Assessment of Rainwater Harvesting In Northern Ghana

by

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ABSTRACT

This study assesses the current state of rainwater harvesting in the Northern Region of Ghana and makes recommendations regarding if and how rainwater harvesting could be used to address Pure Home Water's goal of reaching 1 million people in the next five years with safe drinking water.

Three principal aspects of the water supply are considered: quality, quantity, and cost. Bacteriological water quality is tested to determine the level of risk. Rainwater supplies ranged from low (1 to 10 *E.coli* CFU/100ml) to intermediate risk (10 to 99 *E.coli* CFU/100ml.) Time-based reliability is simulated using a simulation model in Microsoft Excel. Reliability ranges from five percent to ninety-nine percent. Unit cost per cubic meter is calculated for surveyed rainwater harvesting systems in Northern Ghana. The unit cost of water from these designs ranged between approximately $\$1/m^3$ and $\$10/m^3$.

Storage-reliability-yield relationship is developed and graphed for the Northern Region. This curve is useful for properly sizing rainwater harvesting systems. The use of a filter to post-treat rainwater before consumption is recommended, both for use with the rainwater, but also for provision of safe water when the users rely on a supplementary unimproved source, usually a dugout or dug well, for water supply.

The feasibility of low-cost underground storage should be investigated. The geology and soil conditions in the Tamale region might provide a suitable match for a cheaper storage mechanism using plastic tarps and constructed pits. If the cost of storage could be lowered, rainwater harvesting could contribute in a larger way to Pure Home Water's mission and reach more people.

Do-it-yourself rainwater harvesting in the Northern Region of Ghana is a fairly widespread. Finding ways to improve the quantity and quality of informal harvesting is a potential means for improving water supply for many low income households in the Northern Region.

Currently, rainwater harvesting presents an opportunity to extend water supply to rural dwellers where few other alternatives are available.

Thesis Supervisor: Susan Murcott
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Abbreviations

COUHES	MIT Committee on Use of Humans as Experimental Subjects
EAC	Equivalent Annual Cost
GPS	Global Positioning System
HWTS	Household Water Treatment and Safe Storage
MDG	Millennium Development Goals
MIT	Massachusetts Institute of Technology
NGO	Non-Government Organization
NTU	Nephelometric Turbidity Unit
PHW	Pure Home Water
RWH	Rainwater Harvesting
SRY	Storage-Reliability-Yield
UNICEF	United Nations Children’s Fund
WHO	World Health Organization

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Chapter 1: Clean Water Supply in Developing Countries:[1]

1.1 Introduction

Access to safe drinking water is critical to maintaining good health. The World Health Organization (WHO) and United Nation's Children's Fund (UNICEF) Joint Monitoring Programme for Water Supply and Sanitation estimate that 1.5 million children will die of diarrheal disease this year resulting from the lack of access to sanitation (JMP, 2008). The water borne disease rate is likely much higher than this figure if other illnesses due to pathogenic micro-organisms such as guinea worm, cholera, typhoid and schistosomiasis are considered. Additionally, access to safe water and sanitation is fundamental to gender equity with 71% of household water collected by women or girls (JMP, 2008). Figure 1 shows percentage of population, by country, with access to safe water.

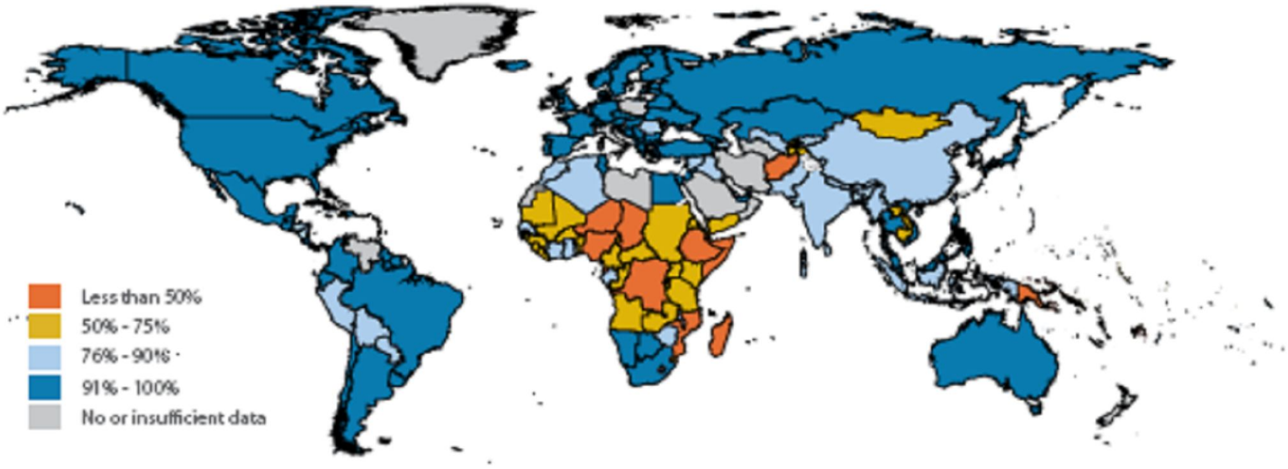

Figure 1: Global Drinking Water Coverage 2006 (Source: WHO-UNICF JMP, 2008)

In a move to eradicate poverty the United Nations set eight Millennium Development Goals (MDG) to meet the needs of the world's poorest by 2015 (UN, 2008a). Under Goal 7 Environmental Sustainability, Target 3 has been set to "Halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation" (UN, 2008a). Since the implementation of the MDGs it is estimated 1.6 billion people have gained access to safe water (UN, 2008b), however, it is estimated that 784 million people worldwide need to gain access to safe drinking water (JMP, 2008). Information to date indicates that Sub-Saharan Africa is making the slowest progress towards meeting the MDG target, making up one third of the population still needing safe drinking water (JMP, 2008).

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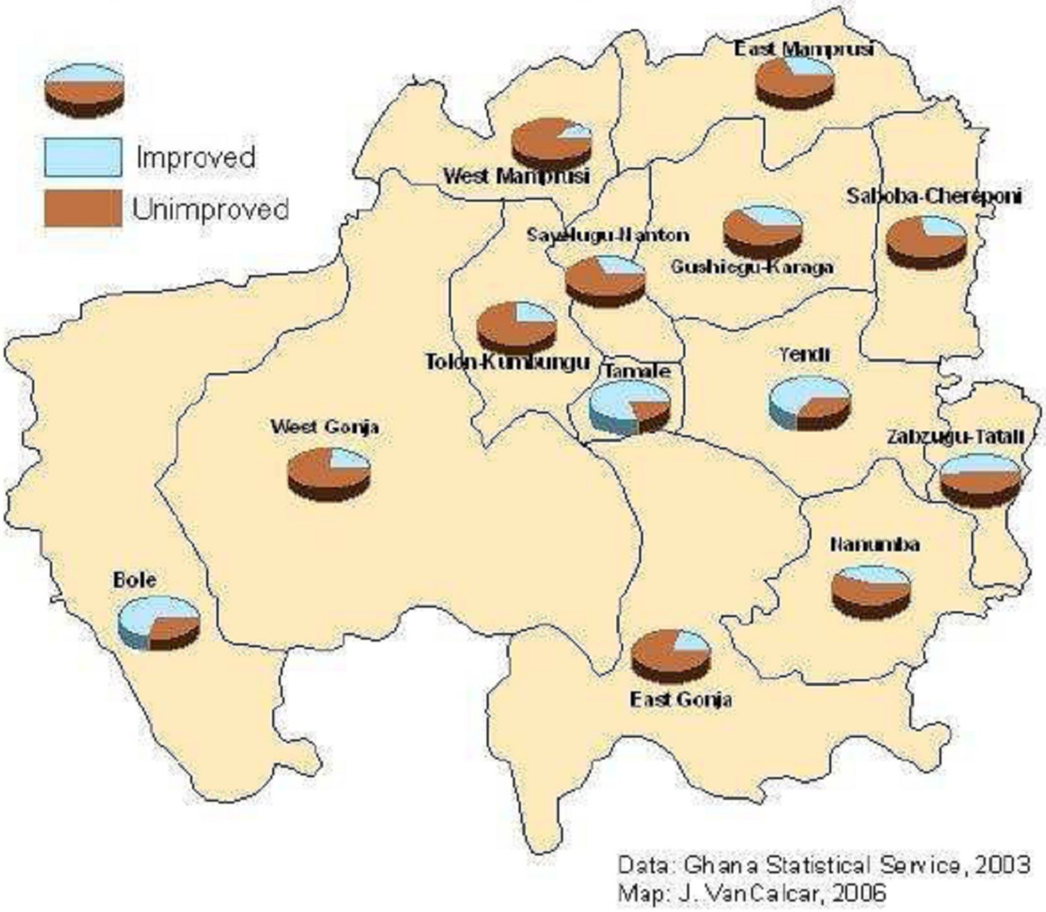
[1] This chapter is the result of a collaboration between fellow Master of Engineering. students Clair Collin, Sara Ziff, Derek Brine and David Barnes

1.2 Ghana Country Profile

Ghana is a West African country bordered to the north by Burkina Faso, to the west by Côte d'Ivoire, and to the east by Togo. It has a population of 23 million people. The climate in the Northern Region is dry and hot while the climate in the South is more humid. Agriculture accounts for 37.3% of total GDP and 56% of the labor force is employed therein. Ghana is rich in natural resources and its industries include mining and lumbering. (CIA, 2008) The life expectancy in Ghana is 59 years and 60 years for men and women, respectively. (Ansah, 2006)

Ghana currently suffers from shortages in clean drinking water, particularly in the Northern Region, where fifty percent use unimproved sources of drinking water. This figure is ten percent higher than the average for the African continent where forty percent lack access to an improved drinking water supply. (Murcott et al., 2008) As a result, incidence of water-borne disease is high. Water-borne diseases include diarrhea, hepatitis A, typhoid and guinea worm. While guinea worm has been eradicated in most all places in the world, Ghana still experienced 69 cases to November 12 in 2008 (CDC, 2008), the second highest rate in the world, after Sudan.



Data: Ghana Statistical Service, 2003
Map: J. VanCalcar, 2006

Figure 2: Map of Improved/Unimproved Water Supply, Northern Region, Ghana (Source: VanCalcar, 2006)

Waterborne diseases are spread through contaminated drinking water supplies. In the Northern Region, 56% of people use unimproved water sources (unprotected well/spring, river/canal) for drinking water supply, (VanCalcar, 2006) an example of which is shown in Figure 3.

Figure 3: Unprotected dugout: Pong-Tamale, Northern Region, Ghana (Photo Courtesy of Shanti Klieman) This is an alternate source for the Boys Correctional School when rainwater or other improved supplies are unavailable

This problem is exacerbated by a lack of improved sanitation, again particularly in the Northern Region where 92% lack access. (VanCalcar, 2006) Diarrhea, which can result in severe dehydration, is a major contributor to morbidity and mortality of children under the age of five. Incidence of diarrhea in the Northern Sector of Ghana ranges between 15% and 27% in this age group. (Ansah, 2006) During January 2009, a team of five MIT graduate Civil and Environmental Engineering, Technology and Policy, and Urban Studies and Planning students undertook thesis and related research in support of the activities of Pure Home Water (PHW.) The goal of each of our respective safe water projects was to address this pressing issue to assist in bringing clean drinking water on a household and community scale to Northern Ghana.

1.3 Pure Home Water

Pure Home Water (PHW) is a social enterprise founded in 2005 by Susan Murcott and local partners in Ghana. PHW is the first organization of its kind seeking to disseminate and scale up household drinking water treatment and safe storage in the challenging environment of Northern Ghana, a region with high poverty rates, low population density, multiple tribes and local languages, strong religious identities – Christian, Muslim, Animist – water scarcity, and limited infrastructure. As a social enterprise, Pure Home Water operates on a for-profit basis with retained earnings being fully reinvested into its work in the form of product improvements, outreach and training and capacity building.

1.4 Pure Home Water Organizational History

After garnering start-up funds from the Conrad N. Hilton foundation in 2005, Pure Home Water (PHW) began selling a range of household water treatment and safe storage products in the Northern regions of Ghana including candle filters, safe storage containers with taps and ceramic pot filters. In its first years, PHW struggled with adequate local management, and a general lack of knowledge about and therefore demand for household water and safe storage products (HWTS). During this time PHW decided to concentrate on promoting and distributing one HWTS product in order to gain the demand necessary to succeed. Accordingly the product line was narrowed to the Potters for Peace-type ceramic pot filter, which is locally branded as the *Kosim*[2] filter. Subsequently from 2006-2008, PHW focused solely on demand generation and sale of the *Kosim* filter.

PHW has faced many challenges and has taken some important steps to establish its organization, management and presence in the Northern Sector of Ghana. In 2007, PHW hired a managing director, a field manager and several new sales staff to cope with distribution and sales growth. As a result the *Kosim* filter can currently be found in over 14,000 households in Northern Ghana, providing safe drinking water to over 100,000 people. Moreover, PHW has monitored filters in over 1,000 households during June to August 2008, gaining valuable feedback from customers as to how to improve the *Kosim* filter and outreach.

But while PHW currently promotes and markets the *Kosim* filter, a mid-term goal is to market a variety of drinking water products successfully so that consumers have a range of choices. To this end, students from the Department of Civil and Environmental Engineering, as well as students from the Sloan School, the Department of Urban Studies and Planning, and elsewhere from the Massachusetts Institute of Technology (MIT) (Cambridge, Massachusetts, USA) support PHW with research, development, monitoring social impact and business studies. In the past this has included testing of existing products and actively researching potential new products to add to PHW's product line. This research is accessed on the Web at: http://web.mit.edu/watsan/project_ghana.htm

1.5 Climate and Precipitation in Northern Ghana

Northern Ghana has a strongly seasonal climate. This seasonality is driven by a shift in predominate wind direction from generally westerly to northeasterly, called the Harmattan, bringing dry air, dust and very little precipitation during the dry months. The dry season lasts

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[2] *Kosim* is a Dagbani word meaning "water from a ceramic pot" and "the best water." It is the drinking water that is served to guests.

from October through March or April. (Figure 4) The rainy season begins in May and lasts until September. The mean annual precipitation for the Northern Region is approximately 1m.

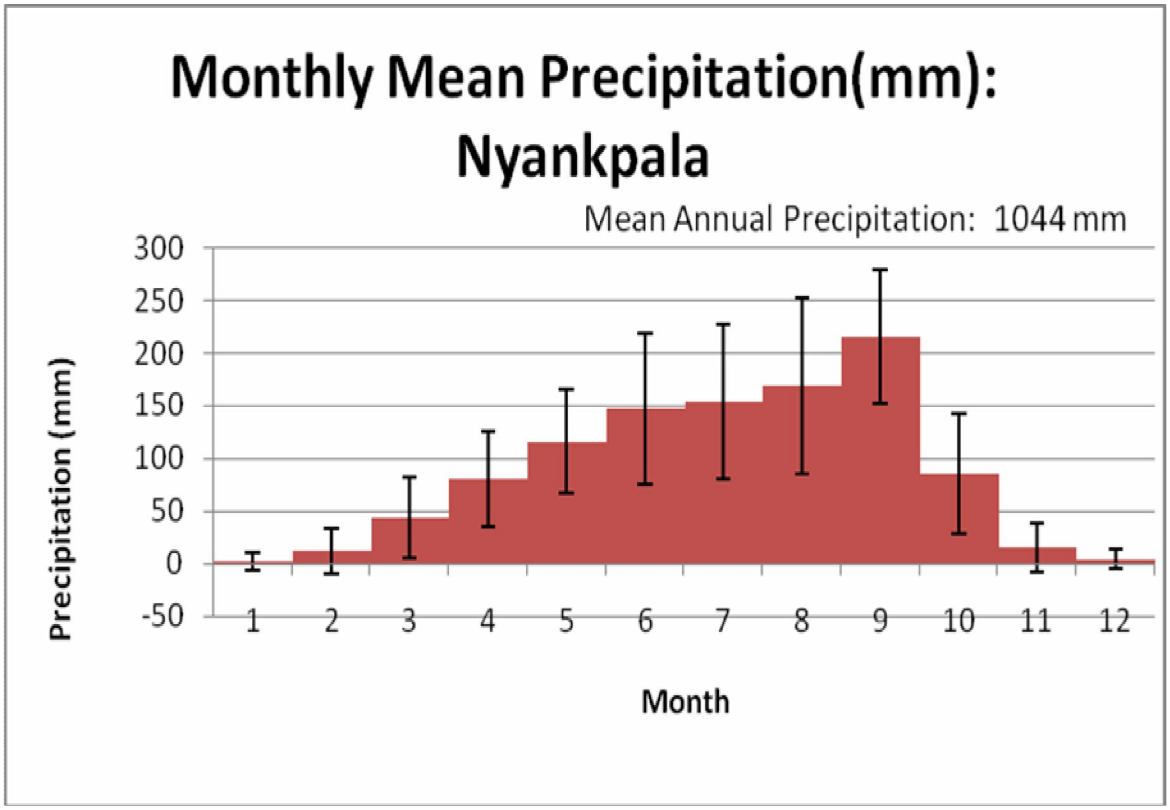


Figure 4: Mean Monthly Precipitation from Nyankpala station, Northern Region, Ghana

Chapter 2: Introduction to Rainwater Harvesting

2.1 General Background

Rainwater harvesting (RWH) is an ancient practice that can be traced back thousands of years and in many different parts of the world. The literature on the topic is as rich, broad and eclectic as the history of the topic itself and the application of the technology around the world. New interest in rainwater harvesting centers around the use of the technology for domestic drinking water supply in urban and rural settings. Growing water scarcity in many parts of the developed and developing world, as well as lack of access to clean drinking water around the world are major problems which could potentially be remedied by the scaling up of RWH technology.

Broadly, rainwater harvesting can be considered any human practice that deliberately captures and stores rainwater for future use. In this sense, pools, ponds, reservoirs, bunds, and riverbed storage all represent forms of rainwater harvesting. Local building methods and techniques for these systems are specific to location, climate and materials availability. A wealth of information exists about traditional building methods and rainwater harvesting techniques. In India for example, forty-five different traditional practices for harvesting rainwater for irrigation and domestic use have been identified (The Centre for Science and the Environment, 2008). The Centre for Science and the Environment in New Delhi provides detailed materials on traditional rainwater harvesting practices in India. The history of rainwater harvesting is described in depth by Pacey and Cullis (1986) and also by Boers (1982). Gould and Nissen (1999) provide a more technical discussion of system design and components, using traditional and contemporary examples from around the world (Gould and Nissen, 1999). They describe both technical and socio-economic considerations of implementing rainwater harvesting projects, including the design, construction and implementation stages.

2.2 Objective

The objective of this thesis is to assess the current state of rainwater harvesting in the Northern Region of Ghana and makes recommendations regarding if and how rainwater harvesting could be used to address Pure Home Water's goal of reaching 1 million people in the next five years with safe drinking water.

The assessment is structured in the following manner. First, current rainwater harvesting practices are described and design successes and failures highlighted. Second, quantity and reliability is analyzed by simulation modeling and a storage-reliability-yield relationship developed and graphed for the Northern Region of Ghana. Third, quality of water stored in tanks and cisterns, both rainwater and other sources, is assessed using bacteriological testing. Finally, unit-cost analyses are conducted and the cost of harvested rainwater is compared to alternative water sources.

2.3 Definition

In this thesis, I will focus both on household and community scale rainwater harvesting providing water for domestic consumption. Rainwater harvesting systems are conceptually made up of five components: a catchment area, conveyance mechanism, first flush diversion, storage area, and a delivery mechanism (DTU, 1999). (Figure 5: Schematic of typical rainwater harvesting system (DTU, 1999)Figure 5)

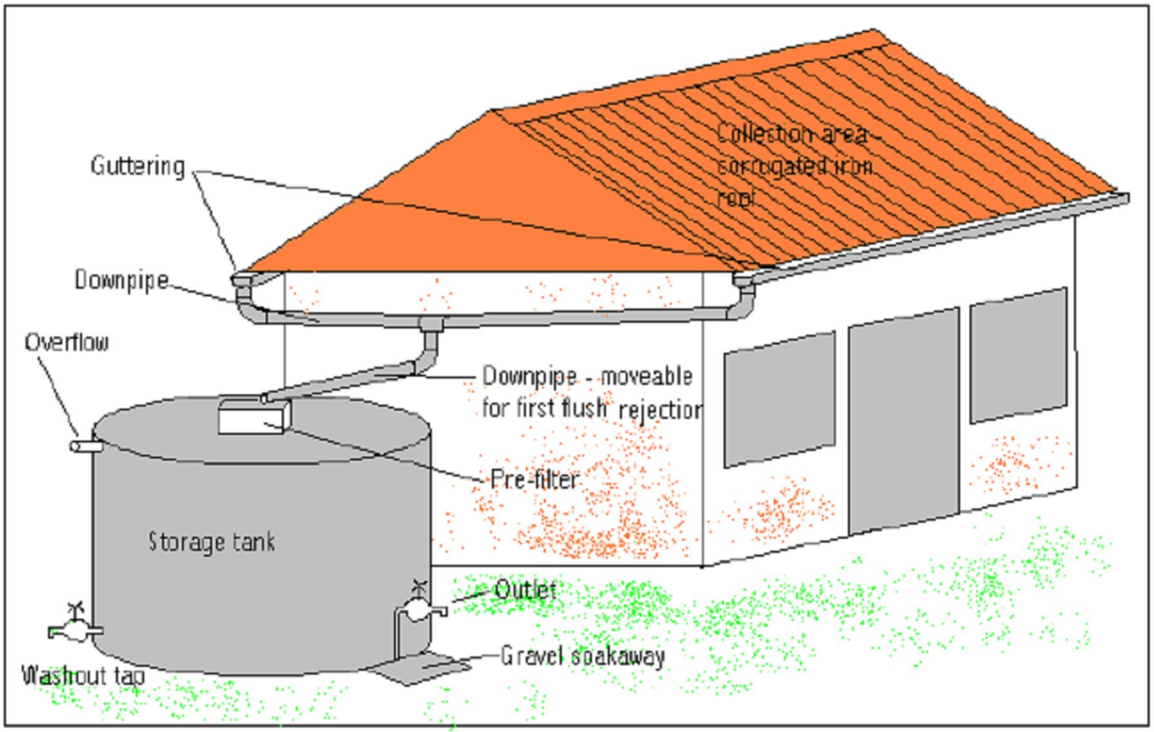


Figure 5: Schematic of typical rainwater harvesting system (DTU, 1999)

Three primary rainwater harvesting catchment methods include ground, rock, and rooftop catchments (Gould and Nissen, 1999). Ground catchments include impervious surfaces and impermeable soils or soils that have been treated to lower their permeability. These systems are easier to contaminate and harder to withdraw water from. They are implemented in regions where annual rainfall is low, suitable rooftop area is not available, and where space is less of an issue. Rock catchments are constructed by constructing masonry walls to seal off natural depressions and create storage reservoirs for natural catchments. Water from these systems can be very low cost but requires a suitable site. Rooftop harvesting allows water to be stored above ground. Water is less vulnerable to contamination than with a ground catchment as well. In this study, I will be focusing on rooftops as the primary catchment area.

A critical component, often the most expensive, is the means of storage. There are a wide range of tank designs, both above and below ground, designed from various materials. The movement to lower the cost of storage and promote quick adoption of RWH in the 1980's led to the hasty adoption of untried and untested construction techniques involving basket and bamboo reinforced concrete. These designs proved faulty due to structural decay and failure of bamboo basket reinforcement. Widespread adoption of these technologies had already occurred (Gould and Nissen, 1999). Successful materials for constructing storage tanks both above and below ground include ferrocement, galvanized steel, plastic, brick, and stone masonry (Gould and Nissen, 1999). Above ground storage makes access to and maintenance of the tank easier. Advantages of below-ground tanks include structural support of the soil, temperature moderation and protection from vandalism. However, it is more difficult to detect and repair leaks in these storage containers. Also, soil properties are a concern. Expansion and contraction of soil, particularly clay-rich soils, can lead to cracking, leaking and structural damage if proper reinforcement of the tank is not present. A good example of a low-cost, below-ground storage method is the one designed by Cresti in Rwanda (Figure 6) using a cover supported by wooden poles and a plastic liner (Cresti, 2007).

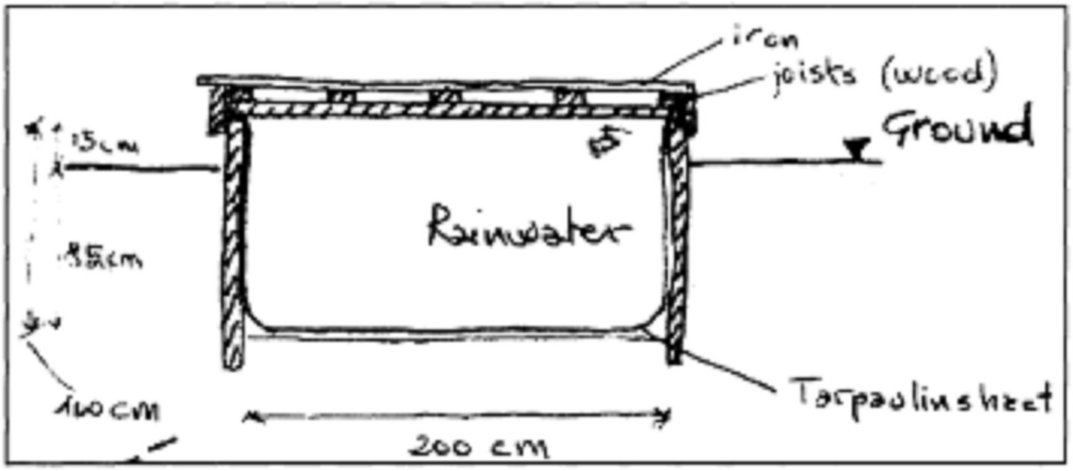


Figure 6: Sketch of low-cost below-ground storage tank design (Cresti, 2007)

2.4 Storage-Reliability-Yield

Storage-Reliability-Yield (SRY) refers to the amount of storage required to yield a certain amount of water with a certain reliability. This technique was first applied to calculations of reservoir reliability, but is easily downsized for application to rainwater storage tanks, as these are simply much smaller reservoirs. A complete reference on water resources yield, the subject matter of which SRY is a subset, can be found in McMahon and Adeloye (2005) but this is beyond the scope of this review. Both Lars Hanson (2007) and Kelly Doyle (2008) have applied SRY calculations to RWH systems in the United States and in Rwanda, respectively.

One problem with SRY calculations in developing countries is the lack of complete precipitation records at a daily or lower time-step. Mean annual precipitation data is widely available, but not useful for simulating SRY behavior because of lack of temporal resolution. Mean monthly precipitation data is of greater resolution and therefore greater use and is generally available even in developing countries (Thomas, 2002). A simple approach for generating a daily precipitation record from monthly data would be to evenly distribute this monthly precipitation over each day. This is crude, and a discussion of the amount of error introduced is included in Thomas (2002). A pseudo-daily precipitation record can be generated from the monthly probability of having a "wet day" and a randomly generated amount of precipitation scaled to match the monthly mean.

This approximation has been shown in the tropics to introduce up to a 5% optimistic estimation of reliability (Thomas, 2002).

Chapter 3: Community & Household Rainwater Harvesting Site Descriptions

3.1 Overview

Rainwater harvesting (RWH) in the Northern Region of Ghana is currently promoted and supported primarily by three non-profit organizations: World Vision, the Presbyterian Church, and New Energy. Rainwater harvesting seems to have undergone a resurgence recently with new interest on the part of these organizations. Previously, in the 1990's, Oxfam, Canadian Children's Fund and Tumakavi supported RWH projects, but currently do not. The earliest system I surveyed at the Veterinary College in Pong Tamale was reportedly constructed in the 1920's. However, most new systems I surveyed have been constructed since 2006.

In this section, results from community and household RWH sites are presented. In total, I visited 6 community scale RWH systems and 15 household scale systems. Below is a map of Tamale and some of the locations of the community and household RWH sites in the surrounding communities. (Figure 7) Community surveys were conducted from January 6th through January 10th. Community sites were located in Savelugu, Pong Tamale, and Tamale. Because January is about mid-way into the dry season, only the community storage tanks at Pong Tamale Veterinary College contained rainwater. All community tanks were filled with piped or trucked water, as their rainwater supplies had run out. Surveys of household scale RWH sites were conducted in Tamale, Kakpaille, Vogyili and Sakpalua from January 13th through to January 23rd. Profiles of these communities are presented. All site survey results are presented in chronological order starting with the first system visited on January the 6th and key characteristics are summarized in Table 1 and Table 2.

Figure 7: Map of Locations of Community and Household RWH Systems Surveyed

3.2 Community Site Descriptions

3.2.1 World Vision Ghana Rural Water Supply Office

Date Visited: 1/06/2009

Name: World Vision Ghana Rural Water Supply Office, Savelugu, Ghana
Location:
Number of Users: Employees at office (≈ 40)
Tank Type: 5 × 10,000 L Polytanks
Guttered Roof Area: 1129m^3
Cost: $8,333
Maintenance Issues: PVC gutters have failed
Water Quality Results: n/a

Figure 8: World Vision Ghana Rural Water Supply Office Rainwater Harvesting Storage Tanks (Polytank Brand)

Description: World Vision is a major international non-profit Christian development organization operating in Ghana for the past 20 years in two major activities – community development and borehole drilling. The World Vision Ghana Rural Water Project Office in Savelugu is the headquarters of the borehole drilling operation. In 2006, with interest in rainwater harvesting as an alternative where borehole drilling had previously been unsuccessful, World Vision decided to construct a demonstration RWH system to supply water to their office headquarters. The system is composed of five 10,000 L Polytanks each costing approximately $1,000. The total storage capacity of the system is 50,000L or 50 cubic meters. (Figure 8) The gutters are constructed of 4” PVC pipe cut in half and mounted with PVC brackets. The gutters were fabricated in Accra, Ghana at a high cost. Maintenance is performed annually by World Vision employees. The system does not have a first flush device of any type. Water from the system is used only for cleaning, washing and toilet flushing, but not for drinking. It is pumped up to rooftop tanks where it is subsequently used to supply one of the main buildings. It was estimated that the rainwater lasts for approximately 3 months after the last rains before it runs out.

3.2.2 Pong Tamale Health Clinic

Date Visited: 1/08/2009

Name: Pong Tamale Health Clinic
Pong-Tamale, Ghana
Number of Users: Unknown
Tank Type: 500L Galvanized Steel Tank
Guttered Roof Area: 46m^2
Cost: Unknown, financed by Ghana Health Services
Maintenance Issues: Storage tank poorly mounted on blocks, tank leaks.
Water Quality Results: n/a

Figure 9: Pong Tamale Health Clinic RWH System

Description: The Pong Tamale Health Clinic provides medical and midwife services to mother's having children. Our contact at this location was the nurse, Emilia. In 2006, she constructed the guttering to supply the 500L galvanized steel tank provided by Ghana Health Services with rainwater. The gutters are constructed of salvaged zinc roof sheet from the neighboring school. The guttered roof area supplying the small tank is 46m^2. (Figure 9) The one weakness Emilia cited was that rainwater stored in the tank did not last long into the dry season. She stated that the tank runs out of water one to two months after the end of the rainy season. Emilia felt the system needed more storage and at a lower cost. She felt that rainwater was a very reliable source of water during the rainy season. Water from the tank is used for washing, cleaning and for sterilizing hospital instruments. She considered it clean but stated that is was not for drinking. Emilia had also constructed a similar guttering system out of bent zinc roof sheet to supply a Polytank brand plastic water tank at her residence with rainwater. The main issue she indicated preventing further adoption of rainwater harvesting was the cost. Informal rainwater harvesting systems of this type, she felt were common among hospitals, health centers, schools and even residences that were able to afford water tanks or had water tanks provided by the government.

3.2.3 Pong Tamale Vocational School Boys Correctional Center

Figure 10: Pong-Tamale Vocational School Boys Correctional Center Rainwater Harvesting Tank #1

Name: Pong Tamale Vocational School Boys Correctional Center Pong-Tamale, Ghana
Number of Users: 200 people
Tank Type: 2 Sintex brand SCT-35 1000L plastic water tanks
Guttered Roof Area: 57m^2 and 69m^2
Total Roof Area: 537m2
Cost: Unknown, financed by International Labor Organization
Maintenance Issues: None.
Water Quality Results: RWH tank #2 positive for total coliform: 99 CFU/100ml (sample fetched using local fetching cup)

Description: Pong Tamale Vocational School Boys Correctional Center is located across from the Pong-Tamale Health Clinic. At this location, I talked with the headmaster of the school, Francis Haruna. The school is a place for juvenile offenders to learn trade skills. Departments in the school include masonry, carpentry, catering and hair dressing. The school also takes in orphans and displaced children. It is a part of the Department of Social Affairs.

The school has two rainwater harvesting systems of similar design in the front of the school. There is also a constructed pit on site, which Mr. Haruna hopes to convert into an underground concrete water storage tank in the future. (Figure 12) The plastic Sintex brand water tanks were provided by the International Labor Organization. The guttering is constructed of zinc roof sheet as at the Pong Tamale Health Clinic. Only a small fraction of the very large roof is used for harvesting. Francis reported that the tanks were more than filled using only a fraction of the roof area and discussed the need for more storage in the system. He envisioned offering a course that taught students reinforced concrete construction. This would allow materials for an underground storage tank to be purchased as part of the course. Labor would also be free as it would be provided by his students.

The current system is cleaned four times a year by students of the school. The tanks are cleaned with soap and hand scrubbing. The two tanks only provide enough water for two days of drinking and cooking water use for the staff, children and people who come from the surrounding community to fetch before the water runs out and hence is only reliably providing water during the rainy season.

Figure 11: Tank #2 Pong Tamale Vocational School Boy's Correctional Center

Figure 12: Pong Tamale Vocational School proposed site of underground storage tank

Figure 13: Pong Tamale Underground Storage: Water from tank used for bathing only

Figure 14: Headmaster Francis Haruna and students in front of Pong-Tamale dugout

The alternative sources for this community include water purchased from the Veterinary Laboratory Treatment Plant, described later in this chapter, and the Pong-Tamale dugout, pictured in Figure 14. The turbidity of the dugout was measured at 554 NTU. The bacteriological quality of this water was 8,900 total coliform CFU/100ml and 1,900 *E.coli* CFU/100ml.

3.2.4 Pong Tamale Health Center

Figure 15: Pong Tamale 75m3 RWH tank

Name: Pong Tamale Health Center
Pong Tamale, Ghana
Number of Users: 55-115 people depending on season, 15 -35 patients, 40-80 fetching (dry, wet respectively)
Tank Type: 1 World Vision 75m^3 octagonal cement block storage tank
Guttered Roof Area: 70m^2
Total Roof Area: 153m2
Cost: $3500 subsidized by World Vision
Maintenance Issues: Gutter failure, fixed in three days

Water Quality Results: n/a

Description: World Vision recently constructed this system (Figure 15) at the outpatient health center in Pong Tamale. General care for Pong Tamale is provided here, while maternal care is provided at the Pong Tamale Health Clinic. The nurse we talked to mentioned that the system had recently been completed in the last several months, during the dry season and as a result, did not have rainwater in it. She also mentioned that the number of people who would be requiring water from it will fluctuate based upon whether it is the wet season or the dry season due to both the number of people fetching water from it from the surrounding communities, but also due to the increase in patients during the wet season. (Rates of diarrheal disease and malaria, among other infectious diseases, are known to increase during the rainy season.)

3.2.5 Savelugu Hospital

Date 1/9/2009

Name: Savelugu Hospital
Savelugu, Ghana
Number of Users: hospital use and 50-100 fetching
Tank Type: 1 World Vision 75m^3 octagonal cement block storage tank
Guttered Roof Area: 76m^2
Total Roof Area: 189m^2
Cost: $3500 subsidized by World Vision
Maintenance Issues: Gutter failure, remains unresolved
Water Quality Results: n/a

Figure 16: Savelugu Hospital 75m3 RWH tank

World Vision also constructed another octagonal storage tank at Savelugu Hospital in 2008. (Figure 16) The tank failed to fill with water during the rainy season due to a problem with the guttering. Water was not diverted to storage at the lowest point in the guttering system so backup and spillage occurred. Also, in this design, as discussed in the Chapter 7, a large portion is considered “dead storage,” water that cannot be accessed via the tap or drained from the tank. This renders this portion of the tank unusable and prevents proper cleaning. The dead storage space can be seen in Figure 16 as approximately the area painted red.

Also, at Savelugu Hospital, a rainwater harvesting system had been constructed reportedly in the 1950’s at the time of the hospital construction. It is currently being used as an underground storage tank for piped water, and no guttering was present. (Figure 17) It is accessed via a door in the conical roof. The tank is a reinforced concrete half dome. The system has a sand inlet pre-filter, which is no longer used, as a municipal water line is connected directly to the tank. The water quality in this tank was compromised due to the access door which was left open for people to fetch. The water quality at this location was 2,000 total coliform CFU/100ml and 99 *E.coli* CFU/100ml. This sample had to be fetched so secondary contamination could also be a contributing factor.

Figure 17: Old Rainwater Harvesting Cistern, Savelugu Hopital (c. 1950's)

3.2.6 Veterinary College

Date Visited: 1/10/2009

Figure 18: Veterinary Laboratory Tank #2

Name: Veterinary College
Pong-Tamale, Ghana
Number of Users: 2000 people in emergency
Tank Type: underground rectangular reinforced concrete
Guttered Roof Area: $460m^2$
Cost: Unknown, constructed 1920's
Maintenance Issues: Gutter failure, three of five tanks still functional
Water Quality Results: 99-200 total coliform CFU/100ml, 0 *E.coli* CFU/100ml

The author visited the Veterinary College in hopes of surveying the water treatment facility supplying water to Pong-Tamale Vocational School. The Veterinary Laboratory was also the site of an extensive rainwater harvesting system reportedly constructed in the 1920's. The entirety of the main complex was guttered and storage was held in three underground storage tanks. One is shown in Figure 18. Water quality in these tanks was relatively unprotected. Fine wire mesh had degraded and did not cover the fetching hole/inlet. The large wire mesh was large enough to allow debris to enter. Sunlight also entered all tanks at the inlet grates. Tank #3's guttering system had failed and had been left non-operational for the last 2 years. The director of the hospital, Ibrahim Seidu, mentioned that he was responsible for making decisions regarding the maintenance of the building and RWH system. He stated that because the RWH system was used only in instances when the Veterinary College Treatment facility was offline, that its maintenance was not a top financial priority. Remarkably, three of five tanks constructed in this manner had survived over eighty years and still hold water. The roofs had collapsed on two others. (Figure 22)

Figure 19: Treatment Facility at Veterinary College: Settling Basin (right) and rapid sand filter (trailer at left, see below)

The treatment facility at Veterinary College provides water to the College and sells water to the surrounding community. People can fetch water at a price of $0.17 per 40 liters. The treatment is composed of three settling basins and rapid sand filtration. Post-treatment chlorination used to occur within a tank inside the trailer also. Now, pre-chlorination happens in the settling basin, (Figure 19) prior to rapid sand filtration, as the chlorination system broke and was never repaired.

Figure 20: Rapid sand filter

Figure 21: Storage Tank used for distribution to Veterinary College

Figure 22: Underground storage tank on Veterinary College premises with collapsed roof

A summary of results from the community site surveys is contained in Table 1 and Table 2.

Table 1: Summary table of community RWH sites visited

Tank Name	**# of Users**	**Rooftop Area (m^2)**	**Storage Capacity (m^3)**	**Demand (L/day)**	**Reliability %**	**Cost ($)**
World Vision	n/a	1129	50	1639	68	8333
Pong Tamale Health Clinic	n/a	46	0.5	16	75	unknown
Pong Tamale Vocational School (1)	200	57	1	992	5	unknown
Pong Tamale Vocational School (2)	200	69	1	992	6	unknown
Pong Tamale Health Center	55-115	70	75	189	91	3500
Savelugu Hospital	50-100	76	75	992	11	3500
Veterinary College #1	2000	174	92	n/a	n/a	unknown
Veterinary College #2	2000	184	81	n/a	n/a	unknown
Veterinary College#3	2000	102	96	n/a	n/a	unknown

Table 2: Water Quality Results

Location	Tot Col CFU/100ml	*E.coli* CFU/100ml
Pong Tamale Vocational School Tank #2	99	9
Pong Tamale Vocational School Tank #2	9	9
Pong Tamale Underground Storage	2100	99
Pong Tamale Vocational School Dam	8900	1900
Savelugu Hospital	2000	99
Veterinary Laboratory Rainwater Tank #2	200	9
Veterinary Laboratory Rainwater Tank #2	99	9
Veterinary Laboratory Treatment Plant Settling Basin Pretreatment	900	99
Veterinary Laboratory Treatment Plant Post Treatment Tower	100	9

3.3 Household Site Descriptions

3.3.1 Kakpaille

Dates Visited: 1/13/2009, 1/21/2009

Name: Kakpaille, Ghana
Number of Users: 7-25
Tank Type: Ferrocement tank, Presbyterian Tank Program
Guttered Roof Area: 18-72m^2
Cost: $708
Systems Surveyed in Community: 10 of 26
Maintenance Issues: Gutter failure, leaky taps, unsupported downpipes
Water Quality Results: 9-99 total coliform CFU/100ml, 9 *E.coli* CFU/100ml

Figure 23: Ferrocement Tank in Kakpaille, Ghana

The Presbyterian Church of Ghana RWH Program funded and helped construct 26 tanks in this community, of which I was able to survey 10. Kakpaille is on the urban periphery in South Tamale. A technician from the Presbyterian Church of Ghana who constructs ferrocement RWH tanks, Herbert Kofi, accompanied the author on his first visit to the community. Kpendua Andrew, a 23 year old Polytechnic School graduate and the community organizer for the project guided the author on his second visit. Mr. Andrew heard of the project through his pastor, and took the initiative to organize members of his community, form a water committee and ask the Presbyterian Church Group's aid in completing a RWH project in this community. Other water sources in the community include a private taps (2 surveyed sites,) public taps, and a dugout. Public taps operate with varying reliability and were reputed to be unreliable and closed frequently. However, according to villagers, reliability had improved recently as a political campaign tactic as national elections were underway at the time of the surveys. Tanks were completed during the summer of 2008.

3.3.2 Vogyili/Sakpalua

Date Visited: 1/23/2009

Figure 24: Ferrocement Tank at Sakpalua

Name: Vogyili, Ghana and Sakpalua, Ghana
Number of Users: 7-25
Tank Type: Ferrocement tank, Presbyterian Tank Program
Guttered Roof Area: 18-72m^2
Cost: $708
Systems Surveyed in Community: 5 of 19
Maintenance Issues: Gutter failure, leaky taps, unsupported downpipes
Water Quality Results: 9-99 total coliform CFU/100ml, 9 *E.coli* CFU/100ml

The communities of Vogyili and Sakpalua are both south of Tamale located along the same dirt road. The area is remote and rural. Herbert Kofi, the tank technician, accompanied us to this site. The pastor in the community was our contact. The only other water sources available to these two communities are unprotected dugouts. Tanks surveyed in this community were constructed in 2005 and 2006, as well as 2008. Villagers reported using RWH water for drinking and cooking purposes, while using fetched water from dugouts for bathing. Women cited not having to fetch as frequently a major benefit to having a RWH system.

3.3.3 Pure Home Water House, Tamale

Figure 25: PHW RWH System in Front of House

Name: Pure Home Water House, Tamale, Ghana
Number of Users: 2-10
Tank Type: 2 Plastic Polytank brand water tanks, 1m^3 (front of house), 3m^3 (rear of house)
Guttered Roof Area: 98 m^2 (front of house) 106m2 (rear of house)
Cost: $1069
Maintenance Issues: Gutter failure at elbow due to sun rot, failed concrete foundation for rear tank
Water Quality Results: Sample from first flush tank, 9 total coliform CFU/100ml, 9 *E.coli* CFU/100ml

Pure Home Water built a RWH system in the summer of 2008. The system was designed by a graduate student from the Rhode Island School of Design (RISD), Ming Wong, and constructed by Pure Home Water employees and students from MIT and RISD, as well as hired laborers. The system consists of two Polytanks collecting runoff from both the front (Figure 25) and rear of the rooftop. The larger storage tank is located in the rear of the tank. (Figure 26) Two types of constant volume first flush devices are used. The first, located in the front of the house, uses PVC pipe, while the second, located in the rear of the house, uses a small storage tank to capture the first flush. Piped water supply in the past had been very unreliable and often water was fetched from public standpipes or purchased from water vending trucks during the dry season. This water is stored in the plastic Polytanks when rainwater supplies run out. A failed PVC gutter elbow was repaired in the rear of the home by the author and a PHW employee, Nurideen Mohammed. The foundation for the rear tank had failed and needed repair. The tap for the rear tank was also leaking around the seal at the tank.

Figure 26: PHW RWH System in Rear of House

A summary of household survey data is presented below in Table 3 and Table 4.

Table 3: Summary Table of Household RWH Sites Visited

Tank#	**# Users**	**Roof Area (m^2)**	**Storage Capacity m^3**	**Cost ($)**
21	20	19	10	708
27	10	38	10	708
19	20	18	10	708
4	20	59	10	708
7	8	25	10	708
3	25	53	10	708
2	7	72	10	708
22	7	59	10	708
20	n/a	35	10	708
26	10	12	10	708
14	20	21	10	708
15	9	35	10	708
Chief 1	11	23	10	708
Chief 2	11	11	10	708
PHW front	8	98	1	388
PHW rear	8	106	3	680

Table 4: Water Quality Results for Household RWH systems

Location	Tot Col CFU/100ml	E.coli CFU/100ml
Kakpailli Tank #19	99	9
Kakpailli Tank #21	9	9
Kakpailli Tank #27	9	9
Kakpailli Tank #27	9	9
Kakpailli Tank #26	99	9
Kakpailli Tank #4	99	9
Kakpailli Tank #7 (tap water/rainwater)	9	9
Kakpailli Tank #3 (mix tap/rainwater)	99	9
Kakpailli Tank#2	9	9
Kakpailli Tank#22	9	9
Kakpailli Tank#20	9	9
Sakpalua Tank #1	99	99
Sakpalua Tank #2	200	99
Sakpalua Chief's	9	9
Duplicate	9	9
Sakpalua Road Stand	99	9
PHW First Flush Tank	9	9

Table 5: Locations Surveyed

	Degrees N	Minutes N	Degrees W	Minutes W
Pong Tamale Vocational School Correctional Center	9	40.999	0	50.01
Pong Tamale Health Center RWHS (across from school)	9	40.938	0	50.018
Pong-Tamale Health Center (with WV RWHS)	9	40.834	0	49.805
Savelugu Hospital (new tank)	9	37.137	0	49.766
Vetinary College (rainwater tank #1)	9	41.648	0	50.201
Kakpaille	9	22.563	0	50.236
Sakpalua	9	14.359	0	48.29

4: Design Study

4.1 First or Foul Flush Diverters

First or foul-flush diverters describe a set of technologies that divert initial runoff containing higher contaminant load from entering the storage tank. The concept and definition of first-flush originated in urban/sewer runoff literature. Doyle (2008) provides a detailed discussion of various technical definitions of first flush. Conceptually, it is the diversion of some initial quantity of water, with higher contaminant concentrations, from storage to improve water quality. Initial runoff from rooftops is the most contaminated and diverting it can significantly improve water quality.

First-flush diverters can be divided into categories based on what type of method is used to divert water from storage. Diverters range in complexity from a pipe which can be manually removed from the inlet of the storage tank so as to discharge first flush water elsewhere, (Figure 27) to complicated tipping-bucket diversion device. (Figure 28)

The three most common types of diversion devices are manual, fixed volume, or fixed mass. Manual devices, like a movable inlet pipe, were the most common system observed in Northern Ghana. While these devices are the most simple, they require the presence of an operator at the beginning of the rain event and for some duration into the storm to operate them. Education as to the proper operation of these systems is important. While they may be mechanically the most simple, they require instruction as to how much water should be diverted from the tank. The amount of time to divert water from storage is dependent on rainfall intensity which varies between rain events. Other factors that affect the first flush include roof material, roof size, slope, exposure, and meteorological factors including rainfall intensity and antecedent dry time (Meera and Ahammed, 2006).

Figure 27: Manual first flush device: Removable Inlet Pipe (Photo Courtesy of Shanti Kleiman)

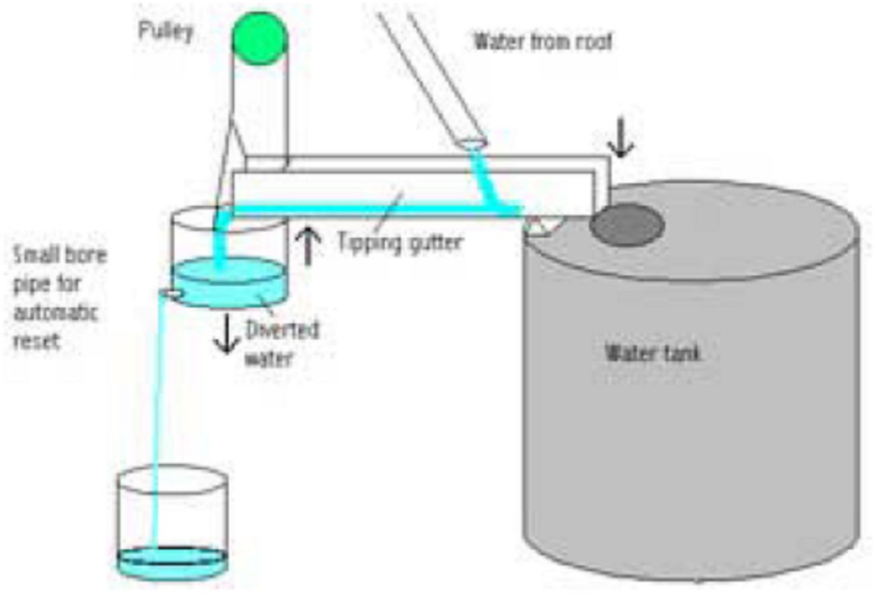


Figure 28: Fixed Mass First Flush Device: Tipping bucket type

Fixed volume devices divert a fixed volume of water from storage. (Figure 29) These have the benefit of not requiring the tank owner or operator to be present during the rain event. They can be emptied after each event or can be left full, depending on whether or not another first flush is desired at the beginning of the next rain. The Presbyterian Tank Program began to implement fixed volume first flush devices in July 2008. The devices also could serve as structural supports for the inlet pipes, which exhibit significant sag in some locations. (Figure 32) The volume sizing of these devices needs to take into consideration the factors listed above (i.e. roof area, climatic factors, roof material) to act as an effective first flush system.

Figure 29: Fixed volume first flush devices: Presbyterian Tank Program

Fixed mass devices (Figure 28) use a weight and counterweight principle to move an inlet pipe. These devices may or may not require resetting after each storm event depending on design. While their mechanical operation seems attractive, it is the opinion of field practitioners that simplicity is a virtue not to be overlooked and that maintaining system simplicity may dictate using one of the other two methods listed above.

4.2 Conveyance

4.2.1 Introduction

Conveyance systems move water from the rooftop to the storage tank. Many different types exist and are detailed in a technical paper by the Development Technology Unit of the University of Warwick (DTU, 1997). Gutter design is a balance between sloping the gutter appropriately to convey enough water while not lowering it too far to prevent interception of water flowing off of the rooftop. An appropriate slope is generally considered to be 1:100 (Gould and Nissen, 1999). Increasing slope increases conveyance. However, the capacity of the gutter to convey flow is more sensitive to increases in area than to increases in slope. The size of the guttering affects cost and performance. A general rule of thumb is to design at least 1 cm^2 of gutter cross-sectional area per 1 m^2 of roof area (Gould and Nissen, 1999).

4.2.2 Materials

Gutters can be constructed out of many different types of materials. Gutters in the author's survey in Northern Ghana were constructed of three types of materials: halved PVC piping, galvanized steel sheets bent into gutters, and bent roof sheeting. (Figure 30) Gutters were mounted using steel or fabricated PVC brackets.

Figure 30: Custom-built gutter system fabricated in Accra using PVC pipe cut in half for gutter (left) and bent steel gutter fabricated by Fuseni gutter (right)

The World Vision Headquarters had a guttering system professionally constructed in Accra and transported to the site. Custom bends and connections were fabricated. (Figure 30) The cost of the system was the highest out of all of the guttering arrangements due to the extra labor, the general expense of PVC as a guttering material ($15 per 20ft 3" PVC), and the fact that it was made in Accra and transported North.

4.2.3 Implementation in Northern Ghana

Out of all of the components of a rainwater harvesting system, guttering was, in the field, the most overlooked and perhaps most difficult to properly implement and maintain. While I did not personally have a chance to witness the performance of any systems during my field surveys, which were performed in January during the dry season, many guttering systems were in disrepair or reportedly leaked. Common failures witnessed in the field were leaky joints or connections between guttering sections and complete failure/detachment from eaves or fascia boards. The guttering system for the third of the Veterinary College's RWH system's had failed near the storage tank and had not been repaired in two years. Durability or ease of repair/replacement should be a key design criterion for any guttering system.

Design issues were also apparent. Sloping of guttering was often inadequate. At Savelugu Hospital, downpipes were not placed at the lowest point in the guttering system, and a corner joint leaked and overflowed during rain events. (Figure 31) The contractor was reportedly returning to fix the issue.

Figure 31: Leakage due to poor design (left) and author replacing sun-rotted PVC elbow joint at PHW house (right)

Eaves of homes in the Presbyterian Tank Program were often almost as low as the tank inlets, forcing downpipes to slope almost evenly into storage tanks. Also, downpipes, constructed usually of 3 inch PVC, and often of lengths ten feet or greater, were not sufficiently supported and sagged below the level of the tank inlet. (Figure 32)

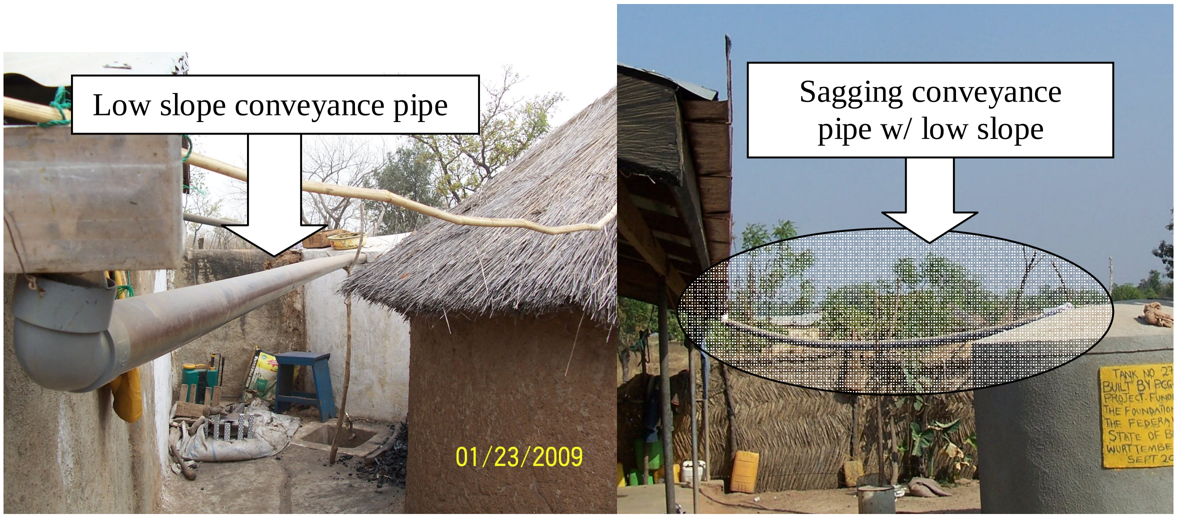


Figure 32: Low slope (left) of conveyance pipe to storage tank and sagging conveyance pipe with low slope (right)

Another design issue that was common was failure to gutter the entire roof area. For the Presbyterian Tank Program, this design decision was based on cost, and the notion that guttering was not the limiting design factor, as tanks would fill by the end of the wet season anyway. From conversations with a technician, each tank was allotted five or six sections of steel guttering. From a cost standpoint, guttering makes up a relatively small portion of the total cost and could represent a cheap way to increase reliability of these systems.

Figure 33: Lack of complete formal guttering, homemade section to far left (left) fabricated guttering using roof sheet (right)

4.2.4 A Note on Durability

Most conveyance systems surveyed in Ghana were relatively new, constructed and operated only in the past one to three years. Semi-circular guttering constructed of PVC is more expensive, and while preferable from a hydraulic perspective, appears less durable than sheet metal guttering. Many of the studies of PVC piping have focused on pressure sewer piping. While PVC sewer piping has a lifetime of 50-100 years, when exposed to the sunlight this lifetime is reduced. Covering pipes exposed to UV light for periods greater than two years is recommended by the Uni-Bell PVC Pipe Association. (Uni-Bell PVC Pipe Association) At the Pure Home Water Office in Tamale, a section of the PVC downpipe exposed to sunlight (Figure 31) failed due to cracking after only 6 months. The section exposed to the sun appeared brown, sun-rotted and brittle. The system was installed in the summer of 2008. Sun degradation in the tropics contributes to lowering the lifetime of PVC and the durability of this option should be studied further.

4.2.5 Local Gutter Fabrication: Fuseni Gutter

No prefabricated guttering is available in Ghana. Extruded aluminum or steel gutters are not available. As a result, one metal-worker name Fuseni in Tamale fabricated guttering out of sheet metal and was contracted by the Presbyterians and by World Vision to construct guttering. I visited his metal working shop to see how he constructed the sheet metal gutters. Sheet metal was trucked from Accra. It was pounded flat, cut and pounded to form the square shape of the gutter. Locations for downspouts were crafted out of sheet metal bent in a circle and crimped. (Figure 34) PHW hired a metal worker to construct gutters from galvanized steel sheet. (Figure 35) Steel mounting brackets and downspouts were also constructed.

Figure 34: Fuseni Gutter Operation: steel sheeting from Accra (left), gutters and downpipe attachments (right)

Figure 35: PHW Bent Steel Sheet Gutter Construction

4.3 Tank Design

4.3.1 Introduction

As discussed in Chapter 2, tanks represent the most significant investment in the construction of a rainwater harvesting system. In terms of labor and materials, they are the most intensive. In Ghana, tanks of three materials were most common. Plastic, cement block and ferrocement made up the majority of the designs surveyed. Plastic tanks are fabricated in Accra and shipped to the Northern Region in various sizes up to $10m^3$. Cement block designs surveyed by the author included a 30 m^3 cylindrical and a 75 m^3 octagonal tank. These designs were constructed at community clinics, schools, and churches. A 10 m^3 ferrocement tank design was the choice of the Presbyterian Tank Program for individual household use.

Figure 36: Four Different Storage Tanks: Plastic Storage Tank: Sintex Brand 1m3 (upper left) Cement Block 75m3 (upper right), Ferrocement 10m3 (lower left), Cement Block 30m3 (lower right)

4.3.2 Leaks

The durability of storage tanks is critical for the success of any rainwater harvesting project. A leak could mean the loss of a storage volume of water and costly repairs. Peter Tisakia, a contractor building 30 m^3 cement block tanks, explained that occasionally the tanks would not set properly and would leak at joints in the blocks. Repairs to cement block tanks involved the purchase of waterproof coating from Accra and expensive repairs which he would have to return to complete after the completion of a project, if leaks occurred. (Figure 37)

Figure 37: Leaky storage tank

While leaks in below-ground storage tanks are difficult to find and repair, leaks in above ground ferrocement tanks are relatively easy to find and easy to repair. The leaking area is chiseled out, wetted, and cement applied to the area. It is then covered and cured for three weeks. Some repairs can even be made while the tank is holding water. (Gould and Nissen 1999) Plastic and steel tanks are very difficult to repair if leaking occurs. One ferrocement tank seemed to seep water during the nightime. This could either be due to expansion/contraction problems or lower evaporation during the nightime making the leak visible. Leaky taps were another issue witnessed in Ghana. The tap on the tank in the rear of the Pure Home Water House leaked around the seal. A few taps in the Presbyterian Tank Program that were surveyed could not be fully closed and dripped constantly.

Properly siting and providing solid foundations for water tanks is also important. Even plastic water tanks require a proper foundation. The foundation was not properly set and cracked after only a year at the Pure Home Water House. At the Ghana Health Clinic, the 500 gallon galvanized steel tank was set on bricks placed at the four corners and allowed to sag in the middle, producing leaks and cracking. (Figure 38)

Figure 38: Foundation issues: Brick support at corners of storage tank causing structural damage and leaks, Pong-Tamale Health Clinic (left), cracked and broken foundation, PHW house (right)

Several issues are involved in properly locating a tap. First, the water from the tank must be able to drain by gravity. For above-ground tanks with bottoms at ground level, this means that a sunken tap box must be constructed. Second, the intake for the outlet pipe should not be located on the very bottom of the tank to avoid sedimentation. Rather, it should be located approximately 5 cm above the base of the tank. The 75m^3 storage tank design being implemented by World Vision in Northern Ghana locates the tap about 50 cm above the bottom of the storage tank, creating a large zone of dead storage, water that cannot be accessed from the tank by the tap. This is a large inefficiency, as well as a problem for annual cleaning the storage tank. (Figure 39)

Figure 39: Dead storage in Savelugu Hospital Tank (funding organization: World Vision) (Painted Red)

4.3.3 Durability of Storage Tanks

Figure 40: Durability: Unknown lifetime of plastic storage tank in full sunlight (left), structural failure of roof of subterranean reinforced concrete tanks, Veterinary college (right)

The design life of storage tanks is a key variable in assessing the cost of water provided and the economic benefit/cost ratio of storage tanks. While underground reinforced concrete tanks might represent a larger initial investment, some tanks surveyed by the author in Ghana remained functional after eighty years in use. Two of the five tanks at the Veterinary College had collapsed roofs but still held water. (Figure 40) While these tanks have long lifetimes, the durability of plastic tanks has not been thoroughly tested and it is unknown how long these tanks will be able to provide water. Durability must be viewed as a primary concern, particularly where subsidy is involved, as project funds dry-up and often, replacement by the same funding agency may not be possible. However, initial capital constraints often outweigh this concern. These two competing issues of capital investment and durability of storage must be resolved and durability maximized within budgetary framework.

4.4 Filtering/Quality Protection

As discussed in Chapter 5, the effectiveness of a rainwater storage tank at preserving water quality is dependent upon several features. Most importantly, the storage tank must prevent sunlight and organic matter from entering the tank and providing energy and food for microorganisms to grow. Secondly, the tank must prevent external macroorganisms from entering the tank. This includes lizards, insects and small animals which may get in and then die in the storage tank and cause serious contamination problems.

Pre-filters remove larger debris from influent water before they can reach the tank. In Ghana, several types of pre-filters were seen. The most common type of filter was a plastic bucket filled with coarse gravel with holes punched in the bottom to allow water through. (Figure 41) Another practice witnessed at the household level in Ghana was the placement of guinea worm filters over the inlet buckets. This is likely the commendable result of the intense Guinea Worm Eradication Campaign and its public outreach and education efforts encouraging people to filter water prior to consumption. At the Veterinary College, wire-mesh and coarse screen was used.

However, the fine wire mesh was in poor repair and did not cover the entirety of the opening. (Figure 41)

Figure 41: Examples of Storage Tank Inlets with Pre-filtering: Rough gravel in bucket pre-filter(upper left), degraded wire mesh partially covering inlet (upper right), cloth filter over gravel pre-filter(lower left), sealed tank entry after first flush with leaf screen (not visible) in guttering (lower right)

The covering of the overflow is equally important. Many overflows in the Presbyterian Tank Program were left uncovered. This allows mosquitoes and animals to access the tank and contaminate it. Fine wire mesh can be used. During the dry season, some use plastic bags but the provisioning of fine wire mesh for the wet season would be important as covering and uncovering the overflow would be impractical due to the frequency of precipitation during the rainy season. (Figure 42)

Figure 42: Overflow Pipes at Presbyterian Tank Program tanks: Covered (upper left), Screened (upper right) and Unscreened (lower left)

Chapter 5: Storage-Reliability-Yield Behavior

5.1 Rainwater Data

Obtaining rainwater data for Northern Ghana was a difficult process. The Ghana Meteorological survey charged $125 for a thirty year Tamale daily time-step precipitation record. This was deemed too expensive and other sources were sought out. While looking for data on the soils in the Northern Region, the author was referred to the Savannah Agricultural Research Institute (SARI) for assistance. While there, I asked the professor Dr. Mathias Fosu, how they collected precipitation data for their farm studies. He discussed the long history of rainfall monitoring and the network of stations maintained by SARI. He mentioned that data was once available for free, but now SARI is expected to operate on a for-profit basis and must sell their data at the government rate. The rate I was quoted was much lower than the current government rate and the record was of reportedly high quality. I finally purchased the rainfall data from SARI for $50.

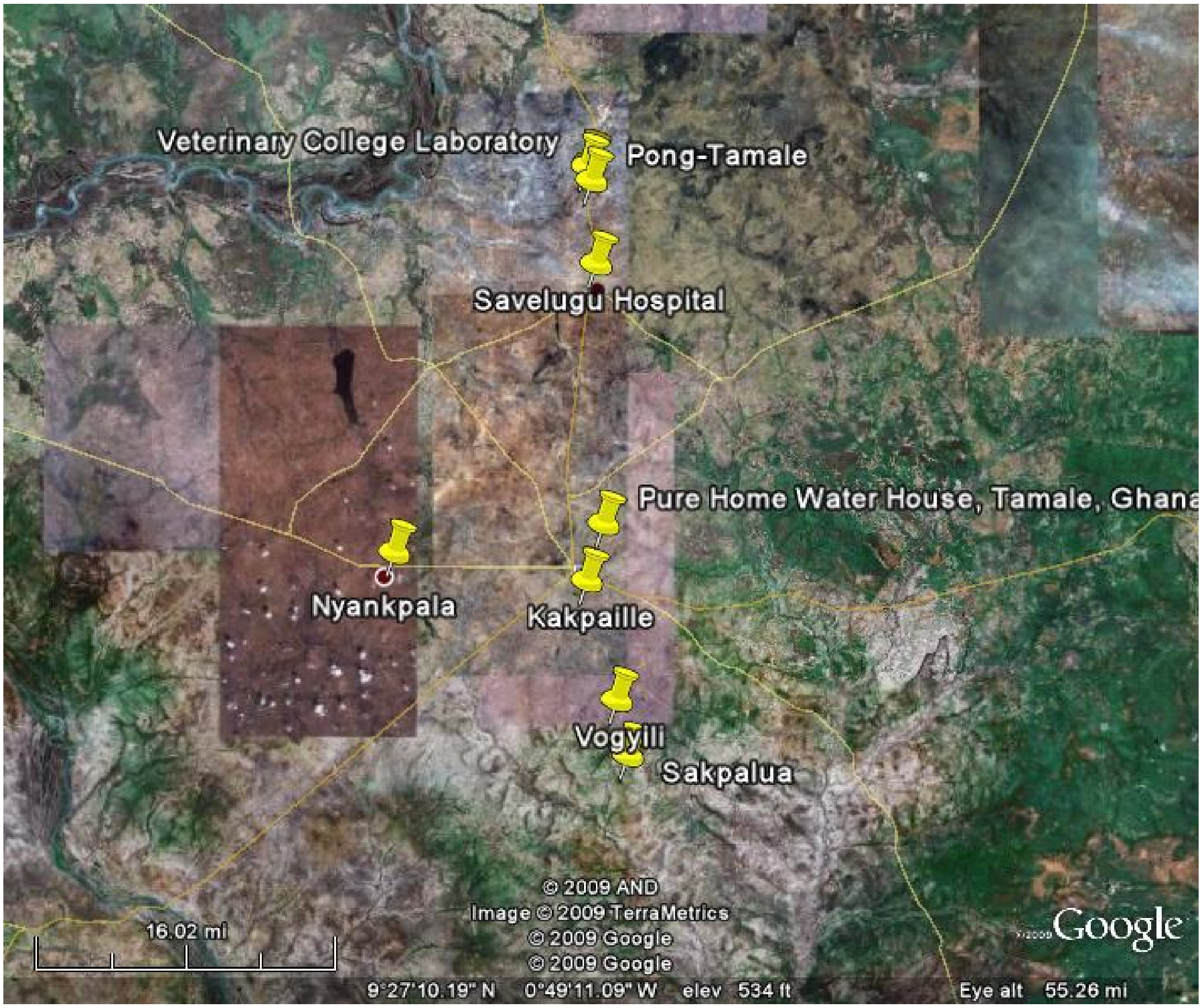


Figure 43: Map showing six site survey locations and Nyankpala, site of rainwater data collection

The precipitation record is at a daily time step for Nyankpala. Nyankpala is approximately 17 km from Tamale to the west. The period of record is from January 1, 1953 to December 31, 2005. The record is complete. Error bars show standard deviation from the monthly mean.

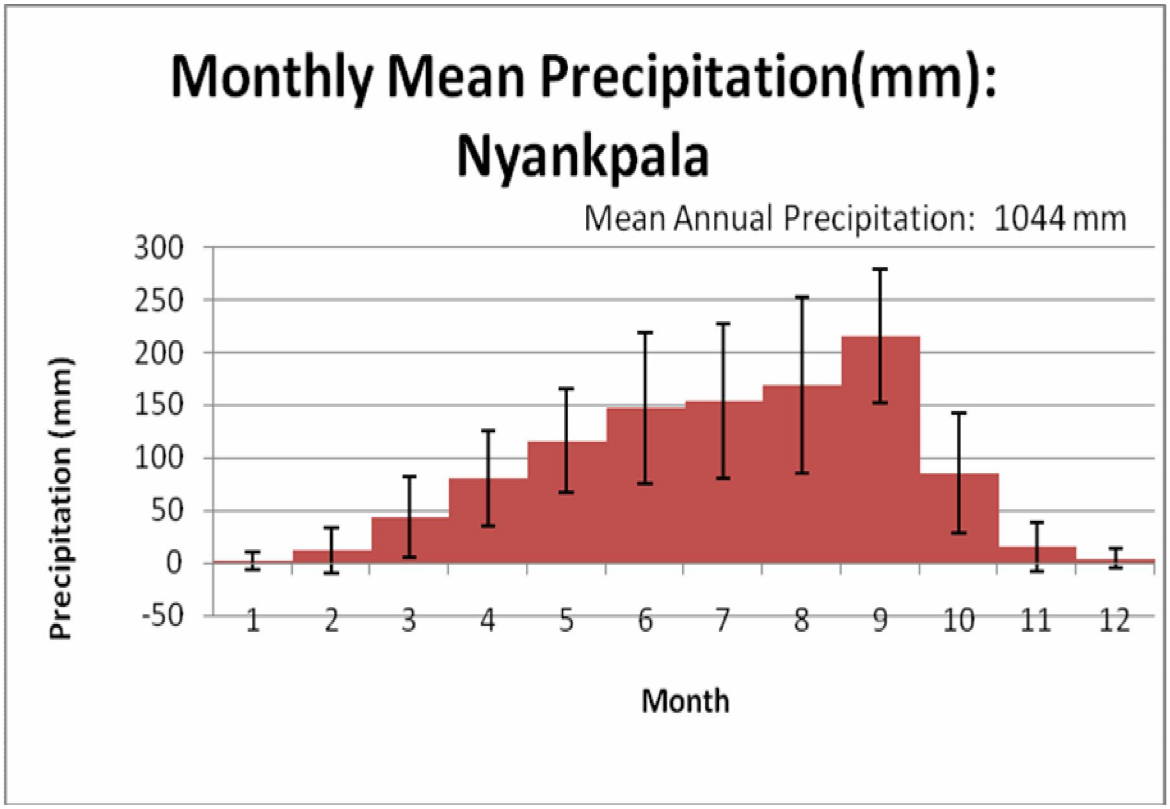
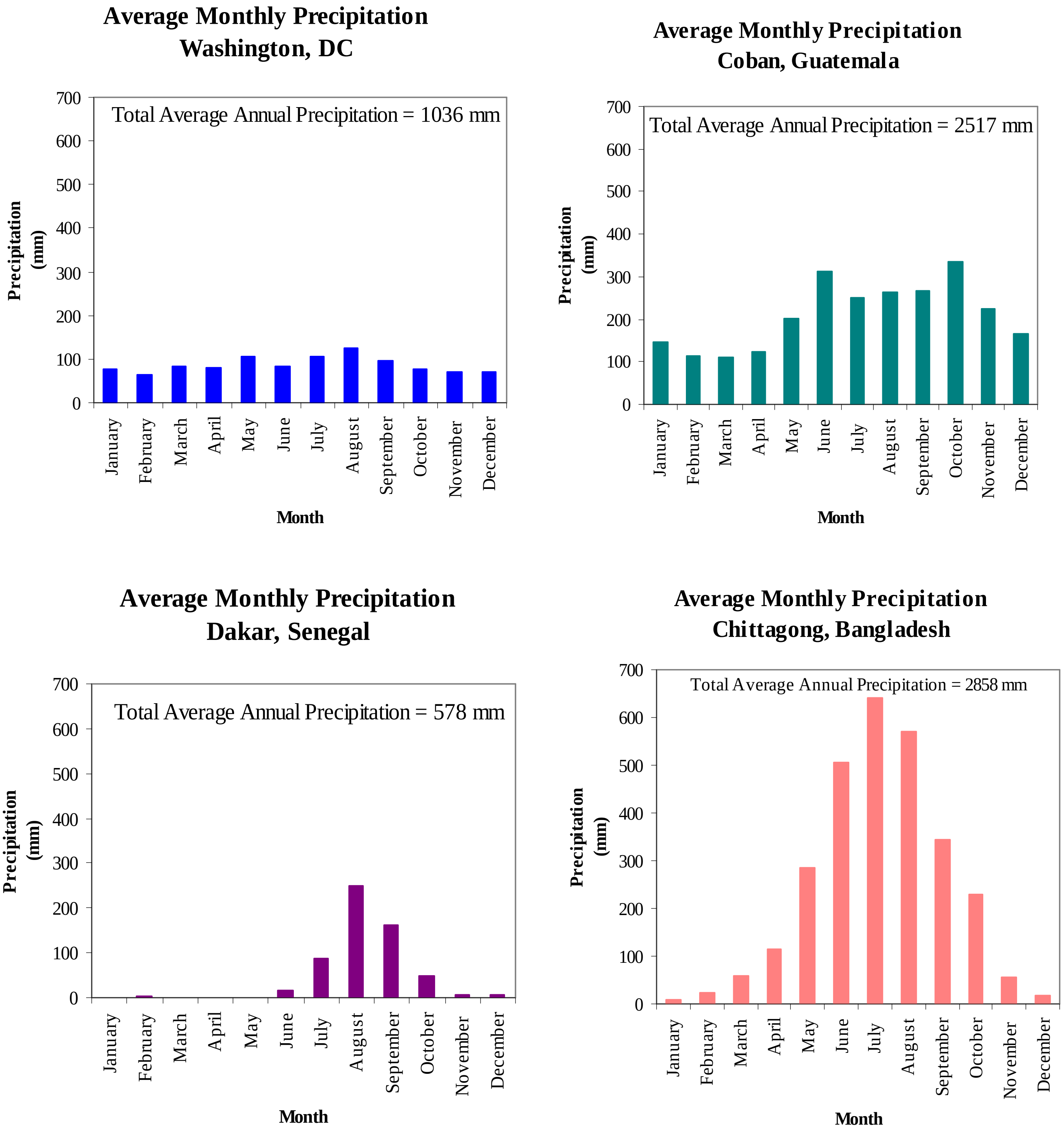


Figure 44: Monthly Mean Precipitation: Nyankpala, Northern Region, Ghana

To put this record into some kind of context, monthly mean rainfall distributions are shown for several other locations globally. Washington, DC has similar mean annual precipitation to Nyankpala, but unlike Nyankpala, little seasonal variation in precipitation exists. Coban, Guatemala has almost two and a half times the amount of precipitation as Nyankpala, but it is also uniformly distributed like Washington, DC. The two climates on the bottom for Dakar, Senegal and Chittagong, Bangladesh respectively, show seasonality of climate similar to Nyankpala, but lower and higher annual mean precipitation. (Figure 45)



Average Monthly Precipitation Washington, DC

Average Monthly Precipitation Coban, Guatemala

Average Monthly Precipitation Dakar, Senegal

Average Monthly Precipitation Chittagong, Bangladesh

Figure 45: Global Rainfall Distributions for Comparison (Murcott, 2009)

5.2 Sizing Rainwater Tanks

To determine the storage capacity of rainwater storage tanks, several practices are commonly used, ranging from simple calculations to more complicated simulation models. Simple approaches include supply-side and demand-side calculations. In many countries, rainfall data is sparse and difficult, even expensive to acquire as described in the previous section, and so simple methods may be the only option. These simple methods can be used to determine bounds for sizing a rainwater tank. Various approaches to tank sizing are summarized in

Table 6 from Hanson (2008).

Table 6: Summary of Methods Used to Determine Storage Capacities for Rainwater Storage Tanks (Hanson 2008)

Method	Multiple Reliabilities[3]	Primary Applications	Examples
"Rules of Thumb"	N/A	Do-it-yourself guides, Building codes	Various websites
Within year water balance	No	Agriculture	Goel and Kumar, 2005
Over-year water balance	Possible		Panigrahi et al, 2007;
Mass Curve (Rippl diagram)	No	Small, urban RWH systems	Handia et al, 2002
Probabilistic	Yes	Various	Ree et al, 1971; Lee et al, 2002 ; Guo and Baetz, 2007 ;
Economic Optimization	N/A	Various	Dominguez et al, 2001; Pandey et al, 1991; Liaw and Tsai, 2004 ;
Yield After Spillage simulation	Yes	Urban RWH	Villareal and Dixon, 2004; Fewkes, 2000;
Other* simulation		Various	Hermann and Schmida, 1999; Ghisi et al, 2007;

*Simulation models of unknown type or not implementing yield after spillage rule.[4]

5.2.1 Supply-Side Approach

The simple supply side approach calculates the annual rainwater supply; the maximum possible volume of rainwater available given all of it can be stored. This can subsequently be compared

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[3] Multiple reliabilities:indicates that tank size can be determined based on the desired level of reliability.

[4] Yield After Spillage rule: Water from rain event overflows from tank before it can be used.

to a calculation of water demand to determine if mean rainwater supply is sufficient to meet mean rainwater demand.

$$\mathbf{S=R*A*C} \qquad \text{Equation 1}$$

Where
S is Mean Rainwater Supply (m^3),
R is Mean Annual Rainfall (m/year),
A is Catchment Area (m^2) and
C is a dimensionless Runoff Coefficient (Volume Collected/Total Runoff Volume)
(Gould and Nissen, 1999)

The runoff coefficient is a function of losses that occur prior to water entering storage. This differs from spillage in that spillage is overflow after water has reached the storage tank. Losses occur as a result of evaporation from the surface of the roof, seepage through the roofing material, splash or drainage off the side of the roof and spillage from gutters. The runoff coefficient for a single event may differ from the long term runoff coefficient. Significant loss can occur when gutters overflow due to high rainfall or blockage, and during storms with high winds or hail. The coefficient ranges from 0 to 1 and typical values are given in the literature for different roofing materials. Roofing material as observed in Northern Ghana was primarily corrugated zinc/galvanized steel roof sheeting or thatch. Range of runoff coefficient for corrugated roof sheet is given as 0.8-0.85 (Gould and Nissen, 1999). In this thesis, I have used 0.85 as the runoff coefficient C for my analysis.

In Northern Ghana, Mean Rainwater Supply is calculated as follows:

$$\mathbf{S=R*A*C} \qquad \text{Equation 2}$$

$$\mathbf{S=1.044m*0.85*A}$$

1.044m is the mean annual runoff from the Nyankpala record. As for rooftop area A, it varies from site to site. Typical rooftops for Presbyterian tanks ranged from 11 to 72 m^2. Community rainwater harvesting systems implemented at hospitals and community buildings had much larger collection areas. Sample results for rainwater supply S for household tanks are tabulated in Table 7.

Table 7: Household tank rainwater supply-side approach results

Tank#	# Users	Roof Area (m^2)	Supply (S) (m^3)
21	20	19	17
27	10	38	34
19	20	18	16
4	20	59	52
7	8	25	23
3	25	53	47
2	7	72	64
22	7	59	53
20	n/a	35	31
26	10	12	11
14	20	21	18
15	9	35	31
Chief 1	11	23	20
Chief 2	11	11	10
PHW front	8	98	87
PHW rear	8	106	94

5.3 Demand-Side Approach

5.3.1 A Note on Water Demand in Northern Ghana

Accurately estimating water demand is difficult. Recommended practice is to conduct a large number of surveys in a community to determine water consumption. For the purposes of this study, per capita water use will be analyzed at 20 L/c/day and 5 L/c/day. These water demand values reflect basic access and intermediate access levels as found in Table 8 (Howard and Bartram 2003). For community centers and hospitals, per capita water use will be estimated based on survey data collected by the author. Table 8 tabulates level of health concern as a function of water access. Of importance, total water consumption and rainwater consumption are not analogous. Rainwater supplies in Ghana (See Chapter 3 of this thesis and Green (2008)) were found to be used in conjunction with other sources, so total water use will be higher. The reader is also referred to Howard and Bartram (2003) for an in-depth review of different levels of water consumption.

Table 8: Summary of water service level in order to promote health (Howard and Bartram 2003)

Service level	**Access measure**	*Needs met*	**Level of health concern**
No access (quantity collected often below 5 l/c/d)	More than 1000m or 30 minutes total collection time	Consumption – cannot be assured Hygiene – not possible (unless practised at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/ bathing difficult to assure unless carried out at source	High
Intermediate access (average quantity about 50 l/c/d)	Water delivered through one tap on-plot (or within 100m or 5 minutes total collection time	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured	Low
Optimal access (average quantity 100 l/c/d and above)	Water supplied through multiple taps continuously	Consumption – all needs met Hygiene – all needs should be met	Very low

The demand-based approach sizes rainwater tanks based on a graphical determination of how much supply differs from demand in any one month. This method is useful for obtaining a rough sizing of a rainwater tank. First, monthly mean precipitation is plotted. Then, it is reordered so that accumulation of precipitation begins in the rainy season. (Figure 46) Then, an inter-annual storage is added to the base of the graph. Demand is estimated and plotted. The appropriate storage size is then equal to the maximum difference between rainwater supply and rainwater demand. In the case illustrated below in Figure 46, 5 m^3 is inter-annual storage and the desired tank size is $17m^3$. (Figure 46)

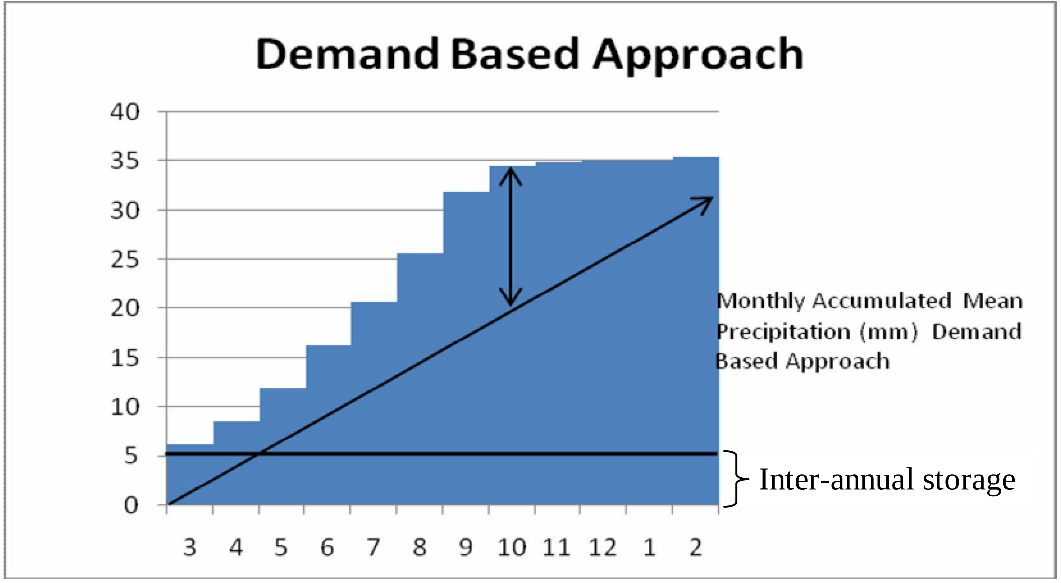


Figure 46: Demand-Based Approach for Sizing Rainwater Tank (Gould and Nissen 1999)

5.4 Reliability

Reliability is a measure of how frequently a system is able to meet demand. Two methods for estimating reliability are volume-based and time-based. Volume-based reliability considers what volumetric portion of the total demand is met. Time-based reliability is based on how much time a system is able to meet demand. Time-based reliability is considered a more conservative measure of reliability and will be used in this analysis. The equation for time-based reliability is below.

$$q = 1 - \frac{d_f}{n} \qquad \text{Equation 3}$$

Where
q is reliability,
d_f is the number of days the tank failed to meet demand, and
n is the total number of days in the simulation.

For our case, the total number of days in the simulation was 19,358. For example, the World Vision Ghana Rural Water Project Office RWH system failed to meet daily demand 6,195 days. Therefore, reliability is calculated as follows:

q= 1 – 6,195/19,358
So,
q=68%
and the reliability for the World Vision Ghana Rural Water Project Office RWH system is 68%. In the computation, yield is subtracted from storage at the end of each time-step. Yield and demand are synonymous in this context. Physically, this means that all water needed for the day is removed from the tank at the end of the day. If the tank cannot supply this demand, that day is considered a failure day, even if the tank was able to meet part of the demand. Values of reliability are bounded by two cases. A tank that meets demand 100% of days in the simulation, (zero failure days) has a reliability of 100%. A tank which meets demand none of the time has a reliability of zero and failure days are equal to total number of days simulated.

5.5 Simulation Model

Simulation of rainwater harvesting tank performance is completed using the technique from Hanson (2007), also used in Doyle's work (2008). The simulation is run at a daily time step either with pseudo-daily generated precipitation record or an actual daily record, which was my case here using the SARI data in Figure 44. It is recommended that at least twenty years of record be utilized to capture hydrologic variability in tank sizing and performance estimations. Longer records are preferable. The record I am using is fifty-three years long. This is considered a very long record, particularly valuable in this context because such records are comparatively rare for West Africa.

A Microsoft Excel spreadsheet is used and a simple algorithm tracks storage in tank on a daily basis. Daily yield (demand) is subtracted from storage at the end of each time-step. This is known as a Yield-After-Storage (YAS) algorithm. It is also referred to as a Spill-Before-Yield approach. This means that if the tank fills up during a rain event, the water is spilled out of the tank before it can be taken and used. The alternative algorithm is Yield-Before-Storage (YBS). In this approach, water is assumed removed from storage before it would overflow from the tank. A YAS approach is used here and is considered more conservative, as water is spilled before it can be used. In contrast with the YBS approach, if the storage tank is at capacity, a user would not be able to utilize rainwater supply from that day before it was spilled from the tank.

5.5.1 Community Center Rainwater Harvesting Demand

The results of simulations for Community Center RWH surveyed by the author in Northern Ghana are presented below. Reliability is dependent on both rainwater supply, a function of roof area, runoff coefficient, tank size and precipitation, as well as demand. (Table 9) Pong Tamale Health Center's system had the highest reliability of 91%. Pong Tamale Vocational School's informal rainwater harvesting collection had the lowest reliability of 5% and 6%. This was a function primarily of lack of sufficient storage and high demand.

Table 9: Summary of Results for Hospitals and Community Center RWH Systems

Tank Name	**Rooftop Area (m^2)**	**Storage Capacity (m^3)**	**Demand (L/day)**	**Reliability %**
World Vision	1129	50	1639	68
Pong Tamale Health Clinic	46	0.5	16	75
Pong Tamale Vocational School (1)	57	1	992	5
Pong Tamale Vocational School (2)	69	1	992	6
Pong Tamale Health Center	70	75	189	91
Savelugu Hospital	76	75	992	11

5.5.2 Presbyterian Tank Household Program Demand

At each location I surveyed, I asked questions in order to estimate current water demand at the Presbyterian RWH system site. I surveyed three different communities with Presbyterian water tanks provided. Each community I surveyed relied on a variety of water sources for domestic supply. Rainwater was used conjunctively with fetched surface water, public tap, trucked tanker water, as well as municipally supplied (but inconsistent) tap water. Usage of rainwater supply was highly variable. Conservation practices and rationing can also affect water use on a seasonal basis. Households I surveyed were unaware of water levels in their tanks at the time of survey, but some mentioned that they used less as the water supply ran out and they began paying more attention to the water level in the tank. In the urban settings, where public tap supply was sometimes available, rainwater was only used when fetching from public taps was not possible. In most locations, rainwater was only used for drinking and cooking. Other water sources were used for bathing. Demand was highly variable. Some rainwater tanks had been almost completely exhausted of their supplies during my surveys, roughly 2 to 3 months into the dry season, while others remained at ninety percent of their storage capacity. This appeared to be related strongly to the availability and quality of other available sources, based on responses to my survey.

5.6 Household Size

The number of members in a household varied significantly. Some households were large with up to twenty members, while others only had five. (Table 7) Projected demand for rainwater harvesting tanks in the Presbyterian tank program was estimated at 5L/capita/day and 20L/capita/day. These demand scenarios are for a very low water use and a low water use scenario. Reliability for these different scenarios can be found in Table 10. Reliability for this one tank design varies from 5% to almost 100%, depending on demand and supply, as a function of roof area. Reliability at 5L/day/capita is excellent for both high and average tank locations. At the higher demand of 20L/day/capita, reliability drops rapidly and ranges from 5% to 77%.

Table 10: Summary of Results for Presbyterian Household Tank Program Systems

			Demand Scenario 1	**Demand Scenario 2**
Reliability	**# of Users**	**Roof Area (ft^2)**	Reliability(5 L/day/capita)	Reliability (20 L/day/capita)
High	7	772	99.9%	77%
Average	14	369	96%	26%
Low	20	200	43%	5%

5.7 Storage-Reliability-Yield Relationships

Another means of sizing rainwater systems can be to create storage-reliability-yield (SRY) relationship curves. These plots encompass the major design variables for reservoirs or rainwater tanks. These relationships have been used to size reservoirs. Hanson (2008) describes how they are analogous to those applied to rainwater tanks. Roof area, storage capacity, and yield are consolidated into two terms. Storage capacity normalized by roof area make up the physical storage ratio (S_r) and yield (y) (daily demand) divided by mean daily precipitation (u_{dp}) and roof area (A_c) make up the dimensionless yield fraction (α). Physical storage ratio represents the storage capacity of a system relative to the amount of roof area that it stores water for. Dimensionless yield fraction represents an average daily demand over an average daily supply. Contours of constant reliability are plotted. Each contour represents different combinations of demand, roof area, and tank size for which reliability is the same. If demand, roof area and reliability are known design variables, then tank size can be determined using the graph. Once these curves have been developed, they can be applied from site to site within the area for systems with different roof areas, storage capacities and yields. To develop SRY relationships, it is necessary to consolidate design variables into two terms.

The first is a physical storage ratio S_r:

$$S_r = \frac{s}{Ac} \qquad \text{Equation 4}$$

Where *s* is the storage capacity of the tank [m^3],

A_c is the collection area [1 m^2]

S_r is measured in meters. Storage capacity is normalized by collection area for an analysis that is independent of collection area, as rooftop area is often not a changeable design variable.

The second term utilized in the analysis is a dimensionless yield fraction, α.

$$\alpha = \frac{y}{u_{dp} \times A_c}$$

Equation 5

Where
y is yield,
u_{dp} is mean daily precipitation and
A_c is collection area.

Various combinations of S_r and α simulated in the above simulation model and associated iso-reliability curves are plotted. Microsoft Excel was used to complete the simulations and results were plotted using MATLAB.

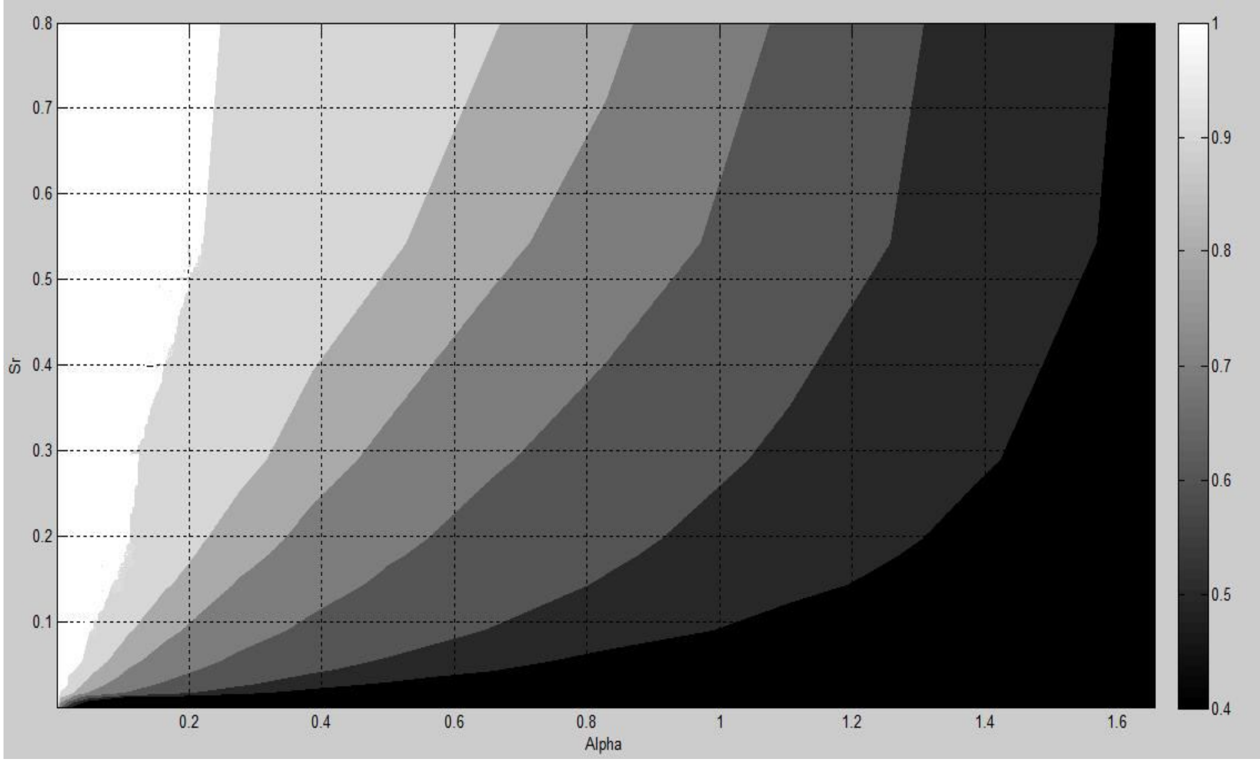


Figure 47: SRY Relationship

6: Rainwater Quality:

“Water is essential to sustain life, and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve a drinking-water quality as safe as practicable.” WHO *Guidelines For Drinking Water Quality, 2004.*

6.1 Objective

The objective of this portion of the study was to test the microbiological safety of water stored in RWH storage tanks in Northern Ghana using total coliform and *E.coli* as indicator bacteria for testing.

6.2 Background

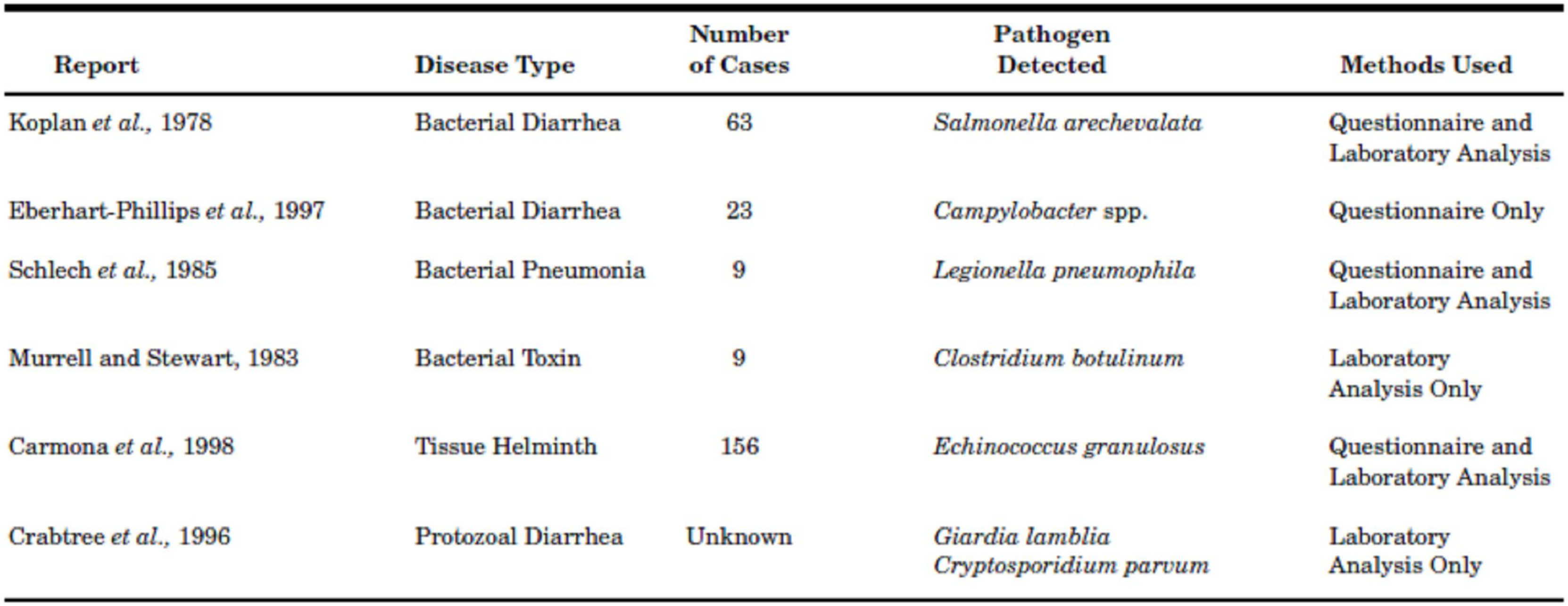
One of the most significant potential benefits of rainwater harvesting is the provision of safe drinking water sufficient in quantity and quality so as to improve the health and hygiene of its users. Rainwater harvesting from rooftops seeks to provide a safe drinking water supply by intercepting rainfall and diverting it to a safe storage tank that avoids contamination. Water supply can be contaminated in four different ways: chemical, microbiological, radiological, and aesthetic. This thesis will focus on microbiological contamination of rainwater supplies, but chemical contamination is also a concern and is discussed briefly below, although chemical testing of RWH tank water was not conducted. The WHO considers infectious diseases caused by microbiological contamination to pose the highest health risk associated with drinking water (WHO, 2004). Minimizing this risk associated with RWH systems is essential.

6.3 Contamination of rainwater

Conceptually, rainwater can be contaminated in four locations. The first is in the atmosphere. Influent rainwater can be contaminated prior to reaching the rooftop by atmospheric pollution from heavy traffic, industrial activity, and smelting. The major chemical pollutants in this case include sulfur dioxide, nitrogen oxides and hydrocarbons. Drinking rainwater within close proximity to urban areas is not recommended for reasons of atmospheric contamination of rainwater. The second location is on the catchment surface or in route to storage. This is the most common location for contamination to occur (Gould and Nissen, 1999). Contamination occurs due to deposition on rooftop areas between rain events. Yaziz (1989) showed that levels of contamination, as measured by total and fecal coliform counts, increased with number of days without rainfall. Bird and animal feces are a particular contamination source of concern. Accumulation of debris in gutters, particularly if it remains wet, can provide habitat for bacteria. The third location at which contamination is possible is in the storage tank. This risk is increased dramatically if the water supply tank is open. Animals can fall in and die, fetching buckets can introduce contamination, and debris can directly enter the storage tank. Also, sunlight can encourage the growth of algae, the production of toxins and the growth of bacteria. A safe mechanism for accessing the water supply, such as a tap or pump, is vital to ensuring the microbiological safety of RWH storage tank water. In addition, inlet and overflow pipes should be screened to prevent the entry of animals and external contamination. The fourth location is at the outlet, whether it be a tap or pump.

The quality of rainwater collected in tanks and cisterns has been the subject of much study and some controversy. The WHO drinking water guidelines recommend 0 *E.coli* or thermotolerant coliform forming units (CFU's) per 100mL for all drinking water supplies. (WHO, 2004) Alternative standards for rainwater supplies in tropical regions and developing countries were proposed by Krishna (2003). He proposed the following three-tiered classification for rainwater supplies:
Class I: 0 fecal coliforms/100ml
Class II: 1-10 fecal coliforms/100ml
Class III: >10 fecal coliforms/100ml
Class I is the highest quality, Class II is considered of marginal quality, and Class III would be unacceptable for drinking. The presence of fecal coliform indicates recent contamination of the drinking water supply by feces, human, animal, or avian. Fecal coliform has been widely used in the past as an indicator of fecal contamination. However, fecal coliform has been found not to be entirely fecal in origin and several genera of non-fecal bacteria such as *Klebsiella*, *Enterobacter*, and *Citrobacter* all can generate false positive results for fecal contamination (Doyle and Erickson, 2006). As a result, a more operational definition was adopted, thermotolerant coliform, which acknowledged the reality that not all fecal coliform was fecal in origin. Currently, thermotolerant coliform continues to be used as an indicator of fecal contamination. *E.coli* is a subset of fecal coliform that indicates human fecal contamination. Currently, using *E.coli* and thermotolerant coliforms as indicator organisms of the overall microbial safety of drinking water supplies is the WHO 3rd Edition Guidelines (2004) recommended practice.

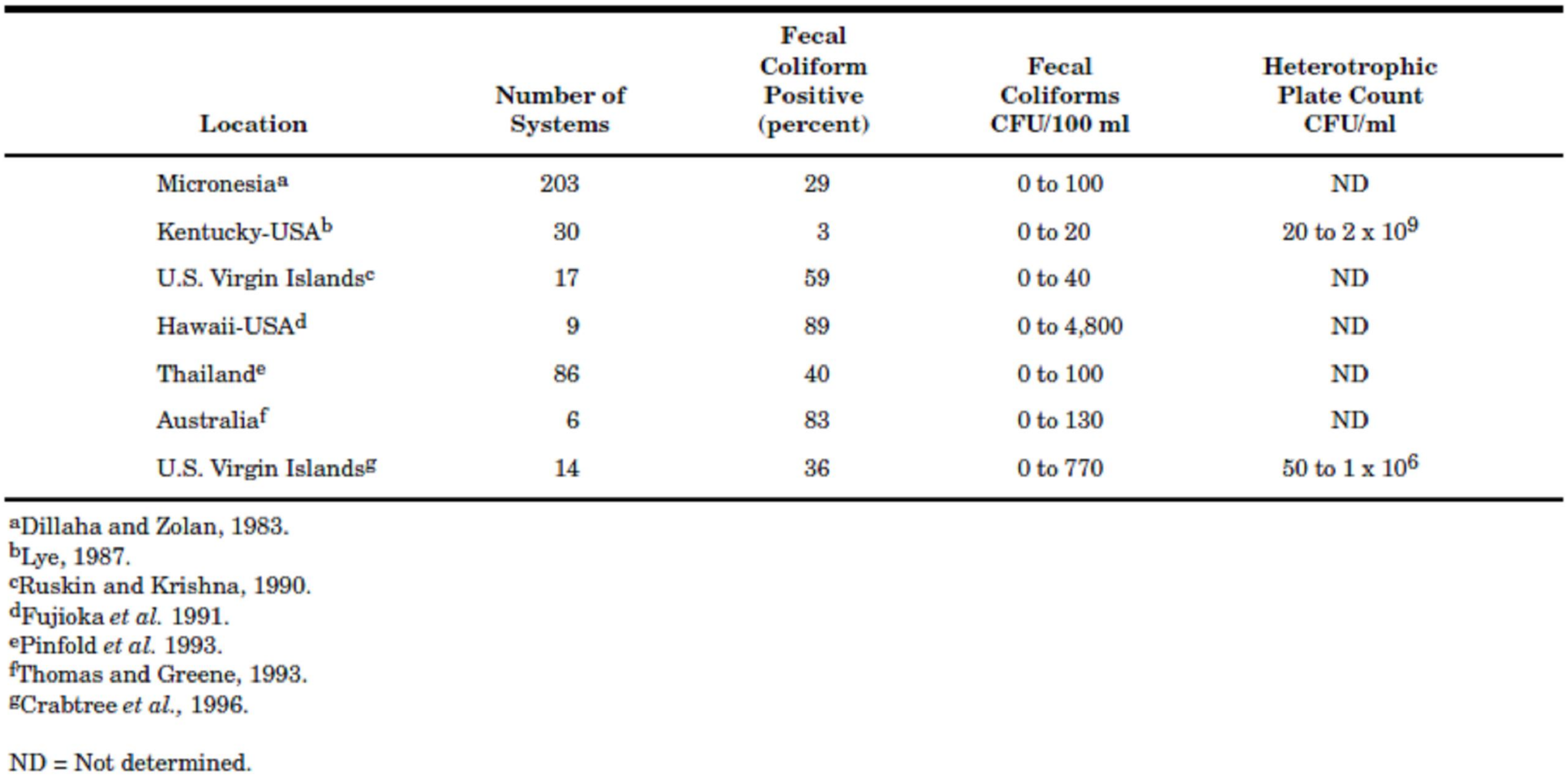
The following microorganisms are regulated by the USEPA to a level of zero CFU per 100 ml for drinking water: coliforms, fecal coliforms, enterococci, *Pseudomonas aeruginosa*, *Salmonella* spp., enteroviruses, *Campylobacter* spp., *Legionella Pneumophila*, *Giardia* spp., and *Cryptosporidium* spp. Absence of fecal coliform does not necessarily indicate the absence of these other microorganisms and there is some controversy as to whether or not fecal coliform is a sufficient metric for application to untreated rainwater harvested from rooftops. Lye (2002) conducted a thorough literature review of disease cases related to the consumption of RWH systems. He suggests that a more thorough approach should be taken to the analysis and recommendation of untreated rainwater from roof catchments for drinking water and that not only should bacterial analysis, but also protozoa and helminth contamination as well. (Figure 48)



Report	Disease Type	Number of Cases	Pathogen Detected	Methods Used
Koplan *et al.*, 1978	Bacterial Diarrhea	63	*Salmonella arechevalata*	Questionnaire and Laboratory Analysis
Eberhart-Phillips *et al.*, 1997	Bacterial Diarrhea	23	*Campylobacter* spp.	Questionnaire Only
Schlech *et al.*, 1985	Bacterial Pneumonia	9	*Legionella pneumophila*	Questionnaire and Laboratory Analysis
Murrell and Stewart, 1983	Bacterial Toxin	9	*Clostridium botulinum*	Laboratory Analysis Only
Carmona *et al.*, 1998	Tissue Helminth	156	*Echinococcus granulosus*	Questionnaire and Laboratory Analysis
Crabtree *et al.*, 1996	Protozoal Diarrhea	Unknown	*Giardia lamblia* *Cryptosporidium parvum*	Laboratory Analysis Only

Figure 48: Review of Disease Cases Attributed to Drinking Untreated Rainwater Supplies (Lye, 2002)

It is the conclusion of Gould and Nissen (1999) however, that a large amount of untreated harvested rainwater from rooftops is being consumed around the globe. They argue that cases of RWH systems implicated in disease outbreaks are small in number. Microbial water quality from various rainwater quality studies is presented in Figure 49.



Location	Number of Systems	Fecal Coliform Positive (percent)	Fecal Coliforms CFU/100 ml	Heterotrophic Plate Count CFU/ml
Micronesia[a]	203	29	0 to 100	ND
Kentucky-USA[b]	30	3	0 to 20	20 to 2 x 10^9
U.S. Virgin Islands[c]	17	59	0 to 40	ND
Hawaii-USA[d]	9	89	0 to 4,800	ND
Thailand[e]	86	40	0 to 100	ND
Australia[f]	6	83	0 to 130	ND
U.S. Virgin Islands[g]	14	36	0 to 770	50 to 1 x 10^6

[a] Dillaha and Zolan, 1983.
[b] Lye, 1987.
[c] Ruskin and Krishna, 1990.
[d] Fujioka *et al.* 1991.
[e] Pinfold *et al.* 1993.
[f] Thomas and Greene, 1993.
[g] Crabtree *et al.*, 1996.

ND = Not determined.

Figure 49: Summary of Fecal Coliform Results in Rainwater Harvesting Systems (Lye, 2002)

6.4 Secondary Microbial Contamination of Water Supply

Safe drinking water at the source of water supply does not indicate safety at the point-of-use. Rainwater harvesting is no exception. Gundry conducted a study in Zimbabwe and South Africa of both “improved” and “unimproved” water sources as classified under the United Nations Joint Monitoring Programme. He sampled bacteriological quality of water at each point in the supply chain. (Figure 50) His results indicated that an improved water supply did not necessarily represent a safe water supply and that levels of contamination of >10 *E.coli* CFU/100ml at the point-of-use existed in 82% of unimproved(unprotected well/spring, river/canal) source households and 51% of improved (standpipe, borehole, protected well water sources) households.

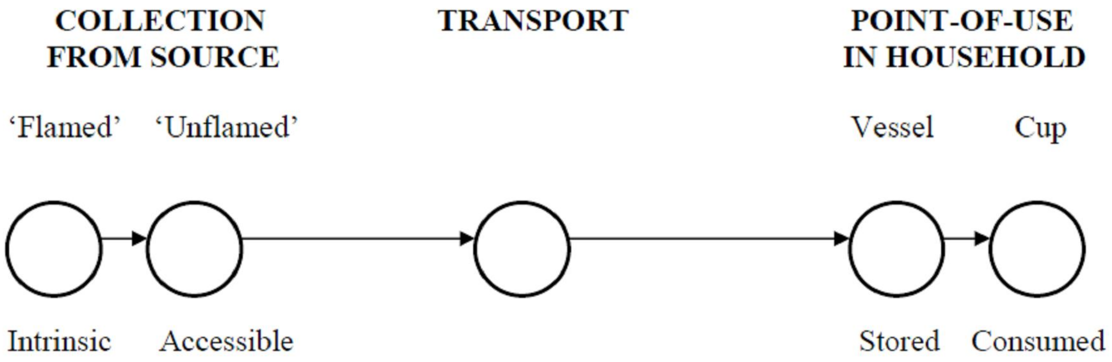


Figure 50: Drinking water supply chain (Gundry 2006)

Gould and Nissen (1999) discuss data that implicate secondary contamination, contamination upon or after removal from storage, as a serious concern. Serious secondary fecal contamination of household storage containers and drinking vessels would undermine health benefits otherwise available to those with access to safe drinking water, from rainwater systems or otherwise.

6.4 Harmattan Winds

The dry season lasts from October or November through April or May in Northern Ghana. (Figure 44) This climate pattern is also correlated with the seasonal shift in wind direction and the onset of what are called the Harmattan winds. The general westerly winds reverse and northeasterly winds from the Sahara desert across West Africa predominates. Storms in the Bilma and Faya-Largeau areas of Chad (Figure 51) generate and lift large quantities of dust into the atmosphere. This dust is transported at up to 30 km/h and can reach Nigeria in 24 hours (Tiessen, 1991).

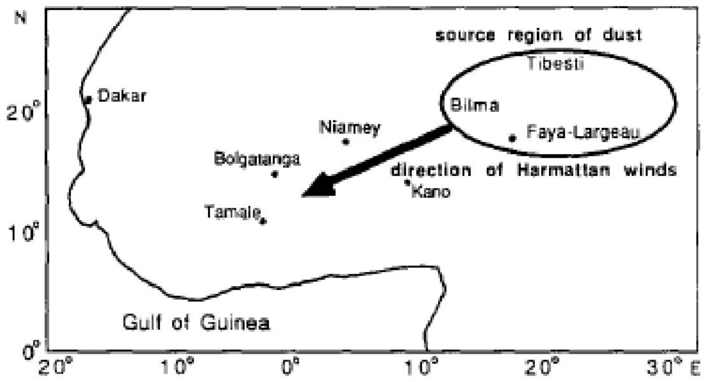


Figure 51: Origin of Dust in Harmattan Winds (Tiessen, 1991)

Dust deposition was measured by Tiessen during Harmattan season at rates of 0.04 – 0.45 g/m^2/day. This dust deposition, along with local burning during the dry season, creates a significant amount of particulate matter accumulation on rooftops in the region of study in Northern Ghana. From observation during my surveys during January 2009, all rooftops appeared to have significant amounts of dust. The practice of the Presbyterian Tank Program is to recommend that the first rainfall event after this season be entirely diverted from storage to ensure that the rooftop is thoroughly cleaned after the dry season. Preventing dust and organic matter from entering rainwater storage tanks is key to protecting the microbiological quality of the water. Doyle's work in Rwanda on sizing first-flush systems recommended that the first millimeter of precipitation be diverted from storage after a period of three days without rain (Doyle, 2008). This recommendation, however, is site specific to a region not affected by Harmattan winds, and therefore not applicable directly to my study site.

6.5 Contamination: Mosquito larvae

It is important to note that microbial contamination is not the only health threat associated with water storage in or near the household. Standing or stored water provides mosquito breeding habitat, often in close proximity to the home, if careful measures are not taken to prevent mosquito access. Mosquitoes serve as vectors for diseases such as malaria, yellow fever and filariasis, all of which are endemic in Ghana.

In Ghana, the disease of primary concern, associated with *Anopheles* mosquitoes, is malaria. Rainwater cisterns often are not the only breeding sites near the home, as they are often not the only water supplies, and larval contamination of household water storage containers, puddled water, and other sites may exist. However, it is very important that measures are taken to prevent mosquito breeding in water cisterns, as this could represent an increased health risk. A study of an urban quarter of Enugu, Nigeria and two neighboring rural villages found that in the rural villages, 53 containers/100 households and 76 containers/100 households were positive for *Aedes* larvae, a vector for yellow fever, and represented a high transmission risk. Other studies conducted in Australia and Thailand show that rainwater cisterns, and to a greater extent, uncovered household water storage containers, represent mosquito breeding habitat (Gould and Nissen, 1999).

The simplest and most effective way to prevent this risk is to prevent mosquito access to the rainwater storage tank. This can be accomplished by covering openings with fine wire mesh or nylon mesh. Inlets to ferrocement and cement block tanks in Ghana were more carefully protected, often with fabric or sand filters and water delivery was accomplished via tap. However, the overflow pipe, located near the top of the tank, was often neglected and left uncovered exposing the water supply as a potential breeding site for mosquitoes. (Figure 52)

Figure 52: Unscreened Overflow Pipe

6.6 Factors Influencing Water Quality in Rainwater Tanks

Several factors influence the bacteriological quality of water stored in cisterns. Often water is most contaminated directly after a rain event. If water is isolated from the sun and organic matter is not present in the tank, bacteriological quality of stored rainwater improves within days after a rain event. Settling and die-off of bacteria improve water quality with time. (Gould and Nissen, 1999) However, chemical quality of rainwater can deteriorate significantly with time in storage if the water has a low pH. Rainwater of this nature is considered “aggressive” and can leach out metals from storage tanks and taps.

6.7 Designing to Protect Water Quality in Rainwater Tanks

Several design features can be integrated into the tank to improve the quality of the harvested rainwater. The first is a clean catchment surface made of non-toxic material free from overhanging trees. This prevents chemical contamination directly from the roofing material and limits fecal contamination from birds. Taps outlets should be elevated from the tank bottom by at least five centimeters to ensure that debris has room to settle and is not caught up in the outlet water. Coarse filtering at the inlet and foul-flush devices prevents debris from entering the tank. Annual cleaning should take place. Sunlight should not enter the storage tank. All inlets and outlets should be screened to prevent animal access. If these measures are taken, rainwater quality can improve significantly (Gould and Nissen, 1999).

6.8 Water Quality Testing Methodology

Water samples were taken from water cisterns at 24 visited sites. The source of water and method for fetching varied among samples. In the event that a sample could not be collected from the tap, the local method for accessing the water source was used, typically involving the use of fetching buckets or cups. Secondary contamination was possible in these tests from the fetching bucket or cup. (Figure 53) Whirl-Pak® 100 mL sampling bags were used to collect water from taps or where necessary, using local fetching practices (cup, bucket.) The method of sampling was noted at each location. Water samples were transported to the laboratory on ice in coolers. The samples were refrigerated until tests could be completed. These samples were processed within twenty-four hours of time of sampling. Two tests were completed to determine the microbiological quality of the samples, Colilert 10mL predispensed presence absence test and 3M Petrifilm.

Figure 53: Collection of Rainwater Sample from Underground Cistern at Veterinary College Using Local Fetching Bucket (Used Food Container,) Pong-Tamale, Ghana.

6.8.1 Colilert

Colilert ™ in 10ml pre-dispensed tubes is a simple vial test for total coliform and *E.coli* at a detection limit ≥10CFU/100ml. 10ml of sample was pipetted into the vial with two nutrient-indicators, 2-Nitrophenyl-β-galactoside **(**ONPG) for total coliform and 4-methyl-umbellipheryl-beta-D-glucuronide (MUG) for *E.coli*, that are metabolized by the coliforms to convert ONPG from colorless to yellow, and cause MUG to fluoresce. The samples were incubated in a Millipore single chamber field incubator (230 V) (Model xx631K230) for 24 hours at 35 degrees Celsius. After incubation, the samples were read. Yellow color change indicates total coliform contamination of ≥10CFU/100ml and yellow with blue fluorescence under a UV lamp indicates *E.coli* contamination of ≥10CFU/100ml.

6.8.2 3M Petrifilm

3M ™ Petrifilm is a low-cost measurement technique for total coliform and *E.coli* at a detection limit ≥100CFU/100ml. One 1ml of sample was pipetted from the Whirl-Pak® bag onto the sample media. The water is allowed to diffuse across the entire media and the film cover carefully rolled down to prevent air bubbles from becoming entrapped. The samples were then incubated in a Millipore single chamber field incubator (230 V) (Model xx631K230) for 24 hours at a temperature of 35 degrees Celsius. After incubation, colonies were counted. Blue colonies with gas bubbles indicate *E.coli*. Red colonies with gas bubbles indicate coliform. The sum of red and blue together represent the total coliform count.

6.8.3 Interpretation of Results

The results of these two tests, used jointly, allow the determination of a risk level associated with the drinking water supply. *E.coli* from both tests can be compared to below to determine this risk level. (Table 11)

Table 11: Risk Level Interpretation from E.coli Results (WHO, 1997) (Metcalf, 2006)

Risk Level (WHO, 1997)	***E.coli* in sample CFU/100ml (WHO, 1997)**	**Colilert *E.coli* Result (Metcalf, 2006)**	**Petrifilm *E.coli* (Metcalf, 2006)**
Conformity	<1	- (clear = below detection)	0
Low	1 to 10	- (clear = below detection)	0
Intermediate	10 to 100	+ (blue fluorescence)	0
High	100 to 1000	+ (blue fluorescence)	1-10(blue with gas bubbles count)
Very High	>1000	+ (blue fluorescence)	>10(blue with gas bubbles count)

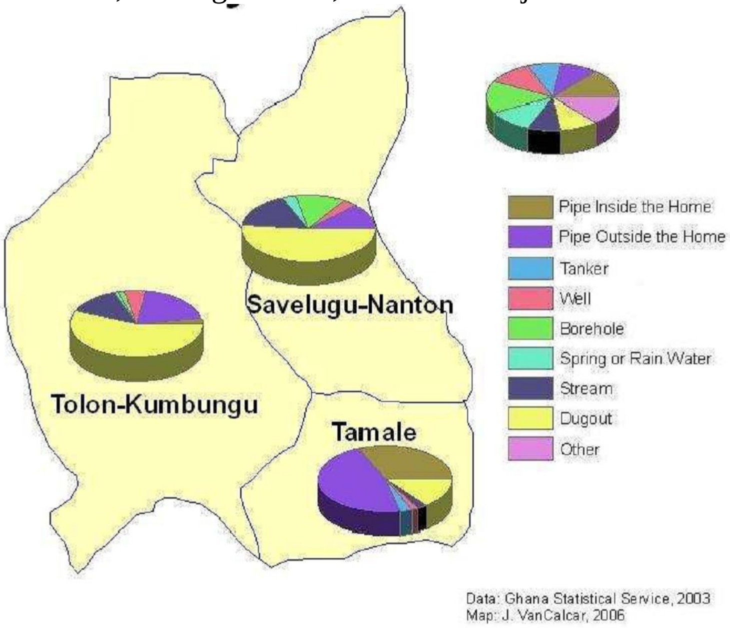
6.8.4 Limitations

At the time of this study, many tanks no longer contained rainwater and were either dry or being used to store water from other sources. Only at community centers where rainwater was being used only in emergency, was there rainwater to sample. At other community locations, rainwater supply had ceased and tanks were either filled with trucked tanker water or with municipal piped water. This allowed the sampling of water stored in community cisterns, but did not allow the study of the bacteriological quality of rainwater harvested water.

Most household tanks in the Presbyterian tank program constructed prior to July 2008 had time to fill during the rainy season, and they contained rainwater supply. These tanks had sufficient water to sample. During the daytime, when household surveys were being conducted, some landlords or heads of households were not present. This posed a problem for sampling as these owners commonly held the keys to the tap. In all, I was able to sample rainwater from 13 Presbyterian RWH storage tanks, and from the PHW RWH system as well as the Veterinary Collegef for a total of 15 RWH storage tanks.

6.9 Quality of Alternative Sources

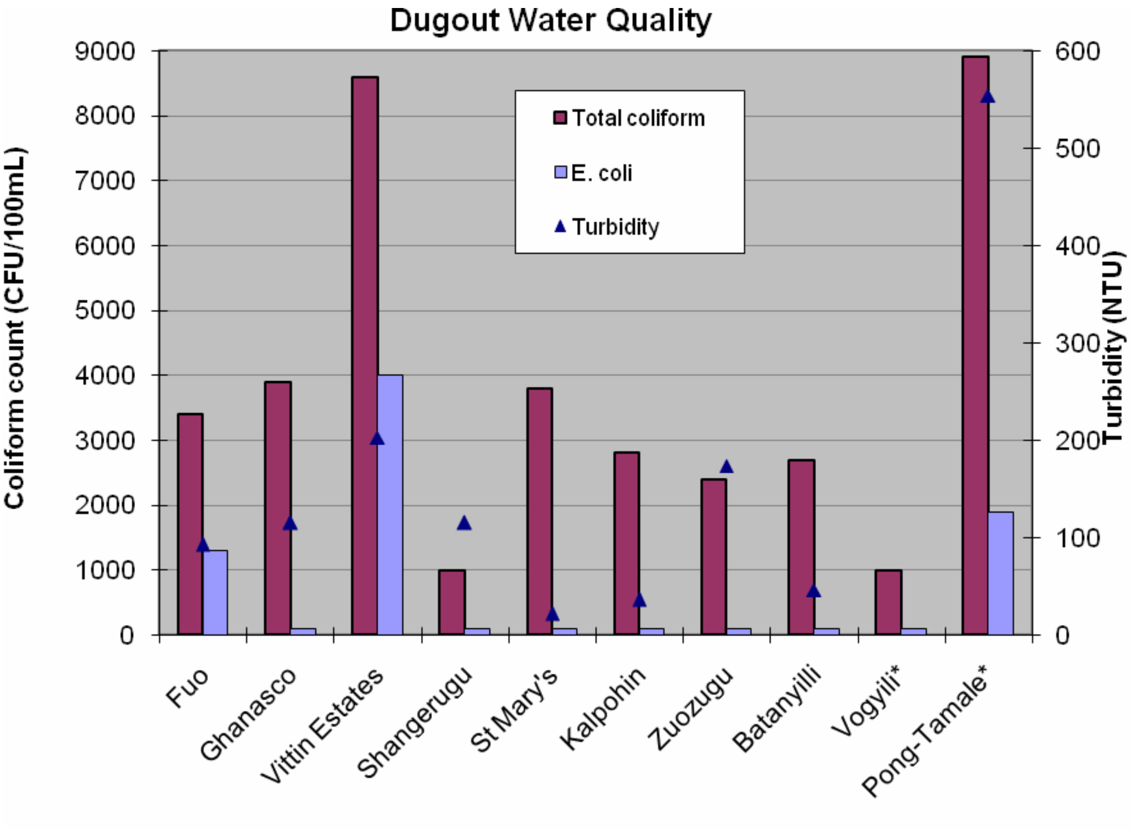
50% of households in the Northern Region of Ghana drink from an unimproved water source. (Ghana Statistical Services, 2005) Figure 54 shows the types of water sources used by households in 3 of 20 districts in the Northern Region of Ghana. The majority of users in Tolon-Kumbungu and Savelugu-Nanton use dugout water. This was the case with most of the Presbyterian household tanks. The Presbyterian church has constructed RWH tanks in 3 districts: Tamale, Zabzugu/Tatale, and East Gonja.



Data: Ghana Statistical Service, 2003
Map: J. VanCalcar, 2006

Figure 54: Map of Types of Water Sources Used by Households in Northern Region, Ghana (VanCalcar, 2006)

In January 2009, as part of her work on biosand filters, Clair Collin, a fellow MIT Master of Engineering student working with PHW, surveyed the water quality at eight dugouts in the Northern Region. (Collin, 2009) In addition, two samples the author took from the Pong-Tamale dugout and Vogyili dugout are plotted together with Collin's data. (Figure 55) The water quality of these sources is very poor. Every dugout shows evidence of *E.coli* contamination ranging from 99-4000 CFU/100ml. Households typically drink, cook, and bathe in this water without treatment.



*=Sampled by David Barnes

Figure 55: Dugout Water Quality (Collin 2009)

Also, in January 2009, Ghana teammate Sara Ziff conducted a survey of bacteriological quality of various water sources in the Tamale city area as part of her assessment of the siphon filter. (Ziff, 2009) Her results suggest that even the piped water supply has significant levels of contamination. (Figure 56 and Figure 57)

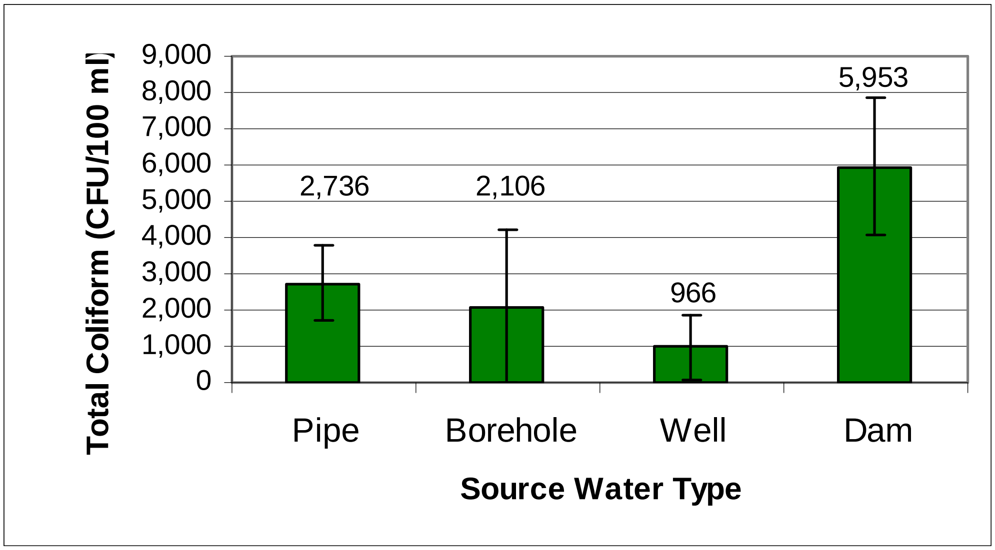


Figure 56: Total coliform by source water type in Tamale area (Ziff, 2009)

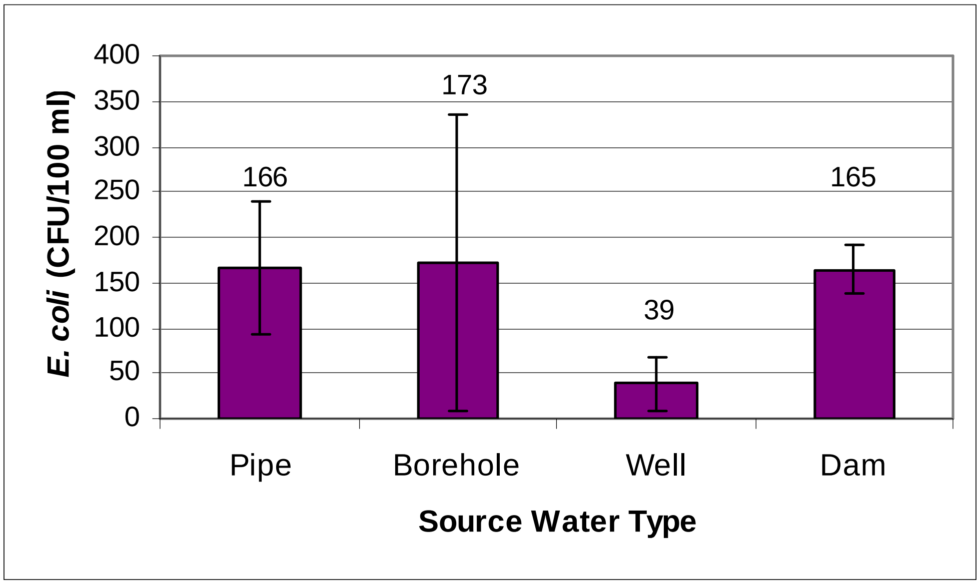


Figure 57: E.coli by source water type in Tamale area (Ziff, 2009)

6.10 Results

Samples were taken from water cisterns and tanks at community centers and households with installed RWH systems. A variety of different source waters were sampled. Community water supplies, with the exception of the Veterinary Laboratory, no longer contained rainwater, and had been filled with an alternative water source. (Appendix I) Unprotected surface sources had the lowest water quality. (Vogyili Dugout, (Figure 55) Pong Tamale Dugout, (Figure 55) Veterinary Laboratory Water Treatment Plant Pretreatment Water (Figure 58)) The Pong Tamale Vocational School Tank #2 was sampled twice. One sample was taken using a fetching cup (1st bar-far left) while the other (2nd bar) was taken directly from the tap. Results suggest that the vessel used for fetching was unclean. (Figure 58)

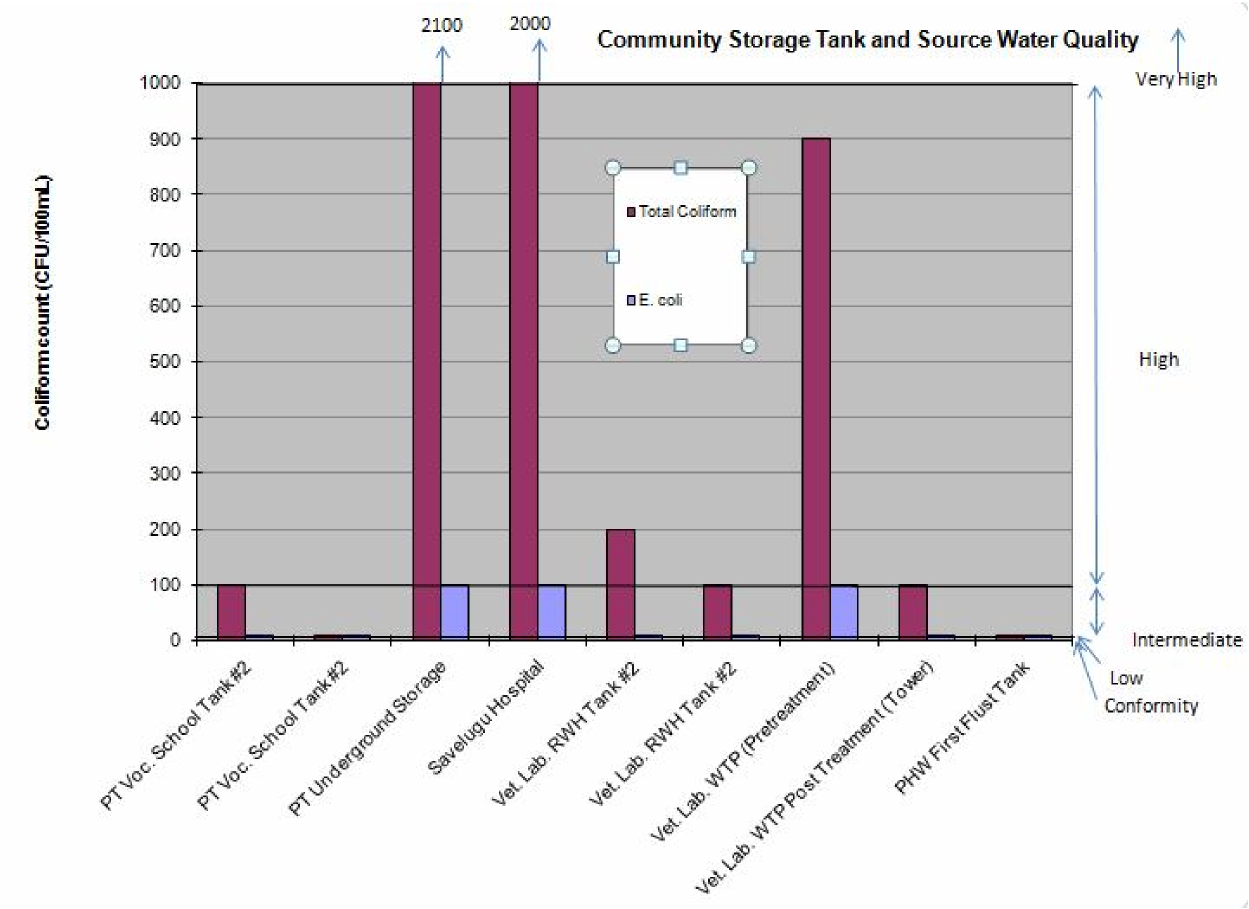


Figure 58: Community Water Quality Results

Presbyterian Tank Program tanks were also sampled. These household tanks contained rainwater with the exception of tanks in Kakpaille, which had been filled with piped water by the Presbyterian Church, as it was the end of the wet season when their construction was completed. Tanks #7 and #3 contained tap water or a mix of tap and rainwater. Quality of harvested rainwater samples in these household tables is much improved over the community water samples in terms of *E.coli* and total coliform. (Figure 59)

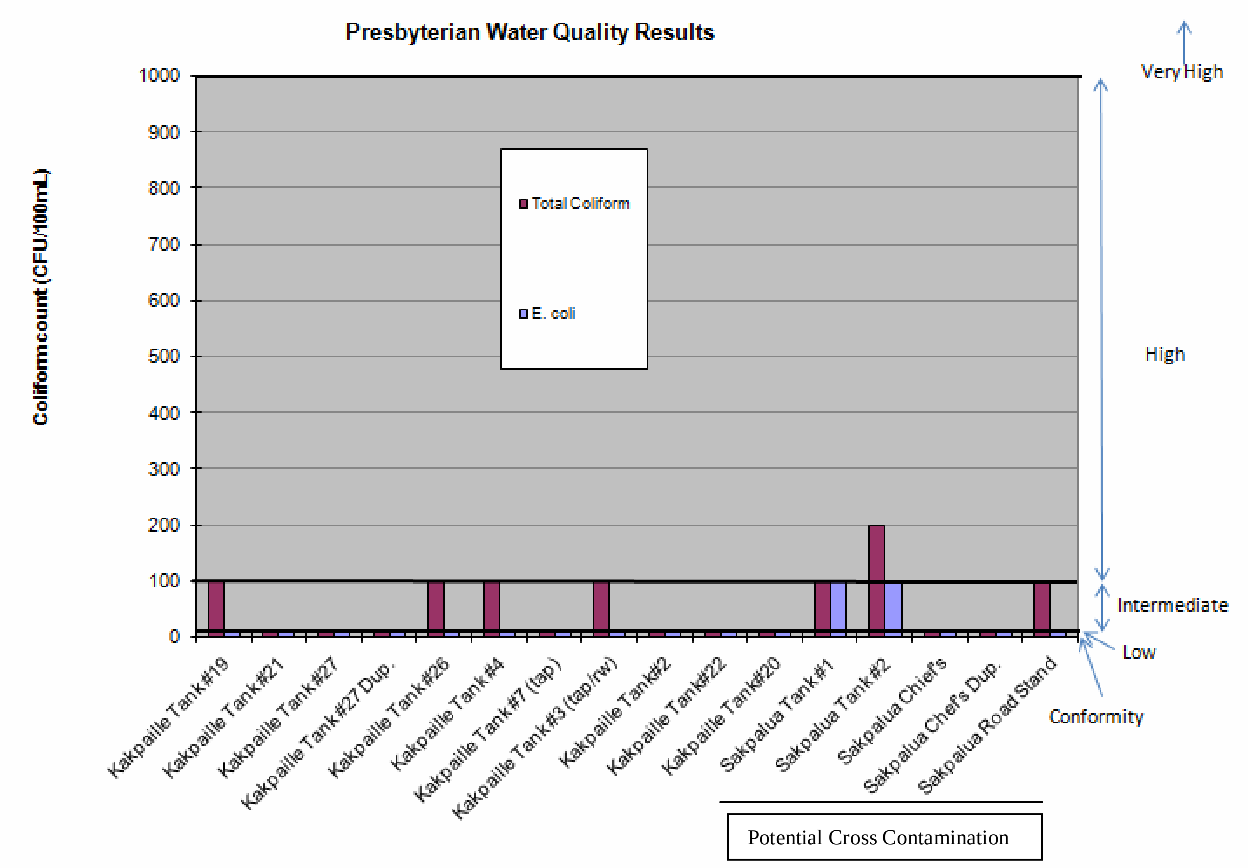


Figure 59: Water Quality of Presbyterian Tank Program

Samples from two more rural locations were also taken. Sakpalua samples showed higher levels of contamination; however, during transport, Sample 21 from the Vogyili dugout leaked, and cross contamination could have occurred. Forty-two percent (6 out of 14) of rainwater samples were positive for total coliform contamination greater than 10 CFU/100 ml but only 1 of 14 was greater than 100 CFU/100ml. This represents a significant water quality improvement over alternative water sources. Fourteen percent (2 out of 14) were positive for *E.coli* contamination greater than 10 CFU/100 ml. These samples could have been cross-contaminated or actually contaminated. Most samples qualified as low risk, with only two samples qualifying as an intermediate risk. Samples from dugouts ranged from intermediate risk to very high risk. Ziff's mean results for pipe, borehole and dam all indicate a mean high risk level. In contrast, harvested rainwater and water stored in RWH tanks posed a low to intermediate risk, which is a substantial improvement over Ziff's improved and unimproved sources.

6.11 Discussion

In general, water quality data indicate that household rainwater supply tanks implemented by the Presbyterian Church in Northern Ghana have generally low levels of *E.coli* contamination and fall into the WHO low risk category. Large community cisterns and tanks show higher levels of total coliform contamination, but still range from low to intermediate risk in terms of *E.coli*. The

Veterinary Laboratory fast-sand filtration plant showed total coliform contamination post-treatment. In comparison to other available sources, water stored in household rainwater tanks, represents a significant improvement in bacterial quality over local unimproved sources but all locations should not be considered "safe" if "safe" is defined as a low risk water <10 CFU/100ml.

Chapter 7: Economic Considerations

7.1 Introduction

Incidence of diarrhea is high particularly in children under the age of five, where, according to a study by Green et al of 237 households in 7 communities in and around the city Tamale in the Northern Region of Ghana, the incidence found was approximately 10%. (Figure 60) This compares with 15% diarrhea rate in the Northern Region based on the Ghana Statistical Surveys Demographic Health Survey data. (Figure 61) Diarrhea is a large contributor to child morbidity and mortality. Access to safe affordable drinking water is a necessity to lower morbidity and mortality.

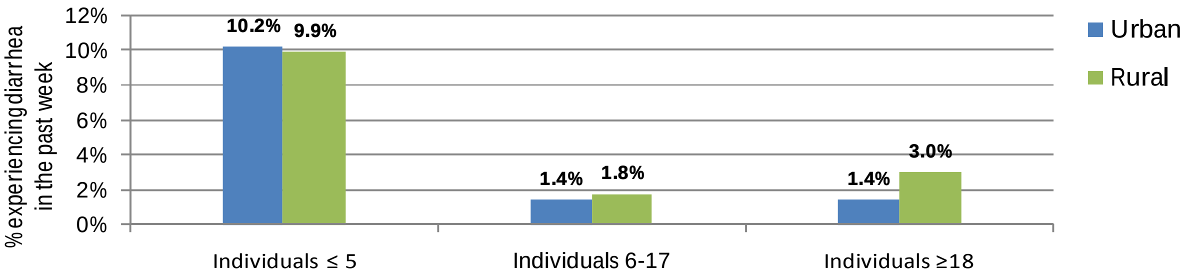


Figure 60: Incidence of Diarrhea (Green et al, 2008)

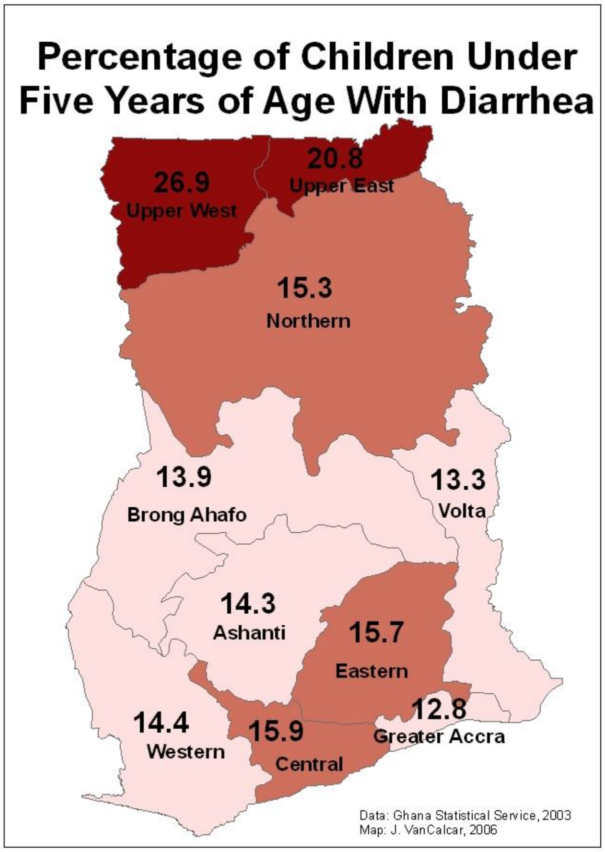


Figure 61: Incidence of Diarrhea (VanCalcar, 2006)

7.2: Current Water Supply

Currently, Ghanaians in the Northern Region around Tamale get their primary water supply from a variety of different sources. (Figure 62) In the 2008 city survey by Green et al., people were asked what they considered to be their primary water sources. Surprisingly, rainwater collection makes up the largest percentage of primary urban water supply and a significant amount of the rural water supply as well. One of the reasons this is surprising is because it was the author's experience that most homes did not have formal RWH systems, suggesting that ad hoc or informal systems make up a large portion of the 58% urban and 50% rural who are harvesting rainwater.

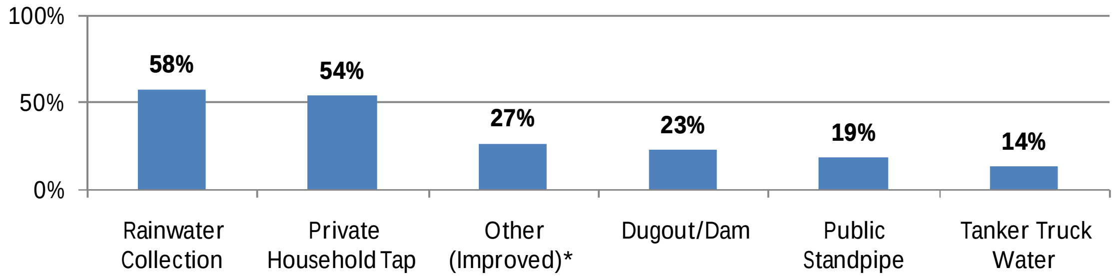


Figure 62: Primary Urban Water Supply (Green et al, 2008)

In the rural areas, 93% rely on dugouts and other unimproved sources for water supply. (Figure 63) This water is highly turbid and a vector for guinea worm, diarrhea, malaria and other water borne diseases. With proper treatment, it could become a safe source of drinking water but still may pose a community health risk as breeding habitat for malaria-bearing *Anopholes* and other mosquitoes.

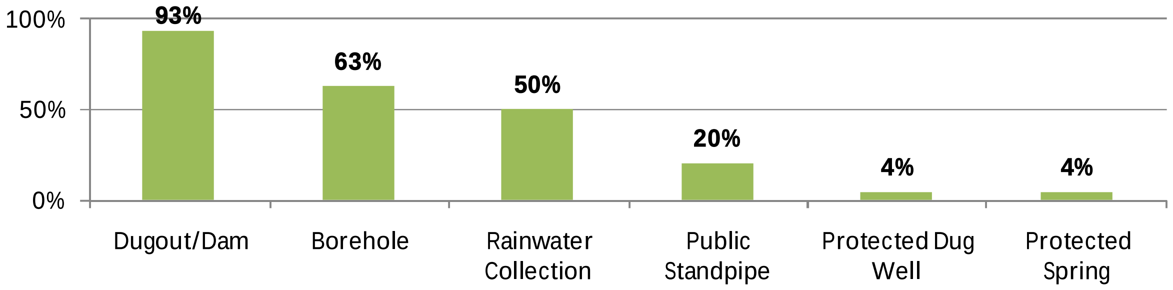


Figure 63: Primary Rural Water Supply (Green et al., 2008)

Rainwater collection, in this context, is often the informal practice of collecting runoff from roofs in jerry cans and buckets. However, if it could be expanded, it could prove a more significant source of water supply in both urban and rural settings.

7.3 Willingness to Pay

Estimating the willingness to pay or ability to pay for water supply is often difficult. Willingness to pay is the price at which a person is willing to purchase something. Ability to pay is an estimation of a person’s capability to purchase or pay for something. Often, a good proxy is to look at what goods households currently own. In Green’s 2008 survey of 237 households around Tamale city in Northern Ghana, about 40% in urban and rural areas have a motorcycle as a means of transit. (Figure 64) This does not indicate that 40% of those in rural areas would be willing or able to pay for a rainwater harvesting tank, but it does suggest that some capital can be saved for big purchases. Income for rural farmers is also highly non-uniform. Because most farmers in Northern Ghana do not practice irrigated agriculture, it means that farmers typically harvest one crop per year. Therefore, at the time of the yearly harvest, most farmers earn all of their money in a very short period of time. Also, large purchases are made by males in the households meaning that perhaps women, who are responsible in large part for collecting water, might not have a chance to reflect their preferences in the market. This is particularly significant when discussing travel time and household labor benefits. (Gould and Nissen, 1999)

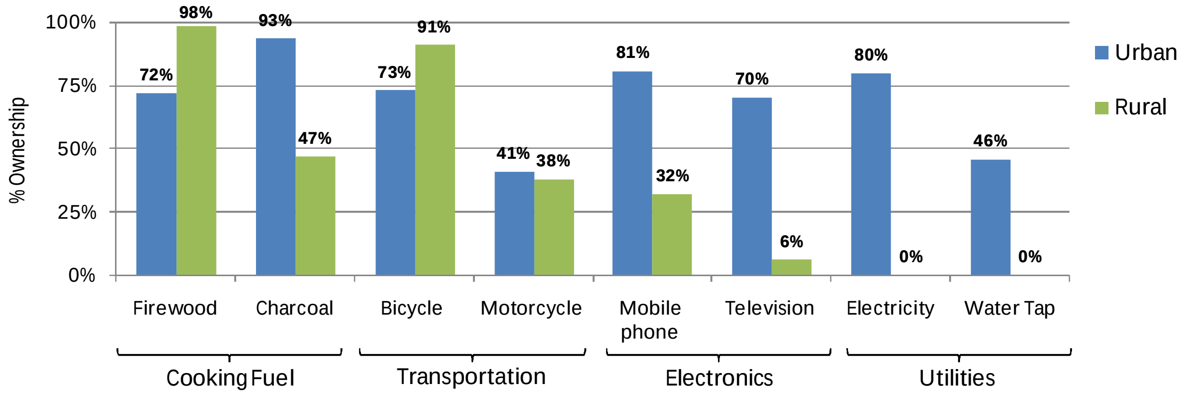


Figure 64: Urban and Rural Ownership of Goods (Green et al., 2008)

7.4 Cost of Storage

In Ghana, many different alternatives have been proposed for urban and rural water treatment. Some are centralized or community scale treatment options, while others are household-based. Rainwater harvesting is a proposed technology that can be applied at either scale. At the household scale, storage volumes are lower and price per cubic meter is higher. At the community scale, storage volume is high and price per cubic meter is much lower.

The principal and most costly component of rainwater harvesting systems is the storage tank. The storage tank for Pure Home Water’s RWH in Tamale, Ghana, detailed by Ming Wong[5] accounted for almost 70% of the materials cost. To thoroughly understand the price of rainwater harvesting systems, it is then essential to understand what influences price of the storage tank, which is the most expensive component of the overall system.

7.5 Unit Cost of Water

Unit cost of water per cubic meter of yield is a useful metric for comparing the cost of different water supplies. According to the calculations used by Gould and Nissen (1999) in Table 12, and excluding any type of discounting, the cost per cubic meter of some water tanks in semi-arid and wetter regimes would be competitive, cost-wise with other types of water treatment in Ghana.

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[5] Ming Wong, a student at the Rhode Island School of Design, designed the PHW RWH system

Table 12 shows the Gould and Nissen pessimistic, realistic, and optimistic costs. Comparing that to Table 17 and Table 18, we see that most RWH systems in Northern Ghana fall in the range semi-arid and realistic, between $0.50/m^3 and $3.00/m^3. This is excluding any type of benefit analysis that might further favor the use of rainwater harvesting.

Table 12: Cost of rainwater storage tanks (Gould and Nissen, 1999)

		Expected tank-life scenarios	
	Pessimistic	Realistic	Optimistic
Assuming tank cost $20-$120 per m^3	10yrs	20yrs	30yrs
Annual rainwater supply in tank volumes	Cost $/m^3	Cost $/m^3	Cost $/m^3
Arid (1 tank volume)	2-12	1-6	0.66-4
Semi-Arid (2 tank volumes)	1-6	0.5-3	0.33-2
Semi-Humid (5 tank volumes)	0.4-2.4	0.2-1.2	0.13-0.8
Humid (10 tank volumes)	0.2-1.2	0.1-0.6	.06-0.4

7.6 Lowering the Cost of Storage

Cresti (2007) examined in detail a cheap 6m^3 tank design implemented in a refugee camp in Uganda which incorporated a standard tarpaulin to line a hole dug by the homeowner. The system was covered with an iron roofing sheet. Using a tank lifetime of 10 years implemented in a semi-arid climate, the Cresti storage tank would yield an annual rainwater supply of 2 tank volumes (tank volume for Cresti design is 6m^3.) (Table 12) This would amount to 12m^3/year and 120m^3 over the 10 year project life. Therefore, the cost of water from the tank would be $0.33/m^3.

Cost per cubic meter of storage capacity is an initial capital cost divided by the storage volume of the tank. Cost per cubic meter of water provided makes assumptions about product lifetime and amount of water provided over the life of the project. In terms of cost per cubic foot of storage capacity, Cresti's design comes to $6.66/m^3 of storage capacity. (Table 13) According to Gould and Nissen, underground ferrocement tanks more than 14 times that capacity, cost $21/m^3 of storage. A plastic Sintex brand tank costs $1000 for 8m^3 of storage yielding a unit cost of $125/m^3 of storage capacity. Clearly, lowering cost of storage by building with cheap materials and using unskilled labor can significantly reduce storage costs of rainwater harvesting tanks.

Table 13: Cost of tarpaulin water tank: 6 m3 (Cresti 2007)

Item	**Quantity**	**Cost ($)**
UNHCR tarpaulin (4×5m)	1	$20
Iron roofing sheet	1	$20
Wood & mud from site	-	-
Labor provided by householder	-	-
Total Cost		$40
Cost/m3 of Storage Capacity		$6.66

7.7 Estimating Ability to Pay

Based on Green's teams' survey, the average urban household income in Tamale, Ghana is \$1,275/yr[6] while the average rural household income is less than half of that at \$516/yr. Using the 5% rule discussed by McPhail, (1993) the following ability to pay for water supply treatment is found. Ability to pay is estimated between \$0.06 and \$0.17 per day per household for rural and urban households respectively. (Table 14)

Table 14: Ability to Pay (Green et al, 2008)

	Household type	
	Urban	Rural
Average income (\$/yr)	\$1,275	\$516
Ability to pay (\$/yr)	\$64	\$26
(\$/day)	\$0.17	\$0.07

Ability to pay does not necessarily indicate a willingness to pay. However, formal willingness to pay is difficult to accurately determine and requires extensive surveying that is generally product specific. Ability to pay is used here as an alternate measure to estimate affordability.

7.8 Equivalent Annual Cost of Two Example RWH Systems for Northern Ghana

Equivalent annual cost (EAC) is the annualized net present value of the costs over the life of the project. Maintenance costs are considered to be negligible over the life of the project.EAC for the Pure Home Water House system and Daria Cresti's low cost design were calculated using a hypothetical interest rate of 4%. This low interest rate of 4% was chosen assuming the only lenders would be either government or NGO's. An interest rate of 4% represents a subsidized rate, one possibly offered by a government or NGO that is seeking to promote a RWH program. Microcredit operations usually charge higher interest rates and expect a return on investment within one year. Hence, these operations usually only make loans for profit-generating activities. Loan schemes are difficult to implement as they require a clear understanding of terms, a willingness to pay by the user, and a mechanism to encourage repayment. (Gould and Nissen, 1999)

According to calculations of the EAC using the 4% interest rate, the ability to pay of the average urban dwelling Ghanaian for the PHW rainwater harvesting system would need to be subsidized by roughly fifteen dollars per year. (Table 15) This system, however, uses the most expensive storage mechanism, plastic water tanks. Less expensive systems might be feasible for urban dwellers and even rural dwellers. For example, the Cresti design is feasible for both urban and rural dwellers. (Table 16)

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[6] Exchange Rate = \$1.00GHC=\$0.83USD (January 2009) used to convert GHC to dollars in this chapter.

Table 15: EAC for PHW System Compared with Urban Ability to Pay

Total Initial Capital Cost	$1,070
Materials	$959
Labor	$111
EAC	$79
Ability to Pay(Urban)	**$64**

Below, the EAC for the Cresti tarp system is calculated as $19 using a discount rate of 4%. For Cresti's low-cost system, both urban and rural users would be able to pay. No subsidy would be required at this total set of costs for either group.

Table 16: EAC for PHW System Compared with Urban and Rural Ability to Pay

Total Initial Capital Cost	$257
Materials	$257
Labor	$0
EAC	**$19**
Ability to Pay(Urban)	**$64**
Ability to Pay (Rural)	**$26**

7.9 Revolving Funds

An alternative funding mechanism to loans is a revolving fund scheme, where users each contribute a specified amount each month. Revolving funds have been shown to be effective. The amount raised by users each month should equal the price of one tank, and a new user is selected to receive the new tank by lottery each month until all tanks are paid for. (Gould and Nissen 1999) In Northern Ghana, the Presbyterian Church was attempting to implement this system with their tank program. However, weekly contributions per household were only $0.41. Also, the program was transitioning from fully subsidizing tanks to charging $83 per tank. In Kakpaille, two users in the group had contributed but had not received tanks, as donor funding had run out. The sustainability of such schemes relies on a greater ability and willingness to pay.

7.10 Unit Cost for Presbyterian Household Tank Program

Three different tank/roof area combinations were each modeled with two different demand scenarios. The three tank/roof area combinations used were:

High Reliability: A tank with lowest number of users but largest roof area
Average Reliability: A tank with average number of users and average roof area
Low Reliability: A tank with the highest number of users and least roof area

The two demand scenarios coupled with these tanks were a basic drinking water provision of 5 L/day/capita and a drinking and cooking water scenario of 20L/day/capita. These demands were assumed constant year around. They are somewhat arbitrary and may not actually represent the average performance of a real tank, as user behavior defines demand.

Total water yield is calculated as:

$$Total\ Yield = Daily\ Demand\ (L/day) * 1m^3/1000L * 365.25 days/yr * 20yr\ Project\ Lifetime * Reliability$$

Unit cost per cubic meter is then calculated as the initial capital cost divided by total yield, assuming the value of a liter of water is not discounted in the future. Using these scenarios coupled with the simulation model, the price per cubic meter of water ranges from \$0.89-\$8.62/m^3.

Table 17: Presbyterian Household Tank Program: Unit Costs for two demand scenarios (\$/m3)

			Demand Scenario 1	Demand Scenario 2	Scenario 1	Scenario 2
Reliability	# of Users	Roof Area (m^2)	Reliability(5 L/day/capita)	Reliability (20 L/day/capita)	Unit Cost (\$/m^3)	Unit Cost (\$/m^3)
High	7	72	99.9%	77.5%	\$2.77	\$0.89
Average	14	34	95.8%	25.7%	\$1.48	\$1.38
Low	20	19	42.6%	5.1%	\$4.13	\$8.62

Cost per cubic meter was also computed in the same manner for community water supplies. Pong Tamale Vocational School's Systems 1 and 2 provide water at a very low cost even though they can only support demand 5-6% of the time. This may not be ideal but shows that even small storage volumes can support high demands occasionally. If storage volume was increased 75 fold, reliability would only double, as more roof area would need to be guttered to increase supply.

Table 18: Community Water Tanks: Unit Cost (\$/m3) (*=Cost estimated)

Tank Name	**Rooftop Area (m^2)**	**Storage Capacity (m^3)**	**Demand (L/day)**	**Reliability %**	**Cost (\$)**	**Unit Cost (USD/m^3)**
World Vision	1129	50	1639	68	8333	\$1.02
Pong Tamale Health Clinic	46	0.5	16	75	*150**	\$1.73
Pong Tamale Vocational School (1)	57	1	992	**5**	*150**	\$0.41
Pong Tamale Vocational School (2)	69	1	992	**6**	*150**	\$0.33
Pong Tamale Health Center	70	75	189	91	3500	\$2.78
Savelugu Hospital	76	75	992	11	3500	\$4.40

Initial capital cost of plastic and ferrocement storage tanks, the two household options surveyed in Northern Ghana, are plotted in Figure 65. Small economies of scale are present with the plastic storage tank capacity. Price elasticity of less than 1 (the exponents of the power curve fits) indicate that price per unit capacity decreases with the size of storage. However, the cost per cubic meter of storage capacity does not increase dramatically with increased storage capacity.

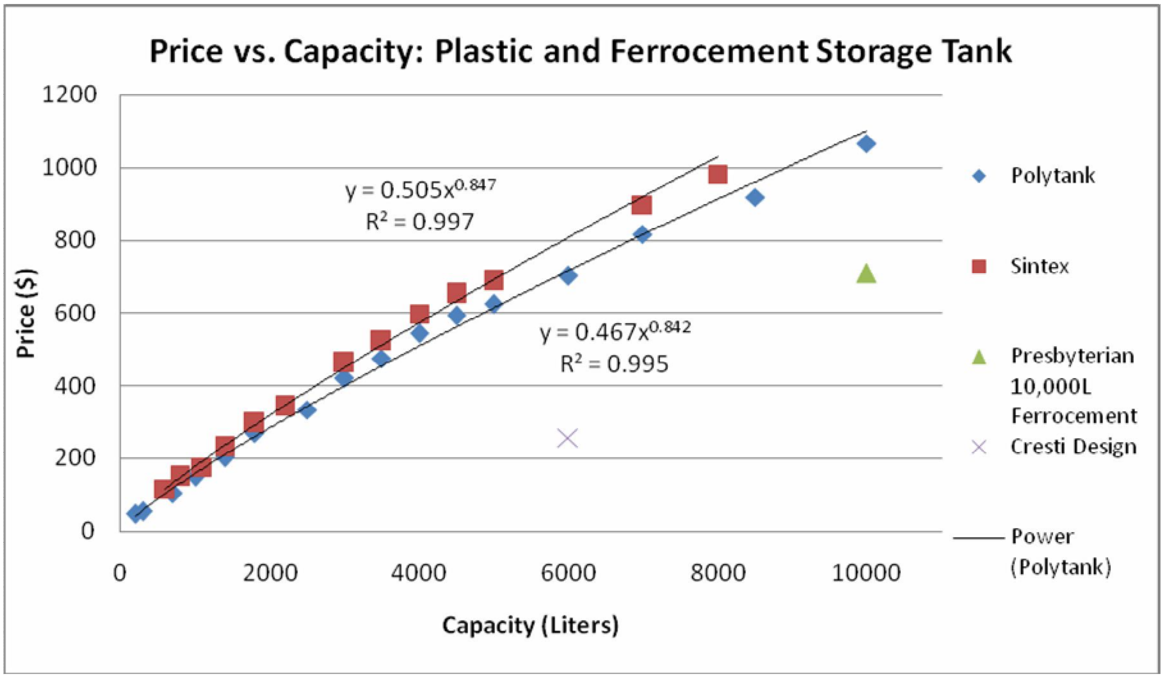

Figure 65: Initial capital cost of household storage options in Northern Ghana

Ferrocement tanks are significantly cheaper, 66% of the cost of an equivalent Polytank. However, they require skilled labor to construct, which is not represented in the cost outlined by the Presbyterian Church. However, even with a fee for labor, the ferrocement tank would be a cheaper alternative. A community member volunteers to be trained as a technician. All other unskilled labor is provided by the community. It takes two weeks to construct one tank. Below, the Presbyterian Ferrocement 10m^3 Tank is compared with larger cement block designs. (Figure 66)

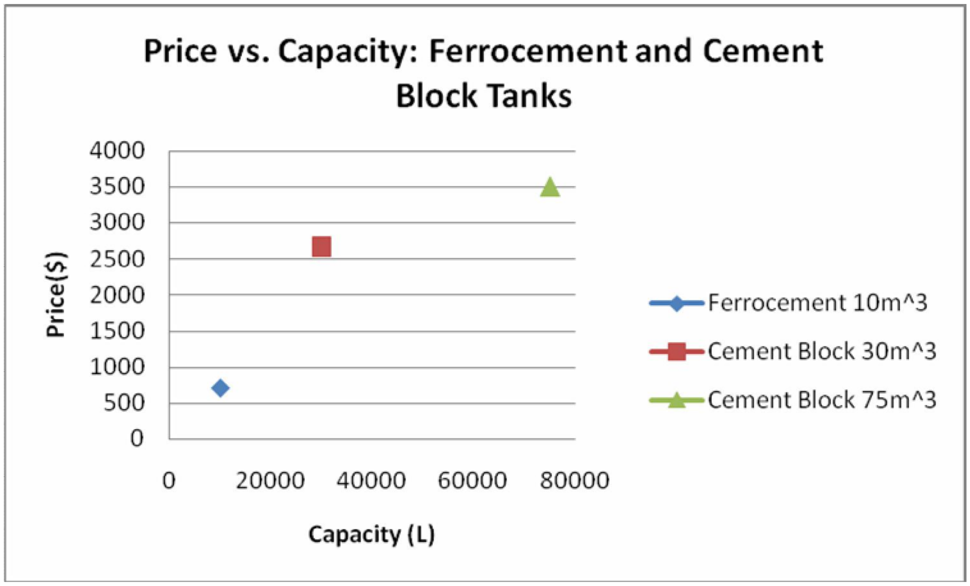

Figure 66: Initial capital cost of on-site constructed storage options in Northern Ghana

7.11 Cost of Alternative Technology

The comparative cost of different RHW supplies is indicated above. (Figure 65 and Figure 66) Compared with alternative supplies in the region, and providing capital is available to make the initial investment and provide the necessary subsidy, effectively designed and implemented, reliable rainwater harvesting systems are competitive with the cost of piped supply (which is also currently subsidized.) At the high unit cost low reliability end, they would be comparable to hand-tied sachet water. (Figure 67) At the low unit cost high reliability end, they would be compable to piped Ghana Water Company water. Clearly, the careful implementation, cost minimization and proper sizing can dramatically effect the competitiveness of rainwater harvesting as an alternative water supply. Rainwater harvesting can be an economically sensible alternative water source, particularly when other sources are not viable or likely options.

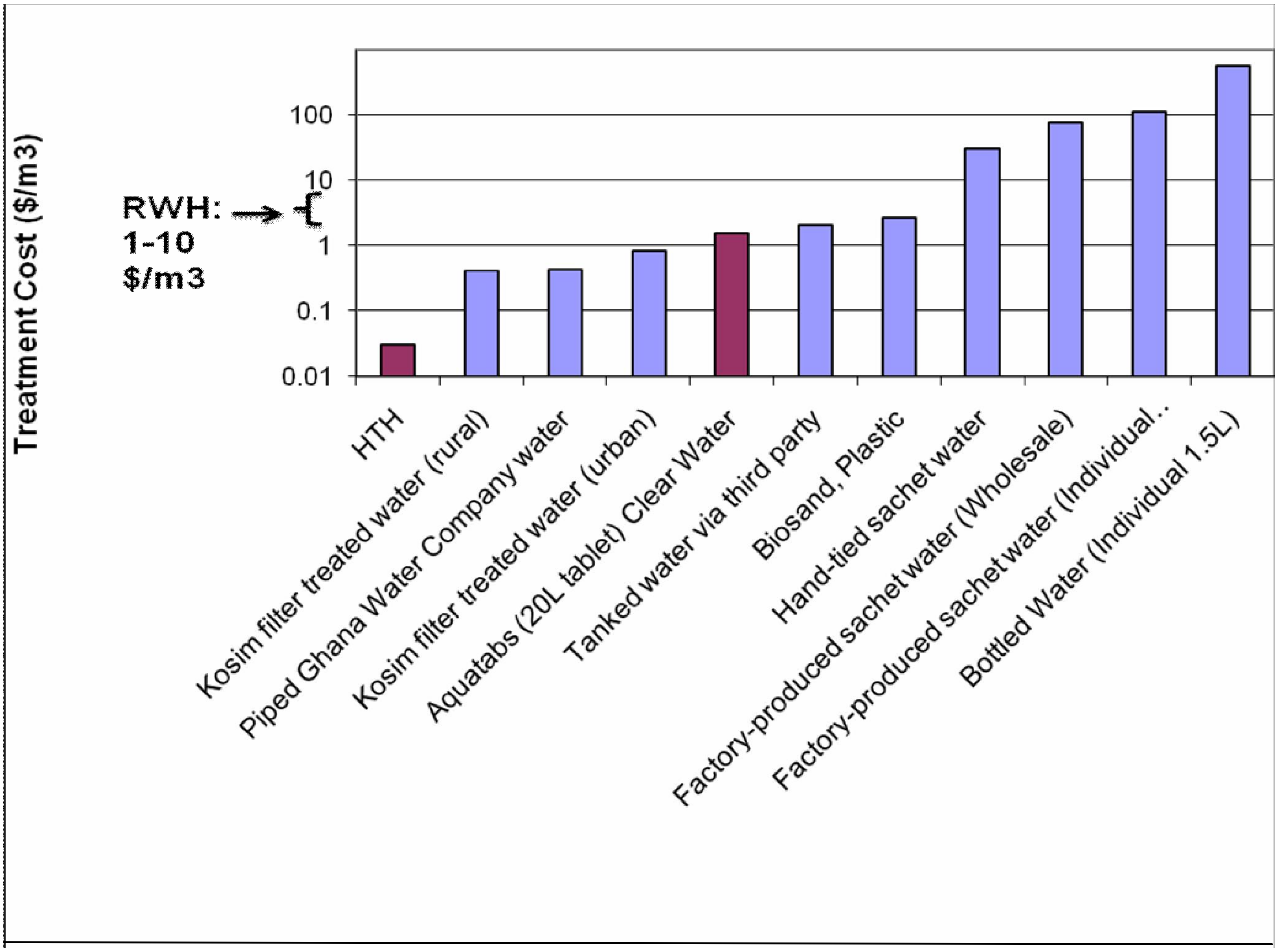

Figure 67: Cost of Alternative Water Sources (Green et al)

Chapter 8: Conclusions/Recommendations

8.1 Economics

A rainwater harvesting system is a costly investment. Formal implementation of RWH in Northern Ghana has been almost exclusively subsided. For further, more widespread adoption and effective, reliable system construction, the cost of the technology needs to be lowered to make it accessible to residents in both urban and rural Northern Ghana. Scale up of this technology depends upon affordability, and until this point is reached, RWH could only proceed with donor funding or government investment and/or lending. That being said, informal rainwater collection practices are widespread, and low-cost ways to improve the reliability of these efforts would make RWH more effective and accessible.

In Ghana, rainwater harvesting could play a role in expanding the clean drinking water supply. However, capital for initial investment is lacking and households would probably be unable or unwilling to come up with sufficient money up front for a system. Rainwater harvesting can take advantage of economies of scale and local materials and skill. However, due to the high initial investment as compared with say $7 siphon filter or a $20 ceramic pot filter, which can be affordable to those in need of safe water, financing or subsidy would be required for widespread implementation, particularly in rural areas.

8.2 Rainwater Quality

In this study, rainwater showed improved bacteriological quality over alternative sources, including dugout water and even piped water. All Presbyterian Tank Program rainwater harvesting systems not subject to potential cross contamination had *E.coli* ≤10 CFU/100ml, which is low risk. Other water sources showed a higher level of mean contamination. Also, further microbiological testing should be conducted during the rainy season to determine water quality during this time period, as water quality varies with time since the last rain event. The Presbyterian Tank program should ensure that tank users have the necessary materials to cover overflow pipes and preserve water quality.

8.3 Reliability

I recommend full guttering of Presbyterian Tank Program $10m^3$ ferrocement tanks. In many locations, guttering was not available to gutter the whole front of the roof, and only rarely were both sides guttered (two instances.) Reliability can be improved dramatically at low cost if these simple measures are taken.

8.3 Future Work

Further study should be conducted in the Northern Region to properly size first-flush systems and provide proper recommendations to users of RWH systems. Doyle’s recommendations were site specific but her method could be applied to properly size first flush systems in Northern Ghana and improve water quality of rainwater supplies.

The feasibility of low-cost underground storage should be investigated. The geology and soil conditions in the Tamale region might provide a suitable match for a cheaper storage mechanism using plastic tarps and constructed pits. Latrite soils with low rooting depths could be ideal for the longevity of such designs, as root growth and puncture of liners tend to be a big problem. Digging is very difficult and soils are hard but the labor could prove to be worth it. If the cost of storage could be lowered, rainwater harvesting could contribute in a larger way to PHW's mission and reach more people.

Do-it-yourself rainwater harvesting in the Northern Region of Ghana is a fairly widespread. Finding ways to improve the quantity and quality of informal harvesting is a potential means for improving water supply for many low income households in the Northern Region.

The author recommends the use of a filter, such as the *Kosim* ceramic pot filter. If distributed in conjunction with RWH tanks, it only represents a small fraction of the total cost of the system, and it could be used to treat supplementary contaminated supplies as well. Most households rely on dugout water for at least a portion of the year. To improve health year round, a *Kosim* filter would improve both the quality of rainwater consumed, but also of other unprotected surface sources.

Currently, rainwater harvesting systems require partial, if not total subsidy. For widespread implementation, the cost of rainwater harvesting needs to be lowered. The biggest potential is lowering the cost of storage. Without lowering this cost, implementation of rainwater harvesting in Northern Ghana will continue to be limited by the amount of subsidy or donor money available to fund system construction. In terms of funding, establishing community revolving funds shows the most promise. However, community contribution should not prohibit those most in need from accessing RWH systems. Rainwater harvesting in Ghana shows significant promise and significant room for improvement by implementing these simple low-cost recommendations.

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Appendix A: Water Quality Information

Water Sample Information: Community Center Cisterns

Sample ID	Date	Time	Location	Method
1	1/8/2009	13:28	Pong Tamale Vocational School Tank #2	Bucket used by girls to fetch
2	1/8/2009	13:29	Pong Tamale Vocational School Tank #2	From tap
3	1/8/2009	13:37	Pong Tamale Underground Storage	Grab sample from door in roof of tank
4	1/8/2009	13:55	Pong Tamale Vocational School Dam	Grab sample from edge of dugout
5	1/9/2009	10:08	Savelugu Hospital Old Rainwater Cistern	Fetching bucket
6	1/10/2009	13:27	Veterinary Laboratory Rainwater Tank #2	Fetching bucket
7	1/10/2009	13:28	Veterinary Laboratory Rainwater Tank #2	Fetching bucket
8	1/10/2009	15:20	Veterinary Laboratory Treatment Plant Settling Basin Pretreatment	Grab from first settling basin
9	1/10/2009	15:21	Veterinary Laboratory Treatment Plant Post Treatment Tower	Grab from large tap to fill trucks

Water Quality Data: Community Center Cisterns

Sample ID	Notes	Tot Col>=10	E. Coli?	Red	Blue	Total
1	Source: Trucked Veterinary College	Yes	No	0	0	0
2	Source: Trucked Veterinary College	No	No	0	0	0
3	Source: Trucked Veterinary College Used for bathing only	Yes	Yes	21	0	21
4	Dugout	Yes	Yes	70	19	89
5	Piped Water Supply Used to Fill Cistern	Yes	Yes	20	0	20
6	Rainwater	Yes	No	2	0	2
7	Rainwater	Yes	No	0	0	0
8	Source Water: Pumped from White Volta	Yes	Yes	9	0	9
9	Collected from slowly dripping large tap	Yes	No	1	0	1

Water Quality Summary: Community Water Sources

Sample ID#	Location	Tot Col CFU/100ml	*E.coli* CFU/100ml
1	Pong Tamale Vocational School Tank #2	99	9
2	Pong Tamale Vocational School Tank #2	9	9
3	Pong Tamale Underground Storage	2100	99
4	Pong Tamale Vocational School Dugout	8900	1900
5	Savelugu Hospital Old Rainwater Cistern	2000	99
6	Veterinary Laboratory Rainwater Tank #2	200	9
7	Veterinary Laboratory Rainwater Tank #2	99	9
8	Veterinary Laboratory Treatment Plant Settling Basin Pretreatment	900	99
9	Veterinary Laboratory Treatment Plant Post Treatment Tower	100	9
21	Vogyili Dugout	1000	99

Water Quality Summary: Kakpaille

Sample ID#	Location	Total Coliform CFU/100ml	*E.coli* CFU/100ml
10	Kakpaille Tank #19	99	9
11	Kakpaille Tank #21	9	9
12	Kakpaille Tank #27	9	9
12(2)	Kakpaille Tank #27	9	9
13	Kakpaille Tank #26	99	9
14	Kakpaille Tank #4	99	9
15	Kakpaille Tank #7	9	9
16	Kakpaille Tank #3	99	9
17	Kakpaille Tank#2	9	9
18	Kakpaille Tank#22	9	9
19	Kakpaille Tank#20	9	9

Water Quality Summary: Sakpalua

Sample ID#	Location	Total Coliform CFU/100ml	*E.coli* CFU/100ml
22	Sakpalua Tank #1	99	99
23	Sakpalua Tank #2	200	99
24	Sakpalua Chief's	9	9
24(2)	Duplicate	9	9
25	Sakpalua Road Stand	99	9

Water Sample Information: Presbyterian Tank Program: Kakpaille, Ghana

Sample ID	Date	Time	Location	Method	Source Water
10	1/13/2009	13:50	Kakpaille Tank #19	Grab from tap	Rainwater
11	1/13/2009	14:36	Kakpaille Tank #21	Grab from tap	Rainwater
12	1/13/2009	15:27	Kakpaille Tank #27	Grab from tap	Rainwater
12(2)	1/13/2009	15:27	Kakpaille Tank #27	Grab from tap	Rainwater
13	1/13/2009	16:20	Kakpaille Tank #26	Grab from tap	Rainwater
14	1/21/2009	11:09	Kakpaille Tank #4	Grab from tap	Rainwater
15	1/21/2009	11:52	Kakpaille Tank #7	Grab from tap	Tap water
16	1/21/2009	12:23	Kakpaille Tank #3	Grab from tap w cup	Mix of tap and rainwater
17	1/21/2009	12:58	Kakpaille Tank#2	Grab from tap	Rainwater
18	1/21/2009	13:28	Kakpaille Tank#22	Grab from tap with bag	Rainwater
19	1/21/2009	14:08	Kakpaille Tank#20	Grab from tap	Rainwater

Water Quality Data: Kakpaille, Ghana

Sample ID	Tot Col>=10	E. Coli?	Red	Blue	Total
10	Yes	No	0	0	0
11	No	No	0	0	0
12	No	No	0	0	0
12(2)	No	No	0	0	0
13	Yes	No	0	0	0
14	Yes	No	0	0	0
15	No	No	0	0	0
16	Yes	No	0	0	0
17	No	No	0	0	0
18	No	No	0	0	0
19	No	No	0	0	0