULL
26	0	NULL	NULL	NULL	NULL	NULL
27	0	NULL	NULL	NULL	NULL	NULL
28	0	NULL	NULL	NULL	NULL	NULL
29	1	0.5	0	48.5	0.5	0.00
30	0	NULL	NULL	NULL	NULL	NULL

Serial No.	Pure Water	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
1	1	1	2	7.5	6.466666667	12.93
2	1	3	0.25	0.75	194	16.17
3	1	1	0.25	0.75	64.66666667	16.17
4	1	3.5	1	3	56.58333333	16.17
5	1	15	0.2	0.5	1455	19.40
6	1	15	0.75	2.25	323.3333333	16.17
7	0	NULL	NULL	NULL	NULL	NULL
8	1	5	0.3	1	242.5	14.55
9	1	2	4	15	6.466666667	12.93
10	1	2	0.3	1	97	14.55
11	1	3	0.3	1	145.5	14.55
12	1	2	0.25	0.75	129.3333333	16.17
13	1	5	0.2	0.5	485	19.40
14	1	10	0.2	0.5	970	19.40
15	1	5	1.5	5	48.5	14.55
16	0	NULL	NULL	NULL	NULL	NULL
17	1	2	0.25	0.75	129.3333333	16.17
18	1	1	0.35	1	48.5	16.98
19	0	NULL	NULL	NULL	NULL	NULL
20	1	1	2	6	8.083333333	16.17
21	0	NULL	NULL	NULL	NULL	NULL
22	0	NULL	NULL	NULL	NULL	NULL
23	1	0.5	8	30	0.808333333	12.93
24	1	0.5	1	3	8.083333333	16.17
25	1	10	0.2	0.5	970	19.40
26	1	2	0.2	0.5	194	19.40
27	1	0.02	0.2	0.5	1.94	19.40
28	1	15	0.25	0.75	970	16.17
29	0	NULL	NULL	NULL	NULL	NULL
30	1	15	0.25	0.75	970	16.17

Serial No.	Karaga Municipal	Time (min)	Cost (GHS)	Volume Collected	(min/ Garawa)	(GHS/ Garawa)
-------------------	-------------------------	-------------------	-------------------	-------------------------	----------------------	----------------------

1	0	NULL	NULL	NULL	NULL	NULL
2	0	NULL	NULL	NULL	NULL	NULL
3	0	NULL	NULL	NULL	NULL	NULL
4	0	NULL	NULL	NULL	NULL	NULL
5	0	NULL	NULL	NULL	NULL	NULL
6	0	NULL	NULL	NULL	NULL	NULL
7	0	NULL	NULL	NULL	NULL	NULL
8	0	NULL	NULL	NULL	NULL	NULL
9	0	NULL	NULL	NULL	NULL	NULL
10	1	90	4.05	50	87.3	3.93
11	0	NULL	NULL	NULL	NULL	NULL
12	0	NULL	NULL	NULL	NULL	NULL
13	0	NULL	NULL	NULL	NULL	NULL
14	0	NULL	NULL	NULL	NULL	NULL
15	0	NULL	NULL	NULL	NULL	NULL
16	0	NULL	NULL	NULL	NULL	NULL
17	1	150	5	208	34.97596154	1.17
18	0	NULL	NULL	NULL	NULL	NULL
19	0	NULL	NULL	NULL	NULL	NULL
20	0	NULL	NULL	NULL	NULL	NULL
21	0	NULL	NULL	NULL	NULL	NULL
22	0	NULL	NULL	NULL	NULL	NULL
23	0	NULL	NULL	NULL	NULL	NULL
24	0	NULL	NULL	NULL	NULL	NULL
25	0	NULL	NULL	NULL	NULL	NULL
26	0	NULL	NULL	NULL	NULL	NULL
27	0	NULL	NULL	NULL	NULL	NULL
28	0	NULL	NULL	NULL	NULL	NULL
29	0	NULL	NULL	NULL	NULL	NULL
30	0	NULL	NULL	NULL	NULL	NULL

Serial No.	Alum	Uses	Sources
1	1	All	Dam
2	1	All	Dam
3	1	All	Dam
4	1	All	Dam
5	1	All	Dam
6	1	All	Dam
7	1	All	Dam
8	1	All	Dam
9	1	All but constr.	All but pure water
10	1	All	Dam
11	1	All	Dam
12	1	All	Dam
13	1	All but constr., shea	All
14	1	All	Dam
15	1	All	Dam
16	0	NULL	NULL
17	1	All	Dam
18	1	All	Dam
19	1	All	Dam
20	1	All	Dam
21	1	All	Dam
22	1	All	Dam
23	1	All	Dam
24	1	All	Dam
25	1	All	Dam
26	1	All	Dam
27	1	All	Dam
28	0	NULL	NULL
29	1	All	Dam and well
30	1	Laundry and dishes	Dam

Serial No.	P&G	Uses	Sources
1	1	All	Dam
2	1	All	Dam
3	1	All	Dam
4	1	All	Dam
5	1	All	Dam
6	1	All	Dam
7	1	All	Dam
8	1	All	Dam
9	1	All but constr.	All but pure water
10	1	All	Dam
11	1	All	Dam
12	1	All	Dam
13	1	All but constr., shea	All
14	1	All	Dam
15	1	All	Dam
16	1	All	Dam
17	1	All	Dam
18	1	All	Dam
19	1	All	Dam
20	1	All	Dam
21	1	All	Dam
22	1	All	Dam
23	0	NULL	NULL
24	1	All	Dam
25	1	All	Dam
26	1	All	Dam
27	1	All	Dam
28	1	Drink and cook	Non-borehole
29	1	All	Dam and well
30	1	Laundry and dishes	Dam

Serial No.	Water Treatment 3	Uses	Sources
1	NULL	NULL	NULL
2	NULL	NULL	NULL
3	NULL	NULL	NULL
4	NULL	NULL	NULL
5	NULL	NULL	NULL
6	Guinea Worm Filter	All	Dam
7	NULL	NULL	NULL
8	NULL	NULL	NULL
9	NULL	NULL	NULL
10	NULL	NULL	NULL
11	NULL	NULL	NULL
12	NULL	NULL	NULL
13	NULL	NULL	NULL
14	NULL	NULL	NULL
15	NULL	NULL	NULL
16	NULL	NULL	NULL
17	NULL	NULL	NULL
18	NULL	NULL	NULL
19	NULL	NULL	NULL
20	NULL	NULL	NULL
21	NULL	NULL	NULL
22	NULL	NULL	NULL
23	NULL	NULL	NULL
24	NULL	NULL	NULL
25	NULL	NULL	NULL
26	NULL	NULL	NULL
27	NULL	NULL	NULL
28	JICA filter	Drink and cook	Non-borehole
29	NULL	NULL	NULL
30	NULL	NULL	NULL

Serial No.	People Do Ablution	Kettles per Ablution	Liters per Ablution	Ablutions per Day	% of Household Doing Ablution
1	34	0.5	0.7	3	100%
2	6	0.5	0.7	4	29%
3	11	0.4	0.6	5	65%
4	2	0.5	0.7	4	40%
5	12	1.0	1.4	3	80%
6	12	0.5	0.7	4	67%
7	5	0.5	0.7	4	50%
8	7	1.0	1.4	5	100%
9	13	1.0	1.4	4	81%
10	5	1.0	1.4	4	71%
11	5	0.5	0.7	5	63%
12	4	0.5	0.7	5	19%
13	15	2.8	4.0	5	45%
14	11	0.6	0.8	5	50%
15	7	0.5	0.7	4	117%
16	6	0.5	0.7	5	67%
17	7	1.0	1.4	5	70%
18	8	1.0	1.4	5	62%
19	9	0.5	0.7	5	60%
20	9	0.5	0.7	5	53%
21	6	0.5	0.7	5	50%
22	7	0.5	0.7	5	47%
23	27	0.5	0.7	4	90%
24	7	0.5	0.7	4	39%
25	1	0.5	0.7	4	17%
26	8	0.5	0.7	5	47%
27	7	1.0	1.4	5	100%
28	42	1.0	1.4	5	100%
29					
30					

Serial No.	Ablution Water Consump per Day per Abl Performer (L)	Household Daily Ablution Consumption (L)	% of Total HH Consumption (Gray Water Reuse Potential)
1	2.11	71.6	6%
2	2.81	16.8	3%
3	2.92	32.2	4%
4	2.81	5.6	3%
5	4.21	50.5	6%
6	2.81	33.7	4%
7	2.81	14.0	3%
8	7.02	49.1	12%
9	5.61	73.0	9%
10	5.61	28.1	14%
11	3.51	17.5	3%
12	3.51	14.0	1.7%
13	19.86	297.9	29%
14	4.21	46.3	2%
15	2.81	19.7	3%
16	3.51	21.1	7%
17	7.02	49.1	8%
18	7.02	56.1	9%
19	3.51	31.6	8%
20	3.51	31.6	4%
21	3.51	21.1	5%
22	3.51	24.6	6%
23	2.81	75.8	9%
24	2.81	19.7	5%
25	2.81	2.8	1.3%
26	3.51	28.1	3%
27	7.02	49.1	9%
28	7.02	294.8	71%
29			
30			

D Opinion Leader Interview Notes

Adrienne Masterton
February 28, 2017
Interview Notes – Nurse

1. Clean – free from foreign mat'ls, see that it's clear, not smelling, opt for borehole, b/c more clean
2. Dam water – trees, bldgs, animals; well water – not as tasty/satisfying as → dam water ; dam water – Rashid not drink, some do; borehole – drink, laundry, dishes, bathing; well – animals, construction, trees
3. Courtyard ablution; squat on ground; willing to change; *by religion: strict rules* – clean area, away toilet/urinal unless clean, tiled, private, (not public use) urinal; after fart, look at certain things
4. 2 pure waters (1L); 5x a time + *bath should be diff than ablution*; 2 @ CHPS; same; same; *ideally should also use 1L*; borehole
5. Dries up or flows away ↔ throw it
6. Yes; aquatabs when available, use on all uses; well water only
7. Watering trees; animals; washing clothes; not drink, bathe
8. Boiling [check mark], moringa [X], clay filter [check mark]; other filters – cloth, straw ones
9. Boil – not drink; yes – bath, dishes, laundry, trees, etc.; *not ablution*; Filter – trees, animals, constr. Only
10. Yes, would be willing; *when carry out test& prove its clean he will use it*
11. Affordable; 80¢ Africlay – yes; different for community memb; *doubt can use for ablution again even if tested, from religious perspective*

Adrienne Masterton
March 3, 2017
Interview Notes – Alhaji

1.
Look at color of water, if color changes it's not good, Tong dam – clean; Gbutugu dam – b/c color is like color of sand → not good.
Borehole – depends on geologist; like one by Gbutugu dam not good
Dam water; good vs. clean water; Tong ppl has own ways vs. geologists but respect geologists opinions & not use
2.
Dam water – preserve kola nut, bldg, dishes
Borehole water – drinking, cooking
Ablution – prefer borehole but water crisis you use what you can get
3.
Where they perform – no particular place, just where you are at time of prayers
How – face sunrise
Rules – when start, no talking until finish abl
4.
How much – can't tell, some use whole kettle, some two people will use; some very dirty to start; no rule about how much to use but don't be lazy & use just some small amount left; start – wash hands 3x, mouth 3x, nostrils 3x, face 3x, right arm to elbow 3x, left same; head to ears once; right leg up to ankle + sandals until look clean; then same on left
5.
No sys. to collect dirty water → just pour it in the ground. Only when bldg they'll mix it w/ sand to build
6.
Alum so that dirt goes to bottom & pour clean off the top & toss dirty water away. & P&G Purify
→ [Alum] hold in water & stir but too much it tastes weird & maybe even diarrhea
Not all, dam, natural well; anything other than borehole & rain they use alum; all houses; when fetch & water reaches certain stage in year (Tong dam not reach) then just always treat it at that point (after rains)
7.
Would do, but only for washing clothes, building; not drink or abl or cook.
8.
Boil (Check mark) Moringa (Check mark) filter (X) P&G (Check mark)
9.
They will use as in 7
10.
They would drink

11.

No money; so maybe can boil or moringa but how collect? No \$ for that; maybe bath area drain can dig & place garawa. But no \$.

Comm. Vs. indiv (if cost = 0\$):

Like in btwn

One at each house best if \$ there

But not if select certain houses.

One at each mosque good too

E Prototype Testing User Survey Notes

Adrienne Masterton

Prototype Testing/ Water Sample Collection Notes

*Alum used on water prior to use for ablution; this was previously unknown but I proceeded as people said that they typically use the alum on all dam water unless used at the dam, consistent with surveys

1PM – 14 people, ~ 5L → 0.36L / person / ablution

1. Comfortable, & no wasting water
2. Yes, good at sitting places rather than at house; house for women
3. Would not pay; then gave specific amounts – 10 cedis yes; 50 cedi or more not pay
4. Yes, they could find strategy
5. Make pavilion clean bigger for many people so overall take less time

3PM – 12 people, ~4.2L → 0.35L / person / prayer

6PM – 19 people, ~6.5L → 2.92L / person / prayer

Other notes:

Filter – takes FOREVER but passerbys impressed

P&G – did as locals already do as opposed to directions

Directions: 1 pack to 10L, 5 min stir; 5 min sit; pour through cloth; sit 20 m

Typical reality: pour into whatever amount “eyeball it,” stir, sit; take off top (maybe)

I let it sit 30 mins for consistency w/ moringa & Trial 1 & 2 pre Tx

Yellow means CI left over

Sample settled more after collectn

Moringa – 5 seeds / ~1.25L

Roughly 1 min shake; pour in & stir 1-2 mins fast; stir 3-5 mins slow visual & settle 30 mins then pour → settled more in bottle for sample.

F Water Quality Testing Laboratory Results

COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
WATER RESEARCH INSTITUTE
WATER QUALITY LABORATORY TAMALE

Analysis Results

Water Research Institute, ECSED Water Quality Laboratory

Vitting (Off Tamale Yendi Road)

Box TL 695

Tamale, Ghana

Phone: (+233-3720) 23449 Fax: (+233-3720) 23449 E-mail: csirwritam@yahoo.com

Client: Adrienne Masterton

Sample ID: Gbutugu Dam, Karaga Dist.

Receipt date: 13/02/2017

Analysis start date: 14/02/2017

Analysis stop date: 22/02/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Odour	-	-	Odourless	Inoffensive
Conductivity	1	$\mu\text{S}/\text{cm}$	184	-
Turbidity	3	NTU	2390	5
pH	4	pH Units	7.50	6.5 - 8.5
Tot. Susp. Solids (TSS)	5	mg/l	-	-
Tot. Dis. Solids (TDS)	6	mg/l	122	1000
Ammonia ($\text{NH}_4\text{-N}$)	13	mg/l	1.380	0.00 - 1.5
Nitrate ($\text{NO}_3\text{-N}$)	14	mg/l	9.873	10
Nitrite ($\text{NO}_2\text{-N}$)	15	mg/l	0.122	1.0
Phosphate ($\text{PO}_4\text{-P}$)	16	mg/l	0.028	-
Silica Oxide (SiO_2)	18	Mg/l	18.43	-
Sulphate (SO_4)	19	mg/l	30.99	250
Fluoride	20	mg/l	0.021	1.5
Total Alkalinity (CaCO_3)	22	mg/l	66.0	-
Calcium	23	mg/l	15.23	200
Chloride	24	mg/l	18.86	250
Total Hardness (CaCO_3)	25	mg/l	78.0	500
Magnesium	26	mg/l	9.70	150
Potassium	29	mg/l	8.2	30
Sodium	30	mg/l	17.6	200
Bicarbonate (CaCO_3)	39	mg/l	80.52	-
Carbonate	39	mg/l	0.0	-
Calcium Hardness (CaCO_3)	46	mg/l	38.1	-
Mag. Hardness (CaCO_3)	47	mg/l	39.9	-
Residual Chlorine	48	mg/l	Nil	-
Manganese	31	mg/l	1.031	0.4
Total Iron	31	mg/l	19.551	0.3

Remarks: The results of the parameters analyzed were within WHO and Ghana Standards Value recommended guidelines for drinking water except turbidity, manganese and total iron.

Gerard Quarcoo
(Office Laboratory Services)

CSIR-WATER RESEARCH INST
WATER QUALITY LABORATORY
EC/EEH DIVISION
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TAMALE

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COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
WATER RESEARCH INSTITUTE
WATER QUALITY LABORATORY TAMALE

ANALYTICAL REPORT

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Tamale, Ghana

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E-mail: csirwritam@yahoo.com

Client: Peace Corps/MTU

Date of arrival: 13:02:2017

Start of analysis: 13:02:2017

End of analysis: 15:02:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Borehole	2.4×10^5	0	0	166
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total coliform counts per 100 ml of the water sample analyzed.

Gérard Quarcoo
(Research Scientist, Microbiology)

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WATER QUALITY LABORATORY
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COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
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ANALYTICAL RESULTS

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E-mail: csirwritam@yahoo.com

Client: Peace Corps / MTU

Date of arrival: 28:02:2017

Start of analysis: 28:02:2017

End of analysis: 02:03:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post Filter Treatment 1	6.5×10^7	2.8×10^7	0	860
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
(Research Scientist, Microbiology)

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ANALYTICAL RESULTS

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E-mail: csirwritam@yahoo.com

Client: Peace Corps / MTU

Date of arrival: 28:02:2017

Start of analysis: 28:02:2017

End of analysis: 02:03:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post Filter Treatment 2	9.4×10^7	$8,2 \times 10^7$	3.4×10^7	976
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
(Research Scientist, Microbiology)

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Client: Peace Corps / MTU

Date of arrival: 28:02:2017

Start of analysis: 28:02:2017

End of analysis: 02:03:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post Filter Treatment 3	5.6×10^7	1.8×10^7	1.8×10^7	954
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic Bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
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WATER QUALITY LABORATORY TAMALE

ANALYTICAL RESULTS

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E-mail: csirwritam@yahoo.com

Client: Peace Corps / MTU

Date of arrival: 28:02:2017

Start of analysis: 28:02:2017

End of analysis: 02:03:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	<i>Enterococci</i> (cfu/100ml) Method: APHA 9213D	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post Moringa Treatment 1	1.03×10^8	0	0	0	1,149
Ghana Standards	0	0	0	0	500
WHO Guidelines	0	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

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COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH
WATER RESEARCH INSTITUTE
WATER QUALITY LABORATORY TAMALE

ANALYTICAL RESULTS

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E-mail: csirwritam@yahoo.com

Client: Peace Corps / MTU

Date of arrival: 28:02:2017

Start of analysis: 28:02:2017

End of analysis: 02:03:2017

Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	E.coli (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post Moringa Treatment 2	9.4×10^8	1.12×10^8	0	969
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
(Research Scientist, Microbiology)

15th FEB 2017
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Post Moringa Treatment 3	9.4×10^7	8.4×10^7	2.1×10^7	1,005
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

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Post P & G Purify Treatment 1	7.5×10^7	6.5×10^7	3.3×10^7	885
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

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Post P & G Purify Treatment 2	7.4×10^7	5.6×10^7	2.1×10^7	1,164
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
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Sample Id.	Total Coliform (cfu/100ml) Method: APHA 9222A	Faecal Coliform (cfu/100ml) Method: APHA9222D	<i>E.coli</i> (cfu/100ml) Method: APHA 9260F	Total Heterotrophic Bacteria (cfu/1ml) Method: APHA 9215B
Post P & G Purify Treatment 3	9.4 x 10 ⁷	0	0	852
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

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Pre Treatment 1	6.72×10^7	3.0×10^7	1×10^7	1,020
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

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Pre Treatment 2	9.4×10^7	8.2×10^7	3.4×10^7	976
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerard Quarcoo
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E-mail: csirwritam@yahoo.com

Client: Peace Corps / MTU

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Start of analysis: 28:02:2017

End of analysis: 02:03:2017

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Pre Treatment 3	5.6×10^7	1.8×10^7	1.8×10^7	954
Ghana Standards	0	0	0	500
WHO Guidelines	0	0	0	500

REMARKS: The water sample is bacteriologically unsafe to be used as drinking water source. It does not conform to WHO Guidelines and Ghana Standard of zero total and faecal coliform count per 100 ml and ≤ 500 total heterotrophic bacteria count per 1 ml of the water sample analyzed.

Gerald Quarcoo
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Client: Peace Corps/MTU

Sample ID: Post Filter Treatment 1

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.033	0.4
Total Iron	31	mg/l	0.679	0.3

Remarks: The results of the parameters analyzed were within WHO and Ghana Standards Value recommended guidelines for drinking water except total iron.

Gerard Quarcoo
(Officer, Laboratory Services)

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Client: Peace Corps/MTU

Sample ID: Post Filter Treatment 2

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.021	0.4
Total Iron	31	mg/l	0.287	0.3

Remarks: The results of the parameters analyzed were within WHO and Ghana Standards Value recommended guidelines for drinking water.

Gerard Quarcoo
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Client: Peace Corps/MTU

Sample ID: Post Filter Treatment 3

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.023	0.4
Total Iron	31	mg/l	0.115	0.3

Remarks: The results of the parameters analyzed were within WHO and Ghana Standards Value recommended guidelines for drinking water.

Gerard Quarcoo
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Client: Peace Corps/MTU

Sample ID: Post Moringa Treatment 1

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.527	0.4
Total Iron	31	mg/l	2.073	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

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Client: Peace Corps/MTU

Sample ID: Post Moringa Treatment 2

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.572	0.4
Total Iron	31	mg/l	4.705	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

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Sample ID: Post Moringa Treatment 3

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.543	0.4
Total Iron	31	mg/l	2.277	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

Gerard Quarcoo
(Officer, Laboratory Services)

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Client: Peace Corps/MTU

Sample ID: Post P & G Purify Treatment 1

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.898	0.4
Total Iron	31	mg/l	86.126	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

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Client: Peace Corps/MTU

Sample ID: Post P & G Purify Treatment 2

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.802	0.4
Total Iron	31	mg/l	36.452	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

Gerard Quarcoo
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Sample ID: Post P & G Purify Treatment 3

Receipt date: 28/02/2017

Analysis start date: 28/02/2017

Analysis stop date: 01/03/2017

Parameter	Method No.	Unit	Value	WHO Guideline
Manganese	31	mg/l	0.746	0.4
Total Iron	31	mg/l	47.716	0.3

Remarks: The results of the parameters analyzed exceeded WHO and Ghana Standards Value recommended guidelines for drinking water.

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