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Environmental Health in the Latin American and Caribbean Region: Use of Water Storage Containers, Water Quality, and Community Perception

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Environmental Health in the Latin American and Caribbean Region: Use of Water Storage Containers, Water Quality, and Community Perception

by

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DEDICATION

This unforgettable journey was not made alone. First and foremost, I would like to thank my Lord and Savior for making a way and for every blessing. Thank You for preserving me and enabling me to find favor and grace from You and those around me, even when I didn't deserve it. Thank You for saving my life more times than I ever thought possible. *Nanpwen lapriye ki pa gen "Amen".*

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Water quality and availability are important issues in many developing countries where portions of populations still lack access to potable water. Throughout the English-speaking Caribbean and parts of Latin America, households and businesses invest in water supply systems even when they are connected to and pay for water services from a private or state owned provider. Inconsistent supplies of water from the water companies have led many people to invest in storage tanks which, if operated correctly, can provide water throughout the day even when the supply from the main is low or zero. While these individual systems help to guarantee a more constant supply of water, they may impact water quality when it does reach the household tap. The tanks could become breeding grounds for vectors of human disease and may also affect the concentrations of bacteria, heavy metals and organics in the water.

The goal of this research was to understand how households use water storage tanks and determine the effect of these tanks and the individual practices on water quality. Target plots were used to visualize linkages between water quality parameters and household surveys of localized water practices and perception on water quality.

The study focused on three field sites: Siparia, Trinidad and Tobago, Region 4 Subset in Guyana, and Villa Litoral, Bolivia. Convenience sampling was used to administer surveys to households in the rural areas of Siparia (39), Region 4 Subset (40), and Villa Litoral (57). The Region 4 Subset is comprised of two rural areas, Mon Repos and Mocha, and Georgetown, the country's capital.

Black, high-density polyethylene (HDPE) tanks and water storage drums are predominantly used in the field sites within Siparia and Region 4 Subset, while cement tanks, drums, and jerry cans are used in Villa Litoral. The average age of household water storage devices was 4-10 years in Siparia and Region 4 Subset, and 0- 3 years in Villa Litoral. These devices were found on various elevations to accommodate piped connection, indoor pumping, and rainwater catchment. Cleaning frequency of tanks in Siparia was every few months, while in Region 4 Subset it varied from weekly to every few months. In Villa Litoral 26.3% of the population surveyed cleaned weekly and 38.6% cleaned annually. Disinfection of water sources was practiced by 30% of residents in Siparia and 60% of residents in the Region 4 Subset. While disinfection was practiced, issues with frequency and correct dosage led to inadequate disinfection. Eighty-four percent of households in Siparia and 50% of households in Region 4 Subset disinfected on a monthly or quarterly basis. Of the households that did disinfect, the bleach and/or disinfectant used was allowed to mix for at least 30 minutes in 50% of households in Siparia and 91.6% of households in the Region 4 Subset. Disinfection was not practiced by the majority of households in Villa Litoral. With regards to health, 15% of households in Region 4 Subset and 40.4% in Villa Litoral reported recent waterborne illnesses among house members.

Water samples were taken from households in Siparia (24), Region 4 Subset (40), and Villa Litoral (26). The majority of households in all three communities relied on piped water from their respective main pump. Those who were not connected to piped water relied on rain water. In the Region 4 Subset, 18% of samples tested positive for fecal coliform and 45% for total coliform. In Villa Litoral, 85% of samples tested positive for fecal coliform and 100% for total coliform. The majority of samples from all three communities exceeded the WHO guideline values for lead (0.01 mg/L) and iron (0.3 mg/L). This was most likely due to the material used in the household plumbing and distribution pipe infrastructure as these could leach.

Five indicators (chemical and biological water quality, reach of risk, storage device, female involvement, and household belief) were conveniently projected on target plots to link the results from water quality assessments with reported household practices and beliefs. The greatest risk factors seen were poor water quality and household beliefs like the security of water storage containers and safety of stored water, perceived water description and pressure, and access to water safety media.

CHAPTER 1: INTRODUCTION

1.1 Global Water Quality Issues

Water availability and quality pose challenges around the world and are compounded by issues like poverty, contamination and climate change. The seventh target of the Millennium Development Goals (MDGs) established by the United Nations (UN) in 2000 is to halve the proportion of those without access to potable water and basic sanitation by the year 2015. According to a 2000 report by the World Health Organization (WHO), an improved water supply was defined as a transition to piped water and water connections in the homes (WHO/UNICEF, 2000). Table 1.1 summarizes which technologies are deemed as improved versus those seen as unimproved.

Table 1.1 Definition of improved versus not improved water supply. (WHO/UNICEF, 2000).

The following technologies were considered "improved":	
Water supply	Sanitation
Household connection	Connection to a public sewer
Public standpipe	Connection to septic system
Borehole	Pour-flush latrine
Protected dug well	Simple pit latrine
Protected spring	Ventilated improved pit latrine
Rainwater collection	
The following technologies were considered unimproved:	
Water supply	Sanitation
Unprotected well	Service or bucket latrines (where excreta are manually removed)
Unprotected spring	
Vendor-provided water	Public latrines
Bottled water*	Open latrine
* Not considered "improved' because of limitations concerning the potential quantity of supplied water, not the quality.	

Since the implementation of the Millennium Development Goals, the global proportion of individuals without access to improved water sources has decreased, as shown in Figure 1.2. Currently 87% of the world's population utilizes an improved source of water supply (WHO/UNICEF, 2010). Roughly 57% of those improved water supplies come from a piped connection that provides running water in proximity to the home (WHO/UNICEF, 2010). However, while more individuals now have access to improved water sources, disparities still exists with regards to access within the urban population versus the rural population. Nearly 84% of the global population without access to improved water supplies resides in rural areas (WHO/UNICEF, 2010).

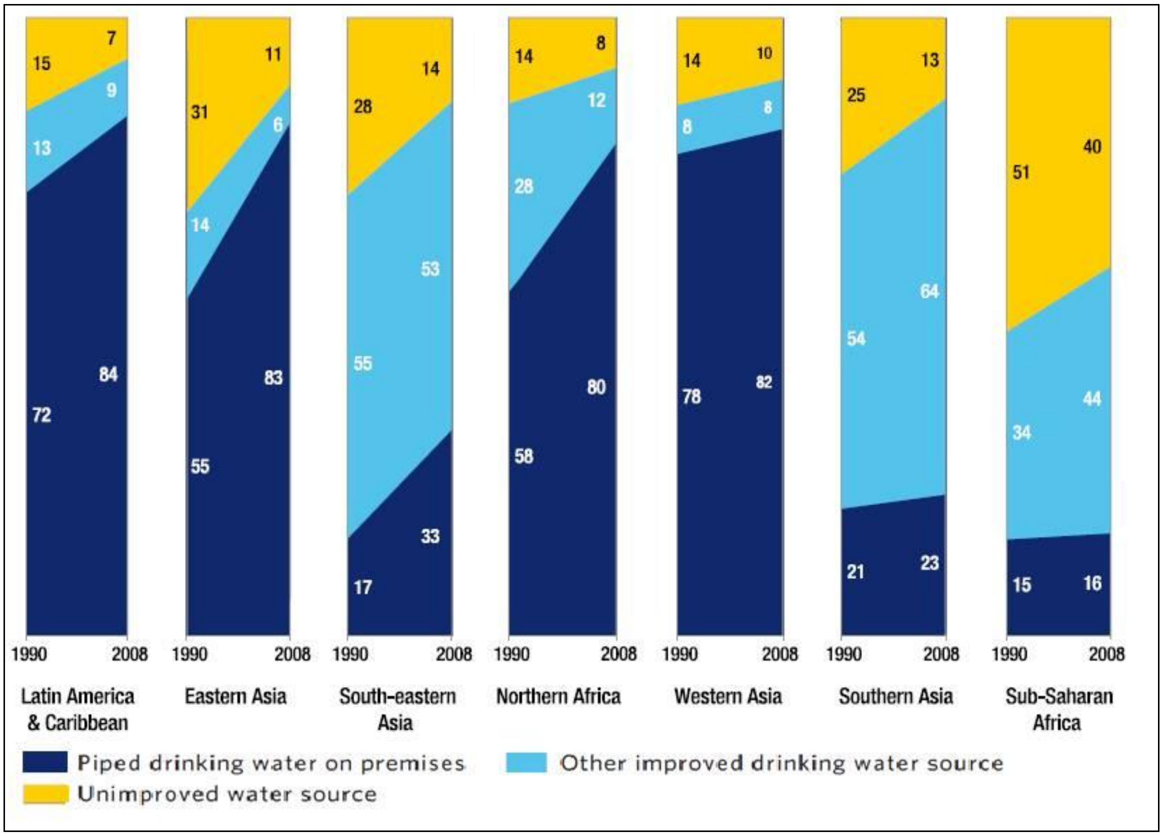


Figure 1.1 Comparison of global water supply as a function of region percentage-wise. (WHO/UNICEF, 2010).

1.2 Water Quality Issues in the Latin American and Caribbean Region

In 2000, 7% of the world's population without access to improved water sources resided in the Latin American and Caribbean region (WHO/UNICEF, 2000). Like the rest of the world, a large disparity in this region exists between access to an improved water supply in urban and rural communities. Within the Latin American and Caribbean region, 96% of those living in the urban area have access to improved water, compared to only 76% of those in the rural area. Disparities were also seen in terms of piped water, of which only 55% of rural populations had access to, compared to 92% in urban areas (WHO/UNICEF, 2010).

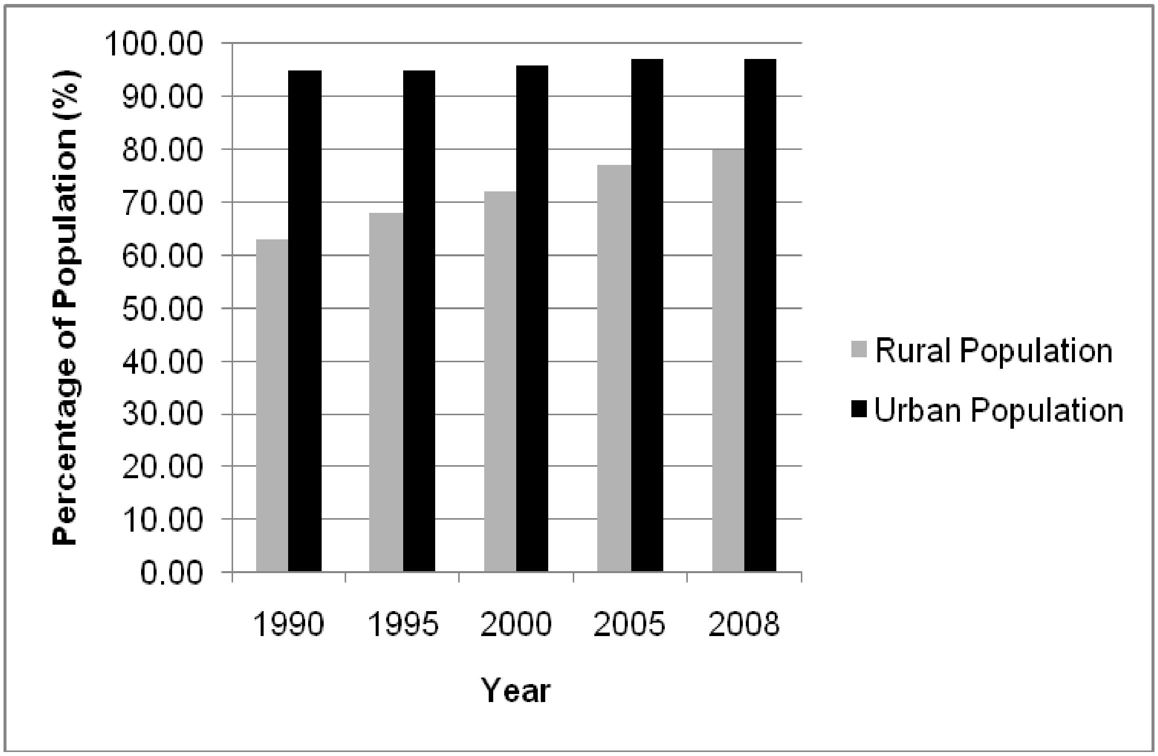


Figure 1.2 Improved water supply within the Latin American and Caribbean region. Percentage of Latin American and Caribbean population with improved water supply. Data obtained from WHO/UNICEF (2010).

Water quality is often a much lower national priority than water coverage, particularly in countries where coverage levels are low (UNICEF, 2008). In many countries, water monitoring and surveillance systems are weak and sectoral professionals with water quality expertise are relatively rare (Fewtrell, 2005; Gundry, 2004; Clasen, 2007; Lee, 2005; Moe, 2006). Consequently, even widespread water quality problems go unnoticed until the public health system begins to register large numbers of water-related disease cases and deaths.

Programming for water quality tends to be reactive – responding to serious problems as they occur rather than focusing on safety and prevention (Hoque, 1996; Colindres, 2007; Pruss, 2002; LeChevallier, 2003). The situation is beginning to change.

Community awareness is increasing in many countries as sources become polluted due to population pressure, intensive agriculture and industrialization. In other countries, especially where coverage is high, additional resources are now being allocated to water quality. In an increasing number of countries, the United Nations Children's Fund (UNICEF) programming in the area of water is shifting from water supply towards water quality. However, because awareness levels continue to be low in most countries, action is necessary to avoid the emergence of more serious water quality problems. UNICEF can play an important role in highlighting the importance of water quality at the national and community levels; contribute to the creation of an enabling policy environment for water quality programming; and help to build capacity to strengthen national surveillance and protection systems.

1.3 Research Objective and Research Questions

The goal of this research was to understand how households use water storage tanks and determine the effect of these tanks and the individual practices on water quality in field sites in Bolivia, Guyana and Trinidad and Tobago. The research questions addressed and the associated tasks were as followed:

1) Will potable water quality vary due to the source of water, type of household water storage device used, and community?
    a. Assess quality of drinking water source for basic water quality parameters, microbial contamination, and presence of chemicals and dissolved metals.
    b. Conduct field based surveys of real water storage systems to determine types of water storage containers being used, their respective locations, and surrounding environment.
2) Will household activities (cleaning of tanks, covering of tanks, treatment of water) improve the water quality of water reaching the household tap?
    a. Conduct community-based household surveys that collect household tank activity data and correlate the information with results produced from Task 1b.
3) Does a simple approach exist that captures and presents how household understanding of water quality, household practices, gender roles, and household location influence vulnerability to waterborne/water-based/water-related illnesses?
    a. Develop indicators based on household survey data and water quality sampling data that capture components that influence potable water use at the household level.

b. Use target plots to show the role of various indicators and apply to various test site locations.

1.4 Scope of Research

Previous studies on household water storage and treatment have focused on either the water quality or the social dimensions of water use. Of the ones that look at both aspects, the water quality is often limited to just microbial analyses. It is necessary to investigate other water quality parameters in an effort to gain a better understanding of the drinking water quality afforded to the residents. When combined with a study on household behavior and perception, better insight is obtained into the relationship that exists between households and their potable water sources.

This study serves as a compilation of three pilot studies attempting to bring more perspective into the household water issues faced in the Latin American and Caribbean region. No known research has been found that compares results from various countries within the region with regards to both the water quality and social aspect. While a pilot study in nature, the intent is that this study will provide a basis for further research, needs assessment, surveillance, and monitoring into the issue of household water storage and treatment seen in the region.

1.5 Dissertation Framework

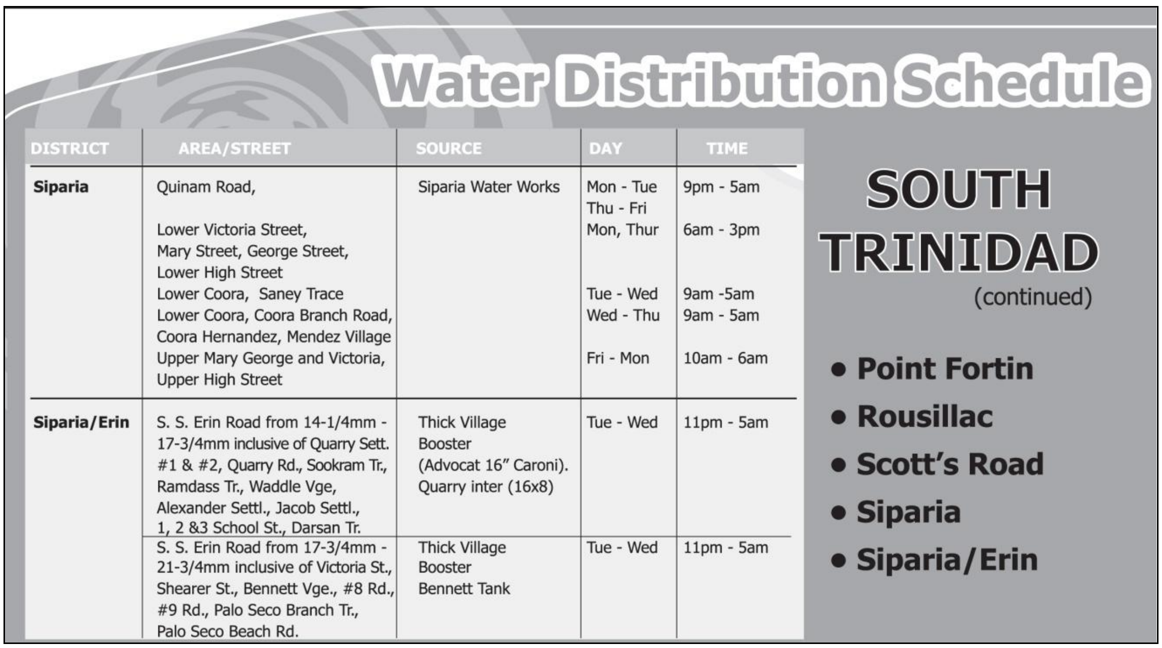
This dissertation consists of eight chapters. Chapter 1 provides a brief overview of the motivation for the research, including the issues stemming from the need for the household water storage, along with the research objectives. Chapter 2 gives a background on water intermittence, household water storage and treatment used in developing countries, and the potential for microbial contamination as a result of activities at the point of use. Chapter 3 discusses the three target countries; Trinidad and Tobago, Guyana, and Bolivia. Chapter 4 describes the methods and approaches used in conducting the water sampling and analyses, along with the household survey administration and analyses. Chapters 5 and 6 discuss the results and findings from the household surveys and water sampling analyses, respectively. Chapter 7 presents an approach for combining the results from Chapters 5 and 6 so that the health of a household water system can be assessed and main influences identified based on a set of key indicators/indicator categories. Chapter 8 concludes the overall research and makes recommendations based on the research findings.

CHAPTER 2: HOUSEHOLD WATER STORAGE AND TREATMENT

2.1 Water Intermittence

Household water storage initially arose from a need for sustainable resources of water when consistent access was not available. Even when fresh drinking water became available, households would transfer the remaining water that had been sitting to other uses, depending on the household's economic status and availability of other sources (Joshi, 2002). In an evaluation on the influence of intermittent versus continuous water supplies in communities in India, Andey et al (2009) found that water consumption depended on whether the water supply was adequate to satisfy the consumers' water demand and not on which approach was used.

Various methods and interventions for managing water shortages exist and are implemented throughout the world. In many developing countries, municipal water is supplied for restricted hours in the morning and evening hours for various reasons under the assumption that residential water consumption would be less compared to consumption under continuous water supply (Andey et al., 2009). In Lima, Peru, 48% of households received water only during limited hours and supply interruptions are common (Alcázar et al., 2002). In Mexico City, 32% of households reported receiving water during only limited hours and most residents suffer routine supply interruptions (Haggarty et al., 2002). Figure 2.1 shows the 2010 water distribution schedule for Trinidad and Tobago, owners of the largest desalinization plant in the western hemisphere. Implemented during droughts and other temporary periods of water storages, the days and times of water availability are based on the residential district and area. Depending on location, municipal water sources may be supplied during the day or overnight.



Water Distribution Schedule

DISTRICT	AREA/STREET	SOURCE	DAY	TIME
Siparia	Quinam Road,	Siparia Water Works	Mon - Tue Thu - Fri	9pm - 5am
	Lower Victoria Street, Mary Street, George Street, Lower High Street		Mon, Thur	6am - 3pm
	Lower Coora, Saney Trace		Tue - Wed	9am -5am
	Lower Coora, Coora Branch Road, Coora Hernandez, Mendez Village		Wed - Thu	9am - 5am
	Upper Mary George and Victoria, Upper High Street		Fri - Mon	10am - 6am
Siparia/Erin	S. S. Erin Road from 14-1/4mm - 17-3/4mm inclusive of Quarry Sett. #1 & #2, Quarry Rd., Sookram Tr., Ramdass Tr., Waddle Vge, Alexander Settl., Jacob Settl., 1, 2 &3 School St., Darsan Tr.	Thick Village Booster (Advocat 16" Caroni). Quarry inter (16x8)	Tue - Wed	11pm - 5am
	S. S. Erin Road from 17-3/4mm - 21-3/4mm inclusive of Victoria St., Shearer St., Bennett Vge., #8 Rd., #9 Rd., Palo Seco Branch Tr., Palo Seco Beach Rd.	Thick Village Booster Bennett Tank	Tue - Wed	11pm - 5am

Figure 2.1 2010 water distribution schedule from the Water and Sewerage Authority (WASA) of Trinidad and Tobago. Image obtained from http://www.wasa.gov.tt/Forms/2010Schedule/WASA%20Schedules%20Feb%2019.pdf, accessed 9/12/10.

The quotation below from a resident of Guyana captures the challenges faced by local homes in getting water and the familiarity of a water supply procedure ingrained from years of bad service.

> *"At 05:00 hours you start to see water trickling in the yard. You can get a twenty foot head from 06:30 but it drops according to general usage. On cold rainy mornings that 20 foot head can last until 09:00 hours. By 09:00 hours it is barely trickling at the standpipe in the yard. By 11:00 hours water starts flowing again and can reach maybe 15 feet. At precisely 13:00 hours a vacuum develops so if you had a 400 gallon tank outlet attached to the yard pipe that tank would be empty in half an hour. At 17:00 hours water starts to trickle again and the pressure rapidly builds up to 20 foot head to drop again as the user demand increases. At precisely 22:00 hours the vacuum develops once more as the Shelter Belt [local treatment plant] pumps are turned off"* (J. Piggott, personal communication, August 14, 2010).

Water intermittence poses several issues, such as change in water quality, low pressures, inability to conduct routine daily activities, inconvenience due to timing of supply, and potential sanitation problems (Ayoub et al., 2006; Joshi et al., 2002). In addition to delay in daily activities and consumption, water intermittence can also affect soil moisture, which can impact agricultural and irrigation processes (Elmaloglou 2008). Additionally, there is the potential for residents to rely on unsafe water sources as a result of intermittent water supply (CDC, 2007). A consumer survey done in India found that residents were satisfied with service from their water provider whenever the water supply was continuous, regardless of the cost of the water (Joshi et al., 2002).

2.2 Types of Water Storage Containers

Inconsistent supplies of water from local water companies have led many people to invest in household systems which, when used correctly, can provide a more continuous supply of water even when the supply from the main is low or zero. More importantly, households can self ration based on their tank water level and the expected length of time until the next refill. This removes a level of uncertainty associated with relying solely on the water main for water to come out of the household tap. As such, households and businesses invest in water storage and supply systems even when they are connected to, and pay for water services from a private or state owned provider. Throughout the developing world, individuals who do not have household water connections or continuous water supplies must transport water from point sources or standpipes and store it in their homes. It is thus important that the water infrastructures and other means of water access are adequate, as this can impact the water quality (Mintz, 1995;

Jensen, 2002; Hoque, 2006; Eshcol, 2009; Oloruntoba, 2007; Levy, 2008; Wright, 2009).

The design of storage and transport receptacles is also an important factor in reducing fecal coliform levels in stored water and in the levels of household diarrhea and other diseases. Studies show clear correlations between the type of container used and both fecal coliform levels and diarrhea incidence in the home (Roberts et al., 2001; Sobsey, 2002).

Water storage containers include traditional clay or metal containers, plastic and metal buckets, jerry cans, collapsible containers, and water storage drums. Several of these container designs also have handles, are lightweight, are made from durable, UV-resistant plastic, and have an affixed label containing informative messages on their cleaning and use (Thompson et al., 2003). Additionally, in many homes, these containers serve multiple uses, aside from solely transporting and storing water. Thus, various factors come into consideration when considering a water storage container, such as size, shape, weight, and durability. Table 2.1 lists the criteria for water storage containers according to the United Nations Children's Fund (UNICEF). While these containers are suitable to store water in the house, larger tank systems are generally used to collect and store water outside of the house.

Table 2.1 Criteria for household level water storage containers. (UNICEF, 2008).

Criteria for home water storage containers

x – somewhat important xx – important xxx – very important	**Importance for water storage containers**	**Importance for water transport containers**
Criteria for minimizing contamination		
Made of easily cleaned material (plastics, most metals, ceramics, polished concrete)	xxx	xxx
Tap to draw water (must not leak or stick) or narrow spout from which to pour water	xxx	
Top opening large enough to pour water into but small enough to discourage the entry of hands, ladles and other faeces vectors (about 8 cm)*	xxx	xxx
Cap for top opening (preferably screw type)	xxx	xx
Stable with a flat bottom (so that container does not tip over allowing contaminants to enter opening)**	xxx	xxx
Usability / user acceptance criteria		
Durable	xxx	xxx
Impact resistant (some plastics are not)	x	xxx
Corrosion resistant (plastics, coated/treated metal)	xxx	xx
Portable: lightweight, less than 25-litre capacity, suitable for local methods of carrying water (e.g., handles, flat bottom for head carrying, not too tall)	x	xxx
Inexpensive	xxx	xxx
Available in local markets	xxx	xxx

* Sometimes 8 cm is too small an opening for transport containers – larger openings are required to capture the water stream when taps or pumps are mounted too high (e.g., tall handpumps mounted on dug well caps), when it is windy, when there are long queues (and so every pump stroke counts) and when water is scarce (and no water can be wasted).

** For example, collapsible plastic containers (sometimes supplied to families during emergencies) are not stable.

2.2.1 Polyethylene Water Storage Tanks

Invented by research chemists Paul Hogan and Robert Banks of Phillips Petroleum in 1951, high-density polyethylene (HDPE) is a polyethylene thermoplastic made from petroleum. It takes 1.75 kilograms of petroleum (in terms of energy and raw materials) to make one kilogram of HDPE. HDPE has little branching, giving it stronger intermolecular forces and tensile strength than lower-density polyethylene. It is opaque and can withstand higher temperatures of 120°C for short periods and 110°C continuously.

In many countries, tanks made of HDPE are used to store water for individual residences, as shown in Figure 2.2. These supply systems usually include storage tanks, pumps, pipes, and a structure to elevate at least one of the storage tanks above the house. These tanks are known for their sturdiness, resistance to the elements, simple shape, and availability. Additionally, HDPE tanks are easily washed and cleaned though their height above ground may make them inaccessible. Prolonged use of a plastic tank at temperatures above ambient will shorten tank life, as will temperature cycling. Temperature effects are directly dependent on the characteristics of the plastic resin, specific gravity of tank contents, tank size and configuration, exterior support, and wall thickness of the tank. For polyethylene, it has been verified that the degradation in heat aging is mainly caused by the oxidation of polymers (Sarathi, 2004). Many of the HDPE tanks sold in the Caribbean and Latin America come with warranties of five or more years.

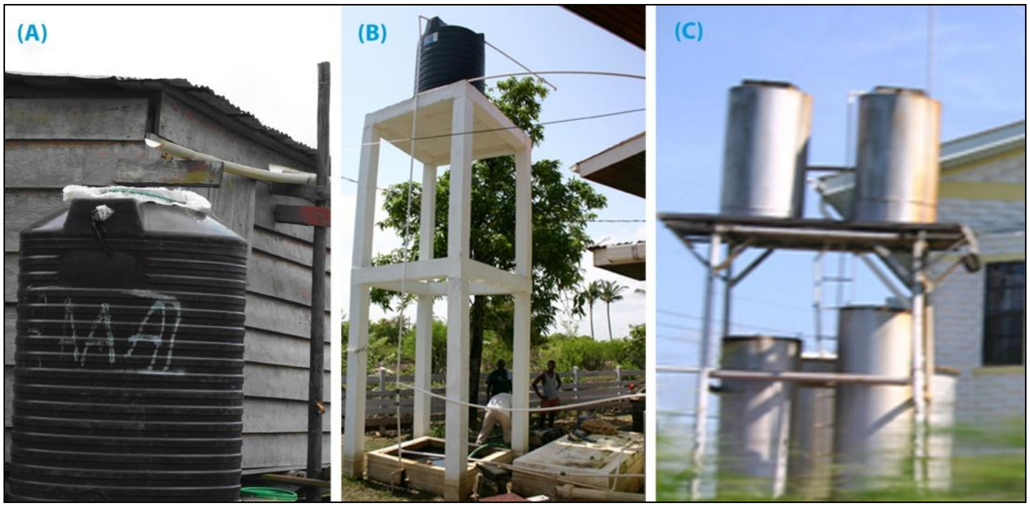


Figure 2.2 Water tanks in Guyana. (A) Rain collection at a rural gold mining camp; (B) Single tank on a concrete trestle at LBI; (C) Tanks on concrete trestle at University Gardens.

Generally, bottom tanks are connected to the main supply lines and are filled when water pressures are high. Water from the bottom tank is pumped to the top tank where it is then connected to all of the house pipes where it is used for drinking, cooking, washing and flushing toilets. Wooden, aluminum and plastic tanks are commonly seen in the Caribbean, with the plastic tanks being the most popular and widely used. Individuals and businesses incur the costs associated with their own water storage system. For places not connected to the main water supply lines, these tanks are filled with rainwater. For places with water connections, individuals and businesses have an additional cost as they must also pay for the local water services.

In Trinidad and Tobago for example, a homeowner would pay a minimum of $2310 TT ($385 US) for a system that includes a 400 gallon HDPE tank ($595

TT), pump ($1695 TT), and piping ($20 TT/foot of half inch pipe), in 2010 currency rates. Companies supplying HDPE tanks have recently started to sell treatment systems with the tanks ranging from simple filters to sand filters, activated carbon beds, UV disinfection and chlorination. In Guyana, the costs for the more extensive household water treatment option starts around $800 US making them inaccessible to the majority of the population.

For wealthier households in the regions studied, more extensive household treatment systems exist for water quality improvements (Figure 2.3). Rotoplastics, a company that manufactures the HDPE tanks, now sells a suite of filters to be used in conjunction with their tanks (e.g. Washable Net Cartridge, Anti-Bacterial Cartridge, Activated Carbon Cartridges, Polyphosphate Cartridge). The growth of the private water industry and cost to individual households poses interesting areas for further research, especially the types of funding or policy changes needed to most efficiently guarantee safe drinking water for all households.

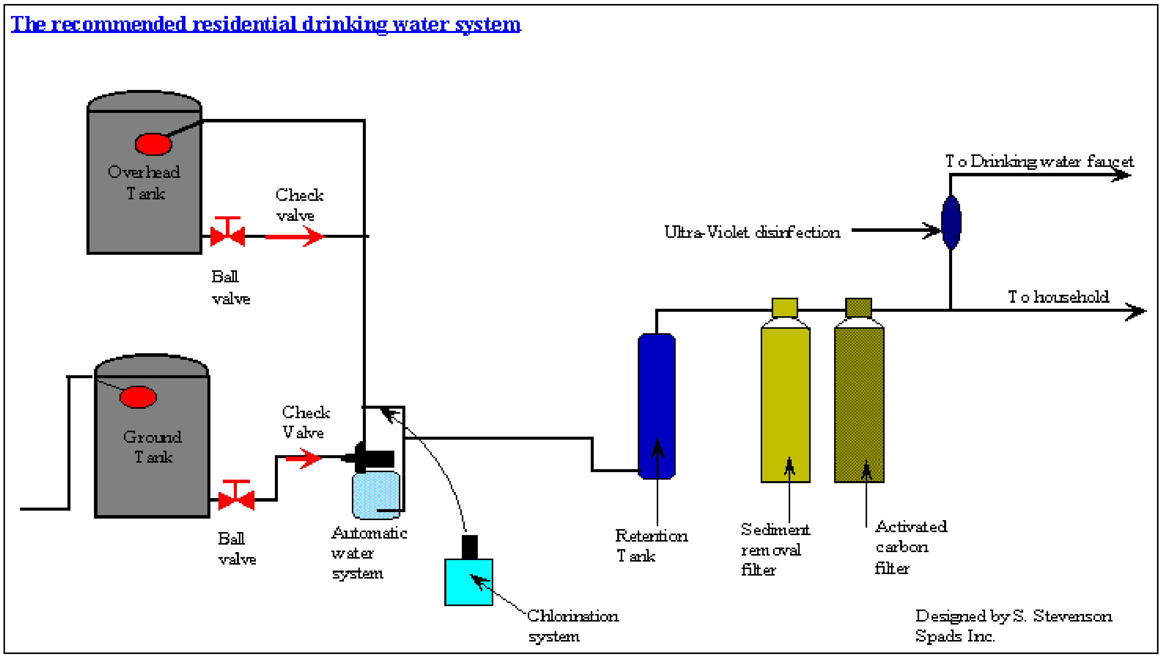


Figure 2.3 Schematic of household water treatment system recommended by SPADS Inc., Guyana. Image obtained from http://www.spadsinc.com/fltsys.htm, accessed 10/1/2010.

2.3 Impact of Household Water Storage Systems on Water Quality

While these individual systems help to guarantee a more constant supply of water, they may impact water quality when it does reach the household tap. The storage containers could become breeding grounds for mosquitoes which are responsible for the spread of diseases like dengue fever (Chadee, 2000). The type of storage container, material construction, and the source of the water (e.g. roof runoff) may also affect the concentrations of bacteria, heavy metals and organics in the water (Ahmad, 2007; Emmanuel, 2007; Levesque, 2008; Magyar, 2007; Tokajian, 2003; Westerhoff, 2008).

As shown in Table 2.2, the drinking water guidelines established by the World Health Organization (WHO), state that the water source should not contain any microbiological agents that are pathogenic to humans (WHO, 2006). Thermotolerant bacteria, such as *E. coli* are often used as indicator species for fecal coliform as they are representative of pathogenic organisms that can live in the intestine of warm-blooded hosts. However, these drinking water guidelines are based on water quality at the point of delivery (e.g. distribution line), not through to the point of actual consumption (Wright, 2004).

Table 2.2 Coliform guideline values for drinking water sources. (WHO, 2006).

Water class	Indicator Species	Guideline value
All water directly intended for drinking	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample
Treated water in the distribution system	*E. coli* or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample

Traditionally, unimproved water sources were thought to be vulnerable; however, current research shows that even improved water sources are at risk for contamination (Thompson, 2003; Clasen, 2007; Tambe, 2008; Moe, 2006; Mara, 2003). Microbiological contamination of drinking water during collection and storage in the home has been reported by several researchers (Clasen, 2003; VanDerslice, 1995; Thompson, 2003; Agard, 2002). Throughout the world, many urban and rural piped water supplies have been found to be microbially contaminated due to factors such as poor influent water quality, inadequate water treatment, long distribution system residence times, and infiltration from sewage and other non-potable water sources (Nordblum, 2004; Mainville, 2002; Batte et al., 2006). Figure 2.4 and Table 2.3 show the various routes of contamination for improved water sources.

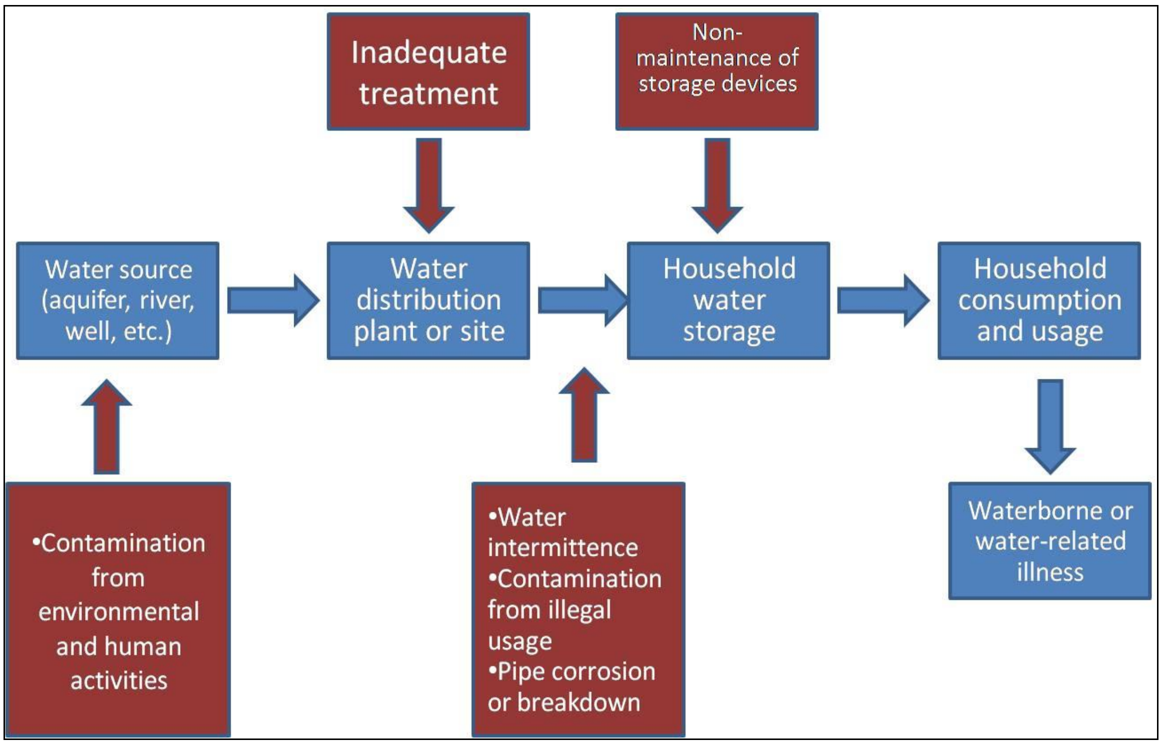


Figure 2.4 Pathway of water delivery, storage, and use.

Table 2.3 Sources and pathways for fecal contamination of water sources. (UNICEF, 2008).

Sources and pathways for the faecal contamination of water sources
Point Sources: tubewells, dug wells and springs o Latrines close to the source* o Latrines uphill of the source* o Other potential sources of faecal contamination close to or uphill from the source (e.g., open defecation, septic tanks, corrals, intensive grazing, abandoned dug wells, garbage pits) o Standing water at or near the source due to poor drainage* o Poorly constructed or maintained headworks (concrete apron and drain, headwall, pump seal) and below-ground sanitary sealing o Irregular maintenance and cleaning of apron and source surrounding o Bucket used in windlass system allowed to touch the ground, buckets from homes dipped in well or in spring reservoir o Animals with access to source (fencing missing or broken) o Erosion around protected spring, dug well or tubewell * The minimum safe distance (MSD) between contamination sources and water sources varies, depending on local hydrogeology and other factors. In some countries rule-of-thumb figures (e.g., 10 m minimum distance between a dug well and a latrine) are used as a guide but, there are cases where these distances should be more carefully estimated to better protect water sources.
Rainwater Harvesting Tanks o Bird and small animal faeces from rooftops and gutters o Cracked tanks, poorly sealed access holes allow entry of animal and insect vectors o Inadequate or poorly maintained filters and/or 'first flush' system
Piped Systems o Groundwater source inadequately protected from contamination (see above) o Surface water intake inadequately protected from local sources of contamination (e.g., no fencing, broken fencing, poorly constructed or damaged intake structures, inadequate screening) o Treatment plant non-operational, operates intermittently (e.g., broken equipment, no treatment chemicals) or inadequately maintained and supervised (e.g., process control tests not carried out regularly, record keeping inadequate, poorly trained operators, incorrect storage of treatment chemicals) o Cracked storage tanks and reservoirs o Tank access covers or vents improperly sealed o Infrequent cleaning of storage tanks and reservoirs o Broken or leaking pipes, exposed pipes due to erosion or poor construction o Service interruptions causing pressure loss and thus potentially allowing the entry of contaminated surface and groundwater into system via pipes and fittings o Standing water around tapstands (standpipes) due to poor drainage o Open defecation near tapstands

Agard (2002) examined the microbial quality of water sources supplied to the San Fernando community in southern Trinidad and Tobago and found that out of the 104 drinking water samples obtained from households, 80.8% tested positive for total coliforms, 53.8% tested positive for thermotolerant coliforms, and 67.3% tested positive for *E. coli*. Out of the 81 water samples collected from the Water and Sewerage Authority (WASA) distribution point, 46.9% tested positive for total coliforms, 16% tested positive for thermotolerant coliforms, and 33.3% tested positive for *E. coli*. As the level of residual chlorine decreased, there was a statistically significant increase in the prevalence of total coliforms in water from 0.0% in treated reservoir water to 80.0% in household drinking water. Agard (2002) concluded that the level of household water contamination presented a public health concern to residents.

Kurup et al. (2010) also found significant water quality degradation in Guyana close to and in the capital of Georgetown, including high turbidity, iron, and microbial levels. Microbial analyses of water and biofilm samples taken from the treatment or distribution plants and household tap identified 12 different species with *Acinetobacter* spp*.* and *Lactobacillus* spp*.* being the most common and Lactobacillus being the most common in the biofilm (Kurup et al, 2010). Batte et al. (2006) found no correlation between the microbial community in the biofilm versus the water of full scale distribution systems in France; however their study was limited to 4 indicator organisms one of which was anaerobic sulfide-reducing bacteria spores (ASRB spores).

Brick (2004) examined the effects of household storage on water quality in a southern town in India. The study showed that two-thirds of the water sources became increasingly contaminated with *E. coli* within nine days of current household storage practices, in spite of receiving safe drinking water from municipal plants. However, the use of brass storage containers significantly decreased contamination of water. While this discovery was unexpected, it indicated that further research was needed to account for this, such as metallurgical analyses of brass on microbial growth.

Trevett (2004) evaluated drinking water quality in three rural Honduran communities that used either a protected hand-dug well or borehole supply. There was frequent and substantial water quality deterioration between the points of supply and consumption. Additionally, it was concluded that none of the storage factors examined made any significant difference to the stored water quality, and that the contamination could have occurred at several points. Based on current literature, it is necessary to assess the microbial quality of the water stored within the households as impacted by factors such as chlorination levels, temperature, residence time, and distribution systems (Besner, 2001; Mainville, 2002; Olsinska, 2007). Table 2.4 shows the various routes for fecal contamination of drinking water sources with particular relevance to developing countries.

Table 2.4 Pathways for fecal contamination during water collection, transport, and storage. (UNICEF, 2008).

Pathways for the faecal contamination of water during collection, transport and storage

Water collection and transport

- o use of wide-mouth containers that allow hands to come into contact with water
- o use of leaves or other material in buckets to prevent water spillage during transport
- o containers used not clean
- o containers 'washed' with contaminated hands or cloths
- o contaminated cups, bowls, ladles or buckets used to draw water
- o dirty source surroundings and pump/tap spouts

Water Storage

- o use of wide-mouth containers for storage that allow hands, cups/ladles and insect and animal vectors to come into contact with water
- o uncovered containers
- o no spigot or spout on containers – water drawn with cups or ladles
- o containers stored on floor, allowing more easy access to water by children and animals
- o infrequent cleaning of storage containers

2.4 Household Water Treatment (HHWT)

In their study on improved water sources, Thompson et al. (2003) reported that,

> *"Use of effective technologies for household water treatment and storage is likely to have direct beneficial effects in the form of reduced infectious diseases, and also contribute to greater productivity and other associated benefits from improved health. Household treatment can often provide these benefits to underserved populations much more quickly than it would take to design, install and deliver piped community water supplies."*

2.4.1 Physical Means

Physical treatment of household water includes water settling, filtration, boiling and UV radiation with the first three being the most accessible and affordable. Common filtration includes using a cloth or granular media (e.g. sand or charcoal) to allow the water to pass through while retaining the unwanted particles and taste. Boiling kills pathogens and requires nothing more than a source of heat and a container in which to boil the water. As such, boiling is often one of the first lines of protection when water sources have been compromised. For turbid water sources, the water is often left to stand for a period of time, enabling the particles to settle. While these methods may be the simplest and most economical, they often only treat the aesthetic issues associated with water quality. Microbiological contaminants and/or microscopic pathogens viruses can still exist in the water that has only been filtered or allowed to settle.

Water can be directly treated by the physical method of solar radiation and then directly stored and dispensed for household use. With the solar water disinfection method (SODIS), clear, plastic beverage bottles which have been painted black on one side are filled with water and exposed to sunlight for several hours to disinfect it prior to use (Conroy, 1996; Rainey, 2005). This system utilizes inexpensive water storage containers and is simple to use. SODIS can be generally acceptable to users, especially if supported by an educational and motivational program to achieve implementation and maintain effective and sustained use (Hei, 2008; Kraemer, 2010; Mausezahi, 2009; Murinda, 2008).

However, several drawbacks exist with utilizing SODIS. First, the amount of water being disinfected is limited to the number of bottles which are available, thus limiting its practicality in providing safe water for an entire household on a daily basis. Second, the effectiveness of SODIS depends on the availability of sunlight and turbidity levels less than 30 NTU (Rainey, 2005). The disinfection process is thus extended or limited during cloudy days (Boyle, 2008; Oates, 2003). Third, while SODIS provides a means of ultra-violet disinfection to the water source, it does not provide any residual disinfectant. Therefore, SODIS water sources must be consumed relatively soon following treatment as microbial contamination can recur (Amin, 2009; Schmid, 2008).

2.4.2 Chemical Means- Chlorination

Chlorination is a common household water treatment method for disinfection. Residents have the option of using either household bleach containing chlorine (sodium hypochlorite) or chlorine tablets to disinfect their water supply. When chlorine gas ($Cl_{2(g)}$) is added to caustic soda, sodium hypochlorite (NaOCl) is formed, as shown below.

$$Cl_{2(g)} + 2NaOH \rightarrow NaOCl + Na^{+} + Cl^{-} + H_2O \quad (2.1)$$

Sodium hypochlorite completely dissociates in water. It reacts with water to form hypochlorous acid (HOCl) according to Equation 2.2. The acidity constant governing the equilibrium between the hypochlorite ion and hypochlorous acid is 7.6. Hence, below pH 7.6 HOCl dominates the speciation. Given that HOCl is stronger than OCl^- as a disinfectant, pH values below 7.6 favor more efficient disinfection.

$$NaOCl + H_2O \rightarrow HOCl + Na^+ + OH^- \qquad (2.2)$$

Following chlorination, contamination can further be reduced by storing water in a vessels designed to minimize further contamination during storage (Mintz et al., 1995; Reiff et al.; 1996; Sobsey, 2003). Sobsey (2003) studied the use of chlorine-safe water storage systems, in which water sources were stored without being disinfected. Disinfection took place in a dedicated plastic container which had a capacity of 12-25 liters. The container's cap served as a measuring device, to ensure that the appropriate amount of 5 mg/L chlorine was being added. Following chlorine addition, the water was then stored for an allotted period of time to allow disinfection to occur. Once the time period had ended, the disinfected water could be poured out through the container's spigot. This system ensured that the correct chlorine dosage was being used and that further contamination would not occur to the newly treated water source. In Table 2.5, various methods of chemical disinfectants are shown. While various methods have proven to be effective, the practicality or constraints (cost, ease of use, availability of the necessary materials) are the deciding factors in their usage.

Table 2.5 Chemical disinfectants for treating household water supplies. (Sobsey, 2002).

Disinfectant	Community/ Household Use	Advantages	Disadvantages	Cost*	Comments
Free chlorine (NaOCl, Ca(OCl)[2]	Yes/Yes (worldwide, but not in some regions)	Easy to use; effective against most pathogens; stable residual	Not available worldwide; some users object to taste and odor	Low	The most widely used drinking water disinfectant; proven technology
Electro-chemically generated oxidant from NaCl	Yes/Yes (limited distribution)	Easy to use; effective against most pathogens; stable residual	Not available worldwide; some users object to taste and odor (mostly chlorine)	Low	Practical for worldwide use; can generate on site by electrolysis of NaCl; proven technology
Chloramines (monochloramine)	Yes/Rare (less widely used than free chlorine; must react free chlorine with ammonia	Stable residual	Less effective microbiocide than free chlorine; requires skill and equipment to generate on-site; household use impractical	Moderate	More difficult to use than free chlorine; potentially available where free chlorine is used but requires ammonia source
Ozone	Yes/Rare(less widely than free chlorine; mostly in Europe)	Highly microbiocidal;	No residual; Generate onsite; hard to use; need special facilities and trained personnel; hazardous	High	Not practical for household use in many regions and countries
Combined chlorination, coagulation-flocculation-filtration systems	Yes/Yes As sequential processes in community systems and as combined processes in household systems	Highly effective for microbe reductions	Availability now limited; requires some training and skill; efficacy varies with water quality;	High	Limited availability and higher cost (compared to chlorine) are barriers to household use in some countries and regions

**Annual household cost estimates in US dollars. Low= Less than $10, Moderate=$10-$100, High= Greater than $100*

2.5 Impact of Water Quality and Household Water Treatment on Community Perception

An integral part of household water storage and treatment is community perception (Canter, 1993). Community, or public, perception on water quality is based on including 1) aesthetics; 2) trust in government and water suppliers; 3) previous experiences; and 4) information from media and peers. The aesthetics of water quality (e.g. taste, smell, color, clarity) are often used by individuals to determine whether a water source is safe for consumption. Such has been the case with chlorinated water. While chlorination reduces the risk of pathogenic and microbial contamination of water, many individuals are averse to the taste and smell of chlorinated water and will avoid it (Colindres, 2007; Lule, 2005; McLaughlin, 2009; Sobsey, 2003). Nevertheless, aesthetic values vary depending on the function and/or intended use of the water source.

The level of trust with the respective government and water supplier is also an important factor. Jorgensen (2009) argued that there is a greater potential for non-compliance with water conservation and security initiatives when the public feels there are reasons for mistrust (e.g., poor management, lack of transparency, and misappropriation of funds). Jorgen further went on to say that individuals are also less likely to comply with water restriction mandates when the individual neither trusts nor believes that those around him (e.g. neighbors, agricultural sector, industry sector) are complying with the mandates.

Previous experiences with water quality also impact the perception. If an individual has gotten ill from consuming water, that individual will be less likely to believe in the safety of that water source for future needs. Similarly, if an individual has consumed a particular water source for a period of time, he is less likely to take heed to warnings about abstaining from that water source or to believe that he will become ill from consumption. Regular precautions (e.g. handwashing, boiling water, consumption of water-based products) may be eschewed when an individual has had mostly positive experiences with water consumption. Doria (2010) argued that, provided an individual has had positive experiences with water quality, he is more likely to speak favorably of the water source, as the perceived risk is lower compared to the individual who had a negative experience. Doria further went on to say how established familiarity with particular water quality aspects could come to be preferred over unfamiliar characteristics, even to the point of considering the former aspects to be something of desire. This may help to explain preferences by individuals for certain water quality traits (e.g. levels of water hardness, mineral composition, chlorine concentration).

Information from media sources and peers can also affect perception. Media outlets (e.g. news, periodicals, movies, public announcements) are considered reliable sources of information and often serve as the main means of communication of water-related information. As such, the severity or insignificant of water-related events are gauged by the frequency and intensity with which they are portrayed in the media (Wray, 2008). Doria (2010) stated that risk perception was lower in areas where fewer people have been exposed to water-related health problems. Between 2002 and 2006,t he U.S. Centers for Disease Control (CDC) and the Association of Schools of Public Health (ASPH)collaborated on a joint project entitled the Pre-Event Message Development Project (PEMDP). Wray (2008) discussed the findings following the conclusion of the project. The project found that, during cases of emergency, the public will looked to gain information from trusted media outlets, law enforcement, and public health experts. Wray further went on to say that, as a result of limited access to media outlets, individuals in the rural area would seek information from local authorities.

CHAPTER 3: TARGET COUNTRIES AND COMMUNITIES

3.1 Introduction

Based on established research connections and collaborations, pilot studies were conducted in Trinidad and Tobago, Guyana, and Bolivia. By having established contacts in these areas, a community representative was available to serve as a liaison and a facilitator of trust between the researcher and the residents. All of the study locations in Trinidad and Tobago and Guyana had high density polyethylene (HDPE) water storage tanks at the household level. Bolivia has faced various documented issues relating to water storage and access (Quick, 1999; Tornheim, 2009; Wutich, 2008; Esrey, 1996; Anderson, 1981; Laurie, 2007). In order to provide a common relationship between the countries, the study focused on rural communities, as those are the ones most affected by access to clean water and household water storage issues (Cotruvo, 2000; Garrett, 2008; Hoque, 2006; Jagals, 2006; Kravitz, 2001; Luby, 2008; Simango, 1992; Trevett, 2004; Trevett, 2008; Welch, 2000). Thus rural communities of Siparia, Trinidad and Tobago; Villa Litoral, Bolivia; and Region 4 Subset, Guyana were selected.

The three communities were selected as they provided insight into varying levels of access to potable water and means of water storage within the Latin American and Caribbean region. In Siparia, Trinidad, residents have long had access to potable water from a relatively advanced water facility and utilize sturdy water storage tanks. In Region 4 Subset, Guyana, there is a mixture of residents with regards to access and water storage system devices. Similar to Siparia, Trinidad, a portion of the residents have had access to water from the municipal plant and have used the HDPE water tanks. However, there is another portion of residents who, until recent years, only received water sources from rain, canals, streams, and other surface waters. A few years ago, many residents within this second group started using the HDPE water storage tanks with access to piped water, while several residents still continue to use water storage drums. In Villa Litoral, Bolivia, the main source of water is the community well and neighboring rivers, as bottled water is not readily available given the relatively remote location of the community. While many residents utilize smaller, portable containers for water storage, many do have large, stationary water storage tanks. Figure 3.1 provides a map of the three research sites.

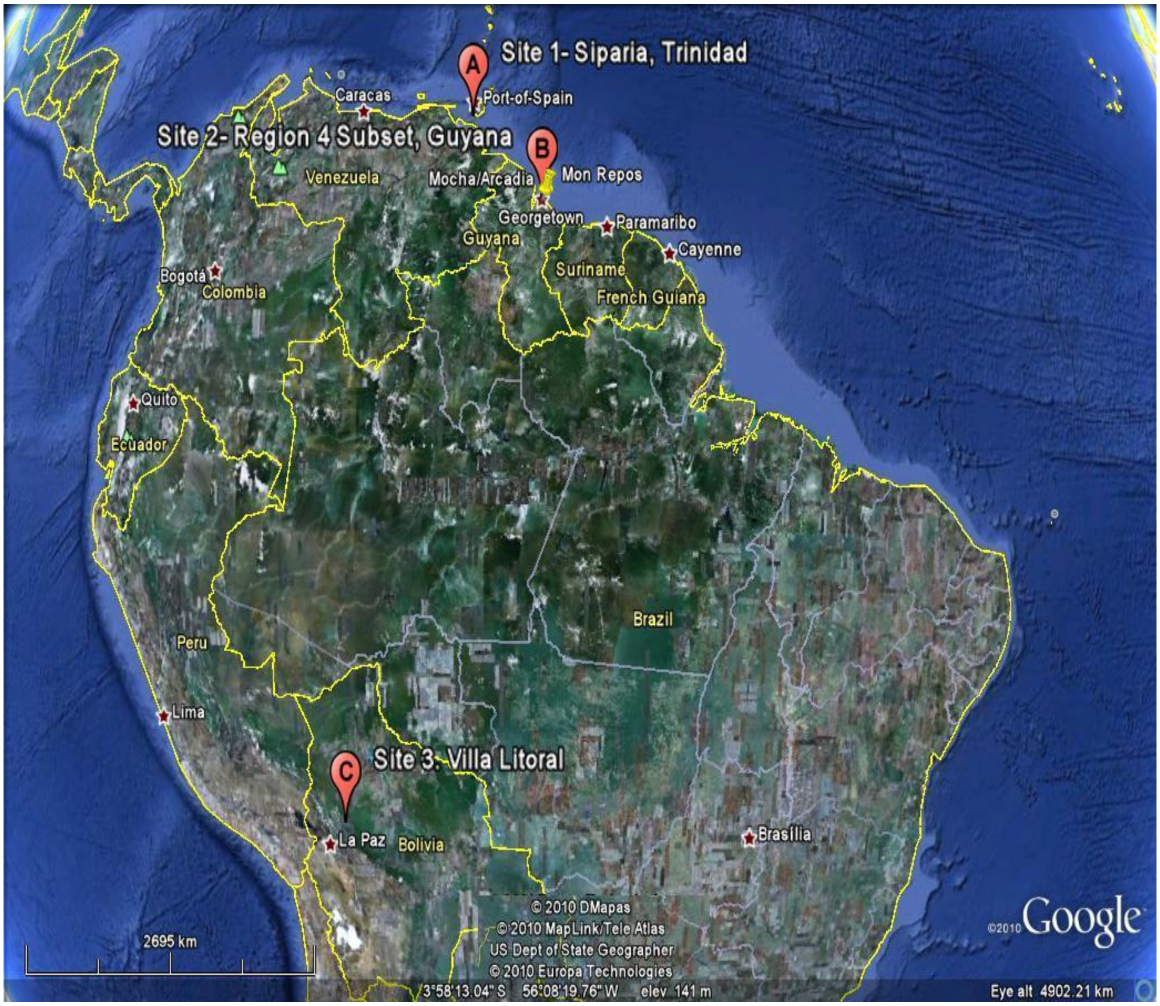


Figure 3.1 Map of research field sites. Point A = Siparia, Trinidad and Tobago, Point B = Region 4 Subset, Guyana, Point C = Villa Litoral, Bolivia. Image obtained from Google Earth on 02/12/2010 at an altitude of 4902.21 km.

3.2 Trinidad and Tobago

Figure 3.2 Map of Trinidad and Tobago. (CIA 2008).

Located between the Caribbean Sea and the North Atlantic Ocean to the east of Venezuela, Trinidad and Tobago (11º 00' N, 61º 00' W) has a population of 1,047,366. Initially colonized by the Spanish, the islands came under British control in the early 19th century before finally gaining independence in 1962. With a gross domestic product (GDP) of roughly $23.8 billion, Trinidad and Tobago has one of the highest growth rates and per capita incomes in Latin America. Trinidad and Tobago exports several products such as petroleum, natural gas, methanol, ammonia, steel products, beverages, sugar, cocoa, coffee, citrus fruit, vegetables, and flowers. The GDP is derived primarily from industry (61.9%), followed by services (37.5%) and agriculture (0.6%). Interestingly, although oil and gas account for about 40% of GDP and 80% of exports, only 5% of the country's employment is derived from this sector. In addition to its natural gas and petroleum, Trinidad and Tobago also has an abundance of asphalt, as is evident by Pitch Lake, the world's largest natural reservoir of asphalt (CIA, 2008).

Trinidad and Tobago faces several environmental issues, such as water pollution from agricultural chemicals, industrial wastes and raw sewage; oil pollution of beaches; deforestation; soil erosion and flooding. Although their total renewable water resources are estimated at 3.8 km^3, the estimated freshwater withdrawal rate in Trinidad and Tobago is 0.31 km^3/yr (CIA, 2008). The majority of this withdrawal is for domestic purposes (68%), followed by industrial (26%), and agricultural (6%) (CIA, 2008).

3.2.1 Water Supply and Sanitation

In a recent report, WHO (2008) made the following assessment on the water and sanitation issues plaguing Trinidad and Tobago:

> *"Poor access to potable water is attributed to several factors, including a 40%–50% loss of water in the distribution system, deterioration of assets, and weak institutional and human resources programs. The quality of water delivered meets World Health*

Organization guidelines for drinking water quality, although this status is challenged by environmental degradation, watershed destruction, and pollution."

The country's public water supply is provided primarily by the country's treatment and supply administrator, Water and Sewerage Authority (WASA). As shown in Figure 3.3, the majority of the country's households (78.9%) receive public water supplies that were either being piped into their homes (60.5%), into their yards (8.8%) or from a public standpipe (9.6%) (CSO, 2000). 54.3% received a continous supply, while 36.9% received water more than at least twice a week.

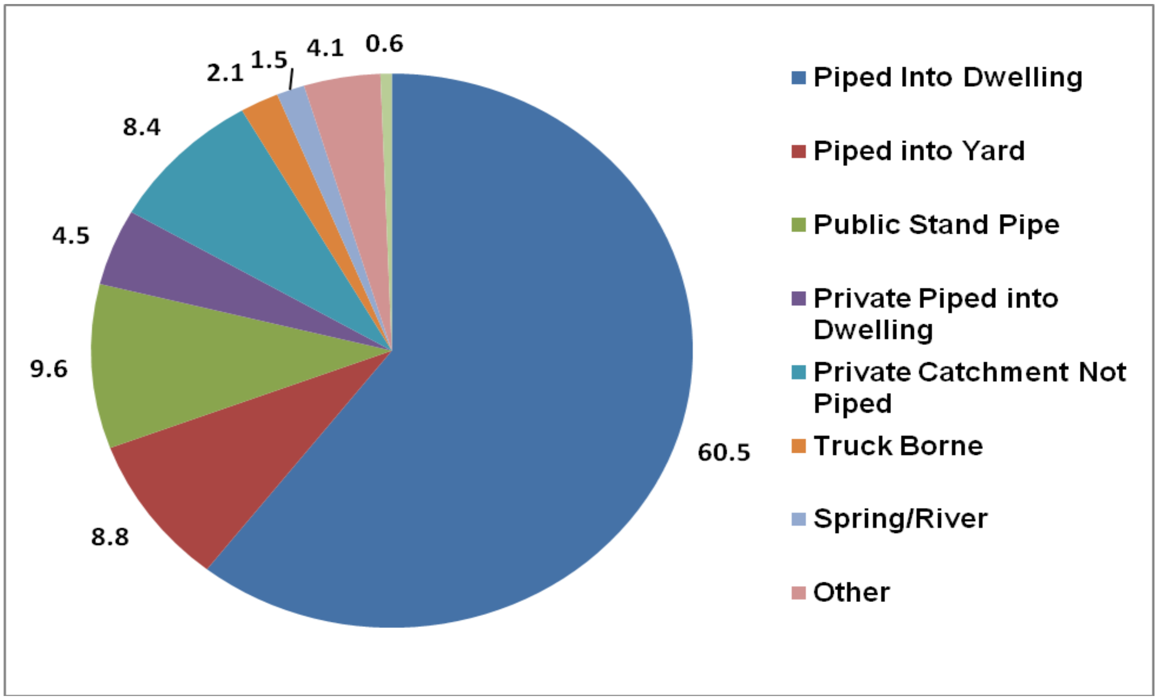


Figure 3.3 Percentage distribution of types of household water supply in Trinidad & Tobago. Data obtained from Trinidad and Tobago Central Statistical Office (CSO, 2000).

For sewage disposal and toilet facilities, 50.3% of the population is served by septic tank systems, while 21.7 percent is served by sewage treatment plants, and 26.8% use pit latrines (CSO, 2000). A small percentage (0.4%) lacked any toilet facilities.

3.2.2 Siparia, Trinidad and Tobago

Located in southern Trinidad and Tobago, the regional corporation of Siparia (10º 08’ N, 61º 30’ W) accounts for 7% of Trinidad and Tobago’s households (CSO, 2000). A predominantly rural area with a population of roughly 81,917 residents, the region is also in proximity to Rotoplastics LTD, the largest water storage tank distributor in the Caribbean. In terms of water supply, 74.2% of households receive piped water into their homes, yards, or through public standpipes (CSO, 2000). For sewage disposal and toilet facilities, 61.9% of the population is served by septic tank systems, while 36.5%t use pit latrines (CSO, 2000).The administrative city of the region, also called Siparia, has a population of 15,634.

3.3 Guyana

Figure 3.4 Map of Guyana. (CIA, 2008).

Guyana (06º 46' N, 58º 10' W) is situated between Suriname and Venezuela on the northeastern coast of South America, as shown in Figure 3.4. Initially colonized by the Dutch, Guyana then came under British control before finally gaining independence in 1966. With a population of roughly 770,000, the economy is dominated by agriculture, fishing, and mining; with major exports being gold, rice, bauxite, sugar, timber, shrimp and prawns. Guyana has a gross domestic product (GDP) of roughly $2.8 billion, which is derived primarily from services (47.1%), followed by agriculture (31.1%) and industry (21.7%) (CIA, 2008).

3.3.1 Water Supplies and Sanitation

Guyana, known as The Land of Many Waters, features multiple rivers and streams. The climate is tropical with two wet and two dry seasons. Along the coastal lowland region, rain falls an average of 200 days a year, with 50% of the average rainfall occurring from mid- April to mid-August and from December to January. Annual rainfall in Georgetown and surrounding coastal areas was 2,163 mm for the period 1985 to 2005 (Figure 3.5). According to the country's Hydromet department, the annual average daytime maximum temperature is 29.6°C and the annual average nighttime minimum temperature is 24.0°C.

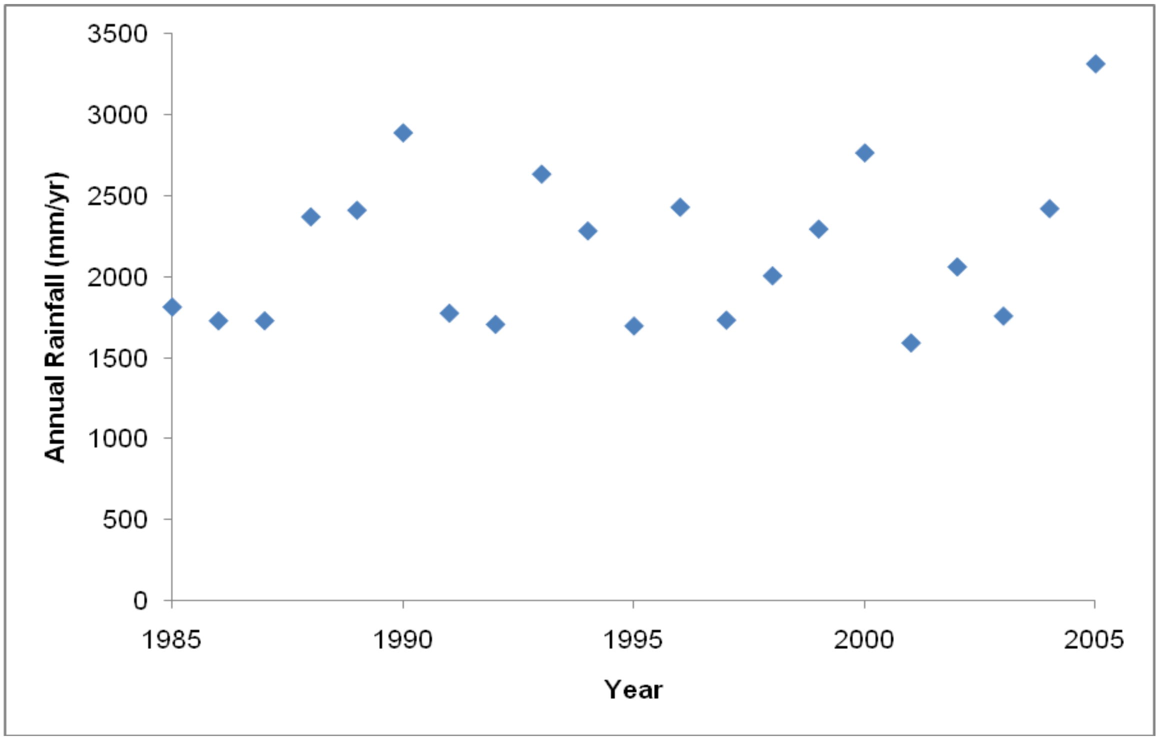


Figure 3.5 Rainfall in Georgetown, Guyana from 1985 to 2005 (average is 2,163 mm/yr). Data obtained from the Hydrometeorological Service (Hydromet) of the Guyana Ministry of Agriculture http://www.hydromet.gov.gy/, accessed on 6/23/2010.

Surface water is used for agricultural and industrial purposes, and services roughly 10% of the country's potable water needs. The majority of the population resides along the coast and is serviced by a series of groundwater wells extending down into a coastal aquifer system that is about 20,000 km^2, extending 250 km along the Atlantic coast and 40 to 150 km inland (USACE, 1998). This coastal aquifer system is made up of three connected but hydrogeologically distinct aquifers called the Upper Sands, the A Sand, and the B Sand which are shown in Figure 3.6.

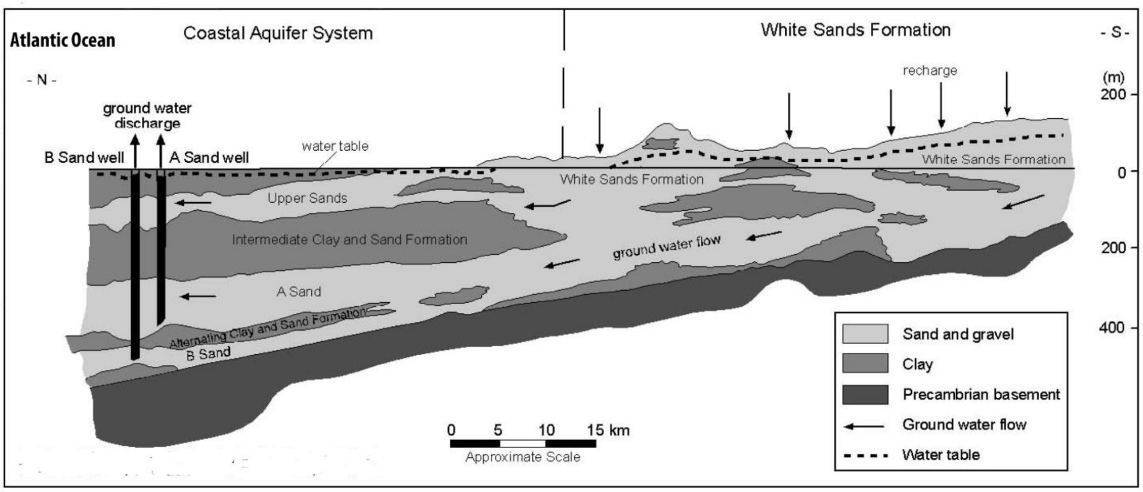


Figure 3.6 Coastal aquifer system in Georgetown, Guyana. Image obtained from US Army Corps of Engineers Water Resources Assessment of Guyana (USACE, 1998), which was based on Arad (1983).

The coast currently relies heavily on water from the A Sands aquifer which is composed of quartz, sand and fine gravel and which is shielded from the Upper Sands aquifer by a 90 m thick Intermediate Clay and Sand formation composed of clay and shale. The A Sand aquifer ranges from 150 to 215 m deep and is 12 to 27 m thick with yields similar to the other three aquifers of between 4,000 and

40,000 liters per minute year-round (USACE, 1995). In general the quality of water withdrawn from the A Sands aquifer has low chloride content and high iron levels.

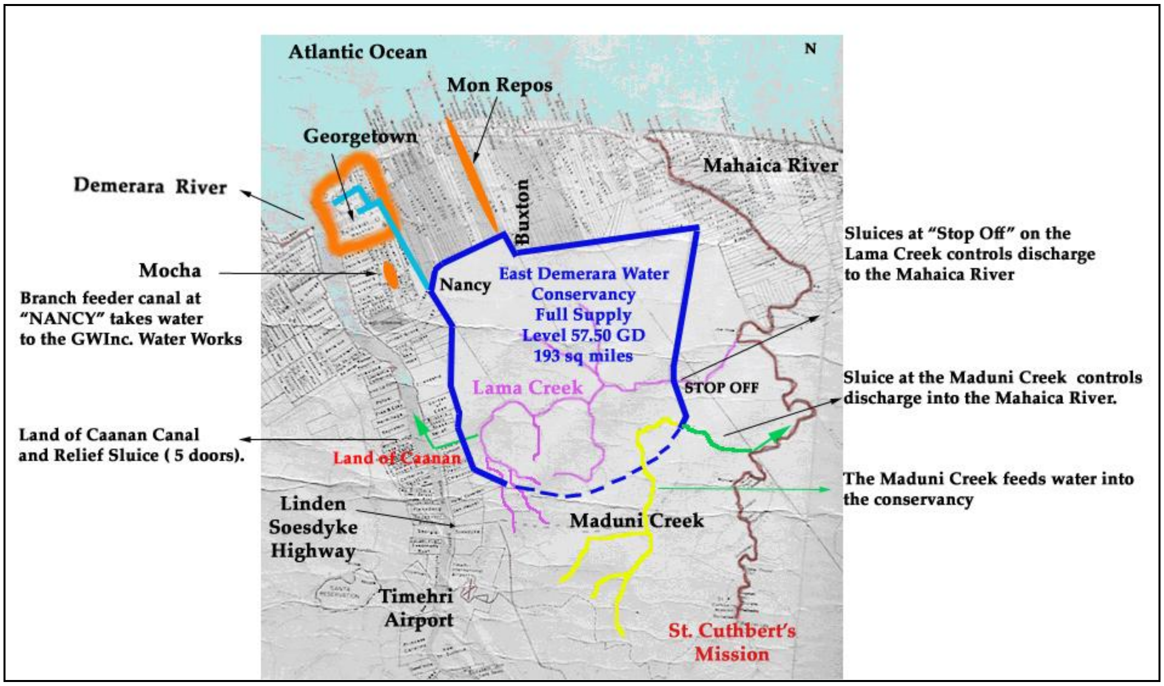


Figure 3.7 Map of Guyana's coast showing study sites of Mocha, Georgetown and Mon Repos. Map not drawn to scale and details were provided by Mr. John Piggott.

Figure 3.7 shows the coastal area of Guyana that was studied during this research. The majority of the population lives in this coastal region which lies beneath sea level at high tide with a seawall to protect it from the Atlantic Ocean and an earthen dam to protect it from the East Demerara Water Conservancy (EDWC). The EDWC was constructed to provide water for irrigational and industrial processes with a small flow going to Guyana Water Inc. (GWI), the municipal body that oversees sewage and water supply for the country. GWI was established on May 30, 2002, resulting from the merger of the Guyana Water Authority (Guywa) and the Georgetown Sewerage and Water Commissioners (GS&WC). In 2003, an international private operator, Severn Trent Water International (STWI), was awarded a 5 year management contract for GWI which was then terminated by the government of Guyana in 2007. At the Shelter Belt treatment facility serving the Georgetown municipality and some suburbs, water from the EDWC undergoes treatment prior to distribution. Some of the water at the Shelter Belt facility is also mixed with groundwater. GWI supplies water to areas outside of the Georgetown Municipality and some Georgetown suburbs mainly through groundwater wells.

Guyana currently faces several environmental issues, such as water pollution from sewage, agricultural and industrial chemicals, along with deforestation. Although the country's total renewable water resource is an estimated 241.8 km^3, the estimated freshwater withdrawal rate in Guyana is 1.64 km^3/yr (CIA, 2009). The majority of this withdrawal is for agricultural (98%) purposes, followed by domestic (2%) and industrial (1%). Roughly 67% of Guyana's population receives their water supply through water piped into their homes, yards or plot (UNICEF, 2006).

The country experiences a wet climate for most of the year, which has led to problems such as floods (Monteiro, 2005; Peller, 1997). Bacterial and viral contamination of surface waters may occur during heavy rainfall which can increase discharges of raw sewage or animal manure. For residents in the Georgetown municipality and a few suburban areas, sewage connections take waste from the house to a discharge facility where it enters the Demerara River untreated. Septic systems and pit latrines are generally used by those not connected to a sewer system. Surface waters are heavily contaminated with pathogenic microorganisms, although viruses have also been detected in groundwater (Pinfold, 1990; Han, 2007; Vollaard, 2005; Evans, 2007). The contamination of drinking water by sewage via pump failure or sewage system blockage, along with inadequate or failed treatment processes, have led to the insufficient removal of viruses from source waters (CDC, 2007; Graham, 2007; Lee, 2005).

Waterborne outbreaks may arise from direct exposure by ingestion of contaminated tap water or water-containing products, e.g., ice cubes, custard, and salads. Waterborne disease outbreaks can cause significant economic impact due to increased cases of waterborne illnesses followed by secondary spread (Fewtrell, 2005; Pruss, 2002; Bessong, 2009; Wright, 2004; Clasen, 2007).

3.3.2 Region 4, Guyana

The Demerara-Mahaica region, known as Region 4, includes the Georgetown municipality and Georgetown suburbs and many smaller areas, each of which has its own National Democratic Council (NDC). The total population of Region 4 is 310,320, with a total of 77,937 households (BOS, 2002).

All of the study sites were in Region 4 and Table 3.1 provides data on each of the areas studies as taken from the 2002 Guyana Census (BOS, 2002). The study areas visited included Mocha (06º 44’ N, 58º 08’ W) and Mon Repos (06º 46’ N, 58º 04’ W), which would be considered rural according to the 2002 census.

The capital Georgetown (06º 48’ N, 58º 10’ W) has a population of roughly 235,000 individuals which includes residents in both the Georgetown Municipality and the Georgetown suburbs. Although the city contains many of the country’s major businesses and governmental offices, much of it and its surrounding communities remain severely water stressed at the household level owing to low water pressure and poor water quality. In this research, Region 4 Subset is used to refer to all of the sites studied in Guyana and Georgetown refers to sites in municipal Georgetown and suburban Georgetown. Figures 3.8 to 3.10 compare characteristics (female headed homes, source of drinking water, and water supply source) of each of the locations studied in Guyana and as reported in the 2002 census (BOS, 2002). The number of female headed households and bottled water use are higher in the municipal Georgetown and suburban Georgetown areas.

Table 3.1 Census 2002 data for Georgetown, Mocha/Arcadia and Mon Repos/La Reconnaissance. Data obtained from Guyana Bureau of Statistics (BOS 2002).

	Georgetown	Mocha/Arcadia	Mon Repos/ La Reconnaissance
Number of Households	35271	732	4355
Male head of Household	58%	61%	75%
Female Head of Household	42%	39%	25%
Main Source of Water Supply			
Private Piped into Dwelling	12%	13%	4%
Private Catchment	2%	10%	5%
Private Piped into Yard	6%	5%	11%
Public Piped into Dwelling	47%	55%	11%
Public Piped into yard	25%	11%	57%
Other	8%	6%	10%
Main Source of Drinking Water			
Piped into Dwelling	34%	60%	12%
Piped into Yard	24%	15%	48%
Public Standpipe	7%	0%	3%
Bottled Water	26%	5%	11%
Rainwater	7%	19%	26%
Other	2%	0%	0%

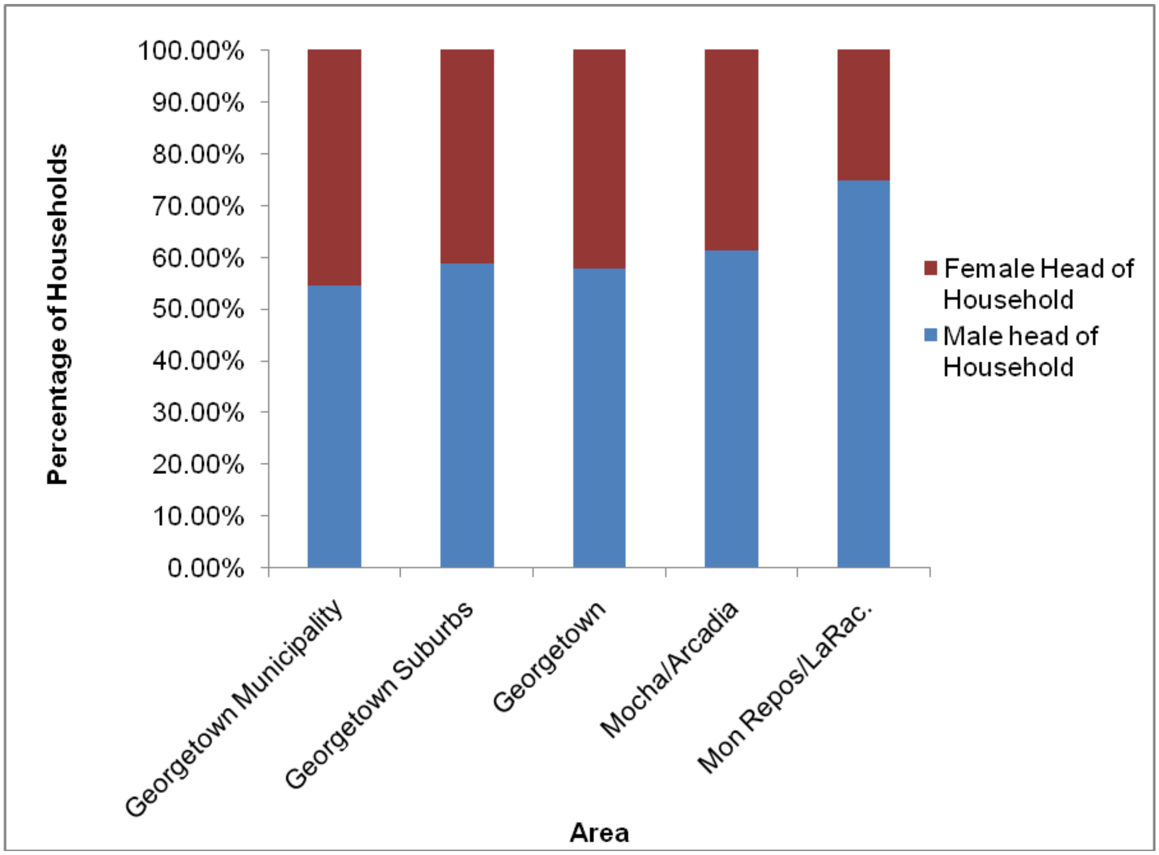


Figure 3.8 Distribution of head of households in select areas in Region 4, Guyana based on the 2002 census. Areas are based in National Democratic Committee (NDC) demarcations and Georgetown sums the Municipality and Suburban NDC. Data obtained from Guyana Bureau of Statistics (BOS 2002.

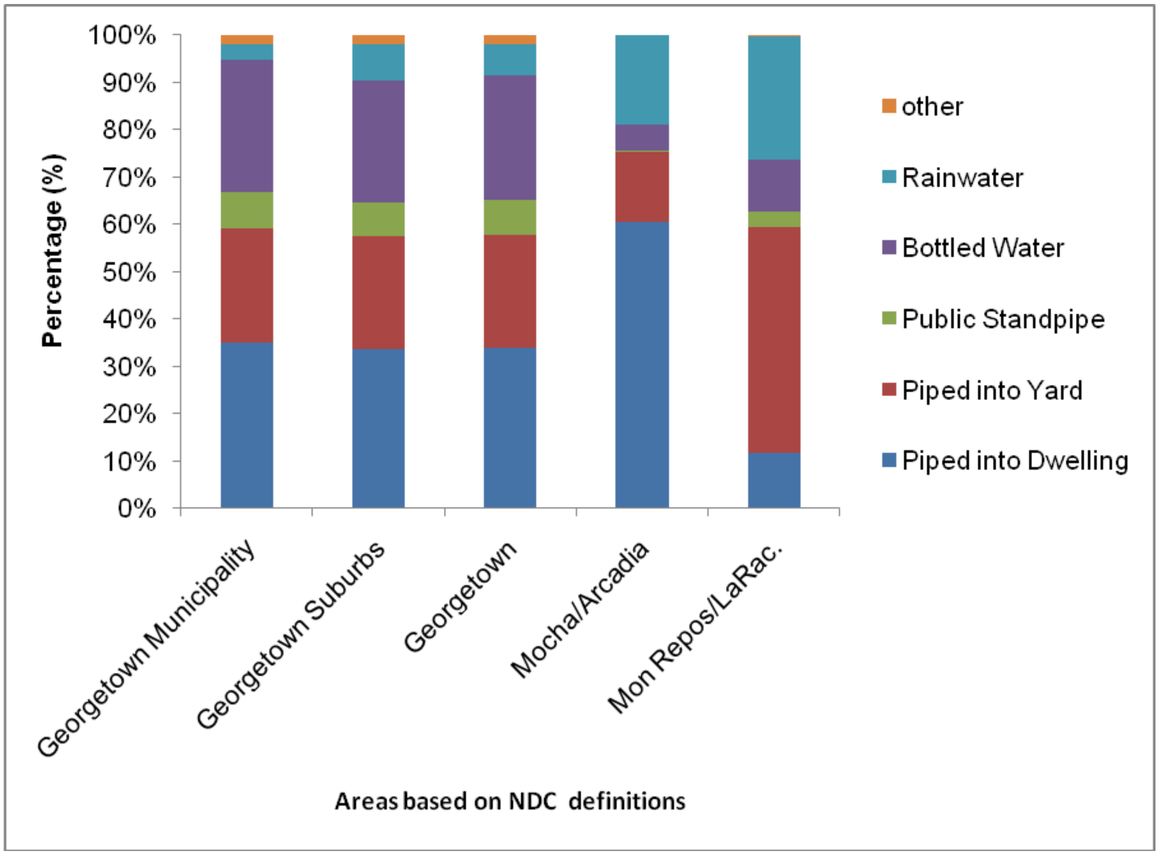


Figure 3.9 Distribution of drinking water sources in select areas in Region 4, Guyana. Areas are based in National Democratic Committee (NDC) demarcations and Georgetown sums the Municipality and Suburban NDC. Data obtained from Guyana Bureau of Statistics (BOS 2002).

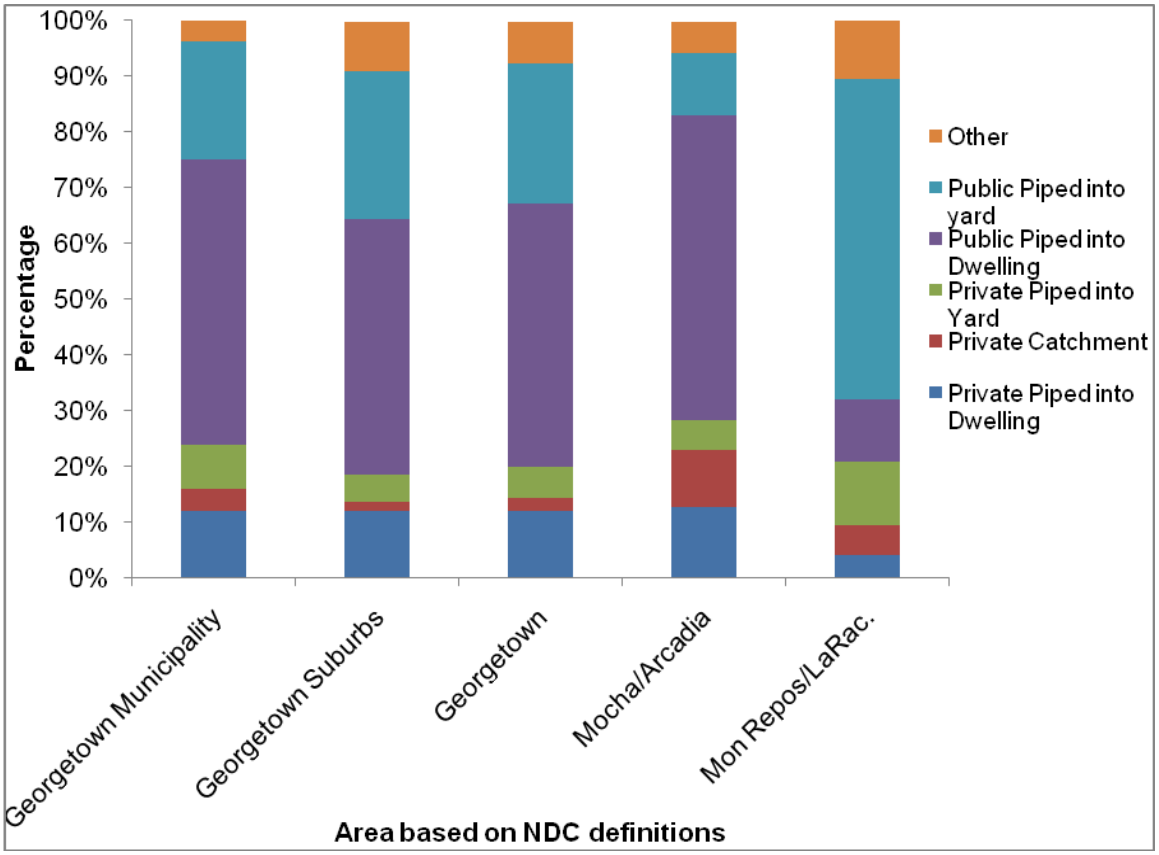


Figure 3.10 Distribution of water supply sources in select areas in Region 4, Guyana. Areas are based in National Democratic Committee (NDC) demarcations and Georgetown sums the Municipality and Suburban NDC. Data obtained from Guyana Bureau of Statistics (BOS 2002).

Research collaboration between our research team and the Guyana Citizen's Initiative (GCI) began in 2005 during a major flood event that rendered much of the coast under stress (Trotz, 2008). Following the floods, our team provided advice to GCI on a community water survey project in the Mocha area where GCI was working with community members to install a series of water storage tank systems to be shared by various members of the community (Rahat, 2007). Based on GCI's 2007 report, 57% of households in the Mocha community relied on rainwater as their main source of drinking water, whereas 19% relied on piped water (Rahat, 2007). This was very different from the 2002 census data where over 50% of the population received drinking water that was piped into the dwelling. For various reasons the water samples collected by GCI during that 2007 study were never processed.

3.4 Bolivia

Figure 3.11 Map of Bolivia. (CIA, 2008).

A landlocked country, Bolivia (16º 30' S, 68º 10' W) is located in the western region of the South American continent adjacent to Peru, Brazil, Chile, Argentina, and Paraguay, as shown in Figure 3.11. Bolivia gained its independence under the leadership of South American revolutionary Simon Bolivar in 1825. Its terrain varies from the rugged Andes Mountains with a highland plateau (Altiplano) and hills, to the lowland plains of the Amazon Basin. Its climate varies from humid and tropical in the lowlands to cold and semiarid in the highlands. Bolivia's natural resources include tin, natural gas, petroleum, zinc, tungsten, antimony, silver, iron, lead, gold, timber, and hydropower. Bolivia's total renewable water resources have a volume of 622.5 km^3 (CIA, 2008). Freshwater withdrawal is used predominantly for the agricultural sector 81%, followed by the domestic sector (13%), and the industrial sector (7%) (CIA, 2008).

Bolivia faces several environmental issues such as deforestation; soil erosion from overgrazing and poor cultivation methods; desertification; loss of biodiversity; industrial pollution of water supplies used for drinking and irrigation. Additionally, the northeast region of Bolivia is prone to flooding from March-April. Although landlocked, Bolivia shares control of Lago Titicaca, world's highest navigable and ancient lake (elevation 3,805 m), with Peru.

Bolivia has a population of ~9,775,246, of which the median age is 21.9 years old. Bolivia's urban population consists of 66% of the total population. The ethnicities of Bolivian residents consist of Quechua 30%, mestizo (mixed white and Amerindian ancestry) 30%, Aymara 25%, and white 15% (CIA 2008). Bolivia has three official languages to coincide with its ethnic groups: Spanish as spoken by 60.7% of residents, Quechua by 21.2%, and Aymara by 14.6%. In Bolivia, the literacy rate is 86.7%, with the country spending 6.4% of its GDP on education. Bolivia has a GDP per capita of $4,600 (CIA, 2008). Bolivia's GDP is derived predominantly from services (51.8%), industry (36.9%), and agriculture (11.3%) (CIA, 2008).

3.4.1 Water Supply and Sanitation

As with several developing countries, water and sanitation are great issues in Bolivia. Over the years, Bolivia has faced several natural disasters, as shown in Figure 3.12. The two most reported natural disaster issues are floods and droughts, which have increased in the past decade. With the increase of floods, drinking water sources are more likely to be compromised with bacterial and chemical contaminants. On the opposite side, the increase in drought cases means that there will be less potable water sources available, particularly for those who rely on rainwater as their main potable water source. Additionally, the governmental expenditure on water sources and sanitation has also decreased in the past decade, as shown in Figure 3.13. Thus, even as water sources become compromised and scarce, government expenditure on water resources has not addressed those needs.

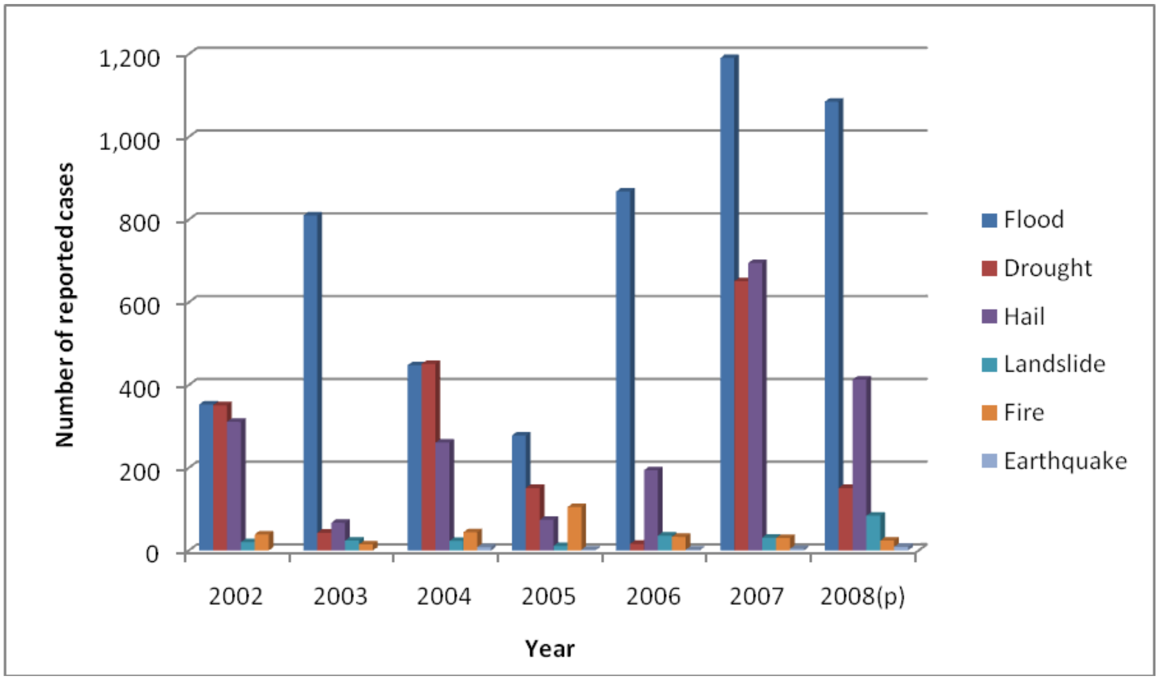


Figure 3.12 Natural disasters reported in Bolivia, 2002-2008. Data obtained from Instituto Nacional de Estadística de Bolivia (INE, 2009).

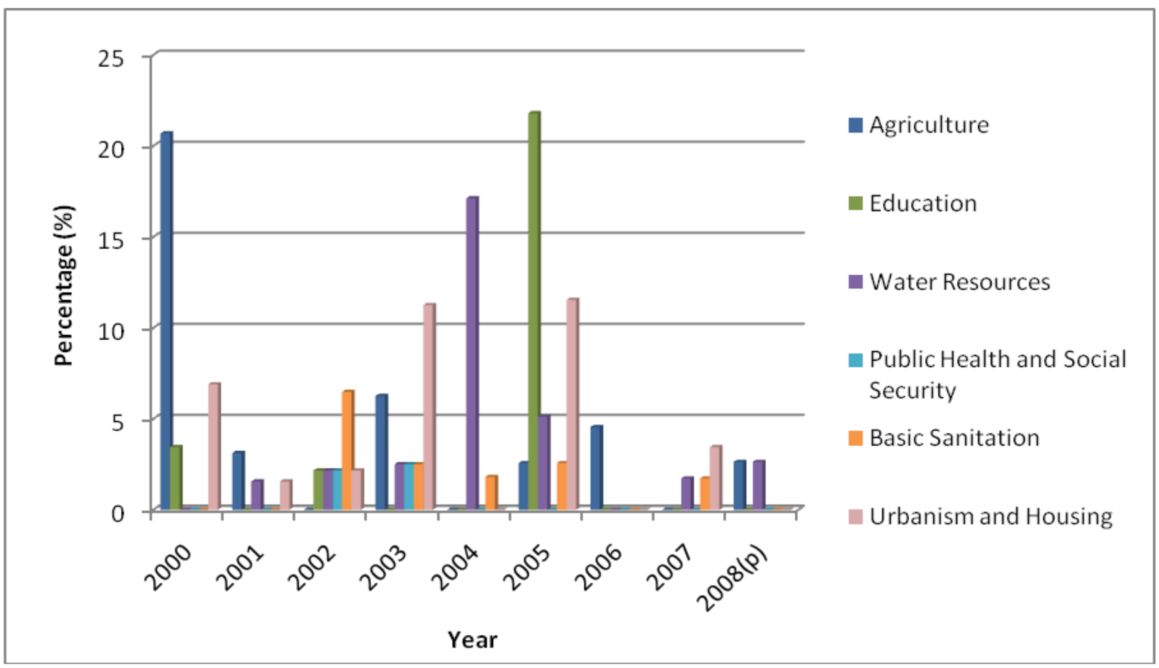


Figure 3.13 Distribution of mitigation and prevention programs in Bolivia by sector, 2000-2008. Data obtained from Instituto Nacional de Estadística de Bolivia (INE, 2009).

3.4.2 Villa Litoral, Bolivia

Bolivia is divided into nine administrative departments: Beni, Chuquisaca, Cochabamba, La Paz, Oruro, Pando, Potosi, Santa Cruz, and Tarija. The Caranavi Province is one of the twenty provinces within the department of La Paz and is situated in the department's eastern area. The province is situated on the Bolivian Altiplano east of Lake Titicaca, on the headwaters of Río Beni. The population of Caranavi province has increased by roughly 40 % over the recent two decades, going from 43,093 inhabitants in 1992 to 59,090 inhabitants in 2010 (INE, 2009). The literacy rate of the population is 83.1 %. 92.7 % of the population speak Spanish, 71.6 % speak Aymara, and 11.1 % Quechua (CIA, 2008). Of this population, 8.7 % of the population has no access to electricity, while 65.6 % has no sanitary facilities. Caranavi Province is not further subdivided into municipalities, but is further subdivided into 22 cantons.

Villa Litoral (15º 35’ 20”S, 67º 18’ 23” W) is located in the Caranavi province. A community of roughly 400 residents, Villa Litoral lies in proximity to the Rio Beni and Rio Tiatche. Villa Litoral is a predominantly agricultural community where the main crops grown are cacao, papaya, and citrus.

3.5 Comparison of the Target Countries

In general, the Latin American and Caribbean region, namely South America, has an abundance of water resources as well as a relatively high rate of precipitation. However, the quality of the available water resources has declined (UNEP, 2007). This can be attributed to factors like deforestation, urban sprawl, untreated sewage, mining and industrial activities, along with increased pesticide usage (UNEP, 2007; Foley, 1993; Mulreany, 2006; Rahat, 2006; Tokajian, 2003; Wright, 2004).

Table 3.2 compares the three countries based on economic and environmental factors. A significant difference is seen when comparing Bolivia to the other countries in terms of the population proportion with access to improved water and sanitation, particularly in the rural sectors. This may be attributed to the fact that Bolivia is considered to be the least economically developed country in South America and that the majority of its citizens reside in rural areas. In each country, a disparity is seen between access to an improved water supply in the urban area versus the rural area.

Table 3.2 Comparison of environmental and economic statistics among target countries. Data obtained from (UNICEF, 2009).

	Latin America and Caribbean	Trinidad and Tobago	Guyana	Bolivia
% of population using improved drinking-water sources, 2006 total	92	94	93	86
% of population using improved drinking-water sources, 2006 urban	97	97	98	96
% of population using improved drinking-water sources, 2006 rural	73	93	91	69
% of population using improved sanitation facilities 2006 total	78	92	81	43
% of population using improved sanitation facilities 2006 urban	86	92	85	54
% of population using improved sanitation facilities 2006 rural	52	92	80	22
Number per 100 population, 2007, phones	67	113	37	34
Number per 100 population, 2007, Internet users	26	16	26	11
Life expectancy, 2008	74	69	67	66
% of population urbanized, 2008	78	13	28	66
GNI per capita (US$), 2008	6888	16540	1420	1460
GDP per capita average annual growth rate (%), 1990–2008	1.6	5.1	2.4	1.5
% of population below international poverty line of US$1.25 per day, 1992–2007*	7	4	8	20
% of central government expenditure (1998–2007*) allocated to:, health	7	6	-	9
% of central government expenditure (1998–2007*) allocated to:, education	14	13	-	24
Adult literacy rate: females as a % of males, 2003–2007*	99	99	-	90

CHAPTER 4: METHODOLOGY

4.1 Introduction

An important factor in improving access to potable water in an area is community engagement and community based surveys are usually used to obtain baseline knowledge of the target communities being studied (Levesque, 2008; Agard, 2002). Household surveys were used to understand the dynamics that exist between people in the three field sites and their water storage devices. In addition to the household surveys, the drinking water sources available to individuals at the household level were assessed through direct observations, sample collection and water quality analyses. Water quality analyses included bacterial enumeration, water quality parameters (DO, Turbidity, pH, Conductivity, Temperature), and dissolved metals. During March 2009, household surveys were administered and water samples collected in Siparia, Trinidad and Tobago; and a subset of Region 4, Guyana. During June 2009, surveying and water sampling were conducted in Villa Litoral, Bolivia.

4.2 Household Survey Development and Implementation

The survey consisted of a questionnaire in which individuals were asked various questions about their habits, lifestyle, and perception as they pertain to household water consumption and handling. Appendix C contains the full questionnaire. In order to maintain anonymity and protect the privacy of the participants, the only means of identification on the surveys were the survey ID number. Personal questions were limited to age, gender, household size, and number of children living in the house. The target areas for the survey distribution were a subset of Region 4, Guyana; Siparia, Trinidad and Tobago; and Villa Litoral, Bolivia. As mentioned in section 3.3.2, Region 4 subset refers to areas studied in the Georgetown municipality, suburban Georgetown, Mon Repos and Mocha/Arcadia.

The household surveys were distributed to various households door-to-door. In Siparia, Trinidad and Tobago, the questionnaires were administered in March 2009 through the assistance of USF graduate students, one of whom is a local resident. In Region 4 Subset, Guyana, the surveys were distributed in March 2009 through the assistance of the Guyana Citizens Initiative (GCI), a local non-government organization (NGO). For the community in Villa Litoral, Bolivia, the survey was translated to the country's official language of Spanish, so as to better facilitate the administration of the questionnaire (Appendix C). The questionnaires were administered with the assistance of the community's Water

Committee members and research students from Universidad Tecnológica Boliviana (UTB).

The surveys were approved through the Institutional Review Board (IRB) at the University of South Florida and were exempt from documentation of consent because they were anonymous with no collection of biological or personal data. Eligible participants were residents aged eighteen and above and a one-page description of the survey and the project was provided to participants prior to asking for their consent to participate (Appendix C). The survey contained a disclosure stating that the survey was voluntary, that no compensation or incentive was given, and that the surveys were anonymous and participants were not asked to disclose personal identifiable information such as name, address, phone number, or social security number.

All responses from the survey were coded into a Microsoft Access program via the Epi Info Version 3.5.1 software (CDC, Atlanta, GA).

4.2.1 Survey Sampling Size

An important aspect in conducting the household surveys was determining the desired sample size and analyzing results based on the actual sample size used. Figures 4.1- 4.3 shows the population and household data for field sites in Trinidad and Tobago, Guyana, and Bolivia, respectively.

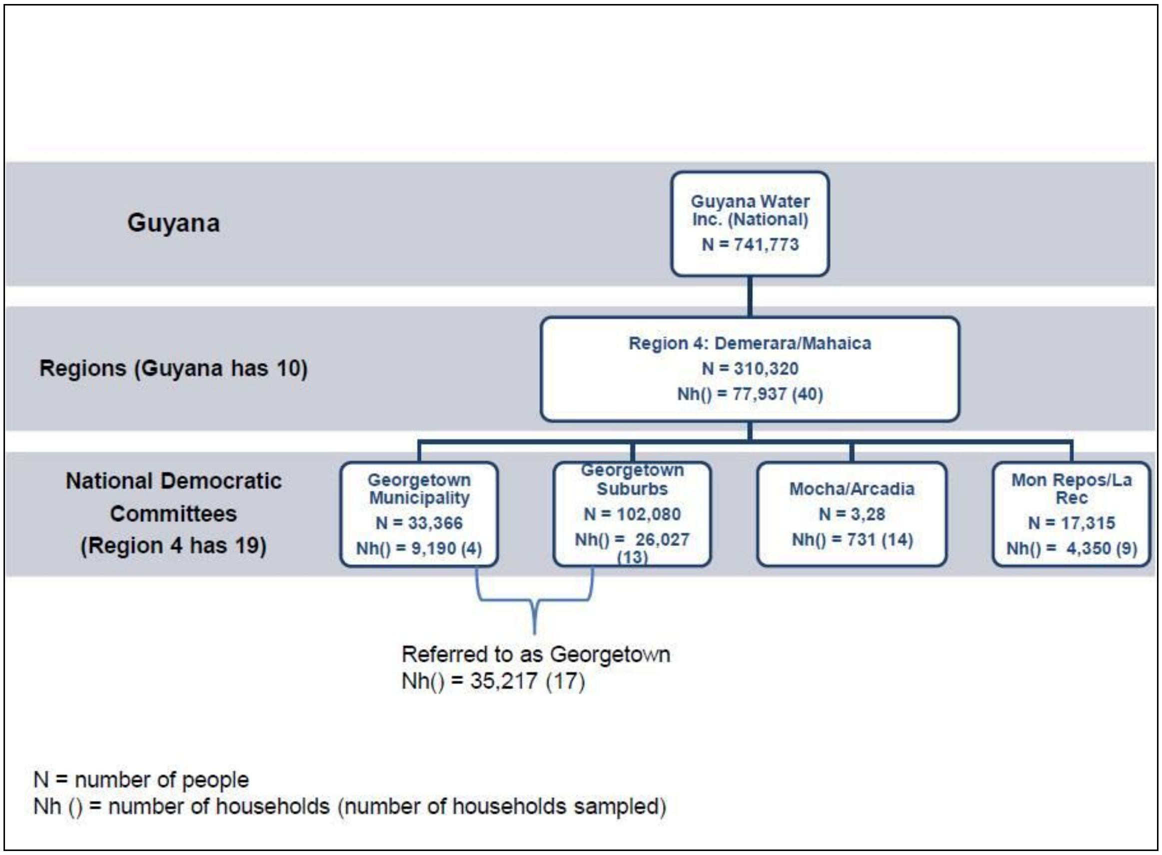


Figure 4.1 Population and household data for Region 4 Subset, Guyana. Data obtained from Guyana Bureau of Statistics (BOS 2002).

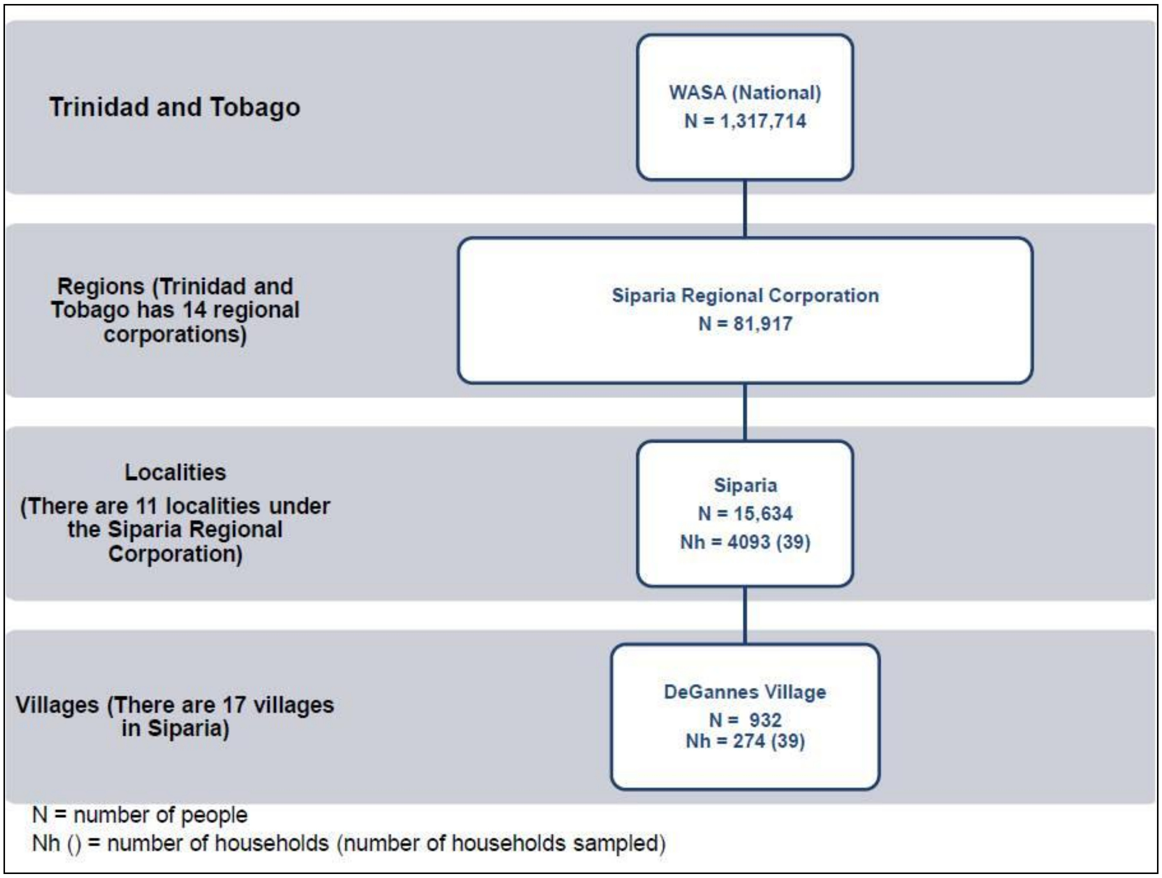


Figure 4.2 Population and household data for Siparia, Trinidad and Tobago. Data obtained from Trinidad and Tobago Central Statistical Office (CSO, 2003).

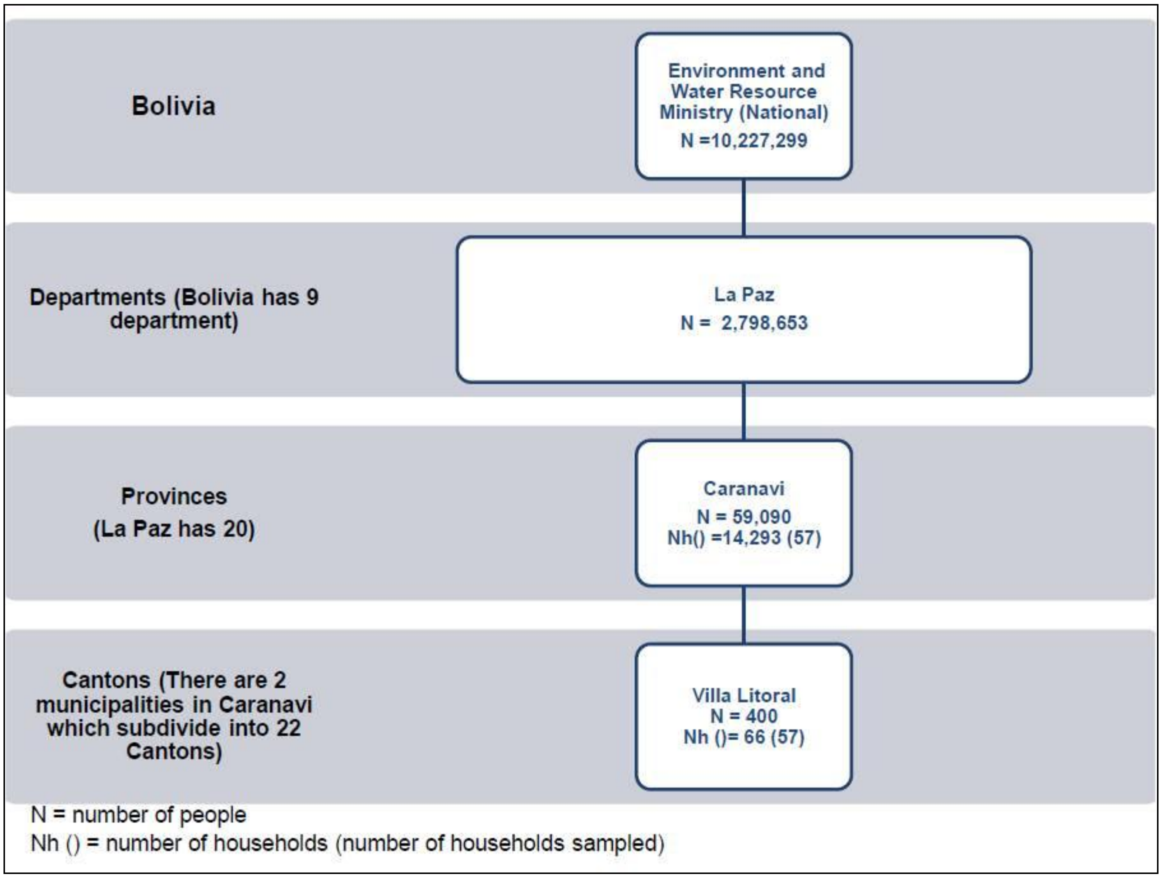


Figure 4.3 Population and household data for Villa Litoral, Bolivia. Data obtained from INE (2009).

In Table 4.1, the criteria for the sampling size are shown. The population size was the number of households found within each target community rather than the number of individuals, as the surveys were distributed to an adult representative from each household. The survey sampling size was determined based on the desired confidence level, population size, and the sampling error (SE) utilized.

Table 4.1 Criteria for determining survey sample size. Population data obtained from (BOS, 2002; Dean, 2009; CSO, 2003; INE, 2009).

Sample Size for Frequency in a Population			
	Siparia, Trinidad and Tobago	Region 4 Subset, Guyana	Villa Litoral, Bolivia
Number of households in population size (for finite population correction factor or fpc)(*N*):	4,093	40,358	66
Hypothesized % frequency of outcome factor in the population (*p*):	50%+/-5	50%+/-5	50%+/-5
Confidence limits as % of 100 (absolute +/- %)(*d*):	5%	5%	5%
Design effect (for cluster surveys-*DEFF*):	1	1	1

Sampling size can be determined by sampling error. The greater the desired sample size, the smaller the SE, because the results become more representative of the actual population. Typically, the SE is chosen to be 5% or 10%, along with a confidence level of at least 95%, where the level of risk (α) is 5%. A lower confidence level (e.g. 80%) will increase the likelihood that the sample values do not reflect the true population value, thus reducing the validity of the test. A higher confidence level (e.g. 99%) improves the accuracy of the test, but may be more costly and time consuming, since it requires a larger sample size. Assuming the confidence level was 95% and the statistical variability (P) value was 0.5, the desired sample sizes are calculated using Equation 4.1:

$$n = N / [1 + N(SE)^2] \tag{4.1}$$

where *n* is the sample size, *N* is the population size and *SE* is the sampling error. In Table 4.2, various household sampling sizes are shown, based on sampling error values for the three field sites.

Table 4.2 Household sampling size based on sampling error.

Confidence Level (%)	Sampling Error (%)	Siparia, Trinidad and Tobago	Region 4 Subset, Guyana	Villa Litoral, Bolivia
95	1	2904.3	8014.22	65.57
95	5	364.4	396.07	56.65
95	10	97.6	99.75	39.76
95	15	44.0	44.40	26.56
95	20	24.8	24.98	18.13
95	25	15.9	15.99	12.88

While Table 4.2 provides ideal sample size calculations, availability of research funding, time, and resources present practical constraints on the actual sample size of any field administered survey. For this work, convenience sampling methods were employed within each of the communities studied due to budget constraints. The areas were chosen because related research being conducted in the areas and the availability of community representatives to assist by serving as liaisons with the residents. In using the convenience method, participants were selected based on availability for participation and residential occupancy within the research locations. As such, these factors ultimately determined the actual number of household surveys taken in Siparia, Trinidad and Tobago (39); Region 4 Subset, Guyana (40); and Villa Litoral, Bolivia (57). Statistical interpretations were conducted through Microsoft Access and SPSS software

(SPSS Inc., Chicago, IL), Descriptive statistics were used to analyze the results from the community survey. Multivariate analyses of variance (MANOVA) with the general linear model (GLM) were used to determine whether significant correlations exist between the various components. In order to account for the small sample sizes and better interpret the data collected, Pillai's Trace (for F) and Tukey's HSD ("Honestly Significantly Different") post hoc tests were utilized and calculated using SPSS.

4.3 Water Sampling and Storage Methods

Duplicate water samples were collected from the source used by residents for obtaining water (water storage tanks, jerry cans, tap, or outdoor standing pipe). Samples were collected via the grab sample method as described in Standard Methods 1060 (Eaton, 2005).

For the HDPE tanks and cement tanks, water samples were taken from the outlet pipe. Water was allowed to run full-force for a minute prior to collecting the sample. The flow rate from the spigot was adjusted so as to prevent further waste of water through splashing. Water from the drums was collected using the same containers (ladle, cup, etc) used by residents to collect water from the drum and poured directly into sample bottles. Water from the jerry cans was poured directly into sample bottles. HDPE water sampling bottles (100 mL and 250 mL) were used to collect water samples for bacteriological analyses and water quality analyses, respectively. In an effort to prevent sample contamination, latex gloves were donned prior to taking the samples and caution was taken so as to not touch the inside or lip of the sampling bottle or its cap. The sampling bottles were filled to the shoulder. Following sample collection, the sampling bottles were capped immediately. The bottles were then labeled, placed in doubly sealed plastic Ziploc™ bags, and then placed in a cooler filled with ice for transport to the designated laboratory space. All bacteriological procedures were conducted within six hours of sample collection.

Once back at the laboratory space, water samples designated for the bacteriological analyses were separated and placed aside from water samples designated for water quality analyses. Portions of the water quality samples were taken so as to conduct the in situ analyses. The remaining water quality samples were acidified to 1 % nitric acid (HNO_3), sealed with Para film™, placed back in their original plastic Ziploc™ bags, and then packaged for shipping. Once the samples were received at the Trotz Research Lab at the University of South Florida, they were kept in the refrigerator until time for further analysis.

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4.4 Microbial Analyses and Enumeration

Microbial analysis of water sources is of great importance and fecal coliform membrane filtration has been used for understanding microbial water quality (Clesceri, 1998; Agard, 2002; Brick, 2004; Trevett, 2004). Method 9222D from the Standard Methods for the Examination of Water and Wastewater (Eaton, 2005) was used for the enumeration of coliform bacteria. In order to account for variations that may be seen in the field, field replicates of 5 to 10 percent of the samples were taken. For drinking water sources, 100 mL of the sample was filtered through a 0.45 µm membrane filter which is capable of trapping all bacteria. The membrane filter was then placed within a Petri dish which contained m-FC agar medium and rosolic acid. The m-FC medium allows for the selectivity of *E. coli*, which is the common indicator organism for fecal coliform (Edberg, 2000). The Petri dish was then sealed with parafilm and then placed in the portable incubator (Thermotote mid-sized incubator; Scientific Devices, Inc., Des Plaines, IL) set at 44.5 ± 0.2°C for 24- 26 hours.

Following incubation, the samples were removed and observed for colonies of coliform bacteria using a magnifier with a 10x magnification. Fecal coliform colonies, which appeared dark blue, were also enumerated. The color arose from the interaction of a metabolite of lactose with the dye that is in the culture medium. The Total and Fecal coliform were reported as the number of colony forming units per 100 pm (# CFU/100 mL). This analytical procedure was used in Guyana and in Trinidad and Tobago.

In Bolivia, a different procedure for determining total and fecal coliform was employed owing to the acquisition of new equipment and its convenience. This analytical technique used the Colilert-18 method (IDEXX Laboratories, Inc., Westbrook, ME), as stated in Method 9223B from the Standard Methods for the Examination of Water and Wastewater (Eaton, 2005). The Colilert-18 method utilized a defined substrate and is based on the Most Probable Number (MPN) method. Water samples of 100 mL were collected in IDEXX Laboratories supplied 120 mL plastic bottles containing the dechlorinating agent, sodium thiosulfate. The samples were then transported back to the designated lab space. Upon arrival, a single packet of the Colilert-18 reagent was added to each water sample and then mixed. The prepared water sample was then poured into a Quanti-Tray®/2000, which had already been labeled with the corresponding sample's ID. The tray was placed face down on the company supplied rubber insert, which was fed into the Quanti-Tray® sealer. The newly sealed tray was then placed in the portable incubator (Thermotote mid-sized incubator; Scientific Devices Laboratory, Des Plaines, IL) at 35 ± 0.5°C for 18-22 hours.

Following the specified time allotment, the tray was removed from the incubator and the yellow colored wells were counted for total coliform determination. In a dark location, a UV light was used to distinguish the wells that fluoresced. The fluoresced well indicated the presence of *E.coli* and were counted for fecal coliform determination. The number of wells for each color were counted and used to determine the number of fecal colonies and total coliform colonies based on the accompanying table provided by the manufacturer (IDEXX Laboratories, Inc., Westbrook, ME).

4.5 Water Quality Parameters

Using a Hach® Hydrolab Quanta multi-sensing system (Hach Company, Loveland, CO), the following water quality tests were conducted in the field: temperature (°C), pH, conductivity (µS/cm), turbidity (NTU), total dissolved solids (TDS), and DO (mg/L and % saturation). The storage cup was rinsed and then filled with the sample water, followed by placing the probe within the sample cup. Data measurements were then recorded for later computer input and analysis. Calibration of the probe was done every few days in accordance with the manufacturer's recommendations (Hach Company, Loveland, CO) using pH standards 4 and 7 (Fisher Scientific); temperature-stable air saturated water; 5 and 50 µS/cm TDS/Conductivity standards (Hach Chemicals); and 10 and 40 NTU turbidity standards (Hach Chemicals).

4.6 Lab-Based Water Analyses

Chemical analyses were conducted in the Environmental Engineering lab at the University of South Florida. Using the LaMotte™ Smart2 test kits and LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05), samples were analyzed for the following dissolved metals: aluminum, cadmium, copper, iron, and lead. The five dissolved metals were selected based on importance in drinking water quality and availability of resources to test for them. Specifications for the tests used are shown in Table 4.3. Total phosphorus was determined using a Hach test kit.

Table 4.3 Specifications of chemical tests.

Analyte	Method	Detection Range	Interference Factors
Aluminum	Eriochrome Cyanine R Method Code 364I-SC	0 - 0.30 mg/L Al	• Calcium greater than 100 ppm (250 ppm CaCO3). • Low concentrations of cerium, iron, manganese, magnesium, sulfur, tin, and EDTA .
Cadmium	Pan Method Code 4017	0 - 1.00 mg/L Cd	• Strong oxidizing agents • Copper and cobalt in excess of 5.0 mg/L.
Copper	Diethyldithiocar-bamate Method Code 3646-Sc	0 - 6.00 mg/L Cu	• Hg^{+1} at 1 ppm. • Cr^{+3}, Co^{+2}, and silicate at 10 ppm. • As^{+3}, Bi^{+3}, Ca^{+2}, Ce^{+3}, Ce^{+4}, Hg^{+2}, Fe^{+2}, Mn^{+2}, Ni^{+2} and • ascorbate at 100 ppm. • Many other metal cations and inorganic anions at 1000 ppm. • EDTA at all concentrations.
Iron	Bipyridyl Method Code 3648-Sc	0 - 6.00 mg/L Fe	• Fluoride • Polyphosphate
Lead	Par Method Code 4031	0 - 5.00 mg/L Pb	• Ag^{+2}, Co^{+2}, Cu^{+2}, Mn^{+2}, Ni^{+2}, Zn^{+2}, Y^{+3}, In^{+3}
Phosphorus	PhosVer 3 with Acid Persulfate Digestion Method 8190	0.00 - 3.50 mg/L PO_4^{3-}	• Arsenate Interferes at any level • Copper and silicate greater than 10 mg/L • Silica greater than 50 mg/L • Zinc greater than 80 mg/L • Sulfide greater than 90 mg/L • Chromium and iron greater than 100 mg/L • Aluminum greater than 200 mg/L • Nickel greater than 300 mg/L

Table 4.4 shows the drinking water quality standards and guideline that were put in place by various governing bodies, such as the World Health Organization (WHO) and the U.S. Environmental Protection Agency (EPA). While the WHO guidelines offer recommendations for the global community with regards to the maximum heavy metal concentrations deemed safe, the EPA standards are enforceable by law in the United States.

Table 4.4 Range of dissolved metals (as mg/L) present in household drinking water supplies within communities in Trinidad and Tobago, Guyana, and Bolivia. Standards from the U.S. Environmental Protection Agency Maximum Contaminant Level (USEPA MCL),the World Health Organization Guideline Values (WHO GV), and the European Union Maximum Acceptable Concentration (EU MAC) are shown. (UNICEF, 2008; Appendix A., Table A.1).

	USEPA MCL	WHO GV	EU MAC
Pb (mg/L)	0.015	0.01	0.01
Fe (mg/L)	0.3	0.3	0.2
Cu (mg/L)	1.3	2	3
Al (mg/L)	0.05 – 0.2	0.1 - 0.2	0.2
Cd (mg/L)	0.005	0.003	0.005

4.6.1 Aluminum

Aluminum was measured with the LaMotte™ Smart2 Aluminum test kit (0.00 – 0.30 mg/L), which utilized the Eriochrome Cyanine R Method Code 364I-SC. Prior to preparing the samples, the LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05) was programmed to 002 Aluminum. In testing for aluminum, 10 mL of sample was added to a colorimeter tube. After wiping the tube's surface with

Kimtech Science™ Kimwipes®, the tube was then inserted into the colorimeter and scanned as BLANK. Following this, 5 mL of the sample was removed from the tube, leaving the remaining 5 mL to be used for further analysis. Approximately 0.05 g of the Aluminum Inhibitor Reagent (7865) was then added to the tube of sample water, capped, and mixed. Afterwards, 2 mL of Aluminum Buffer Reagent was pipetted into the tube, followed by the pipetting of 1 mL of Aluminum Indicator Reagent (7867). The contents of the tube were then mixed and allowed to sit for 5 minutes to ensure optimal color development. Following the allotted time period, the tube surface was wiped with Kimtech Science™ Kimwipes®, then inserted into the colorimeter and scanned as SAMPLE.

Prior to analyzing the water samples, a reagent blank was determined. This was done by adding 5 drops of Aluminum Complexing Reagent (7868) to a tube containing 10 mL of deionized water, followed by the above-mentioned procedure. The concentration of the reagent blank was subtracted from all subsequent test results so as to account for any test contribution by the reagent system.

4.6.2 Cadmium

Cadmium was measured with the LaMotte™ Smart2 Cadmium test kit (0.00 – 1.00 mg/L), which utilized the Pan Method Code 4017. Prior to preparing the samples, the LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05) was programmed to 012 Cadmium. In testing for cadmium, 10 mL of sample was added to a colorimeter tube. After wiping the tube's surface with Kimtech Science™ Kimwipes®, the tube was then inserted into the colorimeter and scanned as BLANK. A measure of 1.0 mL of Buffered Ammonia Reagent (4020) was pipetted to the tube of sample water, followed by the addition of two drops of Sodium Citrate 10% (6253), 0.5 mL of PAN Indicator (4021), and 0.5 mL Stabilizing Reagent (4022). The contents of the tube were then mixed, the tube then wiped with Kimtech Science™ Kimwipes®, and inserted into the colorimeter and scanned as SAMPLE.

4.6.3 Copper

Copper was measured with the LaMotte™ Smart2 Copper test kit (0.00 – 6.00 mg/L), which utilized the Diethyldithiocarbamate Method Code 3646-Sc. Prior to preparing the samples, the LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05) was programmed to 32 Copper DDC. In testing for copper, 10 mL of sample was added to a colorimeter tube. After wiping the tube's surface with Kimtech Science™ Kimwipes®, the tube was then inserted into the colorimeter and scanned as BLANK. Afterwards, 5 drops of Copper 1 (6446) were added and the contents of the tube mixed. In the presence of copper in the water sample, the solution would turn yellow. The tube's surface was wiped with Kimtech Science™ Kimwipes®, then inserted into the colorimeter and scanned as SAMPLE.

4.6.4 Iron

Iron was measured with the LaMotte™ Smart2 Iron test kit (0.00 – 6.00 mg/L), which utilized the Bipyridyl Method Code 3648-Sc. Prior to preparing the samples, the LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05) was programmed to 051 Iron Bipyr. In testing for iron, 10 mL of sample was added to a colorimeter tube. After wiping the tube's surface with Kimtech Science™ Kimwipes®, the tube was then inserted into the colorimeter and scanned as BLANK. A measure of Iron Reagent #1 (V-4450) was pipetted to the tube of sample water, capped, and then mixed. Afterwards, 0.1 g of *Iron Reagent #2 Powder was added to the tube. The contents of the tube was then mixed vigorously for 30 seconds then allowed to sit for 3 minutes to ensure optimal color development. Following the allotted time period, the tube's surface was wiped with Kimtech Science™ Kimwipes®, then inserted into the colorimeter and scanned as SAMPLE.

4.6.5 Lead

Lead was measured with the LaMotte™ Smart2 Lead test kit (0.00 – 5.00 mg/L), which utilized the Par Method Code 4031. Prior to preparing the samples, the LaMotte Smart2 colorimeter (LaMotte™ Model SCL-05) was programmed to 054 Lead. In testing for lead, 10 mL of sample was added to a colorimeter tube. After wiping the tube's surface with Kimtech Science™ Kimwipes®, the tube was then inserted into the colorimeter then scanned as BLANK. Following this, 5 mL of the sample was removed from the tube, leaving the remaining 5 mL to be used for further analysis. A measure of 5 mL Ammonium Chloride Buffer (4032) was pipetted to the tube, followed by 3 drops of Sodium Cyanide, 10% (6565), 0.5 mL PAR Indicator (4033), and 0.5 mL Stabilizing Reagent (4022).

The contents of the tube were mixed, wiped with Kimtech Science™ Kimwipes®, then inserted into the colorimeter and scanned as SAMPLE. This first result was recorded as Reading A. Following the reading, 3 drops of DDC Reagent (4034) were added to the tube's content then mixed. The tube's surface was wiped with Kimtech Science™ Kimwipes®, then inserted into the colorimeter and scanned as SAMPLE. This second result was recorded as Reading B. The final lead concentration was then measured by subtracting the result of Reading B from the result of Reading A.

4.6.6 Phosphorus

The total phosphorus levels present in the water samples were measured using the Hach® Total Phosphorus Test N' Tube™ (0.00 – 3.5 mg/L PO_4^{3-}) test kit, which utilized the PhosVer 3 with Acid Persulfate Digestion Method 8190. After setting the COD reactor to heat to 150°C, the spectrophotometer (Hach® DR/4000U) was programmed to 3036 P Total As. TNT, with a corresponding wavelength of 890 nm. A sample aliquot of 5 mL was added to a respective pre-prepared test tube. A blank was also prepared by adding 5 mL of 18.1 MΩ-cm

Deionized (DI) water to a pre-prepared test tube. Following the addition of the water sample, a single packet of the Potassium Persulfate powder was added to the tube then capped. To ensure adequate mixing, the test tube was shaken and inverted several times. The tube was then placed in the heated COD reactor for 30 minutes. Following the allotted time period, the test tube was placed on a rack to cool to room temperature. Once cooled, a 2 mL aliquot of 1.54N Sodium Hydroxide solution was added to the tube. After wiping the tube's surface with Kimtech Science™ Kimwipes®, the test tube was then inserted into the spectrophotometer to be zeroed. Following this, a single packet of the Phos Ver 3 powder was added to the tube then capped. To ensure adequate mixing, the test tube was shaken and inverted several times for 10-15 seconds, then allowed to sit for 2 minutes. Following the allotted time period, the surface of the tube was wiped clean then inserted into the spectrophotometer for a final reading, measured in mg/L PO_4^{3-}.

4.7 Target Plotting

Target plots were used to better assess the linkages between the various household survey questions and collected water quality data. Target plots present data in a visually striking way that allows for easy identification of the importance of different variables compared to one another and have been used in environmental engineering research to compare sustainability indicators for wastewater treatment (Muga, 2008) and ecotourism management (Thomas, 2010). Using household survey response data and water quality data collected, five indicators were selected to characterize the field sites. The five indicators selected were:

1) Chemical and Biological Indicator: representing the quality of the water based on field sampling and analyses.
2) Reach of Risk Indicator: capturing the exposure of members of the household to potential threats from potable water practices.
3) Storage Device Indicator: capturing the storage device characteristics which may contribute to observed water quality.
4) Female Involvement Indicator: representing the gender roles in activities related to household water provision.
5) Household Belief Indicator: capturing the household attitude towards, and understanding of, potable water provision, quality and use.

The household survey was initially developed to capture the information required for indicators 2-5 and a subset of questions from the survey was selected to represent each of these indicators. Answers to each question were rated on a scale of 1 to 2 with the lowest number representing least impact or most desired outcome. The responses given by survey participants and findings from water quality analyses were then transformed onto this indicator scale. The scores for the questions associated with each indicator category were then tallied to give an overall indicator value that was between 1 and 2. To do this, the total points for each indicator category was divided by the product of the number of households/water samples and the number of questions and then scaled to the 1-2 scoring range. This new number represented the impact value for the given indicator.

The risk analyses were conducted among the three research field sites: Siparia, Trinidad and Tobago; Region 4 Subset, Guyana; and Villa Litoral, Bolivia. In Guyana, there were three sub-groups within the field site- Mocha/Arcadia, Mon Repos, and Greater Georgetown- and as such, risk analyses were conducted on each sub-group and on the total field site. There was an interest in seeing whether there were differences in the impact levels and overall risks among the three field sites, along with the urban and rural communities in Region 4 Subset.

CHAPTER 5: HOUSEHOLD SURVEY ANALYSES

5.1 Introduction

Household surveys designed to understand the dynamics that exist between people and water storage play an important role in interventions that can improve water use (Levesque, 2008; Agard, 2002). During the spring and summer of 2009, a total of 136 household surveys were administered in the communities of Siparia, Trinidad and Tobago (39); Region 4 Subset, Guyana (40); and Villa Litoral, Bolivia (57). This chapter describes field site observations and presents and discusses survey responses as they relate to household level storage containers.

5.2 Field Observations of Each Community

Table 5.1 summarizes the total number of households surveyed per community and the corresponding sampling error as a function of confidence interval. The sampling error was calculated for each field site based on the total number of households within the respective community, the number of households surveyed, and the desired confidence interval as given in Equation 4.1. Using a

95% confidence interval, the sampling errors for Siparia, Region 4 Subset, and Villa Litoral were 15.6%, 15.5%, and 4.80%, respectively. Based on these numbers, the results from Villa Litoral are most representative of the community under study whereas Region 4 Subset and Siparia results are less representative of those places. The Region 4 subset refers to areas classified as both urban and rural according to the Guyana census. To better identify the differences seen within the Region 4 Subset, the rural communities of Mocha and Mon Repos will be looked at both separately and as part of the Region 4 Subset.

Table 5.1 Calculated sampling errors based on confidential intervals for household surveys collected within field sites in the Latin American and Caribbean region. Population data obtained from (CSO, 2003; INE, 2009; Rahat, 2006).

	Siparia, Trinidad and Tobago	Region 4 Subset, Guyana	Mocha and Mon Repos, Guyana	Villa Litoral, Bolivia
Household population size	4093	40,358	5081	66
Household sample size	39	40	23	57
Confidence Level	Sampling Error			
99.9	26.2%	26%	34.20%	8.1%
99	20.5%	20.4%	26.80%	6.3%
95	15.9%	15.8%	20.40%	4.8%
90	13.1%	13.0%	17.10%	4.1%
80	10.2%	10.0%	13.30%	3.2%

Figures 5.1 and 5.2 are schematic representations of tank storage systems seen at all locations with the two tiered system more popular in Guyana. Figures 5.3-5 are actual pictures taken in the field at each of the sites.

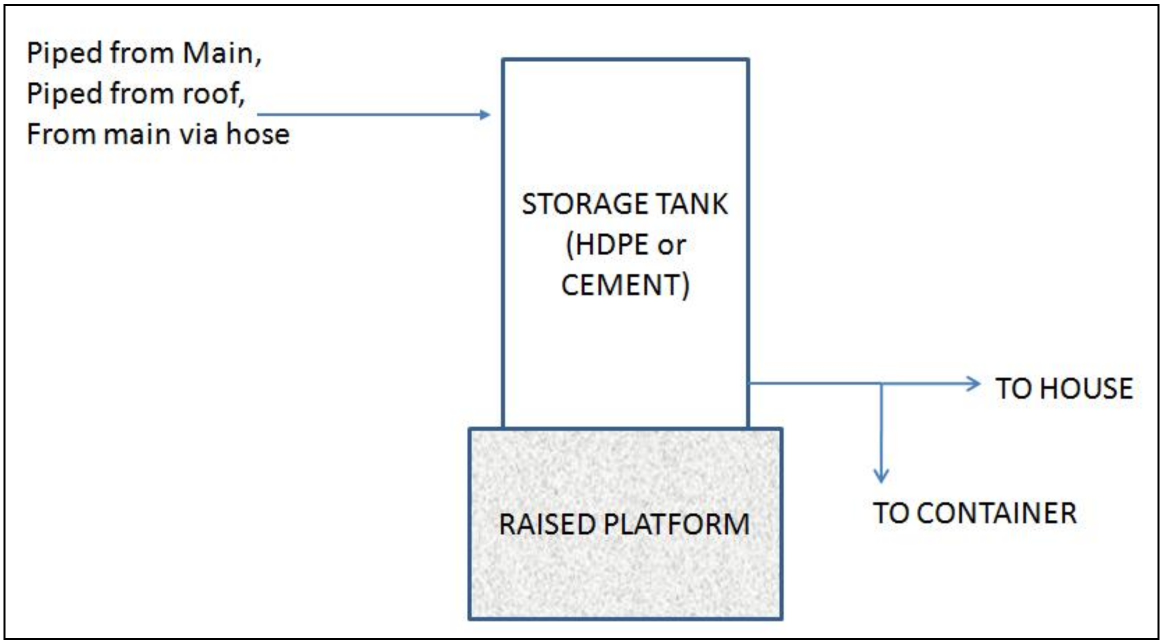

Figure 5.1 Schematic representation of a storage tank made from either high density polyethylene (HDPE) or cement tank. The tanks collects water directly from the main (piped connections or from a hose), after which it is either piped into the house (if house is below tank elevation) or used to dispense water into smaller storage containers. Image is not drawn to scale.

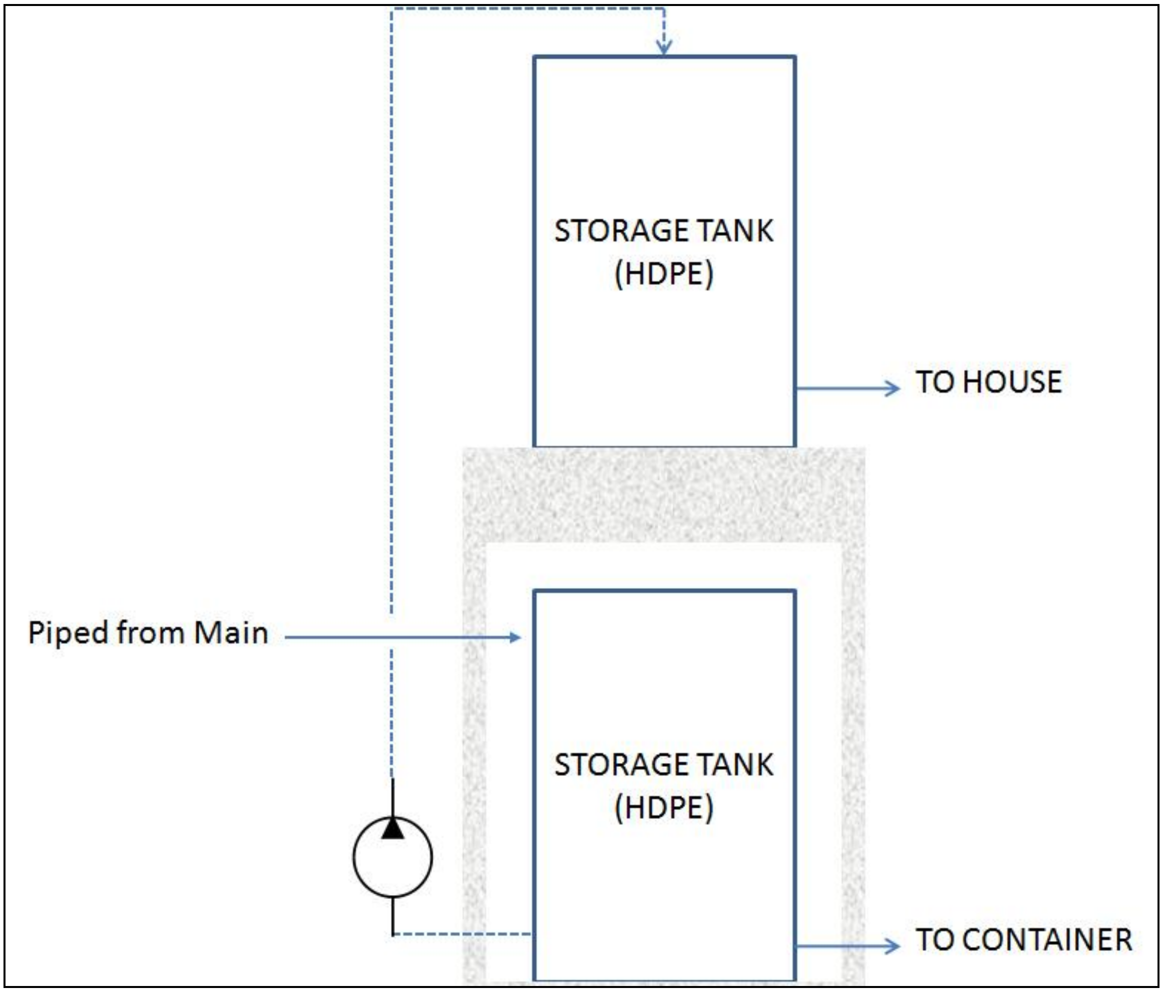

Figure 5.2 Schematic representation of a two tiered storage tank system made from high density polyethylene (HDPE) that collects water directly from the main into a lower tank. Water from the lower tank is then pumped to an elevated tank which is then piped into the house. Image is not drawn to scale.

Figure 5.3 Representative water storage in Siparia, Trinidad and Tobago. (a) a 55 gallon HDPE storage drum (located next to a larger tank); (b) 400 gallon HDPE storage tanks being filled by a hose connected to a standpipe from which water is collected directly from the base; (c) 400 gallon HDPE storage tanks collecting rain water and water from the main from which water is obtained directly from the base and piped to the house; and (d) 400 gallon HDPE storage tank from which water is pumped from the ground to the rooftop tank prior to being piped to the house.

Figure 5.4 Representative water storage in Region 4 Subset, Guyana. (a) 450 gallon HDPE storage tank being filled with rainwater (roof runoff) from which water is collected at the base; (b) 450 gallon HDPE storage tanks on a trestle with the bottom tank collecting water from the main which is then pumped to the higher tank that then delivers water directly into the house; and (c) 55 gallon HDPE storage drums filled with water from a standpipe connected to the main.

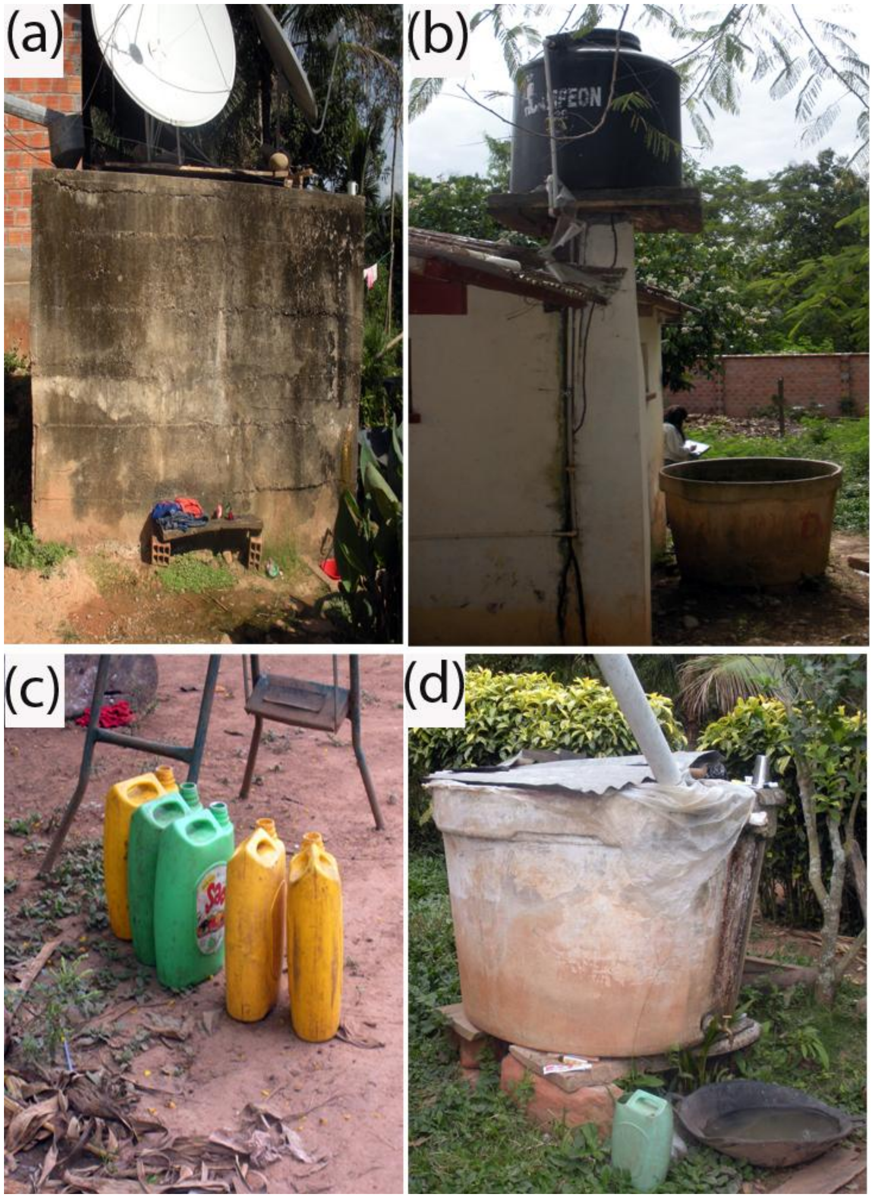

Figure 5.5 Representative water storage in Villa Litoral, Bolivia. (a) cement storage tank being filled with rainwater (roof runoff) and/or piped water from which water is collected at the base; (b) 400 gallon HDPE storage tank on the roof of a house that gets water from the main via a pump before it is piped to the house; (c) 5 gallon jerry cans used to collect water from standpipes; and (d) rain water collecting in a cement tank from which water is obtained from the base.

5.3 Characteristics of Water Storage Devices

Table 5.2 summarizes the household size, water storage device age and its capacity. In 61% of the total households surveyed, households consisted of 4-7 individuals. Smaller households represented 30% of the sample size and households with more than 7 people represented only 9% of the sample size. Demographics were similar for Region 4 Subset and Siparia, whereas a larger percentage of the Villa Litoral households had greater than 4 people. Guyana and Trinidad and Tobago are culturally similar which could possibly explain this demographic difference. Although the GNI of Guyana and Bolivia are similar, it was evident from field work that greater levels of poverty existed in the areas visited in Villa Litoral than in the areas visited in Region 4 Subset.

In all of the households surveyed, some form of household water storage device was used. The average age of the tanks in Siparia and Region 4 Subset ranged from 4-10 years whereas in Bolivia it ranged from 0-3 years.

Table 5.2 Characteristics of household water storage devices used within communities in the Latin American and Caribbean region.

Water Storage Device Characteristics	Siparia, Trinidad and Tobago (39)		Region 4 Subset, Guyana (40)		Region 4- Rural, Guyana (23)		Villa Litoral, Bolivia (57)	
	No.	%	No.	%	No.	%	No.	%
[redacted]								
Household member size								
1-3	16	41	15	37.5	7	30.4	10	17.5
4-7	21	53.8	22	55	15	65.2	40	70.2
More than 7	2	5.1	3	7.5	1	4.3	7	12.3
Age of storage device								
0-3 years	9	23.1	17	42.5	11	47.8	38	66.7
4-10 years	23	59	21	52.5	11	47.8	9	15.8
11-15 years	2	5.1	2	5	1	4.3	6	10.5
16-20 years	4	10.3	0	0	0	0.0	1	1.8
Older than 20 years	1	2.6	0	0	0	0.0	3	5.3
Storage device capacity								
0-50 gallons	0	0	2	5	1	4.3	30	52.6
51-100 gallons	0	0	6	15	5	21.7	5	8.8
101-500 gallons	36	92.3	34	85	17	73.9	6	10.5
501-1000 gallons	7	17.9	1	2.5	1	4.3	0	0
1001-5000 gallons	0	0	1	2.5	0	0.0	14	24.6
10000 gallons and above	0	0	0	0	0	0.0	2	3.5

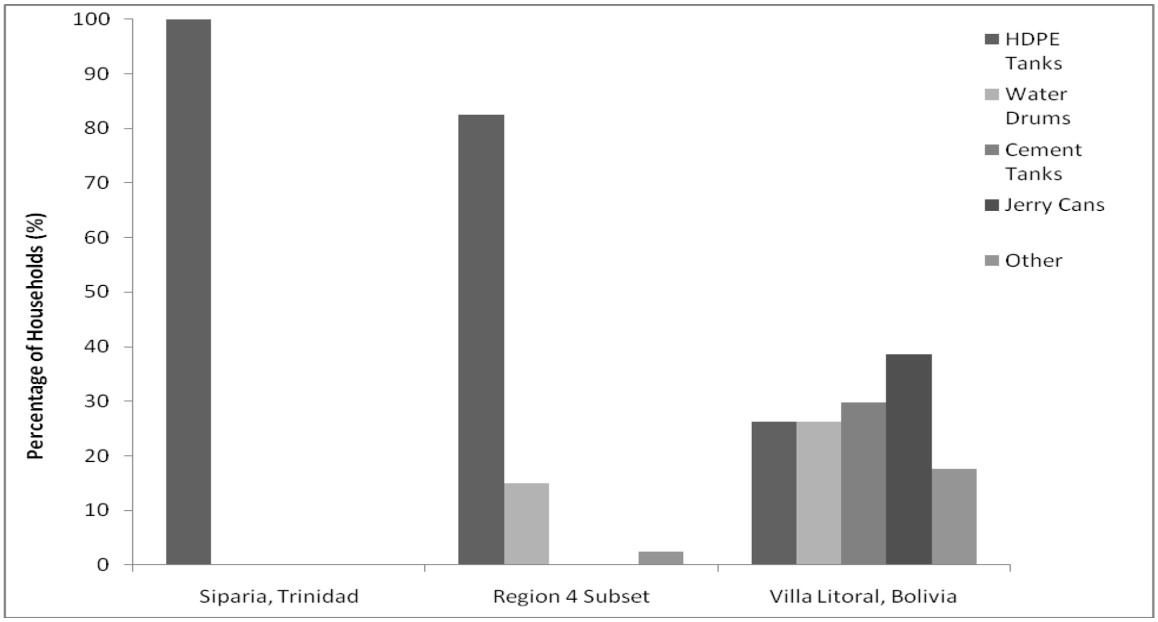

Figure 5.6 Distribution of household water devices within field sites in the Latin American and Caribbean region. Number of households: Siparia Trinidad and Tobago (39); Region 4 Subset, Guyana (40); Villa Litoral, Bolivia (57).

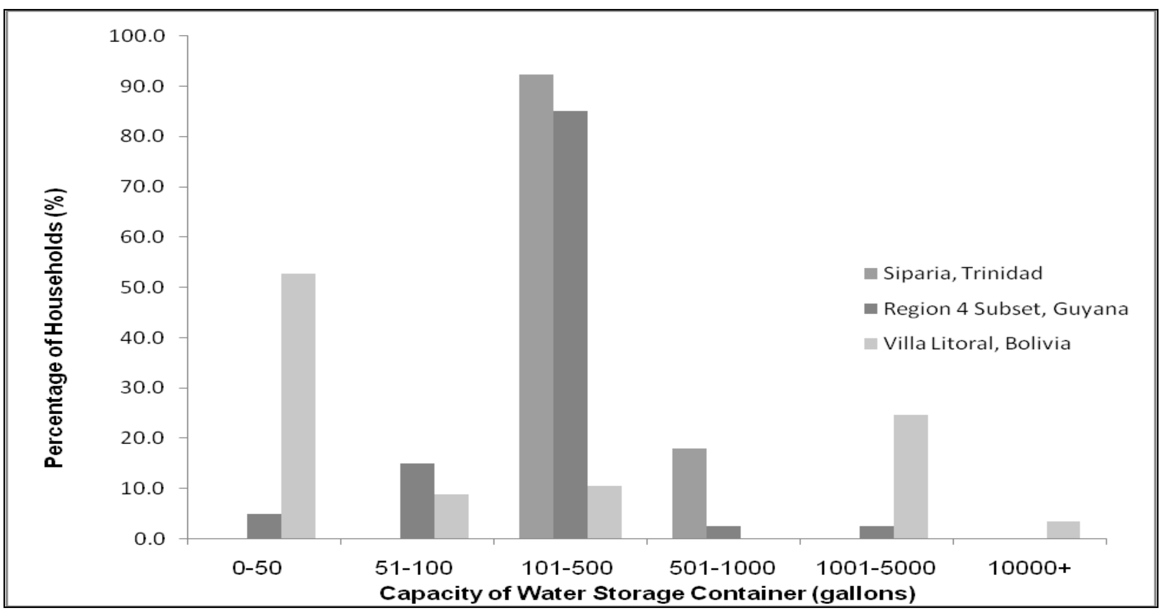

Figure 5.7 Distribution of water storage container capacity among households surveyed. Number of households surveyed in Siparia, Trinidad and Tobago (n=39); Region 4 Subset, Guyana (n=40); and Villa Litoral, Bolivia (n=57).

Figure 5.6 shows the types of devices sampled in each location, while Figure 5.7 shows the capacity of the devices. Within Siparia and Region 4 Subset, the predominant form of water storage device used was the black HDPE tanks with storage capacities of 400-500 gallons. Table 5.3 provides information on the HDPE tanks produced in Trinidad and Tobago which have, or are similar to the types of tanks that have the majority of the market in Siparia and Region 4 Subset. Information in Table 5.3 was taken from the manufacturer and provides data on tank dimensions as that information was not recorded during the field surveys. The tanks in the table below are contoured and taper at the top (see Figure 5.8), hence the reported capacity is smaller than the capacity calculated if one used the given diameter and height in the table.

Table 5.3 Specifications of typical HDPE water storage tanks. Data obtained from Rotoplastics Trinidad and Tobago Limited, http://www.rotoplastics.co.tt/content/download-pdfs/tufftank.pdf, accessed 3/21/2010.

Model	Capacity	Diameter	Height	Weight
CT200	200 gallons	37”	56”	32 lbs
	757 liters	93 cm	143 cm	14.5 kg
CT400	400 gallons	44”	67”	50 lbs
	1514 liters	112 cm	170 cm	23 kg
CT450	450 gallons	46”	70.5”	55 lbs
	1703 liters	117 cm	179 cm	25 kg
CT600	600 gallons	52”	77.5”	80 lbs
	2271 liters	132 cm	197 cm	36 kg
CT800	800 gallons	61.5”	87.5”	110 lbs
	3028 liters	156 cm	222 cm	50 kg
CT1000	1000 gallons	65.5”	100”	140 lbs
	3785 liters	167 cm	254 cm	64 kg

Figure 5.8 Image of a HDPE storage tank manufactured by Rotoplastics in Trinidad and Tobago. Image obtained from http://www.rotoplastics.co.tt/content/download-pdfs/Approved-Tuff-Tank-20x4-fc.jpg, accessed 10/1/2010.

In Villa Litoral, close to 53% of households utilized drums, jerry cans and small buckets with capacities less than 50 gallons. Roughly 25% of households surveyed utilized cement tanks, predominantly with a capacity of 2,642 gallons (10,000 L).

Multiple types of storage devices (e.g. an HDPE tank and an HDPE drum) were seen at the houses in 78% of households surveyed. Residents were asked to identify the storage device that supplied drinking water and that was the unit sampled at that location. If the household did not use the storage device for drinking, they were asked to identify the one used for cooking and then bathing and that device was sampled. With regards to device material, 61% percent of the storage devices used in the homes were made of plastic, while 28% were made of cement with the remainder made of metal. Figure 5.6 shows the occurrence of storage devices in each of the three locations. Additionally, 90% of households surveyed reported that their storage devices had a covering, usually the covering that came with the device. Older HDPE tanks in Guyana featured a lid that was of similar diameter to the bottom (M. Trotz, personal communication, November 12, 2007); however, many of the tanks surveyed in Guyana had a smaller lid diameter, which has implications for access to cleaning.

The location of the water storage devices varied within the communities. The water storage systems were elevated on a trestle or some form of embankment in the majority of households surveyed in Siparia (70%) and Region 4 Subset (71.8%) and in roughly 5% of households in Villa Litoral. The elevated water storage system provided greater water pressure so that water could flow into the home by gravity. The other water storage systems were located on the ground. While few of these systems were HDPE tanks, this ground-level group consisted predominantly of water drums, jerry cans, and cement tanks.

5.4 Household Drinking Water Practices

Household drinking water practices were assessed within the three target communities, and Table 5.4 summarizes the results. The questions refer to the use of the water from the storage device for drinking.

Table 5.4 Household drinking water practices as they relate to water from storage devices within communities in the Latin American and Caribbean region.

Household Drinking Water Practice in Relation to Water Storage Device	Siparia, Trinidad and Tobago (39)		Region 4 Subset, Guyana (40)		Region 4- Rural, Guyana (23)		Villa Litoral, Bolivia (57)	
	No.	%	No.	%	No.	%	No.	%
Water used for drinking?								
Yes	36	92.3	10	25	8	34.8	47	82.5
No	3	7.7	30	75	15	65.2	10	17.5
Water boiled?								
Yes	11	28.2	1	2.5	1	4.3	43	75.4
No	28	71.8	39	97.5	22	95.7	14	24.6
Water filtered?								
Yes	6	15.4	2	5	1	4.3	15	26.3
No	33	84.6	38	95	22	95.7	42	73.7
Bottled water used for drinking?								
Daily	9	23.1	28	70	13	56.5	0	0
Weekly	4	10.3	2	5	0	0.0	3	5.3
Rarely	17	43.6	1	2.5	1	4.3	15	26.3
Not at all	9	23.1	9	22.5	9	39.1	39	68.4

With regards to usage, 92% of the households surveyed in Siparia used their water storage device for drinking with Villa Litoral having the next highest percentage of 82.5% and Region 4 Subset having the least with 25%. While water boiling is one of the most widely used and accessible methods of household point-of-use water treatment (Brown, 2009; Christen, 2009; Clasen, 2007), the majority of the households surveyed in Siparia (71.8%) and Region 4 Subset (97.5%) did not practice it. This was different in Villa Litoral where 75.4% of the population boiled their water. Water filtration was even less widespread among the communities in Siparia (15.4%), Region 4 Subset (5%), and Villa Litoral (26.3%). In the households where it was practiced, filtration was achieved through the use of a cloth or a sieve. Several participants surveyed in Siparia commented that they allowed the water to “stand” prior to usage so that any sediment or particles present could settle to the bottom.

The frequency of bottled water usage was assessed among the communities surveyed. Roughly 33% of households surveyed in Siparia used bottled water for drinking on a daily or weekly basis, compared to 75% of households surveyed in Region 4 Subset. Only 5% of households in Villa Litoral used bottled water on a regular basis. Households surveyed in Siparia reported that the water from their storage tank was safe to drink, but often supplemented their water sources with bottled water during abnormal circumstances (emergencies, shortages, health purposes for the children or elderly, provision for guests/visitors). In Region 4 Subset, the 25% of households who rarely or never used bottled water were also the same 25% who used water from the storage device for drinking. These were mainly people from Mon Repos and Mocha as opposed to the more urbanized areas close to Georgetown. Similarly, bottled water was used by 100% of the households in municipal and suburban Georgetown. Chapter 7 reduces the data from the Region 4 subset into urban and rural.

5.5 Storage Device Maintenance

Maintenance guidelines for the upkeep of household water storage tank systems are not readily available in Trinidad and Tobago, Guyana or Bolivia. Survey questions were designed to capture that information and the results are presented in this section.

Figure 5.9 compares storage device maintenance practiced by households in the three different communities. In all three communities, greater percentages of households cleaned their water storage devices compared to the percentage of households who practiced water disinfection. The water disinfection question as delivered in the survey (Appendix C) resulted in responses that did not distinguish whether the chemical disinfectant was added to the tank or to a storage device used inside the home. Hence, the results presented on disinfection represent any disinfection at the household level. The majority of households in Siparia (92.3%), Region 4 Subset (67.5%), and Villa Litoral (87.7%) reported cleaning their respective storage devices. Households in

Siparia and Villa Litoral were three and four times, respectively, more likely to clean their storage devices than to disinfect their water. Water disinfection was only common among the Region 4 Subset households, where 60% reported disinfecting the water. It is interesting to note that only 25% of surveyed Guyanese households drank water from their storage devices, the majority of which were the larger HDPE tanks.

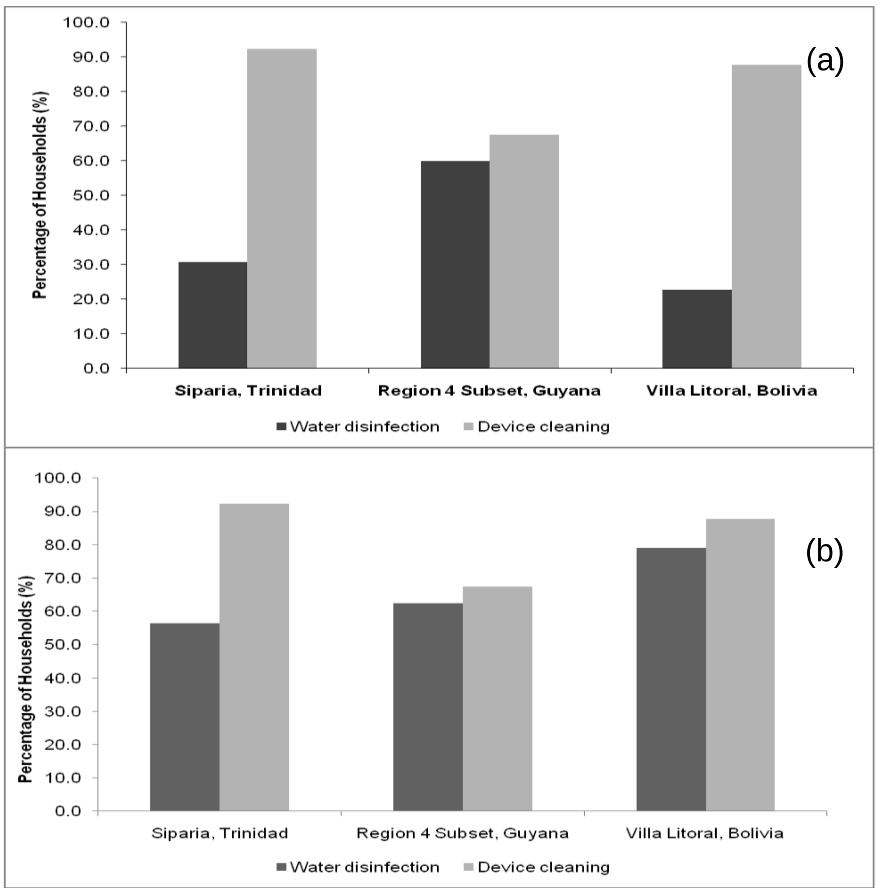

Figure 5.9 Maintenance practices of household water storage devices within communities in the Latin American and Caribbean region. Number of households surveyed: Siparia, Trinidad and Tobago (39); Region 4 Subset, Guyana (40); Villa Litoral, Bolivia (57). For (a), disinfection refers to chemical disinfectant and device cleaning refers to any activity related to washing the water storage device. For (b) disinfection refers to boiling and/or chemical disinfectant.

Various reasons were given by all households surveyed for not disinfecting, such as an aversion to the taste of the disinfected water, inaccessibility of disinfection materials, and inconvenience. Participants were more apt to clean their storage device as no additional materials were needed and they did not have to remember correct dosages. Several residents said they left the tops of their tanks and devices open so that rainwater could flush out the interior of the device thereby cleaning it. Some residents also used this approach to fill their storage devices.

The frequency of the disinfection and cleaning were also assessed. Figure 5.10 shows the chemical disinfection frequency within households in Siparia. Fifty-nine percent of households who reported disinfecting the water within their storage device did so every few months, while 25% reported doing so on a monthly basis. Eight percent of households disinfected their water weekly or annually.

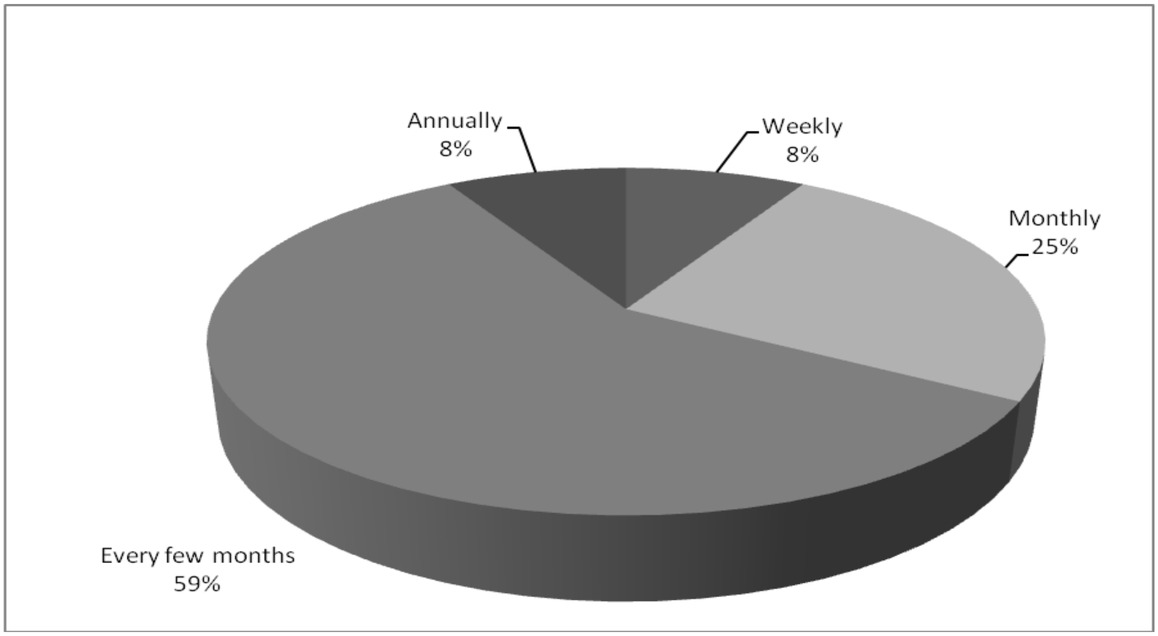

Figure 5.10 Frequency of household water disinfection within Siparia, Trinidad and Tobago. The number of households surveyed in Siparia reporting water disinfection was 12 out of a total of 39 households.

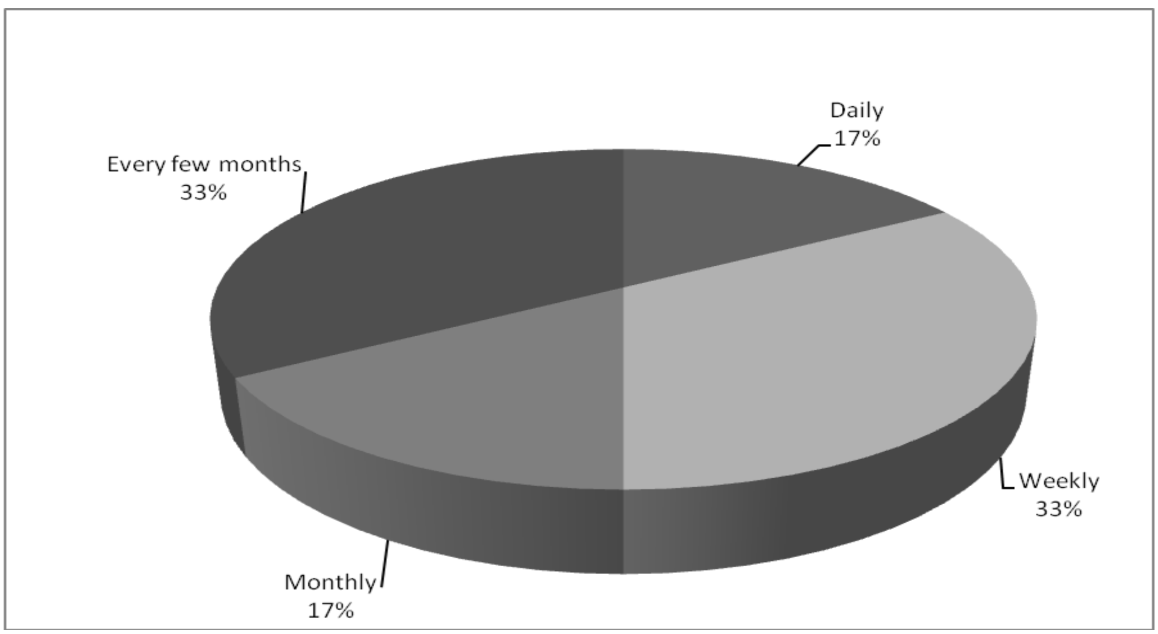

Figure 5.11 Frequency of household water disinfection within Region 4 Subset, Guyana. The number of households surveyed that disinfected was 24 out of a total of 40 households.

In Figure 5.11, the disinfection frequency is shown for households in Region 4 Subset. The Region 4 Subset households surveyed practiced household water disinfection on a more frequent basis than households surveyed in Siparia. Fifty percent of households who disinfected did so on a daily or weekly basis, while 17% of households disinfected on a monthly basis and 33% did so every few months. Various reasons may attribute to the higher rates of disinfection and frequency in Region 4 Subset, such as availability and accessibility of chlorine in liquid and tablet forms, increased awareness and promotion by NGOs and the government. A major flood event in January 2005 impacted Region 4 Subset and much of Guyana's densely populated coastal region, resulting in widespread dissemination of health advisories and suggested water disinfection practices (Figure 5.12). Despite the small percentage of Guyanese who used tank water for drinking, the flyer makes it clear that bleach should be added to water used for drinking, washing hands, bathing, cooking, washing fruits and vegetables, and brushing teeth.

Close to 23% of households in Bolivia reported adding sodium hypochlorite (*lavandina*), a chemical disinfectant, to their water storage devices. This, however, was done very rarely during the lifetime of their water storage devices. Approximately 75% of households surveyed in Villa Litoral boiled their water (see Table 5.4). Roughly 19% of households surveyed reported practicing both boiling and disinfection. However, as the residents stated that they rarely disinfected their water sources over the lifetime of their containers, it can be stated that boiling and filtration were not both practiced regularly within a household.

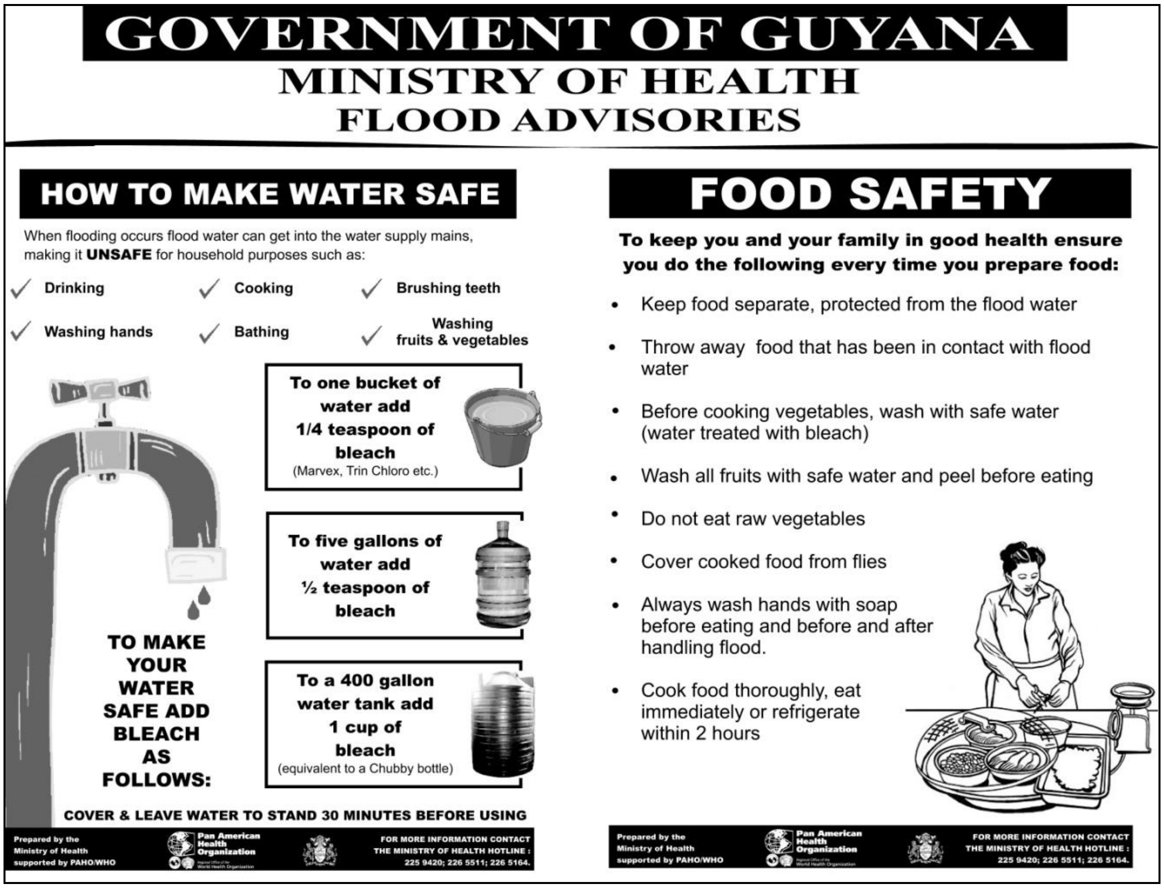

Figure 5.12 Water safety awareness flyer widely distributed in Guyana following the January 2005 floods. Image obtained from http://www.gina.gov.gy/ads/fullpage-healthadvisories-jan%2018.pdf, accessed 10/1/2010.

Households were then asked to report the time of the most recent chemical disinfection and the type of disinfection practice used. In both Siparia and Region 4 Subset, chemical disinfection of water storage devices had occurred within a month of the survey. Dosages varied among the households, as shown in Table 5.5. In Siparia, 83% of households who disinfected used a cork-full of bleach in water storage devices. Others reported using a tablespoon or a teaspoon of bleach to disinfect water storage devices. In Region 4 Subset, 45.8% of households who reported disinfecting their water sources used a cork-full of bleach. Roughly 29% of all households who reported disinfecting their water sources used a cork-full of bleach. The remainder of households used 2 drops of chlorine (4.2%), one teaspoon (12.5%), or other sources such as chlorine tablets (8.3%).

Bleach mix time also varied among the households, as shown in Table 5.5. In Siparia, 33.3% of households who disinfected allowed the treated water to mix for roughly 15 minutes before use, while 25% of households allowed 30 minutes. Other residents allowed the water to mix for less than 10 minutes (16.7%) or overnight (25%). In Region 4 Subset, 83.3% of households who disinfected allowed the treated water to mix for roughly 30 minutes before use. Other residents allowed the water to mix for less than 10 minutes (4.2%), 15 minutes (4.2%), or overnight (8.3%).

Table 5.5 Household water disinfection practices within communities in Trinidad and Tobago and Guyana based on the number of respondents who said they disinfected their water.

	Siparia, Trinidad and Tobago (12)		Region 4 Subset, Guyana (24)		Region 4-Rural, Guyana (11)	
	No.	%	No.	%	No.	%
Recent Chemical Disinfection						
Within the last two weeks	3	25	12	50	5	45.5
Within the last month	3	25	5	20.8	3	27.3
Within the last six months	4	33.3	7	29.2	3	27.3
Within the last year	2	16.7	0	0	0	0.0
Bleach dosage						
2 drops	0	0	1	4.2	0	0.0
1 teaspoon	1	8.3	3	12.5	1	9.1
1 tablespoon	1	8.3	11	45.8	7	63.6
1 cork-full	10	83.3	7	29.2	3	27.3
Other	0	0	2	8.3	0	0.0
Bleach mix time						
Less than 10 minutes	2	16.7	1	4.2	0	0.0
10-15 minutes	4	33.3	1	4.2	1	9.1
15-30 minutes	3	25	20	83.3	9	81.8
Overnight	3	25	2	8.3	1	9.1

While chemical disinfection holds several benefits, it is only effective when the adequate dosage is applied and adequate chlorine retention time is allowed. In several of the households, chlorine was being used to disinfect various volumes of water such as a water jug, a gallon jug, a pitcher, or an entire water storage tank/device. Additionally, information may have been distributed in which case a particular amount of chlorine was erroneously thought to be the universal amount needed for every volume of water to be disinfected. Even when the correct dosage is used, the chlorine is not allowed to sit for an adequate amount of time. In such cases, microbial reduction has not been optimized, a strong taste is present, or there is inadequate chlorine residual. Inadequate mixing time results in an inadequate residual in the water, which increases the potential for microbial re-growth in water sources (LeChevallier, 1996). In Table 5.6, proper chlorine dosage measurements are shown with corresponding volumes. For each of the dosage measurements shown, the treated water should be allowed to sit for at least 30 minutes to ensure adequate disinfection (USEPA, 2010).

Table 5.6 Dosage measurements for chlorine disinfection of water sources. Obtained from EPA Emergency Disinfection of Water http://water.epa.gov/drink/emerprep/emergencydisinfection.cfm, access on 5/13/2010. Marvex and Trin Chloro information obtained from http://www.gina.gov.gy/ads/fullpage-healthadvisories-jan%2018.pdf, accessed 10/1/2010.

Chlorine Method	Dosage
1% free chlorine liquid	10 drops per quart of water 10 drops per liter of water 40 drops per gallon of water
4-6% free chlorine liquid	2 drops per quart of water 2 drops per liter of water 8 drops per gallon (1/8 teaspoon) of water 1 cork-full per 5 gallons (for Chloro-sol) of water
7-10% free chlorine liquid	1 drop per quart of water 1 drop per liter of water 4 drops per gallon of water
Prepared calcium hypochlorite	1 part chlorine to 100 parts water ½ liter to 50 liters of water
Chlorine tablets	1 tablet per quart of water I tablet per liter of water
Marvex or Trin Chloro bleach*	½ teaspoon to 5 gallons of water 1 cup to a 400 gallon water tank

*Marvex and Trin Chloro are the main bleach brands in Guyana and Trinidad and Tobago.

In Table 5.7, household practices for cleaning water storage devices are shown. In Siparia, households reported cleaning their storage devices on a monthly (12.8%), quarterly or seasonal (41%), or annual basis (28.2%). About 10% of homes who reported cleaning their storage devices did so on rare occasions. In

Region 4 Subset, cleanings were done predominantly on a weekly (22.5%) or quarterly basis (25%). Ten percent of households who cleaned their storage devices did so on an annual basis. In Villa Litoral, storage devices were cleaned predominantly on a weekly basis (26.3%) or on an annual basis (38%).

Table 5.7 Water storage device cleaning practices within communities in Trinidad and Tobago, Guyana, & Bolivia.

Household Cleaning Pra	Siparia, Trinidad and Tobago (36)		Region 4 Subset, Guyana (27)		Region 4-Rural, Guyana (16)		Villa Litoral, Bolivia (57)	
	No.	%	No.	%	No.	%	No.	%
Cleaning frequency								
Daily	0	0	0	0	0	0.0	7	12.3
Weekly	0	0	9	22.5	8	50.0	15	26.3
Monthly	5	12.8	3	7.5	1	6.3	4	7
Every few months	16	41	10	25	5	31.3	1	1.8
Annually	11	28.2	4	10	1	6.3	22	38.6
Rarely	4	10.3	1	2.5	1	6.3	1	1.8
Recent cleaning								
Within the last two weeks	4	10.3	10	25	8	50.0	23	40.4
Within the last month	6	15.4	3	7.5	1	6.3	2	3.5
Within the last six months	13	33.3	9	22.5	5	31.3	15	26.3
Within the last year	13	33.3	5	12.5	2	12.5	10	20

Various factors may impact the frequency at which household water storage devices were cleaned. Over 65% of the households surveyed either owned water storage devices with capacities above 400 gallons (Table 5.2), had devices which were elevated well above ground level, or were connected to pipes leading into the kitchen and bathrooms. It is likely that these attributes make it difficult to clean the storage devices as frequently as one would wish or is needed, though guidelines for cleaning water storage devices in the regions studied are non-existent. As was previously mentioned, flushing the storage tanks with rainwater was used to clean tanks in some places. Hence, household members coordinate device cleaning with rain episodes. This could explain why many households clean their tanks on a quarterly, annual, or even rare basis. However, smaller water storage devices are seen within some households, particularly in Villa Litoral. In Villa Litoral, water drums and jerry cans were ubiquitous among households surveyed. Due to their ease in portability, these smaller containers could be cleaned on a more frequent basis.

Table 5.8 shows the amount of water required as a function of household size, assuming a daily requirement of 50 gallons per person which falls in the range of the 25-79 gallons per person for optimal access to water (Mihelcic et al., 2009). Actual values on household usage rate in each of the three communities were not collected and may differ from this assumed value. Nevertheless, the information in the table provides an estimate of the frequency with which the tanks would be refilled for domestic purposes. One can use these numbers to estimate the frequency of disinfection required assuming inadequate disinfection residual reached the household yard from the main. Based on the data from Tables 5.6 and 5.8, if a household of four in Guyana utilizes 200 gallons of water per day and has one 400-gallon tank, one cup of bleach would need to be added to the tank each time the tank is filled. This equates to a minimum of 3.5 cups of bleach on a weekly basis just to maintain adequate chlorine residual.

Table 5.8 Daily household usage rate of water and number of refills required per week depending on storage device size assuming a 50 gal/day requirement per person.

# people/house	gal/day/house	# refills/week 50 gal	# refills/week 400 gal	# refills/week 1000 gal
1-3	50-150	7-21	0.9-2.7	0.35-1
4-7	200-350	28-49	3.5-6.2	1.4
8	400	56	7	2.8

5.6 Household Water Access and Collection

In Table 5.9, means of household water access, collection, and transport are shown for the three communities. Almost all the households surveyed in Siparia, Trinidad and Tobago and Region 4 Subset, Guyana are connected to a municipal water source, while close to 42.1% of those in Villa Litoral, Bolivia are connected. In Siparia and Region 4 Subset, households are billed a quarterly statement based upon the established water tariff for the designated area. In Villa Litoral, each household pays a flat $7Bs per month (~$1USD) for water, a price that was determined by the water personnel.

Those who are not connected often rely on rain water, river water, or the sharing of a neighbor's pipe for water. Although, the majority of households in all three communities are connected, only households within Siparia had access to water all day. Sixty percent of households surveyed in Region 4 Subset had access to water half of the day, while 81% of households surveyed in Villa Litoral had access for a only a few hours a day. Close to 16% of households in Villa Litoral reported not having access to any piped water at all and thus relied solely on rain water or river water.

The times of water availability varied between the target communities. In the households surveyed in Region 4 Subset, access to water from the main was normally available in the mornings. In Villa Litoral, access to water occurred when a member of the local water committee went to turn on the water pump. Additionally, water access alternated between the sides of the main street with each side getting access for a few hours.

In accessing water from the water storage tanks, most residents either used a bucket to bring water into the home or had the water directly piped into the kitchen from the tank via PVC or metal pipes.

Table 5.9 Means of household water access, collection, and transport within communities in the Latin American and Caribbean region.

Water Access, Collection, and Transport	Siparia, Trinidad and Tobago (39)		Region 4 Subset, Guyana (40)		Region 4- Rural. Guyana (23)		Villa Litoral, Bolivia (57)	
	No.	%	No.	%	No.	%	No.	%
Municipal connection								
Yes	37	94.9	40	100	23	100.0	33	57.9
No	2	5.1	0	0	0	0.0	24	42.1
Water access								
All day	39	100	5	12.5	1	4.3	2	3.5
Half a day	0	0	24	60	13	56.5	0	0
A few hours a day	0	0	11	27.5	9	39.1	46	80.7
Collection method								
Bucket	19	48.7	21	52.5	16	69.6	39	68.4
Pot	0	0	0	0	1	4.3	1	1.8
Bottle	2	5.1	0	0	0	0.0	1	1.8
Piped into home	18	46.2	19	47.5	7	30.4	15	26.3
Other	0	0	0	0	0	0.0	1	1.8
Water covered for transport								
Yes	13	33.3	13	32.5	10	43.5	16	28.1
No	8	20.5	8	20	6	26.1	26	45.6

5.7 Community Perception about Water Quality

Community residents were asked to describe the water quality that they received from the municipal water source (Figure 5.13). The majority of the households in Siparia, Trinidad and Tobago (74%) and Region 4 Subset, Guyana (58%) reported the water source as being brown. Residents would often let the water settle or utilize filtration mechanisms prior to drinking, as was mentioned in Section 5.4. The brown color could be attributed to several factors. The majority of the households received water access in the morning, when the pumps would be turned on. As a result, all the sediment build-up within the pipes from the previous day was also brought in with the water source. A second factor could be high organic, iron, and/or manganese content in the water (Fass, 2003; Han, 2007; Magyar, 2007).

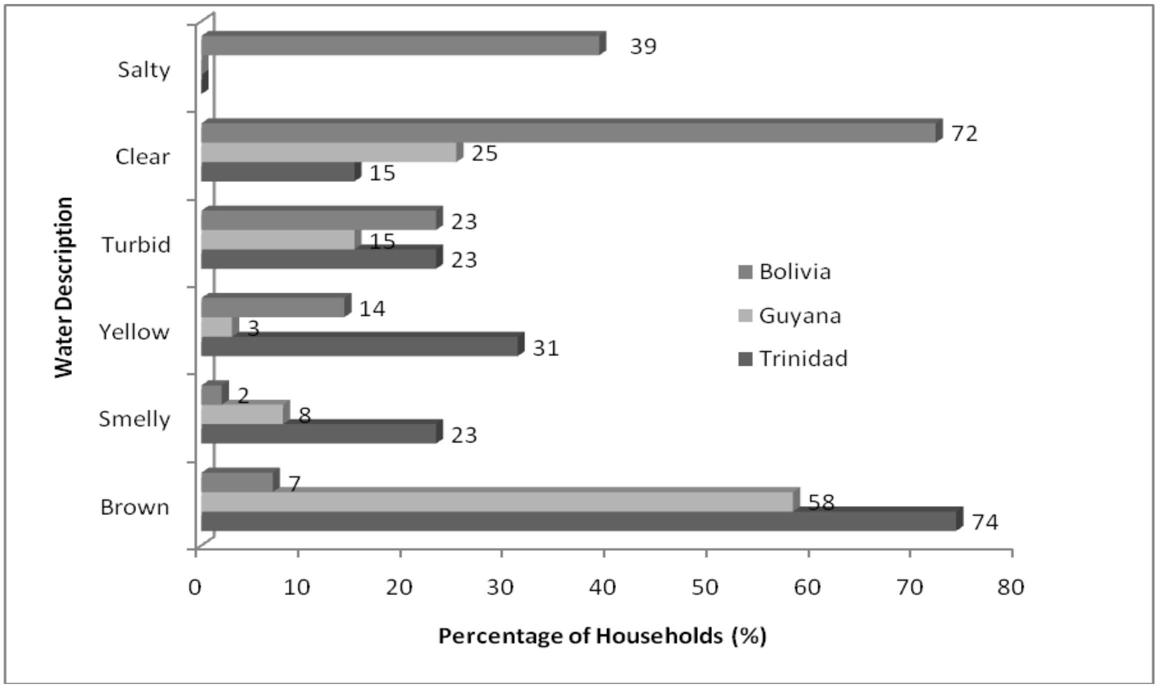

Figure 5.13 Reported water description among communities. Number of households surveyed: Siparia, Trinidad and Tobago (39), Region 4 Subset, Guyana (40); Villa Litoral (57).

While the majority of households in Villa Litoral (72%) reported their water source as being clear, 39% reported water sources as being salty, often to the point of not being potable. During this point those who relied on piped water sources would revert to using rainwater if available or would collect water from the river. Experiences with the municipal water pressure varied between the households connected to water. Participants were asked to describe the water pressure from the main according to the following categories:

1) Good: strong and constant flow when the water was turned on-
2) Average: steady, constant flow
3) Bad: water would often trickle out or take a while before coming out.

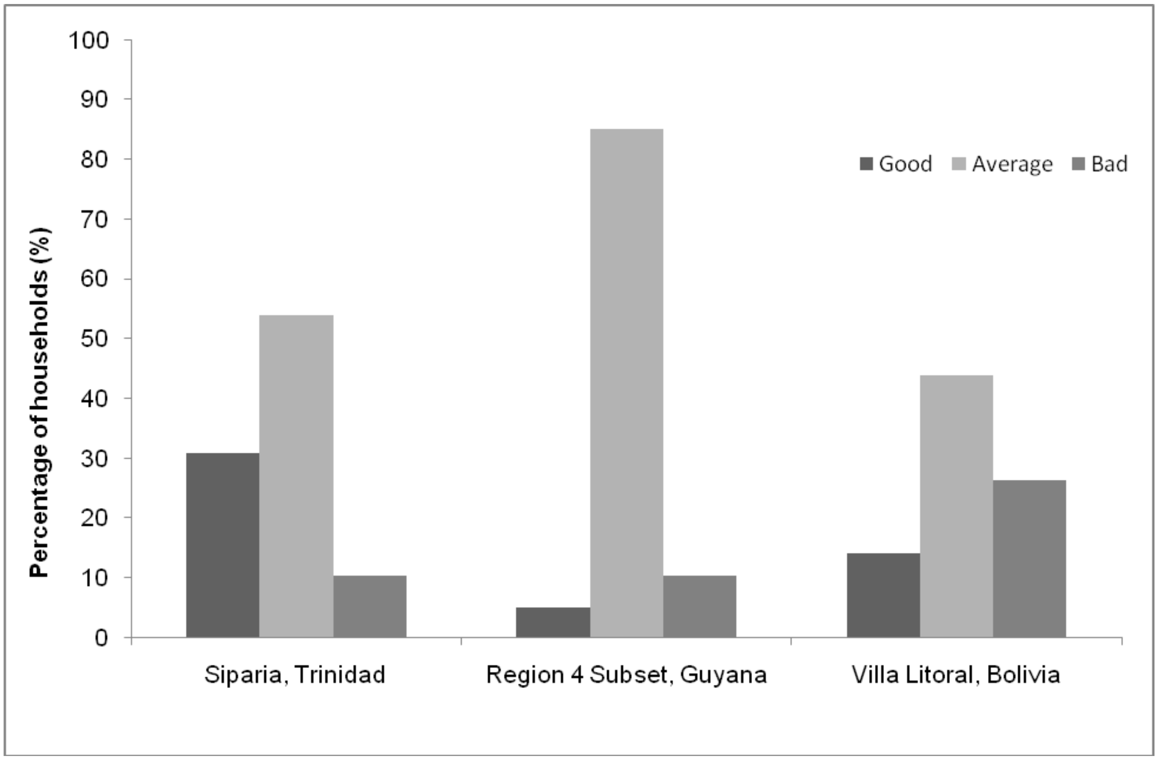

Figure 5.14 Reported description of water pressure received at the household level (ex. at point where water for drinking comes from). Number of households surveyed: Siparia, Trinidad and Tobago (39), Region 4 Subset, Guyana (40), Villa Litoral (57).

Figure 5.14 shows a comparison of water pressure description among the three communities. In Siparia, 16% of households reported their water pressure as being good, while 48% reported their water as average. Five percent of households in Region 4 Subset reported their water pressure as being good while 85% reported it as average. Good water pressure was reported among 14% of households in Villa Litoral, whereas 40% reported water pressure as being average. Five percent of households in Siparia and 16% of households in Villa Litoral did not have access to water from the main and thus did not report on the water pressure. While the majority of households in all three communities reported water pressure as good or average, a percentage of households reported the water pressure as being bad. This can be attributable to water loss during distribution as a result of deteriorating or leaky pipes (Besner, 2001; Lamka, 1980; LeChevallier, 2003, Lee, 2005; Olsinska, 2007), or aggressive water theft. This can also be attributed to the water intermittence that occurs within the community.

While many of the residents in all three communities were concerned that the appearance and taste of the water sources could be indicative of the dismal quality of the water, they felt that there was little that could be done at the local level to help resolve this. For those who were able to do so, bottled water became either the main or supplemental source of drinking water.

5.8 Household Responsibilities for Water Provision

For the majority of households in all three communities, the stored water lasts for up to three weeks when initially filled, while a quarter of households in Siparia and Villa Litoral have stored water sources that last more than three weeks, partly due to owning multiple or very large storage devices. Hence, the practices used to ensure the safety of the water source were assessed.

In households without direct water connections into the house, the majority of participants reported that water sources were covered when being transported into the homes in Siparia (61.9%), Region 4 Subset (66.7%), and Villa Litoral

(52.4%). This was done to protect water sources from being contaminated both during transport and upon arrival in the home, as it would likely remain in the same covered container for daily use. This was of particular importance as many homes had children present. Households had water sources within the reach of toddlers in Siparia (15.4%), Region 4 Subset (35%), and Villa Litoral (57.9%). These consisted of water sources within the storage device or water sources being transported from the device to indoors. In a third of the households in Villa Litoral, the objects and toys have been thrown in the water sources by children, compared to 5% of households in Siparia and Region 4 Subset. This could be attributed to parents possibly carrying children while tending to water sources or to children having access to water sources, particularly to smaller and ground-level water storage devices.

Household water responsibilities for Siparia are shown in Figure 5.15. In terms of filling the storage devices and ensuring there were no leaks, the duty was performed primarily by the male head of the house (53.8%), followed by the female head (30.8%), a child of the homeowner (17.9%) or other persons (17.9%). Five percent reported that no one takes filling responsibilities for the storage devices, as they simply allow the rain to fill them. Additionally, the male head is primarily responsible for cleaning the devices in 64.1% of households, compared to the female head (30.8%) and child (23.1%). The responsibility of collecting water from the storage device is primarily that of the male head (51.3%) or the female head (46.2%).

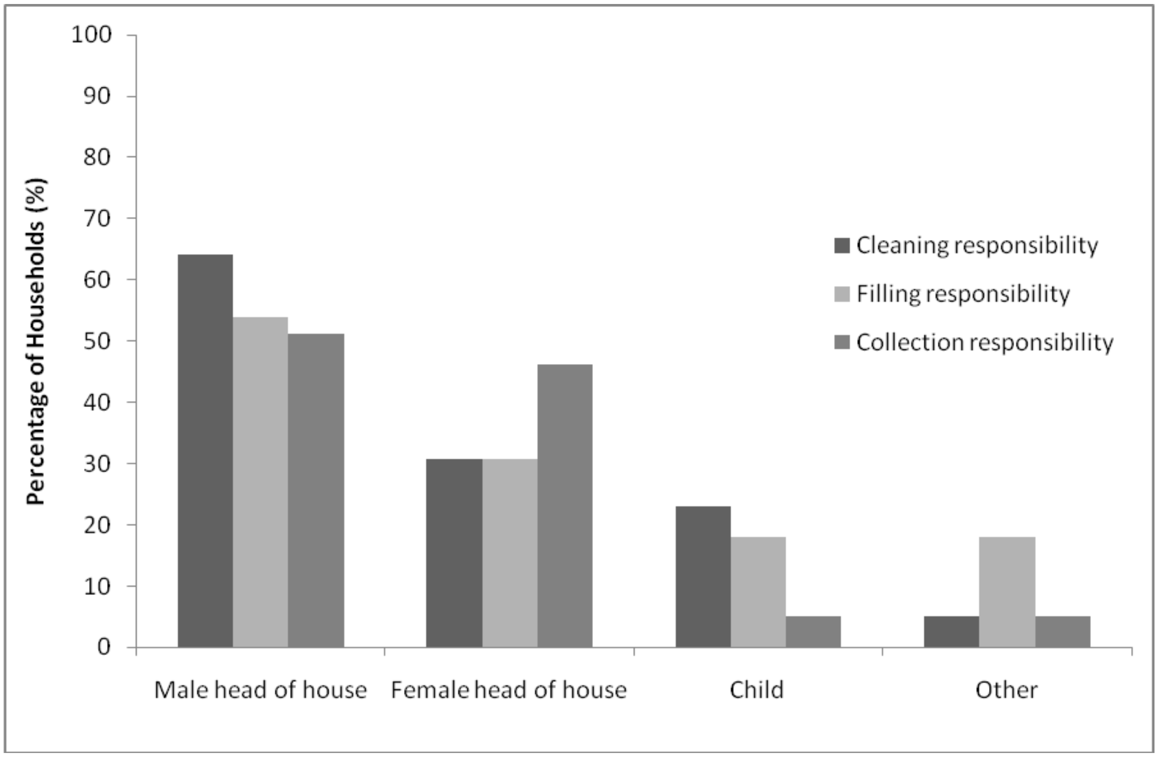

Figure 5.15 Household water responsibilities within Siparia, Trinidad and Tobago. The number of households surveyed was 39.

Household water responsibilities for Region 4 Subset are shown in Figure 5.16. In 47.5% of the homes, the male head is responsible for both cleaning and filling the water storage devices, followed by the female head (30%). Close to 13% of households reported that no one takes cleaning or filling responsibilities for the storage devices, as they simply allow the rain to clean and fill them. However, the responsibility of collecting water from the storage device is primarily that of the female head (62.5%), followed by the male head (12.5%) and other individuals (7.5%).

The Region 4 subset does consist of urban and rural areas which have differences in the percentage of male headed households with more male headed households seen in the rural versus urban sites (BOS, 2002). Despite this difference, the trend remains the same for both the urban and rural areas studied that female heads of household contribute more to water collection than their male counterparts and contribute less to tank cleaning and filling than their male counterparts. The role of females in water collection is significantly higher in the rural compared to the urban areas studied.

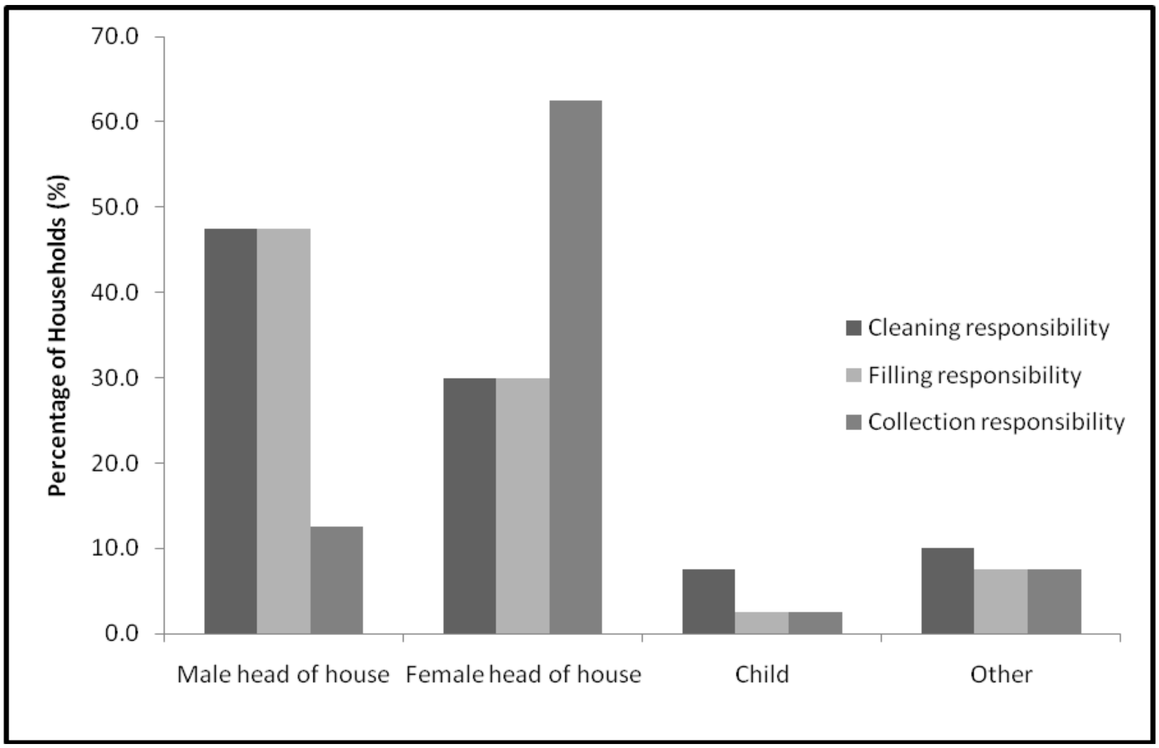

Figure 5.16 Household water responsibilities within Region 4 Subset, Guyana. The number of households surveyed was 40.

Household water responsibilities for Villa Litoral are shown in Figure 5.17. In terms of filling the storage devices and ensuring there are no leaks, the duty is performed primarily by the male head of the house (40.4%), followed by the female head (35.1%), another person such as a neighbor or friend (21.1%), and the child (5.3%). About 9% of households reported that no one takes cleaning or filling responsibilities for the storage devices, as they simply allow the rain to clean and fill them. The male head is primarily responsible for cleaning the devices in 61.4% of households, compared to the female head (31.6%) and child (7%). The responsibility of collecting water from the storage device is primarily that of the female head (64.9%), followed by the male head (36.8%).

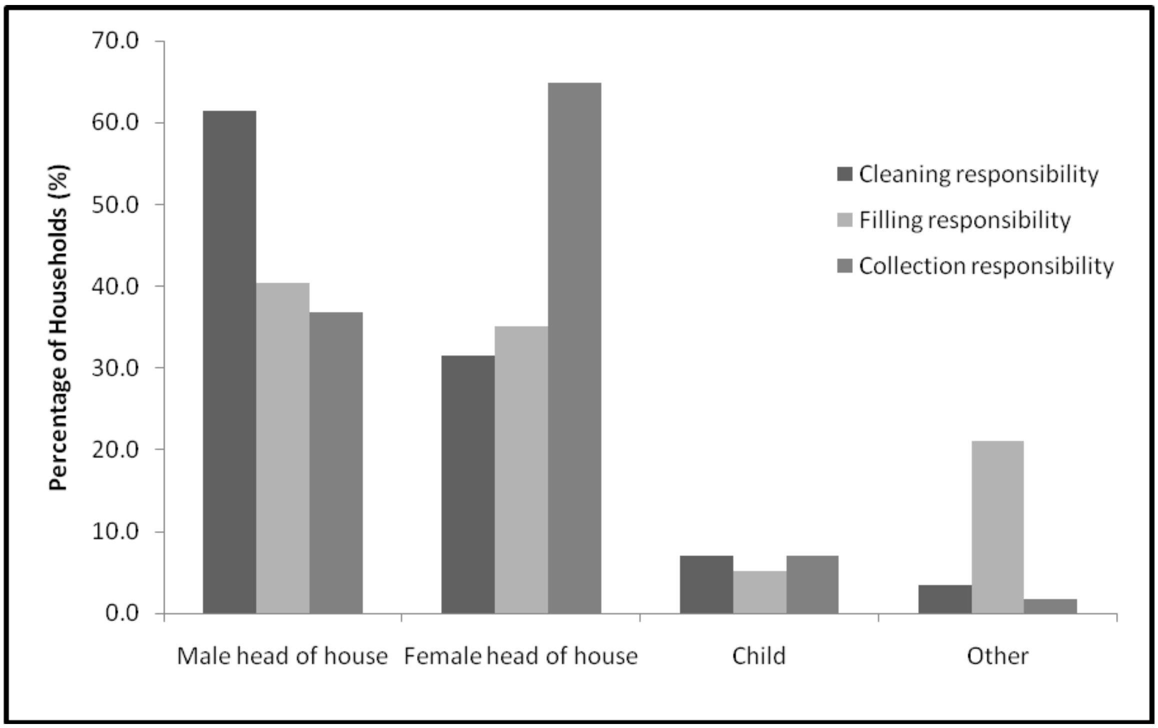

Figure 5.17 Household water responsibilities within Villa Litoral, Bolivia. Number of households surveyed: 57.

While collecting and tending to the water needs of a household are traditionally the responsibility of the woman (WHO/UNICEF, 2010), there is a shift and a sharing of these responsibilities as household water storage has become more advanced and durable. In a large percentage of households in Siparia, the male head was responsible for all three duties (cleaning, filling, and collection). In Region 4 Subset, the male head was responsible for cleaning and filling the water storage device in a large percentage of households, while the female head is responsible for the collection. In Villa Litoral, the male is responsible for the cleaning while the female head is responsible for the collection. There is an almost even split among percentage of households where the male head and the female head are responsible for filling.

The presence and the role of the male household head are of particular interest as the number of households headed by females continues to increase (Rutstein, 2004). Table 5.10 summarizes the global distribution of households headed by females. In the Latin American and Caribbean region, between 17-27% of households are headed by a female. However, the results from this study show different demographics with regards to female-headed households. Based on the household responsibilities data, one can conclude that 60-70% of households are headed by men, leaving the remaining 30-40% of households to be headed by women. The data results obtained could indicate that the percentage of female heads in the Latin American and Caribbean region is underestimated. This realization shows that further gender-specific interventions may be needed in order to better address household water issues seen in the Latin American and Caribbean region.

Table 5.10 Global distribution of female heads of households by region and wealth quintile. Obtained from (Rutstein, 2004).

Percentage of female household heads in each wealth quintile, by region Quintile (percent)						
Region	Lowest	Second	Middle	Fourth	Highest	Total
Sub-Saharan Africa	22	22	23	26	24	24
Near East and North Africa	8	8	9	11	9	9
Europe and Central Asia	14	14	16	20	29	19
South and Southeast Asia	8	10	10	11	14	11
Latin America and Caribbean	17	22	25	27	26	24
Total	17	18	20	22	22	20

5.9 Health and Community Perception

Community perception and health were assessed within the three study areas, in terms of perceived risks and benefits associated with the water storage devices and with the current water quality. Responses from the surveys are summarized in Table 5.11.

Table 5.11 Community perception and health among households within communities in the Latin American and Caribbean region.

Community Perception & Health	Siparia, Trinidad and Tobago (39)		Region 4 Subset, Guyana (40)		Region 4 Subset, Guyana (40)		Villa Litoral, Bolivia (57)	
	No.	%	No.	%	No.	%	No.	%
Media access								
Yes	13	33.3	39	97.5	23	100.0	42	73.7
No	26	66.7	1	2.5	0	0.0	15	26.3
Handwashing practiced								
Yes	17	43.6	27	67.5	13	56.5	36	63.2
No	14	35.9	12	30	9	39.1	19	33.3
Sometimes	8	20.5	1	2.5	1	4.3	2	3.5
Confidence in H_2O potability								
Very confident	16	41	1	2.5	1	4.3	11	19.3
Somewhat confident	17	43.6	8	20	6	26.1	16	28.1
Not confident	6	15.4	31	77.5	16	69.6	30	52.6
Confidence in tank								
Very confident	8	20.5	0	0	0	0.0	9	15.8
Somewhat confident	22	56.4	5	12.5	3	13.0	15	26.3
Not confident	9	23.1	35	87.5	20	87.0	33	57.9
Recent waterborne illness								
Yes	1	2.6	6	15	3	13.0	23	40.4
No	38	97.4	34	85	20	87.0	34	59.6

Survey participants were asked whether they had received water-related advisories or information through various sources of media (TV, radio, flyers, etc.) in the past year. While the majority of households surveyed in Region 4 Subset (97.5%) and Villa Litoral (73.7%) reported receiving some advisory or information, only a third of the households surveyed in Siparia reported receiving any information or advisories within the past year. In Region 4 Subset, media access often involved boil notices or other advisories (for example, Figure 5.11), information through non-governmental organizations (NGOs), or information through the radio. In Villa Litoral, media access and information was predominantly through radio or through town forums presided over by the water committee.

The frequency of handwashing prior to water handling was assessed. The majority of households surveyed in Region 4 Subset (67.5%) and Villa Litoral (63.2%) reported to regularly washing their hands prior to handling water from the water storage device. Roughly 44% of households in Siparia reported frequent handwashing. Various reasons were given as to why handwashing was not practiced. One common reason was that individuals did not remember to wash their hands before dealing with the water. A second reason was that they could not afford to waste precious water by washing their hands all the time, and would wipe their hands on a towel or clothes. A third reason was that the water supplies were piped into the home and accessed through the faucets, thus negating a need to wash their hands.

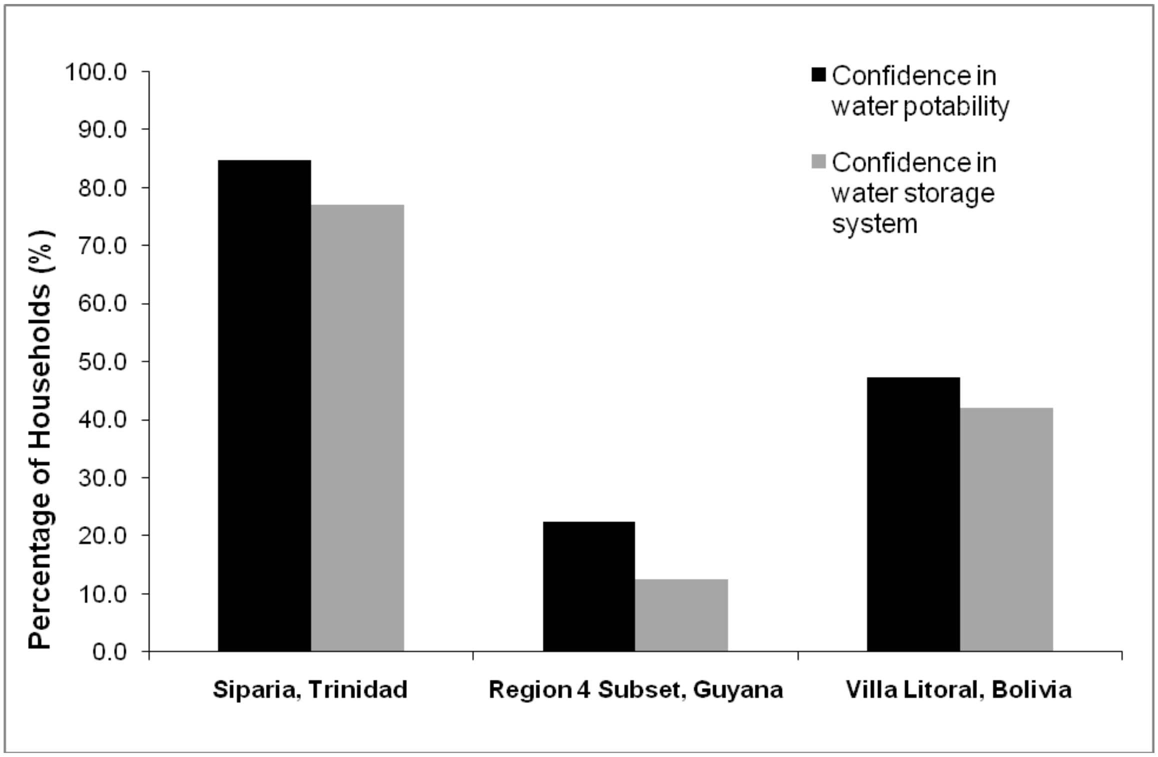

Figure 5.18 Confidence levels regarding household water sources and water storage systems among communities in the Latin American and Caribbean Region. Number of households surveyed: Siparia, Trinidad and Tobago (39); Region 4 Subset, Guyana (40); Villa Litoral, Bolivia (57).

Confidence and trust in the water sources and water storage systems were assessed, as shown in Figure 5.18. When asked about their confidence in the potability and security of their drinking water sources, the majority of households surveyed in Siparia (84.6%) were either very confident or somewhat confident that their water sources were safe for consumption, compared to only 22.5% of households in Region 4 Subset and 47.4% of households in Villa Litoral. When asked about their confidence in the water storage systems to keep their water safe, the majority of households surveyed in Siparia (76.9%) were either very confident or somewhat confident that their water sources were safe for consumption, compared to only 12.5% of households in Region 4 Subset and 42.1% of households in Villa Litoral. Participants who felt confident in their water sources reported reasons such as adequate treatment at the municipal water plant/pump, regular household water treatment, no reported cases of waterborne illnesses or advisories, and perception that rainwater was free of contaminants. Reasons for lack of confidence included aesthetic aversion (color, smell, and taste), perceived risk, previous advisories, and distrust of the local governmental agency in charge of water provision.

Participants were asked how confident were they that having water stored in the storage tanks would reduce their risk of water-related illnesses. Fifty-six percent stated that they were not confident at all, whereas 17% stated that they were very confident and 27% stated they were somewhat confident. Thus, while 48% of households were very or somewhat confident in their water quality, 44% of households were very or somewhat confident in the reduced risk of water-related risks as a result of using water storage devices. Participants who were confident reported feeling as such because the water storage systems were sealed, robust, and sturdy. Reasons cited for not being confident in the systems were that the water source itself was contaminated, the system was within reach of children and pets, and that minimal maintenance was done by owner thus the likelihood for lack of confidence.

Participants were asked whether there were any recent water-related illnesses among those living within the respective home. In Siparia, Trinidad and Tobago, only one household reported having a recent water-related illness, in which case the individual experienced headaches following consumption of the water. In contrast, 15 % of households in Region 4 Subset, Guyana and 40.4% of households in Villa Litoral reported recent illnesses.

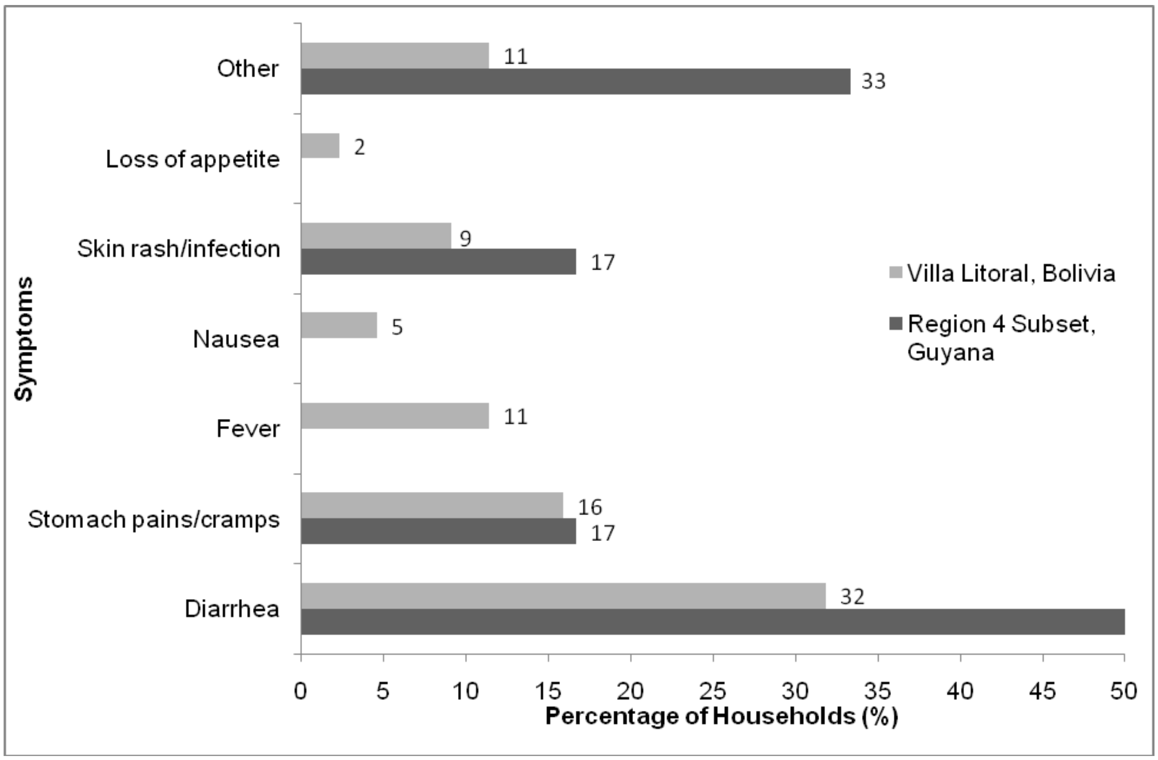

Figure 5.19 Distribution of symptoms reported among households following recent waterborne illnesses. Number of households surveyed: Region 4 Subset, Guyana (6); Villa Litoral, Bolivia (23).

Among those households reporting illnesses, various symptoms were observed by household members, as shown in Figure 5.19. Diarrhea was the most common symptom reported among households in Region 4 Subset (50%) and

Villa Litoral (32%). Participants reported household members having diarrheal episodes which lasted 1-3 days. In both communities, participants also reported household members experiencing stomach pains/cramps and skin rash. In Villa Litoral, 18% of households also reported symptoms of fever, nausea, and loss of appetite.

In spite of the various symptoms presented, none of the individuals who had a waterborne illness in Siparia or Region 4 Subset had the illness medically diagnosed, while only half of those in Villa Litoral had the illness diagnosed. Various reasons for not visiting a medical facility were given, such as inability to pay, lack of access to care, lowered perceived risk of the symptoms due to commonality, potential inconvenience of a doctor visit, and time constraints. Currently, only one medical facility exists in Villa Litoral and it is headed by one medical personnel. There is a hospital located in Palos Blancos, which is situated across the Rio Beni. Although the hospital does take in some Villa Litoral residents, the community is predominantly serviced by the hospital within the Caranavi province, as this is the province to which the community belongs.

The prevalence of diarrheal episodes following consumption of water sources poses a great threat to the welfare and development of the communities. One of the most acute effects of diarrhea is dehydration due to the loss of electrolytes (sodium, chloride, potassium, and bicarbonate) and water. Fatality can occur when the body reaches a fluid loss of 10%. Even if fatality does not occur, dehydration can make one more susceptible to infections. This is of particular concern for those with children.

5.10 Summary

While water storage devices do provide additional and constant water supplies, it is evident that water quality can be compromised without adequate device maintenance and water treatment at the point of use. As most households have multiple water storage devices- several of which may have a capacity over 400 gallons-, it becomes exceedingly difficult to clean these storage devices. As such, many households relegate device cleanings to coincide with rainfall episodes, where rainwater can flush out the storage devices. The problem of infrequent cleanings is compounded with inadequate water disinfection. In Villa Litoral, chemical disinfection is rarely practiced. In Siparia and Region 4 Subset, household water disinfection is practiced, but the reported chlorine dosage and mixing time are inadequate to provide optimal disinfection. While water advisories have been distributed in the communities, there is sometimes a misunderstanding as to whether the disinfection should take place in a separate, smaller container or in the storage device itself.

While many households had connections to the main, water access was often limited to half a day or a few hours a day. Even though residents paid to receive piped water, issues with water aesthetics, taste, and pressure forced many households to purchase bottled water as an alternative drinking water source, as was the case in Siparia and Region 4 Subset. As a result of household practices and water distribution issues, many households have experienced water-related illnesses with varying symptoms. It is thus necessary to build increased awareness on proper household water storage practices, particularly among those responsible for the collection of water sources and the cleaning of storage devices. It is also important to provide accurate information of chemical disinfection of household water sources as there are various device shapes and capacities present within the communities.

CHAPTER 6: WATER QUALITY ANALYSES

6.1 Introduction

Water samples were taken from twenty-four households within Siparia, Trinidad and Tobago. Within the Region 4 Subset, Guyana, samples were taken from forty households. Water samples were taken from twenty-six sites within Villa Litoral, including two samples from the main pump and from the Rio Tiatche and Rio Beni. Using a multi-parameter system (Hach® Hydrolab® Quanta, Loveland, CO), the following water quality tests were conducted in the field: temperature, pH, conductivity, turbidity, salinity, total dissolved solids, and DO. GPS measurements of the sample sites were taken with a GPS receiver (Garmin® eTrex®, Olathe, KS) using the datum World Geodetic System 1984 (WGS 1984). Table 6.1 summarizes the number of samples taken by community, water source, and storage device. Region 4- Rural consists of only the rural communities of the Region 4 Subset- Mocha and Mon Repos. Piped water consisted of water distributed from the main pumping station, municipal plant, or community system. In each of those three sources, the water source was derived from groundwater.

Table 6.1 Summary of water samples taken from Siparia, Trinidad and Tobago; Region 4 Subset, Guyana; and Villa Litoral, Bolivia.

	Siparia, Trinidad and Tobago (24)		Region 4 Subset, Guyana (40)		Region 4-Rural, Guyana (23)		Villa Litoral, Bolivia (26)	
	#	%	#	%	#	%	#	%
Source of water								
Main pump (piped water)	22	91.7	24	60	14	60.9	14	53.8
Rain water	0	0.0	13	32.5	8	34.8	10	38.5
Mixed rain (rain & piped)	2	8.3	1	2.5	0	0	0	0.0
Other sources	0	0.0	2	5	1	4.3	2	7.7
Type of water storage device								
Tanks	23	95.8	36	90.0	20	87	11	42.3
Water drums	1	4.2	3	7.5	3	13	3	11.5
Other (jerry cans, buckets, etc.)	0		1		0	0	10	38.5

Microbial analyses were done on the water samples taken from the three countries. In Trinidad and Tobago and Guyana, field analysis of fecal coliform and total coliform were conducted using the membrane filtration method and incubation within the portable incubator (Thermotote medium, Scientific Device Laboratory, Des Plaines, IL) for 44.5 ± 0.2°C for 24-26 hours. In Villa Litoral, microbial analysis was conducted using the Colilert-18 method (IDEXX Laboratories, Inc., Westbrook, ME) followed by incubation within the portable incubator for 35 ± 0.5°C for 18-22 hours.

6.2 Microbial Analyses

WHO guidelines for microbial measurements state that drinking water should be free of both fecal and total coliforms (WHO, 2006). Figure 6.1 shows total and fecal coliform present in homes within all three target communities. In Siparia, 4% of households tested positive for fecal coliform while 25% tested positive for total coliform. All of the fecal positive samples came from water piped from the municipal distribution line, while 83% of samples testing positive for total coliform came from that source.

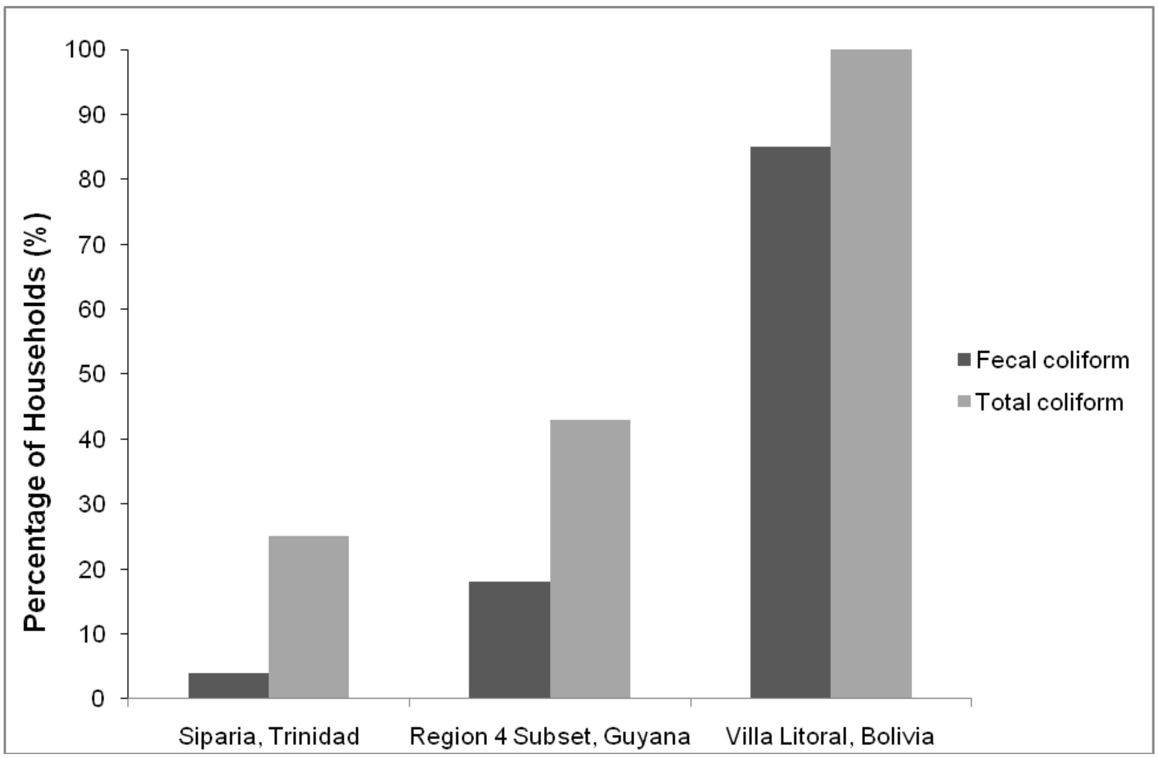

Figure 6.1 Percentage of households with positive levels of microbial contamination within their household water sources, by community. Number of water samples tested: Siparia, Trinidad and Tobago (24); Region 4 Subset, Guyana (40); Villa Litoral, Bolivia (26).

Of the 40 water samples taken in Region 4 Subset, close to 18% of the samples tested positive for fecal coliform and 45% tested positive for total coliform. Figure 6.2 compares the source of the water samples that tested positive for fecal coliform. Of the seven water samples that tested positive for fecal coliform, 71% were derived from water piped from the main distribution system. Half of the eighteen water samples that tested positive for total coliform were derived from piped water sources, with the remainder derived from rain water sources (44%) and mixed rain water sources (6%).

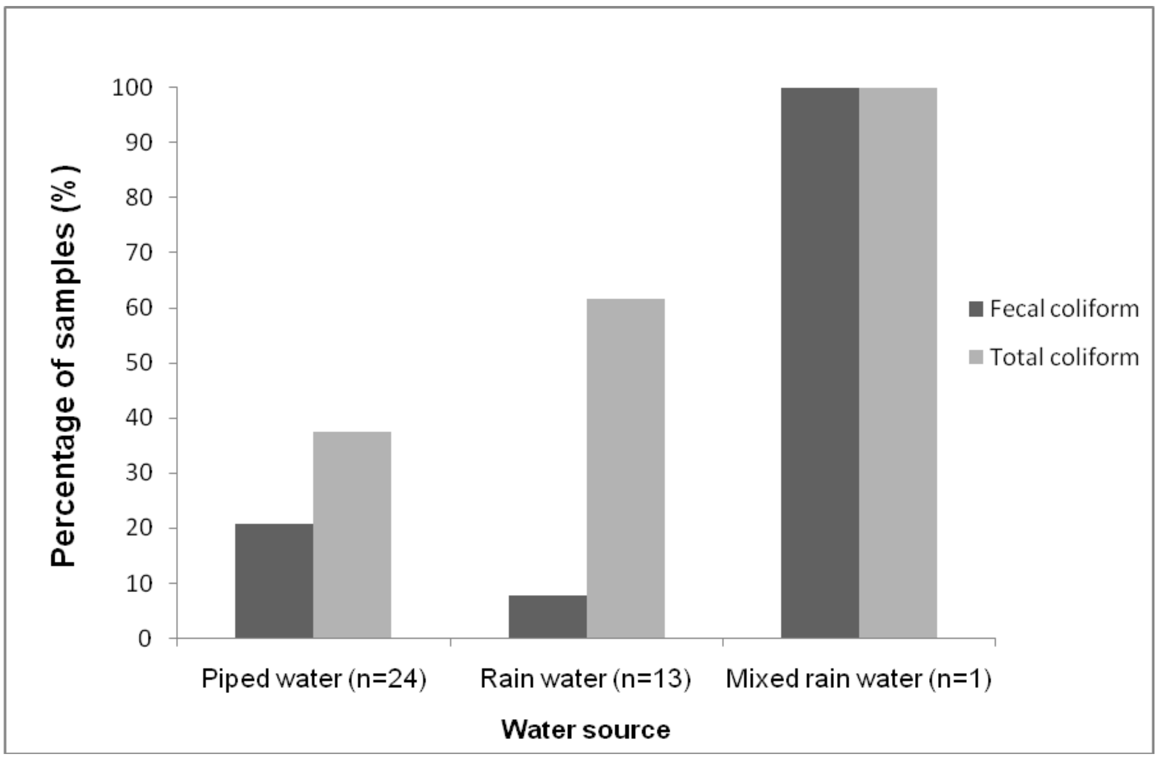

Figure 6.2 Presence of bacterial contamination within water samples by type of water source in Region 4 Subset, Guyana. Contamination was not detected in other sources of water used (n=2). Number of water samples tested: 40.

In terms of water storage, 89% of samples that tested positive for total coliform were from tank storage, whereas 100% of samples that tested for fecal coliform were from tank storage, as shown in Figure 6.3. None of the samples taken from the municipal pump station of Guyana Water Incorporated (GWI) in Mocha tested positive for either fecal or total coliform. This suggests that the contamination is taking place either along the distribution line or at the household point-of-use, as was mentioned in other studies (Clasen, 2003; Levy, 2008; Jagals, 2006; Luby, 2006; Sobsey, 2008; Stauber, 2006).

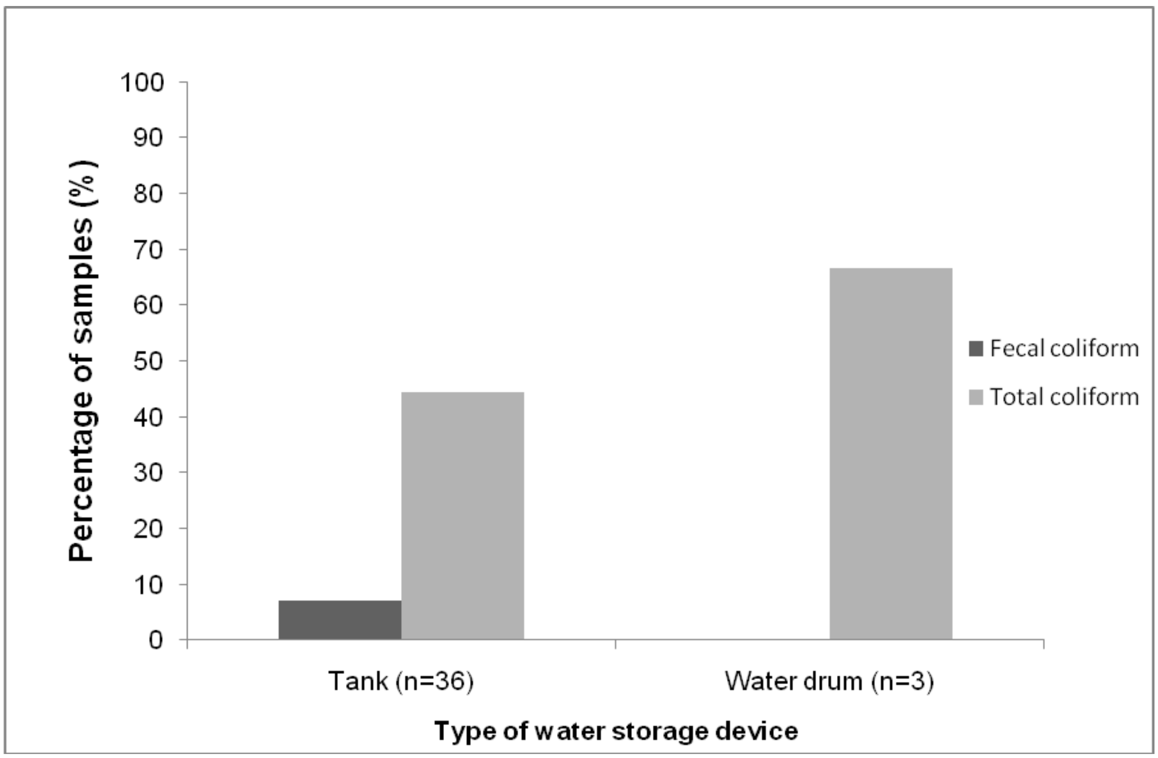

Figure 6.3 Presence of bacterial contamination by type of water storage device (black tank or water drum) in Region 4 Subset, Guyana. Contamination was not found in other sources of water storage used (n=1). Number of water samples tested: 40.

Of the twenty-six water samples taken In Villa Litoral, fecal coliform was found to be present in 85% of samples, while total coliform was present in 100% of the samples. In an effort to better understand the frequency of microbial contamination within the Villa Litoral community, the distribution of microbial contamination was analyzed in terms of the type of water source utilized and the means of water storage, as shown in Figures 6.4 and 6.5, respectively. Fifty-four percent and 42% of water samples that were derived from piped water tested for total coliform and fecal coliform, respectively. Thirty-eight percent of samples taken from water storage tanks tested positive for fecal coliform compared to samples taken from water drums (12%) and other storage containers such as jerry cans, buckets, and pots (27%). The same trend was observed for total coliform contamination, as the highest percentage of contamination was seen in water storage tanks (42%), other containers (38%), and water drums (12%). It appears that households with storage tanks had a higher risk for microbial contamination due to their relative larger size and difficulty in cleaning tank systems.

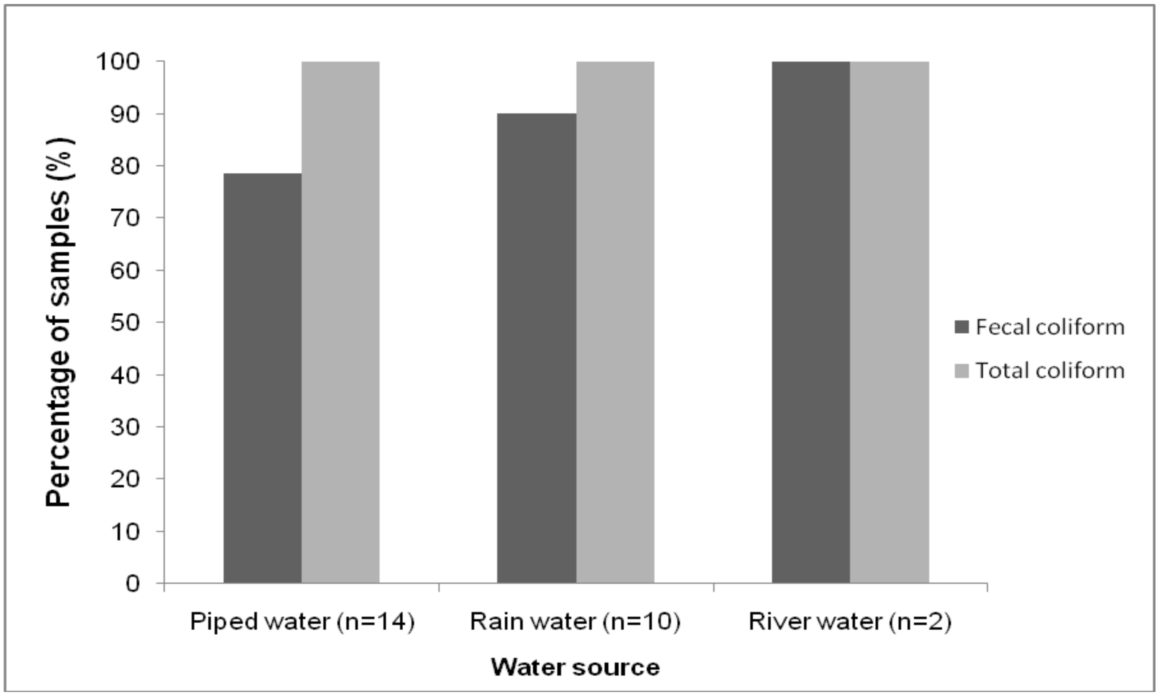

Figure 6.4 Presence of bacterial contamination by type of water source in Villa Litoral, Bolivia. Number of water samples tested: 26.

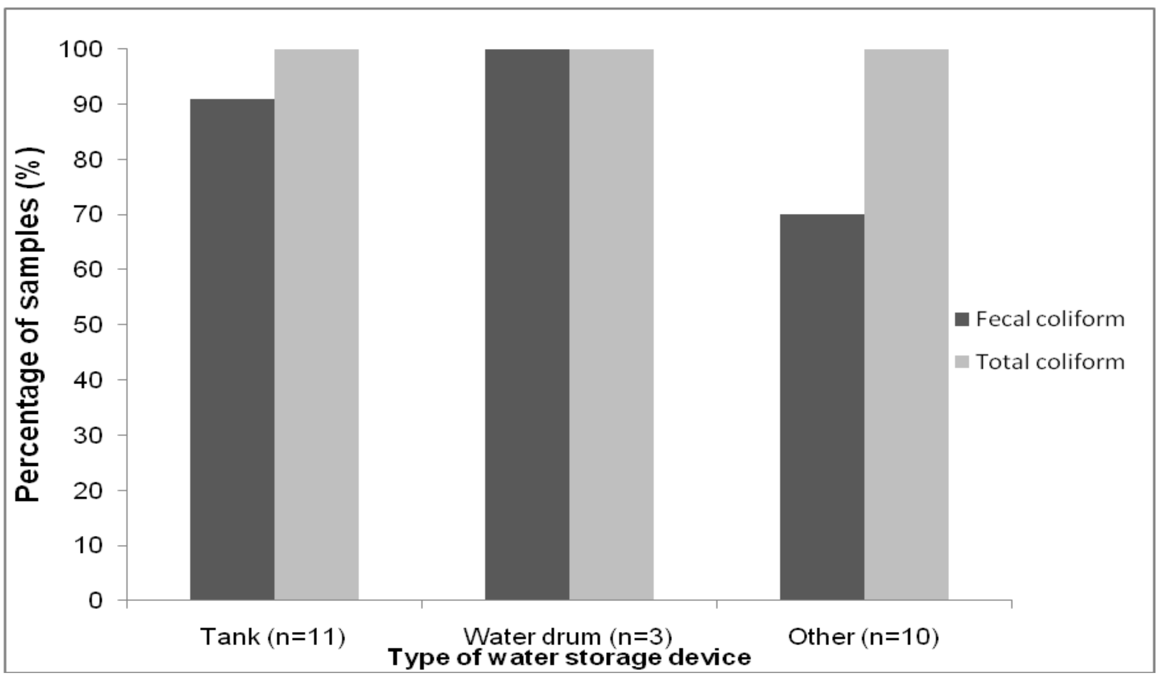

Figure 6.5 Presence of bacterial contamination by type of water storage in Villa Litoral, Bolivia. Number of water samples tested: 26.

Unlike results from Siparia and Region 4 Subset, both fecal and total coliform were found at the head of the distribution line for the community's water supply in Villa Litoral. The presence at the pre-distribution line is indicative that the issue that is being seen must be addressed prior to point-of-use. The presence of coliform in the water could be attributed to several factors, such as increased rain levels, unsanitary handling of water, inadequate disinfection both at the distributing plant and in the household (Agard, 2002; Tokajian, 2003; Moe, 1991; Semenza, 1998; Jagals, 2006).

In Siparia and Region 4 Subset, the water distribution systems are more robust, as they provide for more residents and households than the one seen in Villa Litoral (Appendix D). At the WASA treatment plant and some of the GWI plants, chlorine disinfection is used to ensure a residual of 0.2 mg/L free chlorine in the effluent water, which is necessary to prevent microbial re-growth (LeChevallier, 1996). Additional treatment of the water is also implemented, such as the use of lime and aeration. At the municipal water source in Villa Litoral, no disinfection is used, as the only means of treatment in the gravitation flow through the sediment. The lack of disinfection and advanced treatment play an important role in the frequency of microbial contamination seen in the water sources (Payment, 1999; Gagnon, 2005; Jin, 1989; Pastre, 2002; Mahmud, 2007). Nevertheless, while the presence of total coliform is not always indicative, or a precursor to, infectious diseases, the significant distribution of the combination of *E. coli* and coliform in the water sources warrants the need for further research. With regards to the total coliform levels, the coliform are common in the environment and do not necessarily indicate pathogenic or harmful contamination. However it does indicate that there is a breakdown in the distribution system.

6.3 Basic Water Parameters

Water quality parameters were measured for water samples from the communities. Table 6.2 summarizes the data findings of the parameters that were tested.

Table 6.2 Water quality parameters of household drinking water within communities in Trinidad and Tobago, Guyana, and Bolivia. Number of water samples tested: Siparia, Trinidad and Tobago (24); Region 4 Subset, Guyana (40); Villa Litoral (34).

	Siparia, Trinidad and Tobago n=24			Region 4 Subset, Guyana n=40			Villa Litoral, Bolivia n=26		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
pH	6.8	8.03	7.53	5.14	9.53	6.97	5.84	7.54	6.65
Temperature (°C)	25.09	31.09	27.84	27.17	41.79	30.83	22.82	30.84	24.88
Conductivity (mS/cm)	0	0.681	0.46	0	0.608	0.20	0	1318	681.70
DO (mg/L)	4.1	13.08	6.99	1.07	14.06	4.97	2.75	9.03	5.73
Turbidity (NTU)	0	21.4	2.48	10	26	13.63	12.9	82.9	17.94
TDS (mg/L)	0	400	260	0	400	120	0	990	480
Total Coliform (#CFU/100mL)	0	86	8.57	0	54	2.35	2	960.6	89.65
Fecal Coliform (#CFU/100mL)	0	5	0.21	0	144	9.70	0	675.1	53.46
Pb (mg/L)	0.1	0.3	0.15	0	0.2	0.07	0	0.6	0.15
Fe (mg/L)	0.05	1.48	0.59	0.08	2.13	0.68	0	3.62	0.94
Cu (mg/L)	0.01	2.32	0.33	0.01	2.52	0.43	0	0.08	0.01
P (mg/L)	0	2.3	0.63	0	3.42	0.41	0	2.3	0.39
Al (mg/L)	0.02	0.25	0.13	0.03	0.36	0.19	0.01	0.27	0.11
Cd (mg/L)	0.01	0.84	0.29	0.04	0.97	0.22	0	0.98	0.52

In Region 4 Subset, Guyana, water samples were taken from Mocha, Mon Repos, and Georgetown. Georgetown includes the Georgetown municipality and suburban Georgetown. In the data analyses, the three areas are grouped together as Region 4 Subset. Table 6.3 summarizes the data for the three areas sampled in Region 4 Subset.

Table 6.3 Water quality parameters of household drinking water within subgroups of Region 4 Subset, Guyana.

	Mocha n=14		Mon Repos n=9		Georgetown n=17	
	Min	Max	Min	Max	Min	Max
pH	5.14	9.53	6.94	8.94	5.87	6.71
Temperature (°C)	27.17	35.35	28.51	36.1	28.89	41.79
Conductivity (mS/cm)	0	0.608	0.021	0.584	0.001	0.22
DO (mg/L)	1.07	14.06	4.26	6.15	2.81	5.8
Turbidity (NTU)	10.4	26.1	10.3	18.2	11.1	20.2
TDS (mg/L)	0	0.4	0	0.4	0	0.1
Total Coliform (#CFU/100mL)	0	2	0	54	0	3
Fecal Coliform (#CFU/100mL)	0	144	0	8	0	46
Pb (mg/L)	0	0.2	0	0.1	0	0.1
Fe (mg/L)	0.08	1.62	0.48	1.02	0.13	2.13
Cu (mg/L)	0.01	1.14	0.01	1.12	0.09	2.52
P (mg/L)	0	0.18	0	0.02	0	3.42
Al (mg/L)	0.03	0.28	0.03	0.31	0.12	0.36
Cd (mg/L)	0.08	0.63	0.05	0.13	0.04	0.97
Water Source	Piped water (11), Rain water (7), Other (1)		Piped water (6), Rain water (1), Mixed rain water (1)		Piped water (7), Rain water (5), Other (1)	

Figure 6.6 shows the pH levels of the water sources. WHO guidelines state that the recommended pH for drinking water range from 6.5 - 8 (WHO, 2008). While the water samples collected in Siparia had the greatest mean pH levels of the three communities (7.53), almost all of the water samples from Siparia met this

guideline. Preliminary research conducted in Siparia indicated that water hardness is prevalent among household water sources. In order to address this, lime softening is used in the water treatment process at Trinidad and Tobago's water distribution plant, WASA. Only 22.5% of water samples In Region 4 Subset and 46.2% of samples in Villa Litoral met this recommendation. Roughly 53% of water samples taken in Region 4 Subset had pH levels below 6.5 while 25% had pH levels above 8.0. In Villa Litoral, 53.8% of households had pH levels below 6.5. High acidity can lead to metal corrosion (Miller, 2004; Wyatt, 2008) while high alkalinity can lead to pipe scaling and taste problems.

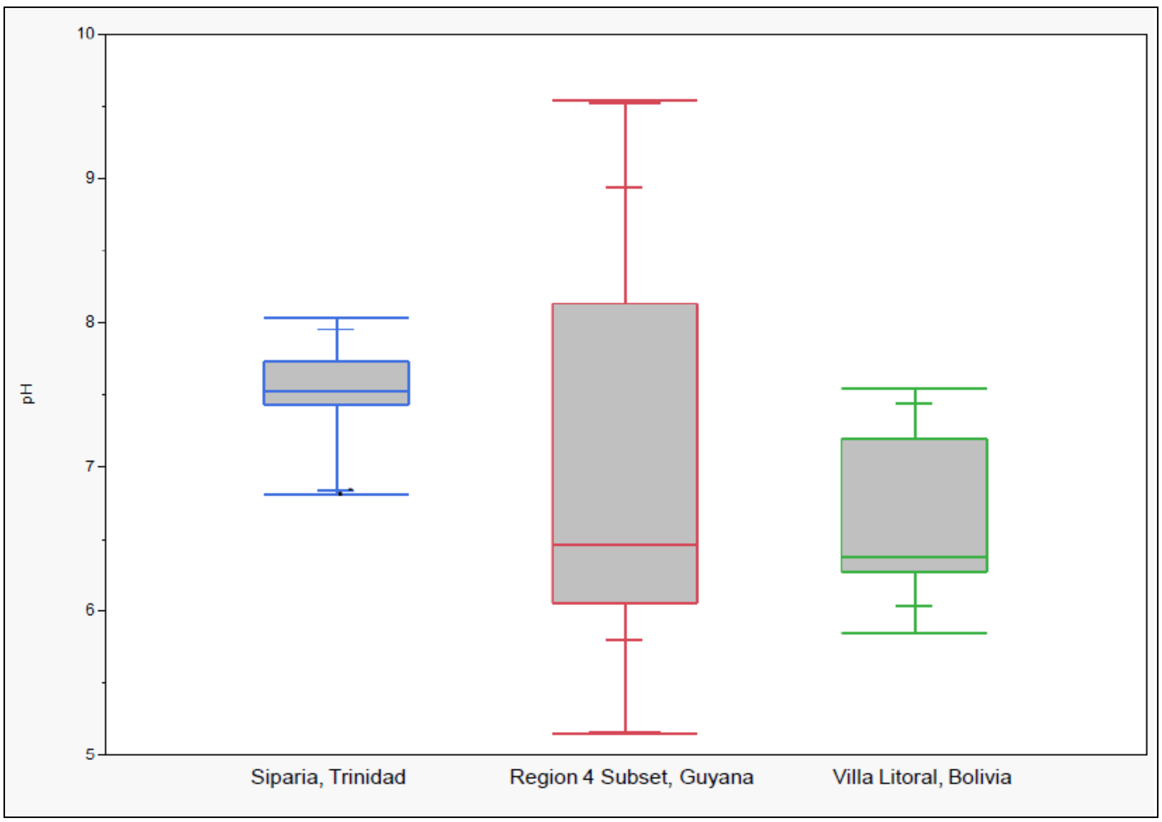

Figure 6.6 Box plot of pH levels of household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

As many of the water storage systems were situated under direct sunlight, it was important to record the temperature of the samples taken from these systems. Research shows that microbial growth increases above 15°C (Evison, 2001) which is lower than temperatures seen in all of the storage devices that were sampled between 8 am and noon for this research. Figure 6.7 shows the water temperatures recorded among samples from Siparia along with the ambient temperature in the community. The mean temperature recorded in the water storage devices was 27.84°C, about 2.1 degrees higher than the ambient temperature of 26.7°C reported by the local authority. Sixty-seven percent of water samples taken exceeded the ambient temperature, exceeding by up to 3.25 degrees. Households surveyed in Siparia reported that water stored in the devices would last at least a week, thus allowing a longer residence time for potential microbial growth or for chemical contamination to occur. While only 4% of households tested positive for fecal coliform, it is possible for further contamination if proper maintenance is not taken.

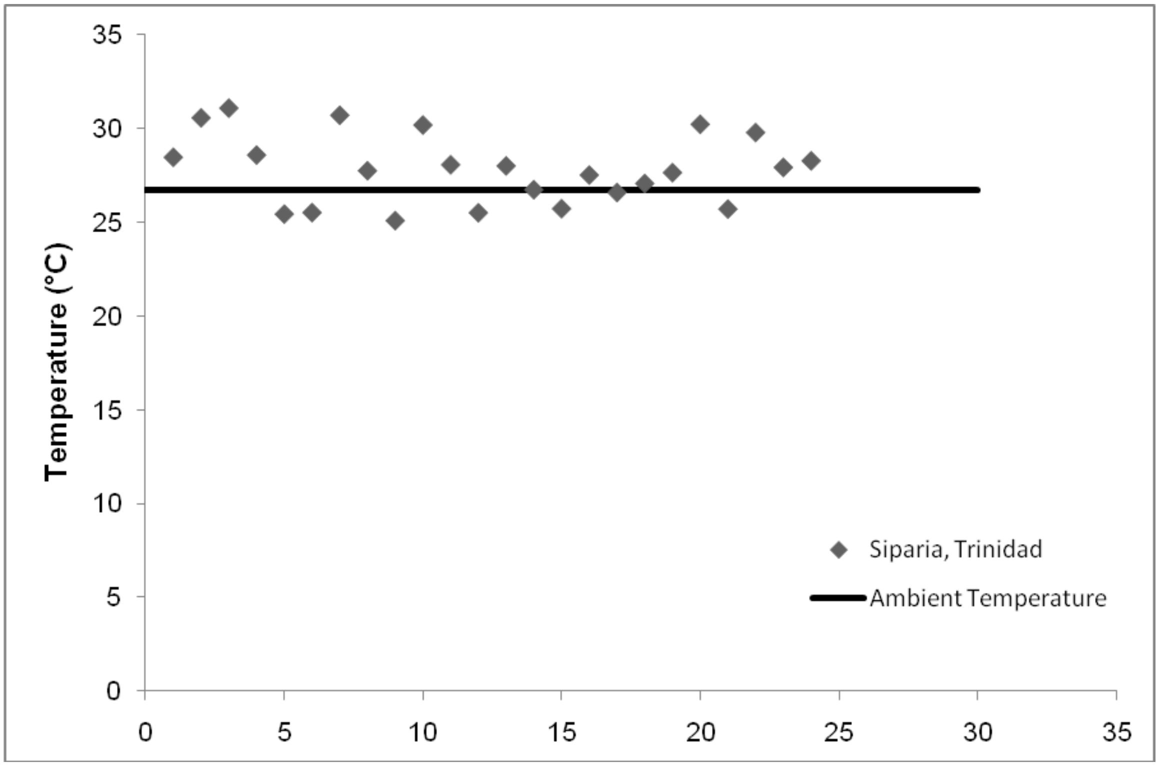

Figure 6.7 Temperature (°C) of household water sources from Siparia, Trinidad and Tobago. Number of samples: 24.

Figure 6.8 shows the temperature of water samples taken from Region 4 Subset. The mean temperature of the samples was 30.83°C, about 4.3 degrees higher than the ambient temperature of 26.8°C. All of the samples taken were above the ambient temperature, with temperatures exceeding by 0.37 - 15 degrees. While a significant correlation was not seen between the temperature of the water samples and the presence of fecal coliform, the increased temperatures are a potential factor for other contaminants not tested (e.g. *Legionella* spp., biofilm, organics) or during other temporal periods (e.g. rainy season).

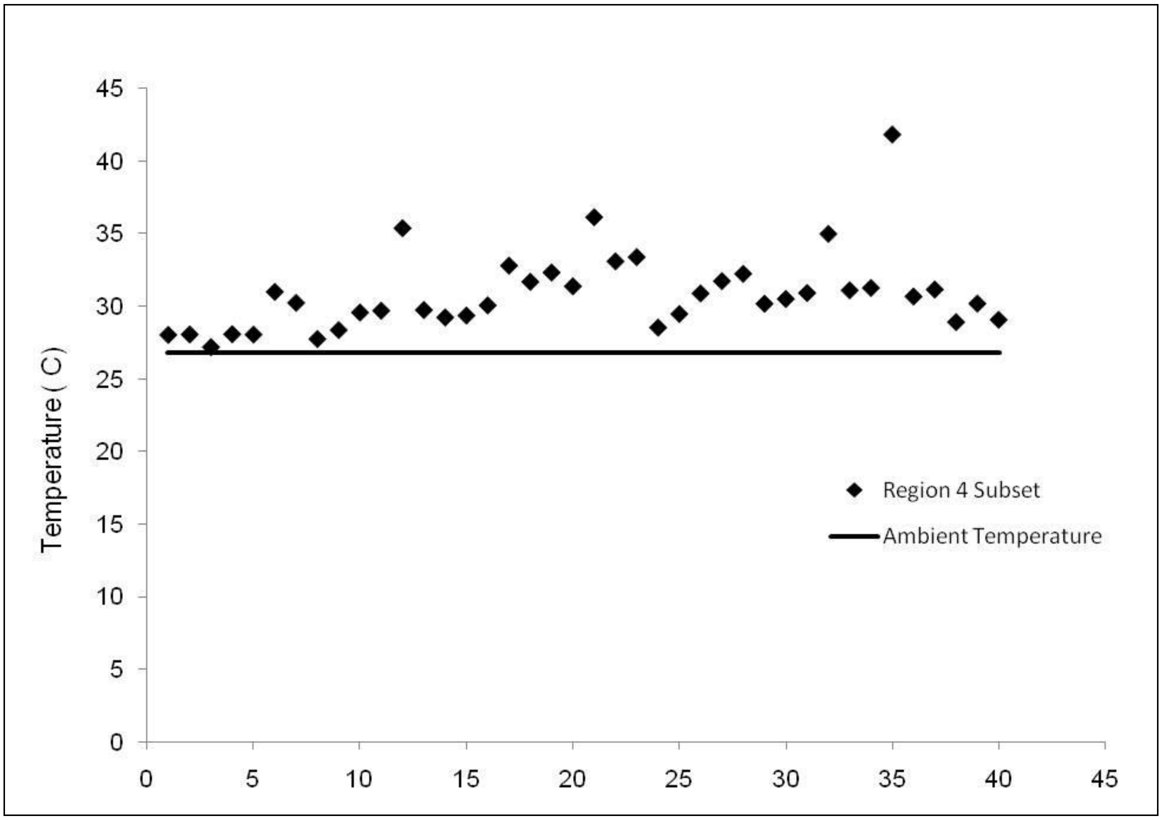

Figure 6.8 Temperature (°C) of household water sources within Region 4 Subset, Guyana. Number of samples: 40.

Figure 6.9 shows the temperature of water samples taken from Villa Litoral. The mean temperature of the water samples was 24.88°C, 2.88 degrees higher than the ambient temperature of 22°C. All of the water samples taken had temperatures that surpassed the ambient temperature by 0.82 - 9.84 degrees. Temperatures recorded in Villa Litoral were much lower than those in Siparia and Region 4 Subset as this was the winter season in Bolivia. Higher temperatures were found among households with a tank compared to those where water was stored in smaller vessels such as buckets and jerry cans. While households with tanks had an equal percentage of fecal coliform contamination as those using smaller vessels (Figure 6.5), there is an increased risk for microbial growth (e.g. biofilm) as a result of the increased temperature and dark environment presented within the containers (Evison, 2001; Tokajian, 2004).

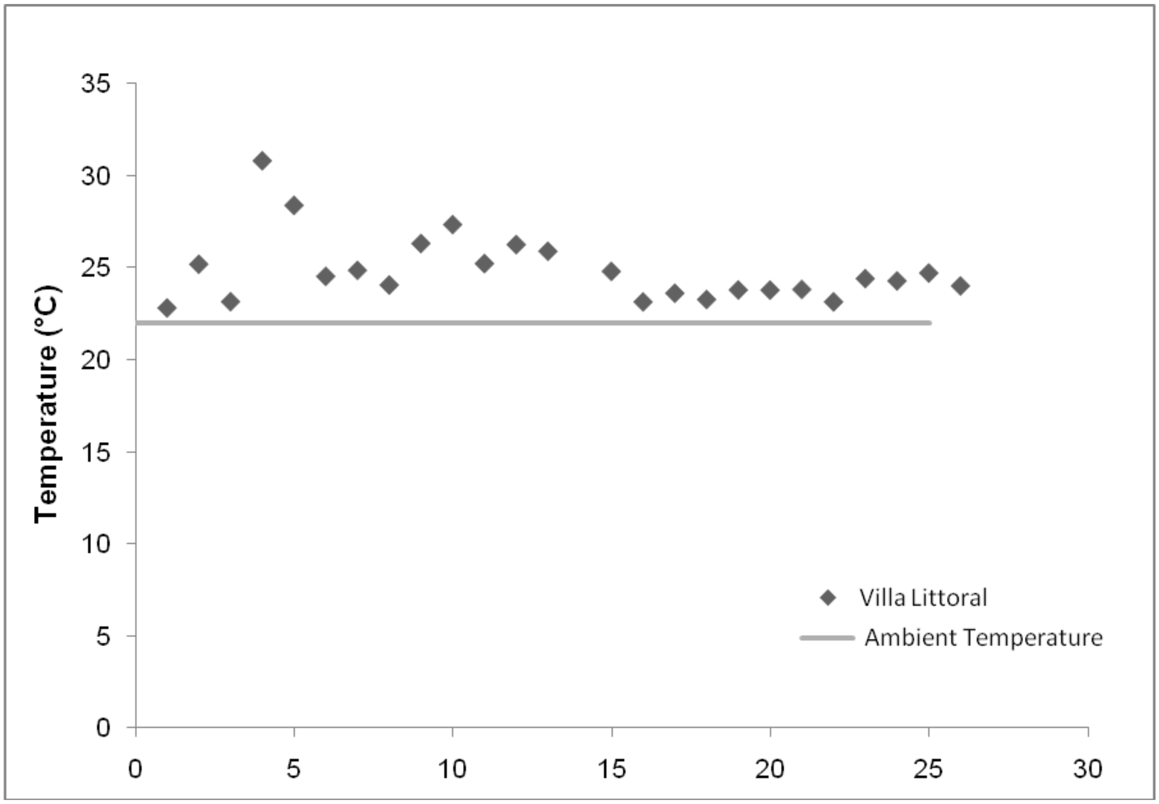

Figure 6.9 Temperature (°C) of household water sources within Villa Litoral, Bolivia. Number of samples: 26.

In Chapter 5, a significant percentage of households surveyed in Villa Litoral reported the water sources as being salty, sometimes to the point of being undrinkable. Figure 6.10 shows a plot of the conductivity levels recorded from the water samples. In the figure, there is a clear increase in conductivity levels between the first set of samples and the second set of samples. The first set of samples was all households whose main source of water was rain water, while the second set relied on piped water. While the conductivity levels of the rain water sources ranged from 0.001 - 0.239 mS/cm, the piped water sources had conductivity levels of 1286 – 1318 mS/cm. The total dissolved solids (TDS) data showed the same pattern, with levels among the rain water sources ranging from 0 – 200 mg/L while piped water sources ranged from 800 – 900 mg/L. WHO states that TDS levels less than 600 mg/L are safe to drink, potable water becomes increasingly unpalatable once it reaches TDS levels of 1000 mg/L (WHO, 2008).

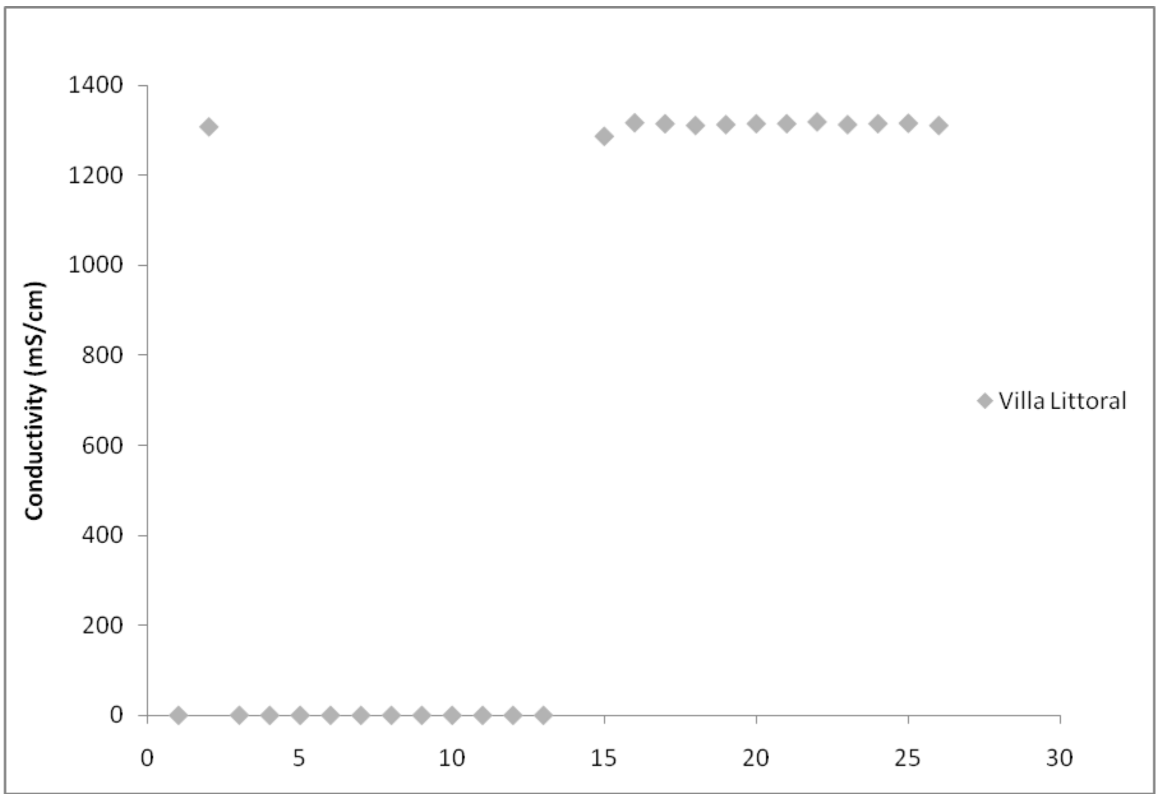

Figure 6.10 Scatter plot of conductivity levels within household water sources in Villa Litoral, Bolivia. Plots 1-14 were derived from rain water sources while 15-26 were derived from piped water sources. Number of samples: 26.

Figure 6.11 shows a comparison of turbidity levels found within the household water sources. While WHO guidelines have a recommended turbidity level of ≤5 NTU, the minimum turbidity levels seen in Region 4 Subset and Villa Litoral were twice the guideline value Residents in Siparia and Region 4 Subset largely reported water sources as being brown (Figure 5.12). High turbidity levels may be attributable to sediment buildup in the distribution pipes during periods of water intermittence and/or sediment levels present in the bottom of the water storage devices (Tokajian, 2003; Kotlarz, 2009; Colindres, 2007; Han, 2007). Additionally, high turbidity allows for the growth of microorganism while hindering chlorination and disinfection processes (Crump, 2004; Han, 2007; Kotlarz, 2009; LeChevallier, 1981; WHO, 2008).

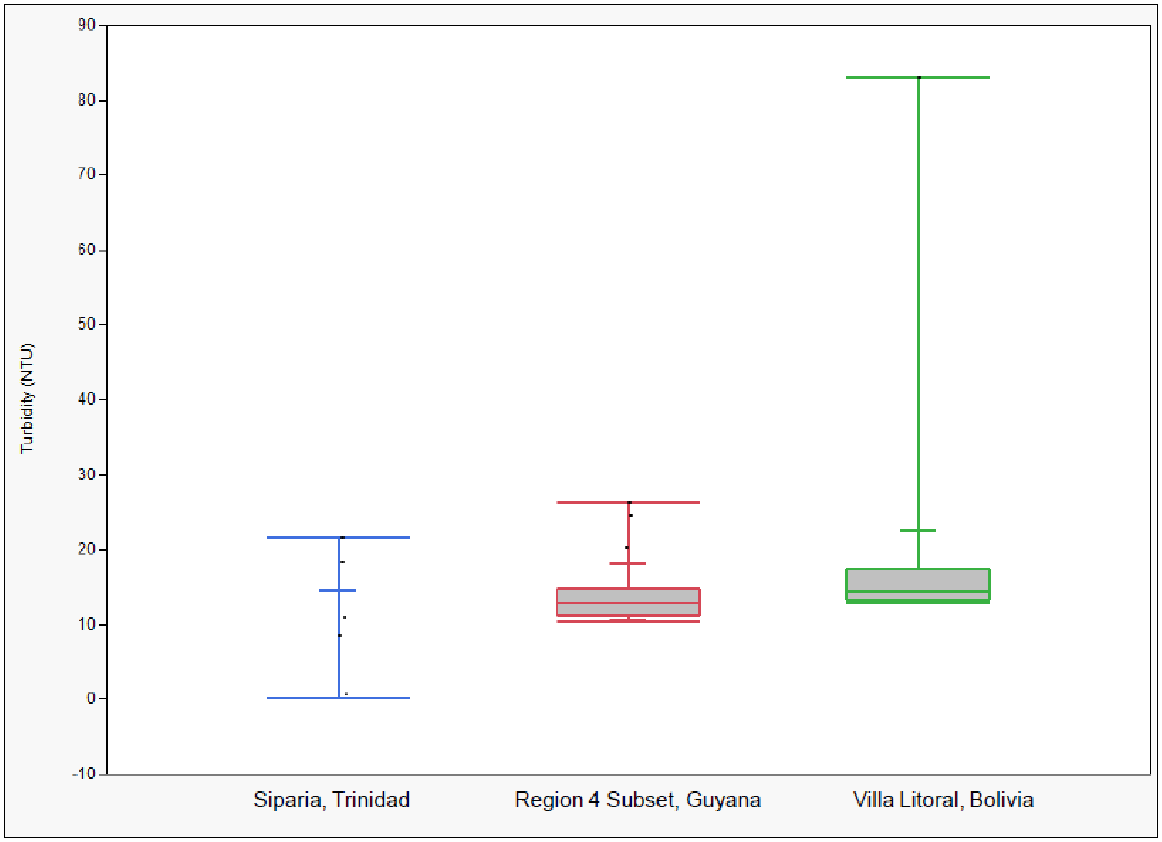

Figure 6.11 Box plot of turbidity levels (NTU) within household water source in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

6.4 Dissolved Chemicals and Metals

In Section 4.6 of Chapter 4, the heavy metal concentration limits set by the World Health Organization (WHO), US Environmental Protection Agency (USEPA), and the European Union (EU) were addressed. Table 6.4 shows a comparison of the ranges of the dissolved metals found in the water samples from the different field sites as measured against those limits. High levels of lead, iron, aluminum, and cadmium were found in each of the three communities. Guideline values have not been established for phosphorus.

Table 6.4 Range of dissolved metals (as mg/L) present in household drinking water supplies within communities in Trinidad and Tobago, Guyana, and Bolivia. Standards from the World Health Organization Guideline Values (WHO GV), U.S. Environmental Protection Agency Maximum Contaminant Level (USEPA MCL), and the European Union Maximum Allowable Concentration (EU MAC) are shown. (UNICEF, 2008; Appendix A., Table A.1).

	Trinidad and Tobago	Guyana	Bolivia	USEPA MCL	WHO GV	EU MAC
Pb (mg/L)	0.1 - 0.3	0 - 0.2	0 - 0.6	0.015	0.01	0.01
Fe (mg/L)	0.05 - 1.48	0.08 - 2.13	0 - 3.62	0.3	0.3	0.2
Cu (mg/L)	0.01 - 2.32	0.01 - 2.52	0 - 0.08	1.3	2	3
Al (mg/L)	0.02 - 0.25	0.03 - 0.36	0.01 - 0.27	0.05 – 0.2	0.1 - 0.2	0.2
Cd (mg/L)	0.01 - 0.84	0.04 - 0.97	0 - 0.98	0.005	0.003	0.005

Elevated levels of lead have been known to cause adverse health effects, such as neurological defects, renal failure, and developmental delays. Lead levels were found in high concentrations among the three communities as shown in Figure 6.12. In Siparia and Villa Litoral, lead pipes were used to connect water sources to the home. In Guyana, while PVC pipes were used in many homes to connect the tanks to the interior of the home, some households stated that lead pipes were still being used in the homes.

In addition to water infrastructure, various other factors may attribute to the elevated lead levels. For example, in Trinidad and Tobago, leaded gasoline was only phased out in 2004.

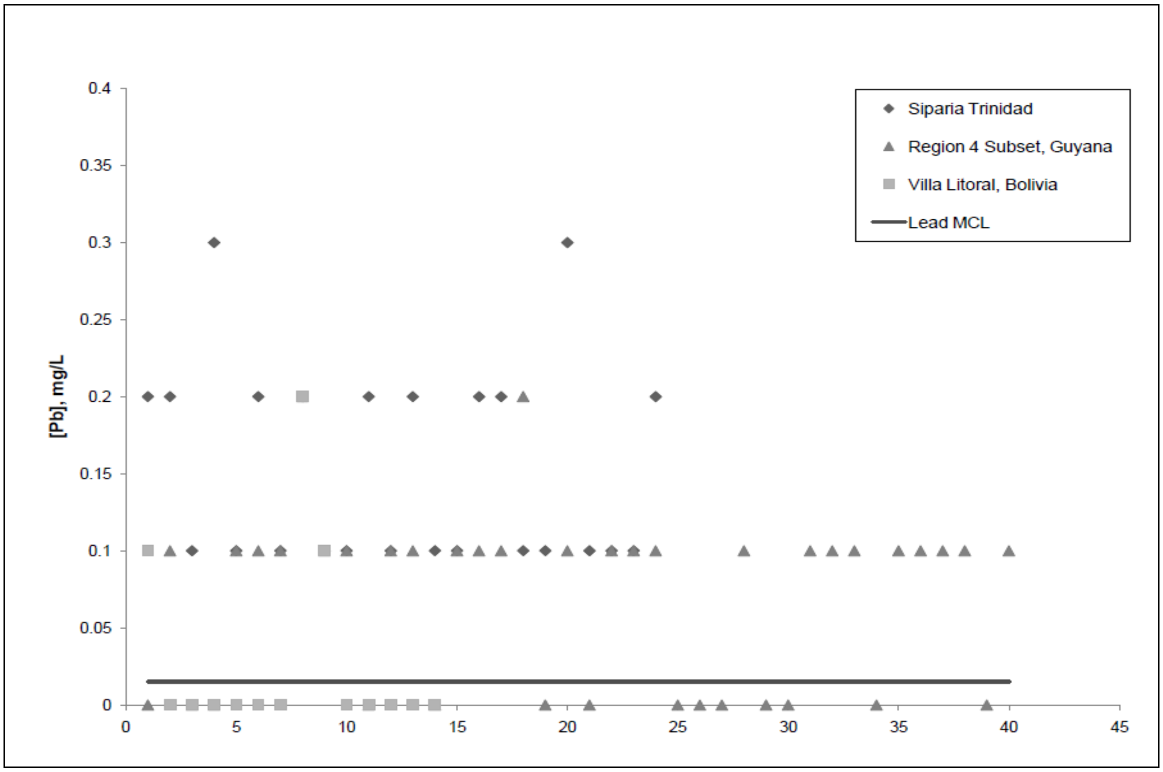

Figure 6.12 Scatter plot of lead concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

While the WHO guideline value for iron is 0.30 mg/L (WHO, 2008), the iron concentration values present in the three communities were sometimes 2-3 times higher than that level. In Villa Litoral, iron concentrations were as high as 3.62 mg/L, twelve times the WHO guideline value. In many of the communities where water is connected, galvanized pipes are used to connect to the main distribution pump or used in faucets and indoor plumbing. As such, there is a risk for pipe materials to leach out over time. While a strong correlation could not be made, higher concentrations of iron were seen in water samples with lower pH levels. Figure 6.13 shows a scatter plot of the iron concentrations from the different communities in addition to the WHO guideline value for iron. With regards to iron levels in groundwater, WHO guidelines state that "*the chemical aggressiveness of some groundwaters may affect the integrity of borehole casings and pumps, leading to unacceptably high levels of iron in the supply, eventual breakdown and expensive repair work. Both the quality and availability of drinking-water may be reduced and public health endangered*" (WHO, 2008).

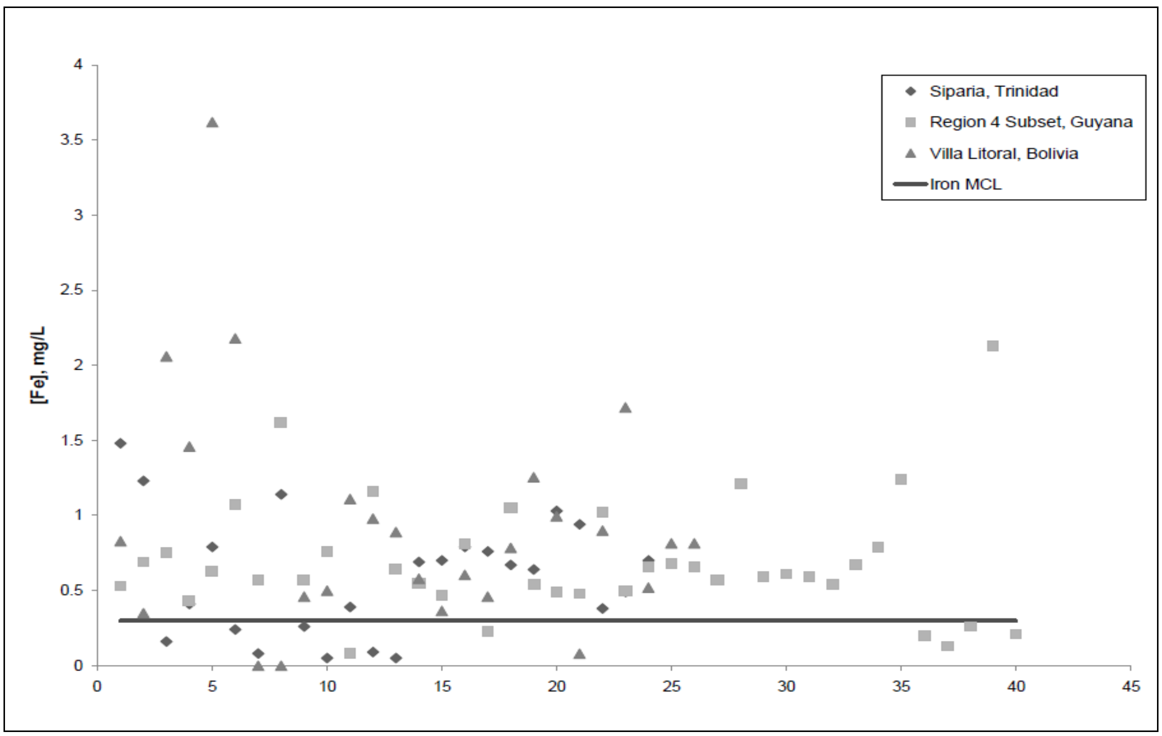

Figure 6.13 Scatter plot of iron concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Figure 6.14 shows the comparison of copper concentrations present in water samples from the three communities. In Siparia and Region 4 Subset, where copper is used a bit more frequently, almost all of the water samples were below the WHO guideline value of 2 mg/L.

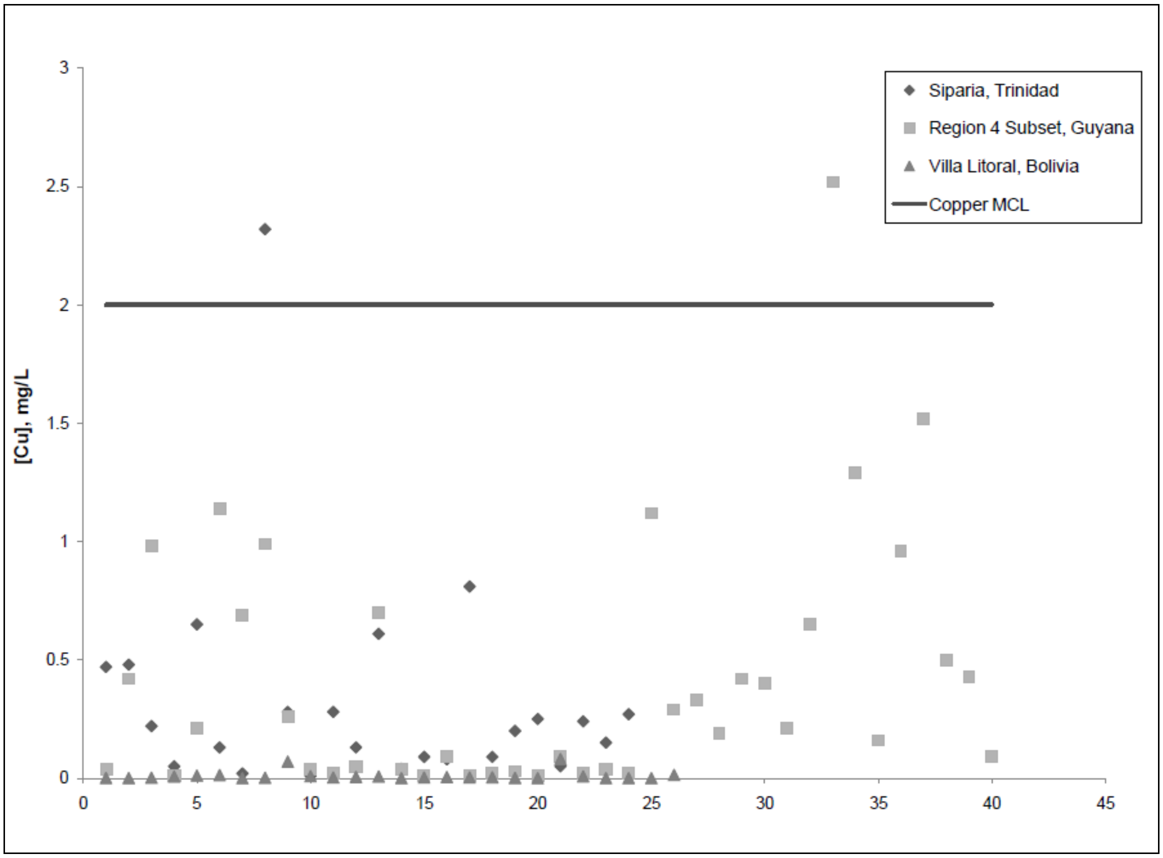

Figure 6.14 Scatter plot of copper concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Figure 6.15 shows comparisons of total phosphorus concentrations within the three communities. While there are no established levels associated with phosphorus concentrations in drinking water, phosphorus levels are still important to measure as they are found in fertilizers and detergent agents and subsequently in wastewater (USGS, 2009). Phosphorus concentrations were highest in Region 4 Subset, with levels reaching 3.42 mg/L. This may be attributable to fertilizer runoff or industrial uses.

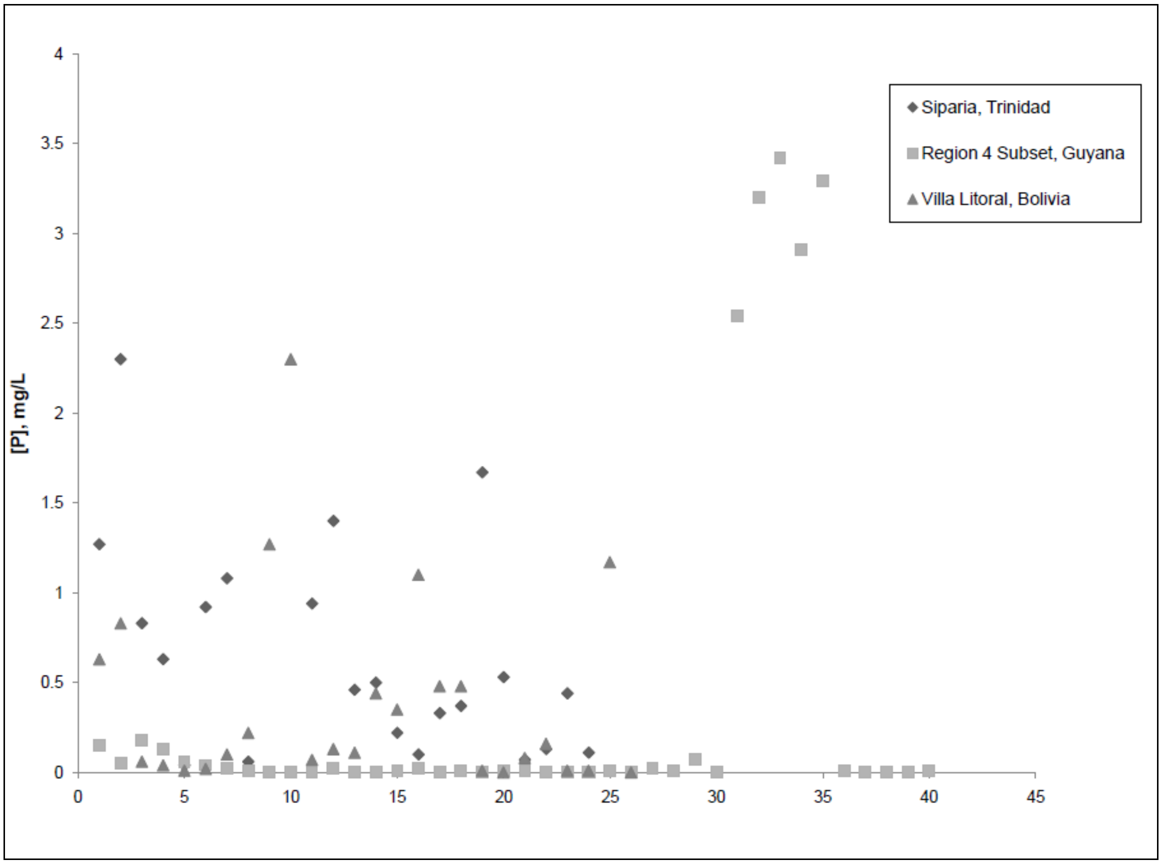

Figure 6.15 Scatter plot of phosphorus concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Figure 6.16 shows the scatter plot of the aluminum concentrations along with the WHO guideline value for aluminum. The shaded region represents the range of the WHO recommended value, which is 0.1 – 0.2 mg/L (WHO, 2008). Aluminum values for each of the communities fell within as well as above the recommended range. In Region 4 Subset, 40% of water samples had aluminum concentrations greater than 0.2 mg/L. Sources of aluminum include alum coagulants from water treatment and trace levels in water sources. Alum is used at the treatment plant for municipal Georgetown and some suburban areas.

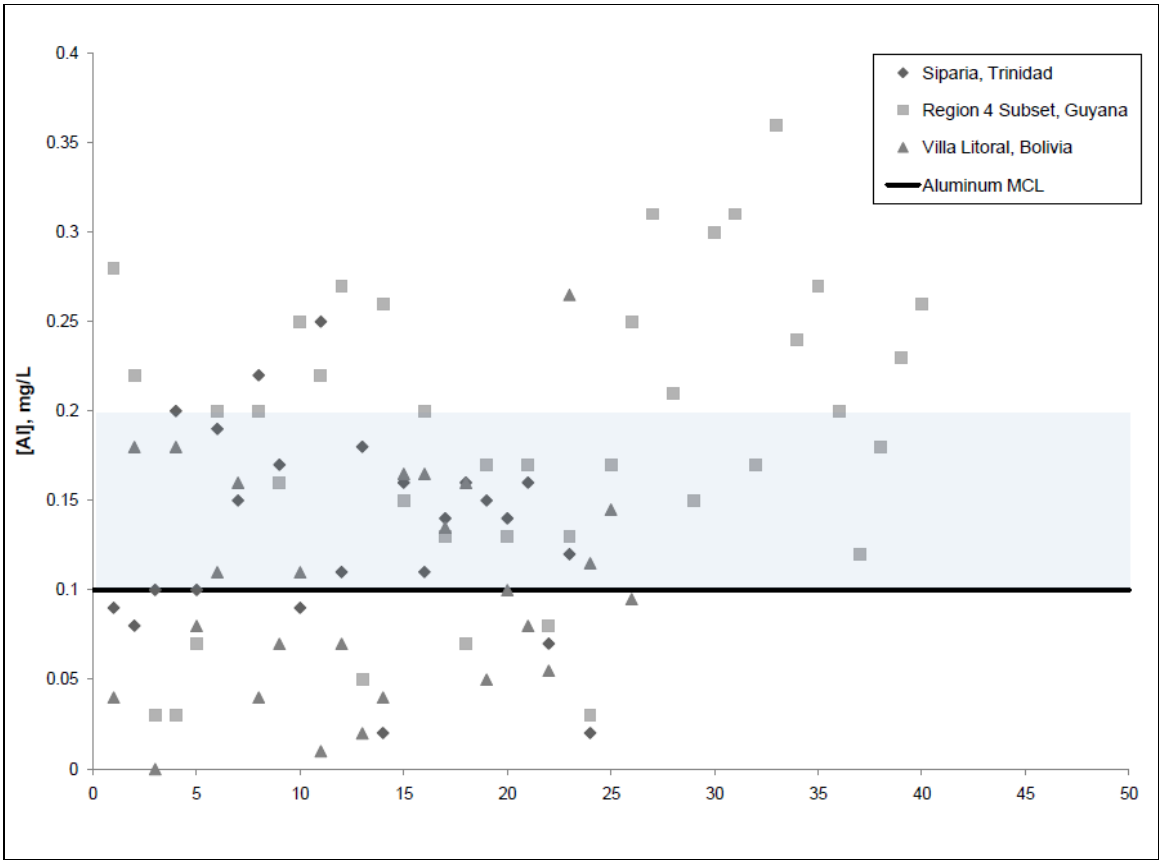

Figure 6.16 Scatter plot of aluminum concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26). Values in the shaded region are within the WHO guidelines values for aluminum.

Figure 6.17 shows the scatter plot along with the WHO guideline value. Given the Minimum Detection Limits of the instrument, it is difficult to determine how many samples exceed the cadmium MCL of 0.003 (WHO, 2008). Cadmium levels could be attributed to increased use and disposal of batteries containing cadmium along with the preparation of metal alloys (USGS, 2009).The highest concentrations were seen among samples from Villa Litoral. Bolivia has several mining operations for the recovery of zinc, of which cadmium is a by-product (USGS, 2009). Various studies have shown elevated cadmium levels as a result of mining ({Wyatt, 1998; Miller, 2004; Oporto, 2007).

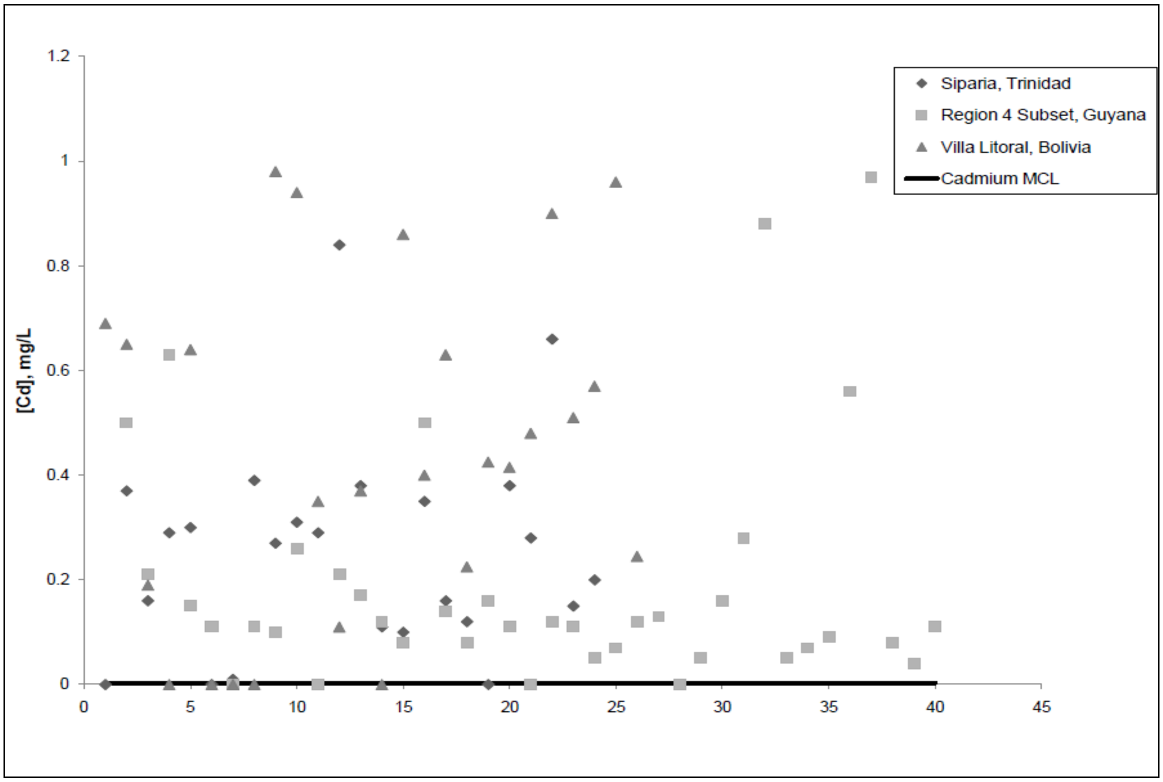

Figure 6.17 Scatter plot of cadmium concentrations within household water sources in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26). Values in the shaded region are below the 0.025 mg/L detection limit of the method.

Distribution of heavy metal concentrations exceeding WHO guideline levels were assessed by community, type of water storage device, water source. Figure 6.18 shows the distribution of heavy metals by type of water storage in Siparia. Lead, iron, and cadmium concentrations were found to exceed WHO guideline values in water supplies stored in both the tanks and water drums. Lead concentrations exceeded WHO guidelines in all of the samples tested, as was also shown in Figure 6.12. Iron and cadmium levels exceeded WHO guidelines in the water drums, but not in all of the tanks. High aluminum and copper were not seen in the water drum, while less than 10% of the water samples from the tanks had exceeded values for both. As there was only one water drum, comparisons could not be made as to the significance of metal concentration by type of device.

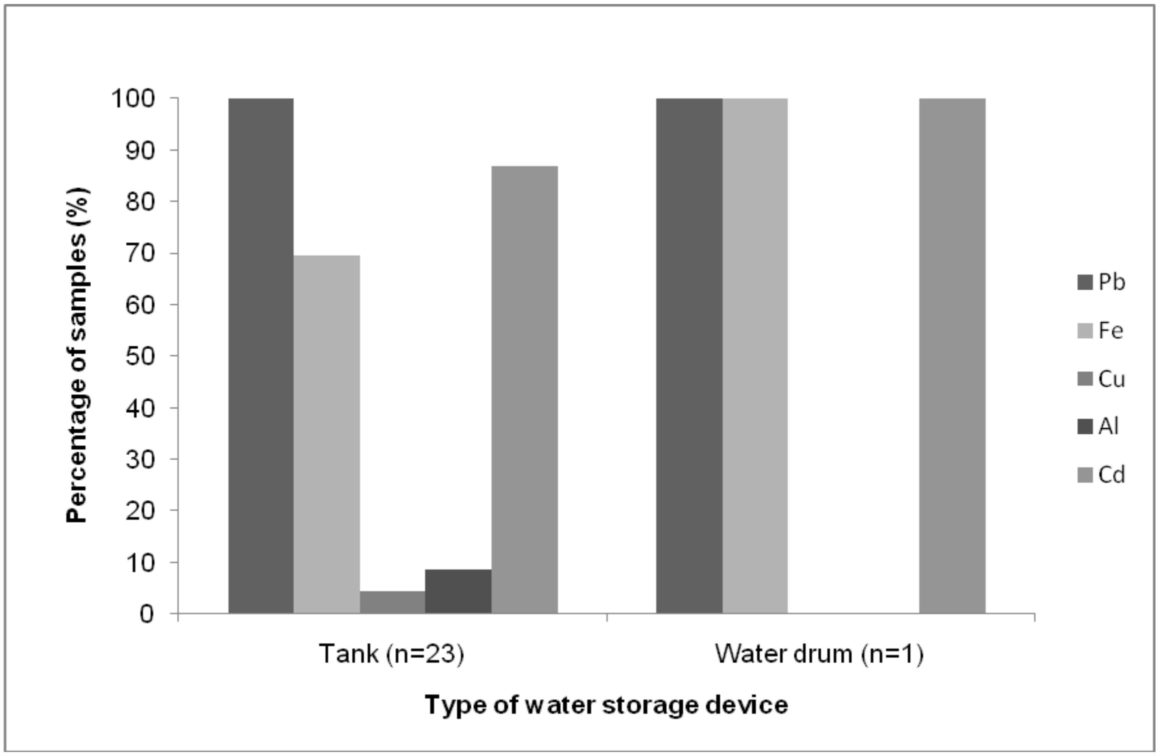

Figure 6.18 Distribution of samples exceeding WHO guideline values based on water storage device in Siparia, Trinidad and Tobago. Number of samples: 24.

Figure 6.19 shows the distribution of heavy metal concentration exceeding WHO guideline values by water sources in Siparia. While exceeding levels of lead and iron were found in all of the water drum samples, exceeding iron levels were found in 68% of samples taken from piped water sources. Aluminum levels exceeding WHO guidelines in 50% of mixed rain water samples, compared to roughly 5% of the piped water samples. Zinc and aluminum are often used to construct rooftops, which may end up leaching into rainwater sources as water is collected into the storage device.

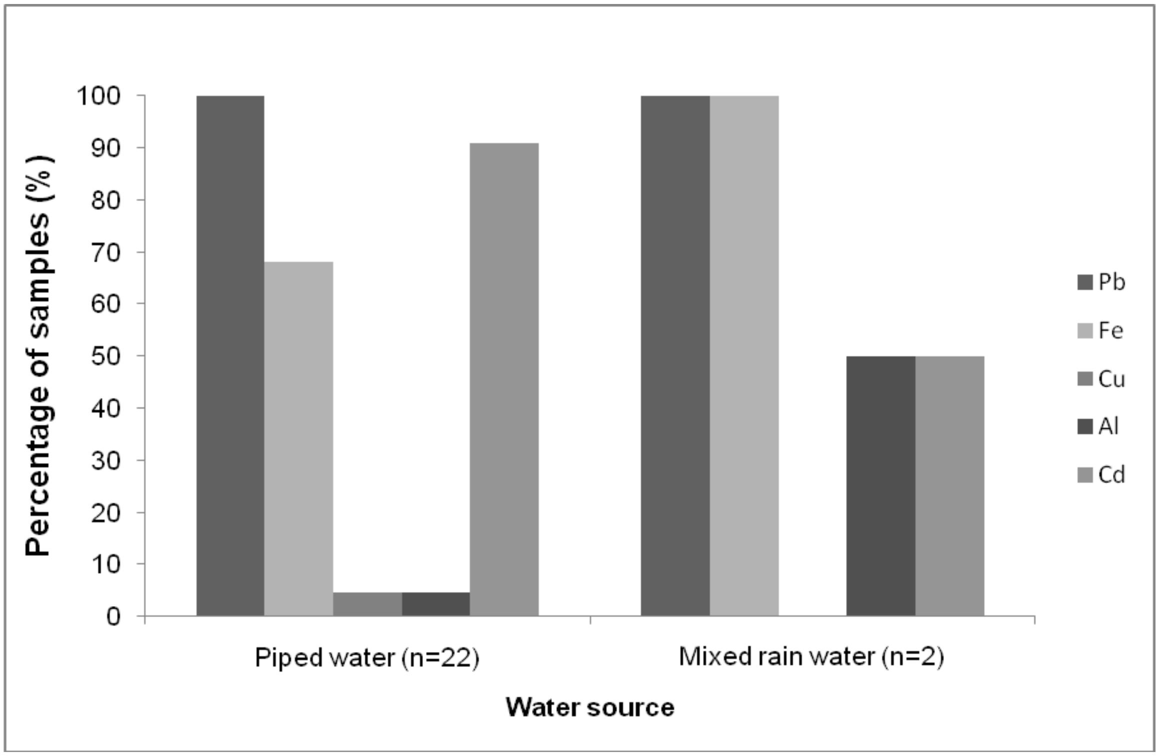

Figure 6.19 Distribution of samples exceeding WHO guideline values based on water source in Siparia, Trinidad and Tobago. Number of samples: 24.

Region 4 Subset water samples with heavy metal concentrations exceeding the WHO guideline values are distributed by type of water storage device and shown in Figure 6.20. Lead and cadmium concentrations exceeding the WHO guideline values were found in 61% and 86% of tank samples, respectively, while the two metals were found in exceeding levels in all of the water drum samples and other devices. Copper concentrations were found in excess of the WHO guideline values in only the tank samples (2.8%).

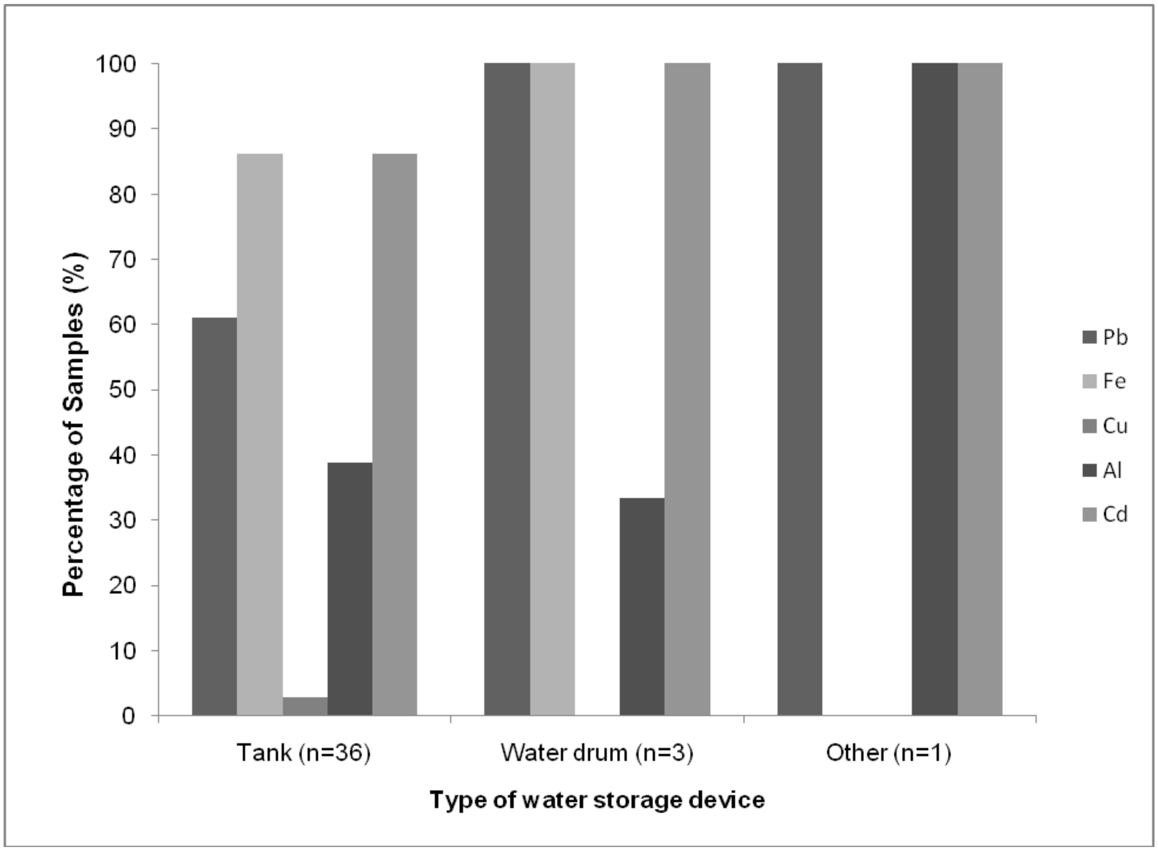

Figure 6.20 Distribution of samples exceeding WHO guideline values based on water storage device in Region 4 Subset, Guyana. Number of samples: 40.

Figure 6.21 shows the exceeding metal concentrations by water source in Region 4 Subset. Rain water samples had the least percentage of metal concentrations exceeding guideline values with only 7.7% of samples each having exceeded guideline values for lead, iron, and cadmium. In piped water sources, which are the predominant source of household water in Region 4 Subset, guideline values were exceeded among concentrations of lead (70.8%), aluminum (37.5%), and (91.7%). High levels of iron, aluminum, and cadmium was seen in the mixed rain water source. While piped water appears to have greater proportion of metal concentrations exceeding WHO guideline values and rain water the lowest proportions, it cannot be determined whether having mixed rain water would produce safer water, as only one mixed water sample was taken.

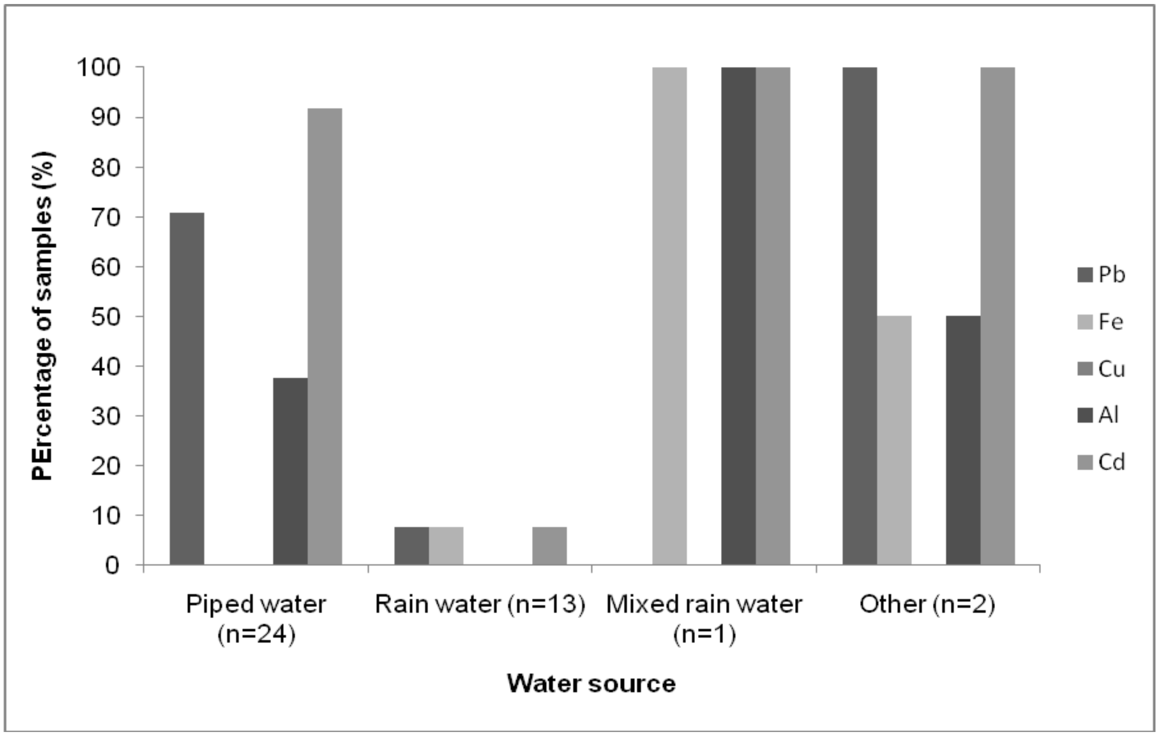

Figure 6.21 Distribution of samples exceeding WHO guideline values based on water source in Region 4 Subset, Guyana. Number of samples: 40.

Figure 6.22 shows the concentrations found in Villa Litoral by type of water storage device. In terms of iron concentrations, over 80% of the samples taken from each of the types of devices exceeded WHO guidelines. Roughly 18% of tank samples had lead concentrations greater than the guideline values, while none of the aluminum concentrations were higher. Exceeding aluminum concentrations were only found in the water drum samples (33%). One can conclude that the tank samples had the least percentage of exceeding heavy metal concentrations. This was different from the outcome in Siparia and Region 4 Subset, partly because of near-exclusivity of tanks in those two other countries.

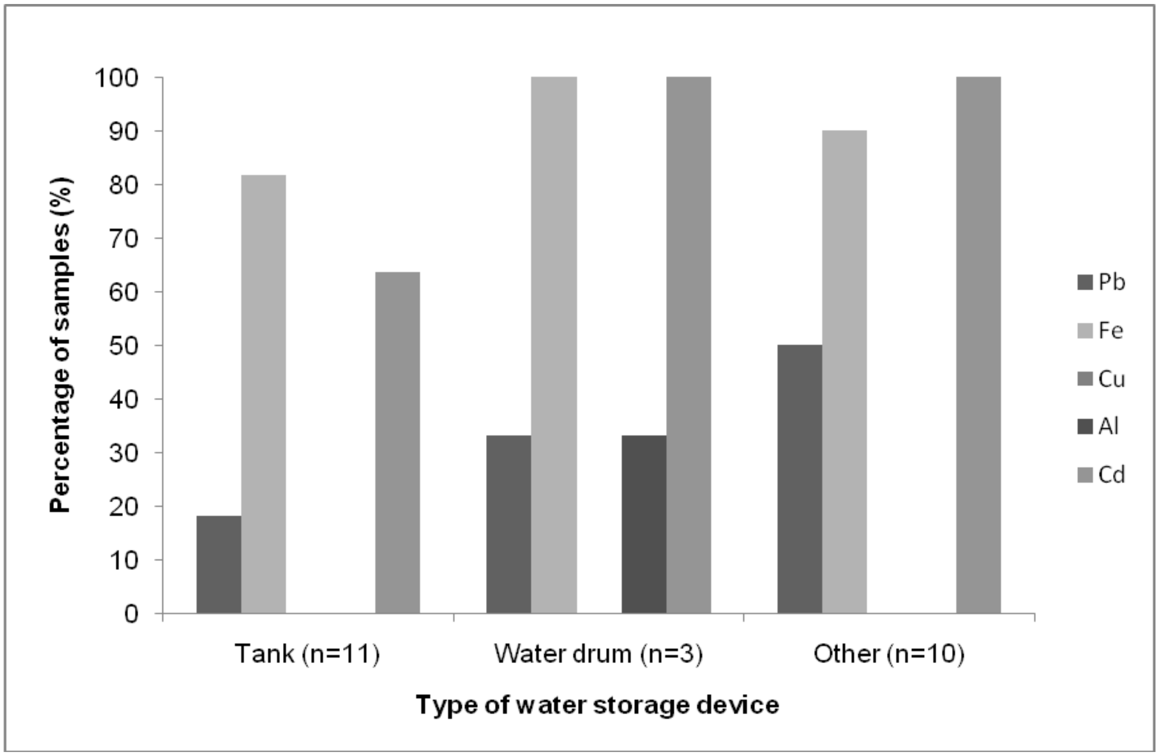

Figure 6.22 Distribution of samples exceeding WHO guideline values levels based on water storage device in Villa Litoral, Bolivia. Number of samples: 26.

Villa Litoral samples with metal concentrations above the WHO guidelines based on water source are shown in Figure 6.23. Iron concentrations above the WHO guidelines were seen in over 80% of samples taken from each of the water sources. Of the three types of water sources, piped water sources had the greatest percentage of samples with exceeding concentrations of lead (42.9%), aluminum (7.1%), and cadmium (100%). Samples from rain and river sources all had aluminum concentrations that met the WHO guideline values. Copper concentrations were below the WHO guideline values for all three types of water sources.

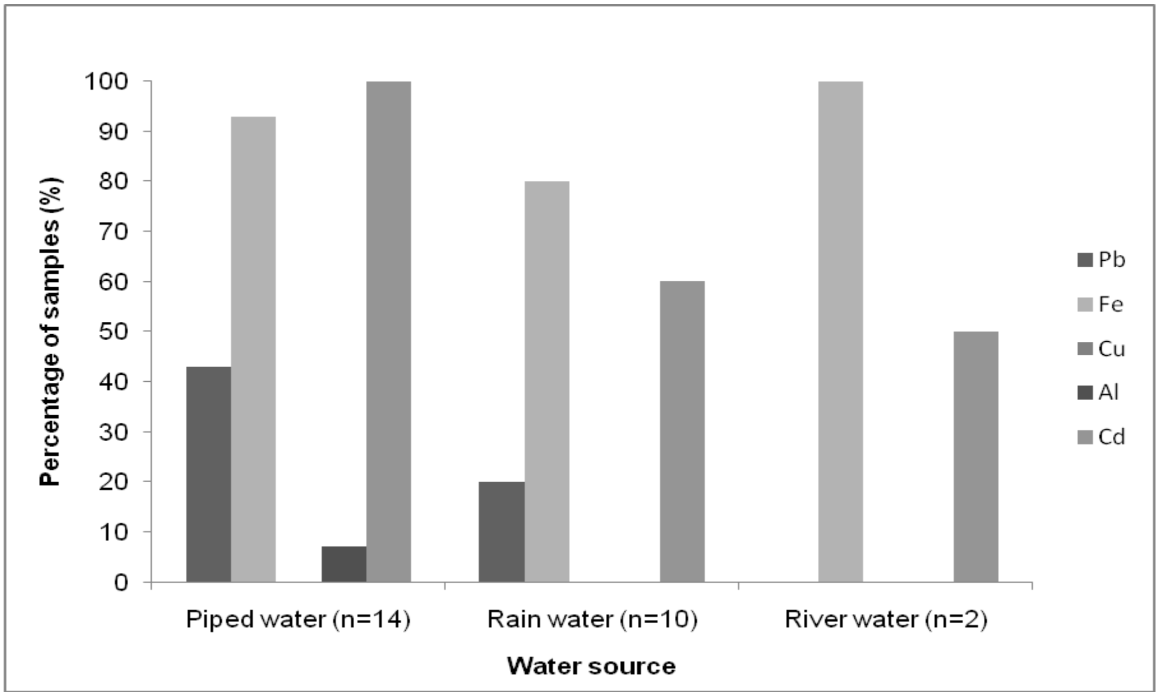

Figure 6.23 Distribution of samples exceeding WHO guideline values based on water source in Villa Litoral, Bolivia. Number of samples: 26.

6.5 Statistical Analyses

To facilitate statistical analyses, the multivariate analyses of variance (MANOVA) with the general linear model (GLM) were used. There is a significant difference ($p < 0.05$) among the various field sites tested (Pillai's Trace test). The significant variances seen among the field sites were in relation to 1) presence of fecal coliform ($p < 0.001$), 2) presence of total coliform ($p = 0.014$), 3) turbidity levels meeting WHO guidelines ($p < 0.001$), and 4) lead levels meeting WHO guidelines

($p < 0.001$). No significant differences were seen among the field sites with regards to copper/iron levels meeting WHO guidelines. Given the relatively small number of samples, the Tukey Honestly Significant Difference (HSD) post hoc test was used to analyze differences seen in the water quality assessment results.

For both fecal coliform and total coliform, there was a significant difference between results found in Villa Litoral versus those found in Siparia, Trinidad ($p < 0.001$) and in Region 4 Subset, Guyana ($p < 0.001$). For turbidity, there was a significant difference between results found in Siparia, Trinidad versus those in Region 4 Subset, Guyana ($p < 0.001$) and Villa Litoral, Bolivia ($p < 0.001$). For lead concentrations meeting WHO guidelines, there was a significant difference between results found in Siparia, Trinidad and Region 4 Subset, Guyana and Villa Litoral, Bolivia ($p < 0.001$). The difference between results in Siparia and Region 4 Subset were found in Mon Repos community ($p < 0.001$) and in the Greater Georgetown community ($p = 0.005$). Significant differences were seen between lead concentrations results found in the three communities in the Region 4 Subset, Guyana. Lead concentrations results in the Mocha community differed from results found in Mon Repos ($p < 0.001$) and Greater Georgetown ($p = 0.021$) and Villa Litoral, Bolivia ($p < 0.001$). For water temperature, there was a significant difference between results found in Siparia, Trinidad and the other field sites.

Statistical analyses were done on the correlation between water source and water quality components. For the presence of fecal coliform, no piped water, rain water, or mixed rain water sources. With regards to turbidity levels meeting WHO guidelines, significant differences were seen between piped water and rain water ($p < 0.001$) and mixed rain water sources ($p = 0.038$). Rain water sources significantly differed from mixed rain water sources ($p < 0.001$). Lead levels meeting WHO guidelines significantly differed between piped water and rain water sources ($p = 0.012$).

Statistical analyses were done looking at correlations between water storage devices and water quality components. In regards to fecal coliform, total coliform, and turbidity, a significant difference ($p < 0.001$) was seen between water samples taken from tanks versus small containers (buckets, pots, jerry cans, etc). No statistical difference was seen between water tanks and water drums.

6.6 Research Limitations

Due to the limitation of resources, traveling capabilities, and time constraints while visiting the target community sites, all sampling and surveying had to be conducted on a one time basis within a confined time period. As such, the amount of samples that could be taken was limited in order to ensure that there would be enough resources to conduct the necessary tests at the other sites. Additionally, the majority of the analyses were done in the field while abroad in the various countries. In conducting the tests, it was necessary to set up a temporary makeshift lab. While the environment was not as sterile or as ideal as one would normally have it in the lab, these are the issues that must be taken into account and dealt with when conducting international field research. Ideally, the goal would be to conduct a robust sampling program to gain a more statistically significant distribution of the populations being studied. Given all of this, it was more prudent to conduct the research and present the data as a collaboration of three pilot studies, which can be built upon in future studies.

Chemical interferences could affect the results of the LaMotte test kits leading to either under or over estimations of actual concentrations of metals in solution. Some of the test kit detection limits are higher than the MCLs of metals like lead and cadmium. For example, the test kits used for lead show interference from calcium greater than 100 ppm (250 ppm $CaCO_3$) and low concentrations of cerium, iron, manganese, magnesium, sulfur, tin, and EDTA. Access to more advanced analytical equipment would overcome this problem, but would likely not be accessible in many developing countries where this work is being undertaken. However, the data generated gives an estimated amount/concentration of the metals analyzed.

6.7 Summary

Even while maintaining water sources in water storage devices, the potential for microbial and chemical contamination still exists. Microbial contamination was seen among households in Siparia, Region 4 Subset, and Villa Litoral. In each of the communities, tanks had the highest proportion of overall contamination among the different types of devices used. However, in terms of fecal coliform in Villa Litoral, contamination was highest in water drums, followed by tanks then other smaller portable containers. This may be a result of their large capacity and subsequent difficulties in maintenance. Water samples from Villa Litoral had the highest percentage of contamination, with 85% of all samples testing positive for fecal coliform and 100% for total coliform. While Siparia and Region 4 Subset have a more advanced and robust water distribution system, Villa Litoral's system does not include any water treatment in addition to gravitation filtration. In Region 4 Subset, fecal coliform contamination was greater among piped water sources (71%), while total coliform contamination was greater among rain water sources (44%). In Villa Litoral 42% of piped water sources tested positive for fecal coliform. This difference could be to microbial contamination through leaks in underground pipes connected to the water distribution network. Turbidity levels were found to be high in each of the three communities, with minimum turbidity levels in Region 4 Subset and Villa Litoral being twice as high as the WHO guideline value. In Villa Litoral, piped water sources had TDS levels between 800-900 mg/L, almost to the point of being unpalatable by WHO guidelines.

With the exception of copper, heavy metal concentrations often exceeded the WHO guidelines in the three countries. Copper concentrations stayed below WHO guideline levels for all of the field sites, except for 4% of the samples taken from piped water sources within tanks in Siparia. Overall, higher proportions of samples with over-the-limit metal concentrations were seen among samples taken from tank water and piped water samples. Villa Litoral had the least proportion of samples with over-the-limit concentrations. This could be due to interferences from dissolved salts which suppress the heavy metal concentrations or it could be due to the source water and geology of the area.

In Chapter 5, survey results showed that households in Region 4 Subset cleaned their devices and disinfected their water much more frequently than those in Siparia or Villa Litoral. As such, one would expect the water quality analyses to reflect lower microbial contamination levels, turbidity, and heavy metal concentrations within Region 4 Subset. However, this was not the case. Lower microbial levels were seen in Siparia while lower over-the-limits metal concentrations were seen in Villa Litoral. This may be indicative of industrial activities, geological variations, water treatment and distribution differences, and overall need for increased disinfection dosage/residency in the storage systems.

CHAPTER 7: TARGET PLOTS TO INTEGRATE HOUSEHOLD AND WATER SAMPLING ASSESSMENTS

7.1 Introduction

A total of 25 component questions were selected for the 5 indicators previously selected. While different questions may have been chosen, the chosen 25 were considered adequate and capable for analyzing risks associated with household water storage and treatment. Tables 7.1 and 7.2 summarize the indicators, component questions, responses, scoring, and risk rationale.

Table 7.1 Indicators i and ii and corresponding component questions for risk analyses.

Indicators and Component Questions	Responses	Score	Rationale
i. Chemical and Biological Indicator			
1.Fecal Coliform Present	Yes	2	Presence in water can cause adverse health
	No	1	
2.Total Coliform Present	Yes	2	Indicative of potential microbial risks
	No	1	
3.Turbidity	≤ 5 NTU	1	Affect disinfection processes
	> 5 NTU	2	
4.Pb ≤ WHO Guideline Value	Yes	1	Risk for adverse health
	No	2	
5. Cu, Fe ≤ WHO Guideline Value	Yes	1	Risk for adverse health
	No	2	
6.Temperature ≤ Ambient	Yes	1	Increased temperature promotes microbial
	No	2	
ii. Reach of Indicator			
1. How many persons are living in your household?	≤3	1	Smaller household, less people affected
	>3	2	
2. How many children (under 18 years)?	≤3	1	More susceptible to health effects
	>3	2	
3. Drinking water kept within reach of young children?	Yes	2	Risk of objects and hands in water supply
	No	1	
4. Is the water stored in the tank used for drinking water?	Yes	2	Risk of adverse health if water is not safe
	No	1	
5. Do you boil or filter water prior to drinking?	Yes	1	Kills pathogens and reduces turbidity
	No	2	
6. Reliance on bottled water.	Weekly or more	1	Safer alternative for contaminated water
	Less than weekly	2	

Table 7.2 Indicators iii, iv, v and corresponding component questions for risk analyses.

Indicators and Component Questions	Responses	Score	Rationale
iii. Storage Device Indicator			
1. Is there a cover on your drinking water storage device?	Yes	1	Coverage reduces contaminant entry
	No	2	
2.Frequency of device cleaning	< 12 times/yr	2	Frequent cleaning reduces contaminants in tank
	12 – 52 times/yr	1.5	
	>52 times/yr	1	
3. What is the age of the storage device?	0-3 years	1	Older devices more likely to wear out, leach, or have leaks
	4-10 years	1.5	
	>10 years	2	
4. What is the capacity of the storage device in gallons?	0-100	1	Larger devices more difficult to clean
	101-500	1.5	
	>500	2	
iv. Female Involvement Indicator			
1. Is the Female head of house responsible for cleaning the storage tank?	Yes	1	The woman is traditionally the homemaker and primary caregiver for household
	No	2	
2. Is the Female head of house responsible for collecting water from the storage tank for use?	Yes	1	
	No	2	
3. Is the Female head of house responsible for filling the storage tank?	Yes	1	
	No	2	
v. Household Belief Indicator			
1. Classify water source as brown, smelly, yellow or turbid?	Yes	2	Indicative of microbial or chemical levels
	No	1	
2. Classify water pressure as good?	Yes	1	Low pressure allows more leaks exposure
	No	2	
3. Seen information about keeping your water safe or about handwashing?	Yes	1	Risks reduction through awareness
	No	2	
4. Confidence that the water stored in the tank is safe for drinking?	Somewhat-Very	1	Considers the water not to pose health risks
	Not very	2	
5. Confidence that using a water storage device will reduce risk of water-related illnesses?	Somewhat -Very	1	Considers the device to be a safe mean for water supply
	Not Very	2	
6. Recently experienced an illness resulting from drinking the water from storage container?	Yes	2	Indicative of water contamination
	No	1	

7.2 Target Plots and Analyses

Once the indicators had been scored and an impact value established, target plots were then created for each of the three communities. Figure 7.1 summarizes the target plot construction and indicators used. In an ideal setting where there is minimal to no risk in each of the indicator categories, the target plot would appear blank. As risk increases for each indicator, a shaded region will appear corresponding with the impact value. The shaded region will illustrate the impact value. Table 7.3 shows the impact values of the environmental indicators.

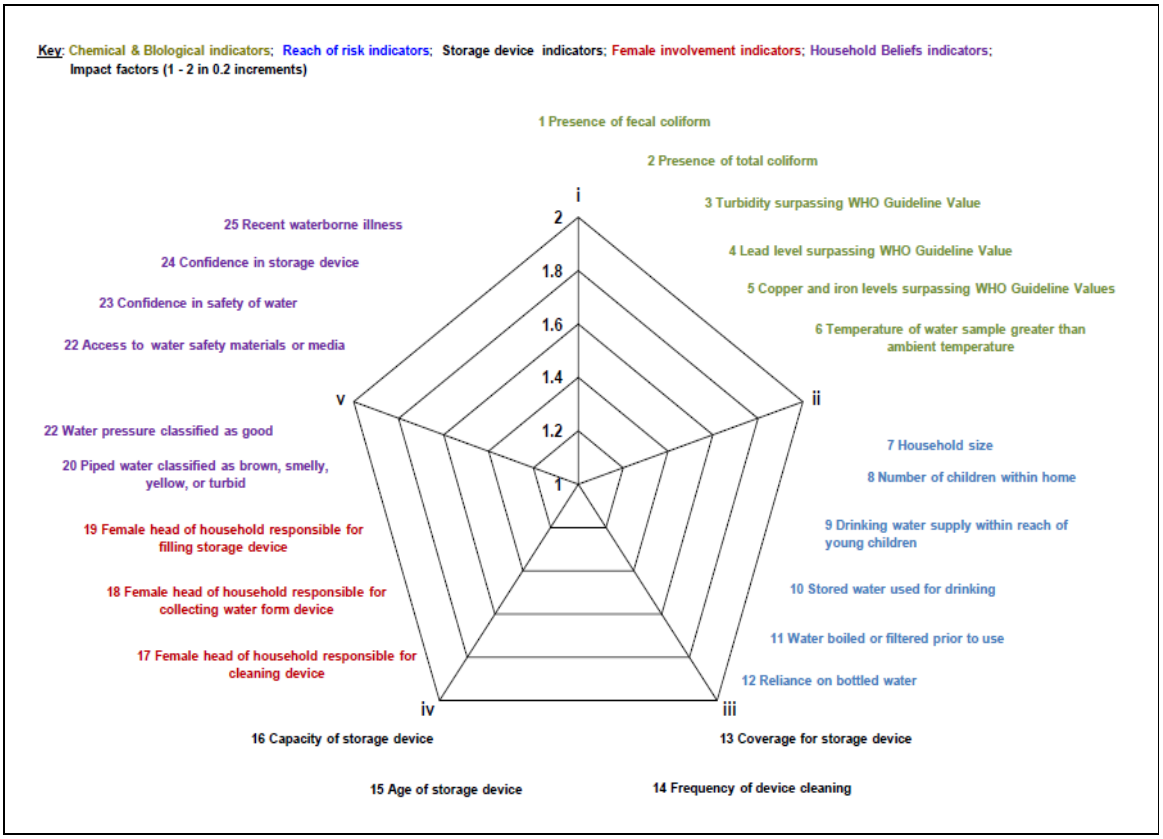

Figure 7.1 Target plot construction with indicators and corresponding component questions.

Table 7.3 Impact values of environmental health indicators.

	Impact Values			
	Mocha	Mon Repos	Georgetown	Total
Indicator Category (# sub-indicators)				
Chemical & Biological (6)	1.7	1.7	1.7	1.7
Reach of Risk (6)	1.4	1.4	1.3	1.4
Storage Device (4)	1.3	1.4	1.4	1.3
Female Involvement (3)	1.5	1.1	1.7	1.5
Household Beliefs (6)	1.6	1.4	1.5	1.6

Figure 7.2 shows the target plot for Mocha/Arcadia. The highest impact was seen in Indicator v (household belief indicator) where there was a value of 1.7 out of 2. Indicator i (chemical and biological indicator), had an impact value of 1.6, while indicator ii (reach of risk indicator) and iii (storage device indicator) each had an impact value of 1.5. The lowest impact was seen in indicator iv (female involvement indicator), with a value of 1.1. The lower the indicator value for category iv, the greater the influence of the female head of household over tank cleaning, filling and water collection activities. However, the higher impact values seen in indicator i and v indicate that the greater risk factors for environmental health issues associated with household water storage and treatment in Mocha are the poor water quality and household beliefs. In Mocha, heavy metal concentrations, microbial contamination, and other water parameters have exceeded WHO guideline values, thus affecting water quality. These issues are further exacerbated by household beliefs in which the water pressure is bad, there is little to no confidence in the security of the water or in storing it in the devices.

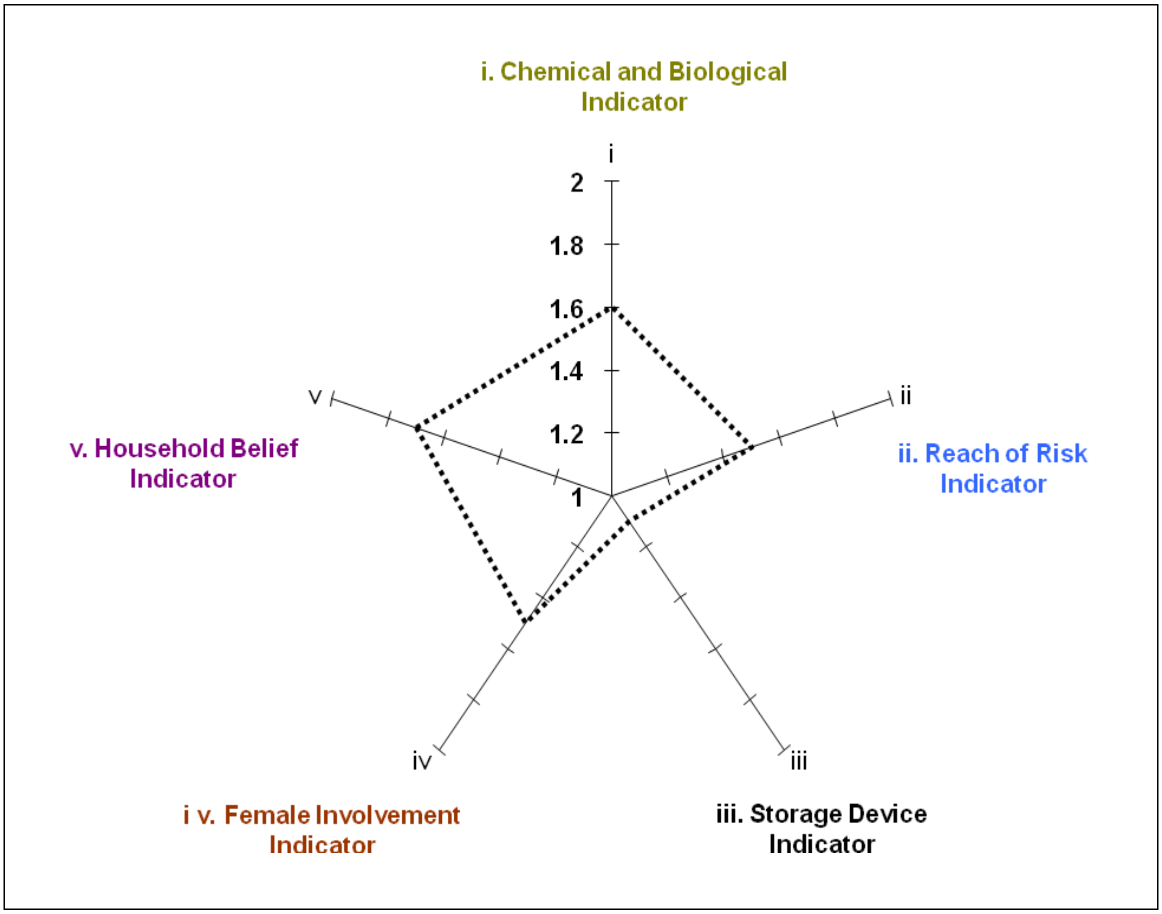

Figure 7.2 Target plot of risk indicators for the Mocha/Arcadia community in Guyana.

Figure 7.3 shows the target plot for Mon Repos. Unlike the Mocha target plot, this target plot is skewed more to the top and to the right. The highest impact was seen in indicator i (chemical and biological indicator), where the impact value was 1.7. The other indicators all had low impact, with the lowest impact value being indicator iv (female involvement indicator) with an impact value of 1.1 The plot showed that water quality was the highest risk factor in the environmental health issues associated with household water storage and treatment in Mon Repos.

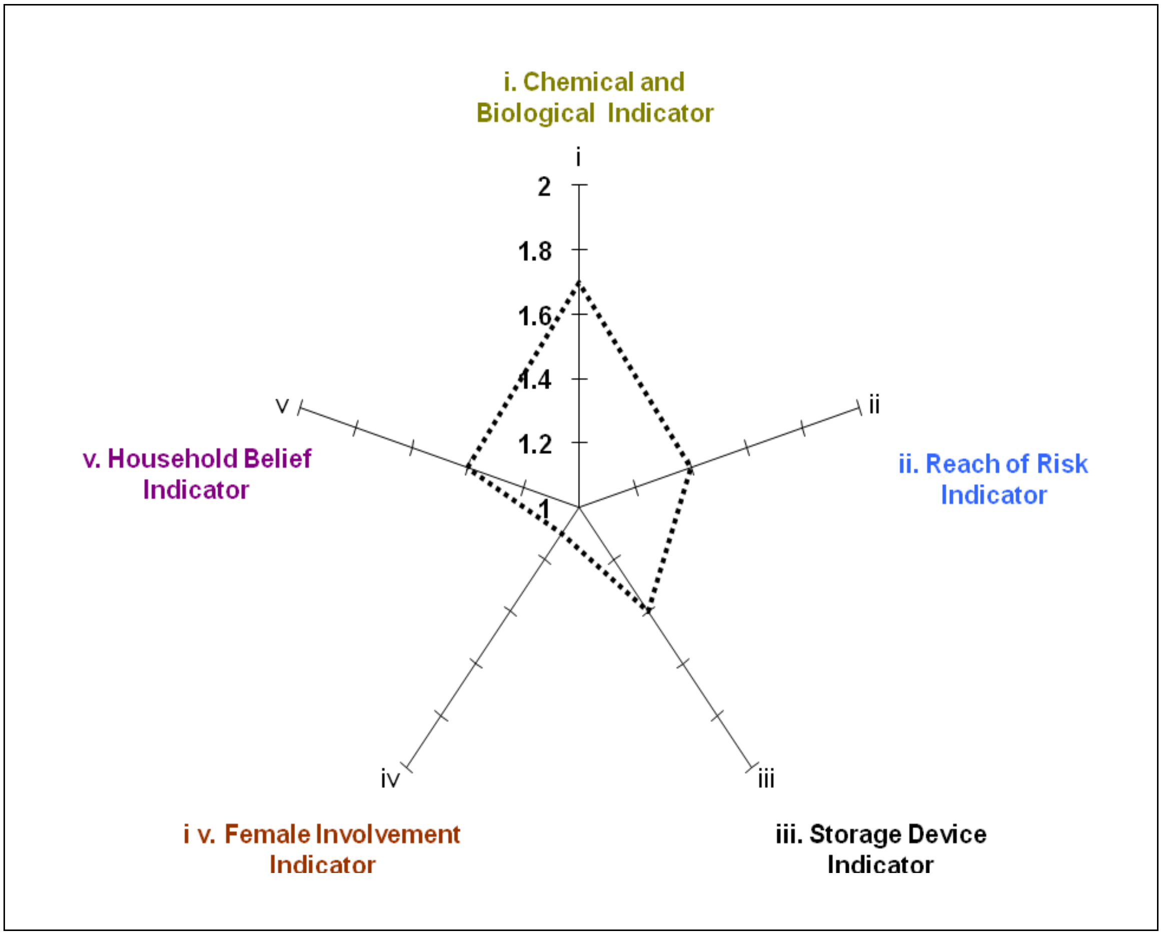

Figure 7.3 Target plot of risk indicators for the Mon Repos community in Guyana.

Figure 7.4 shows the target plot for Georgetown community. Unlike previous plots, the plot area is skewed to the bottom left. The highest impact was seen in indicator i (chemical and biological indicator) and indicator v (female involvement indicator), where each had an impact value of 1.7. A moderate impact was seen in indicator v (household belief indicator), while low impact was seen in indicator ii (reach of risk indicator) and iii (storage device indicator). The plot shows that poor water quality and low female involvement in storage device responsibilities were the highest risk factors for environmental health regarding household water storage and treatment in the area.

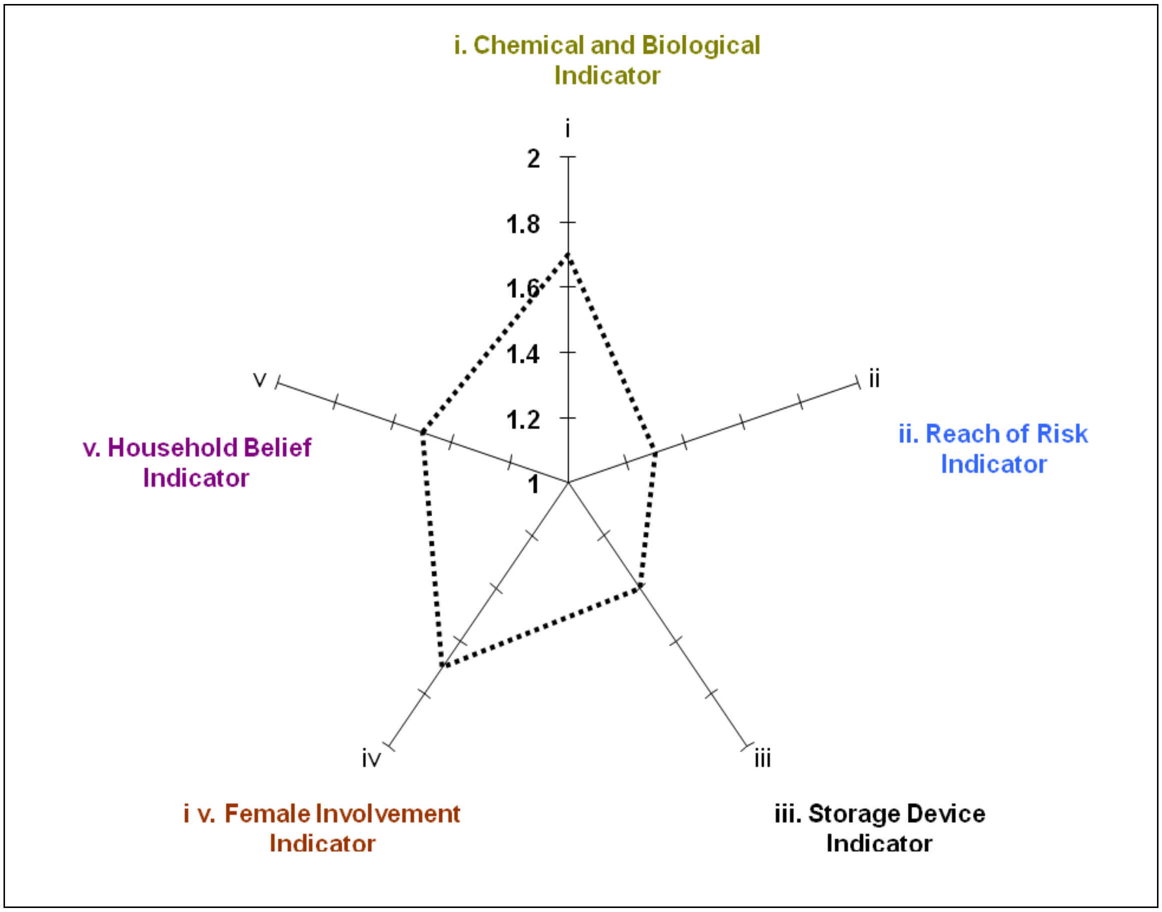

Figure 7.4 Target plot of risk indicators for the Georgetown community in Guyana.

In Figure 7.5, the three target plots are compared and overlaid to see the overall risk for the Guyana field site. The highest impact is seen in indicator i (chemical and biological indicator) with a value of 1.7, followed by indicator v (household belief indicator) with an indicator of 1.6. Moderate impact was seen in indicator iv (female involvement indicator), while low impact was seen in the remaining indicators. This plot shows that water quality and household beliefs are the biggest risk to environmental health regarding household water storage and treatment within the overall Guyana field site.

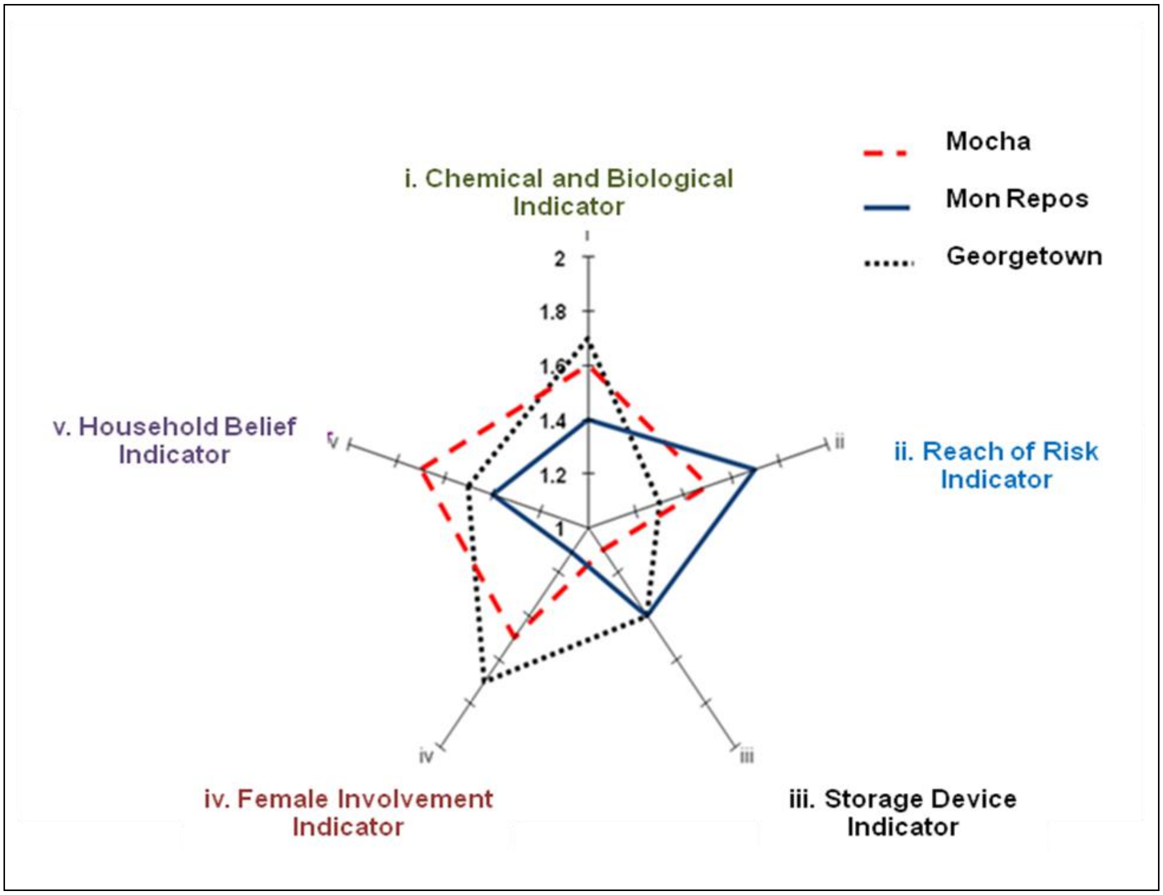

Figure 7.5 Target plot of risk indicators for the entire field site in Guyana.

Figure 7.6 shows the target plot for Siparia. The target plot is skewed more to the left. The highest impact was seen in indicator i (chemical and biological indicator), where the impact value was 1.8, followed by female involvement indicator with an impact value of 1.6. The reach of risk indicator, indicator ii, had a moderate impact, while low impact levels were seen among the remaining indicators. The plot showed that water quality was the highest risk factor in the environmental health issues associated with household water storage and treatment in Siparia, followed by reduced female involvement, and reach of risk.

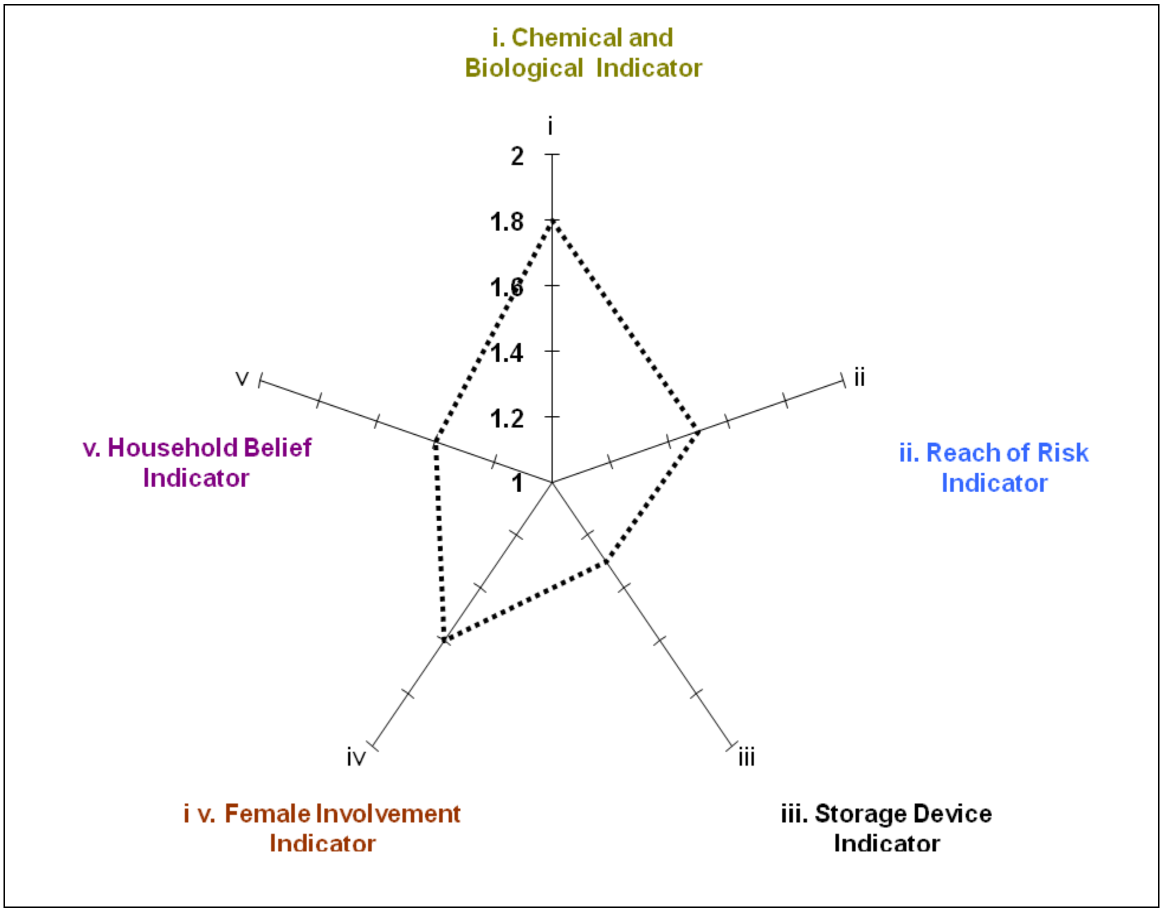

Figure 7.6 Target plot of risk indicators for Siparia, Trinidad and Tobago.

Figure 7.7 shows the target plot for Villa Litoral. The target plot covers a large area than the plots constructed for the other sites. The highest impact was seen in indicator i (chemical and biological indicator), where the impact value was 1.9. The reach of risk, female involvement, and household belief indicators each had an impact value of 1.6. The storage device indicator, indicator iii, had the lowest impact, with a value of 1.3. The plot showed that while water quality was the highest risk factor in the environmental health issues associated with household water storage and treatment in Villa Litoral, all of the other indicators were also high risk factors, save for storage device. This is indicative of how the water quality is influenced by household behaviors & practices and vice-versa.

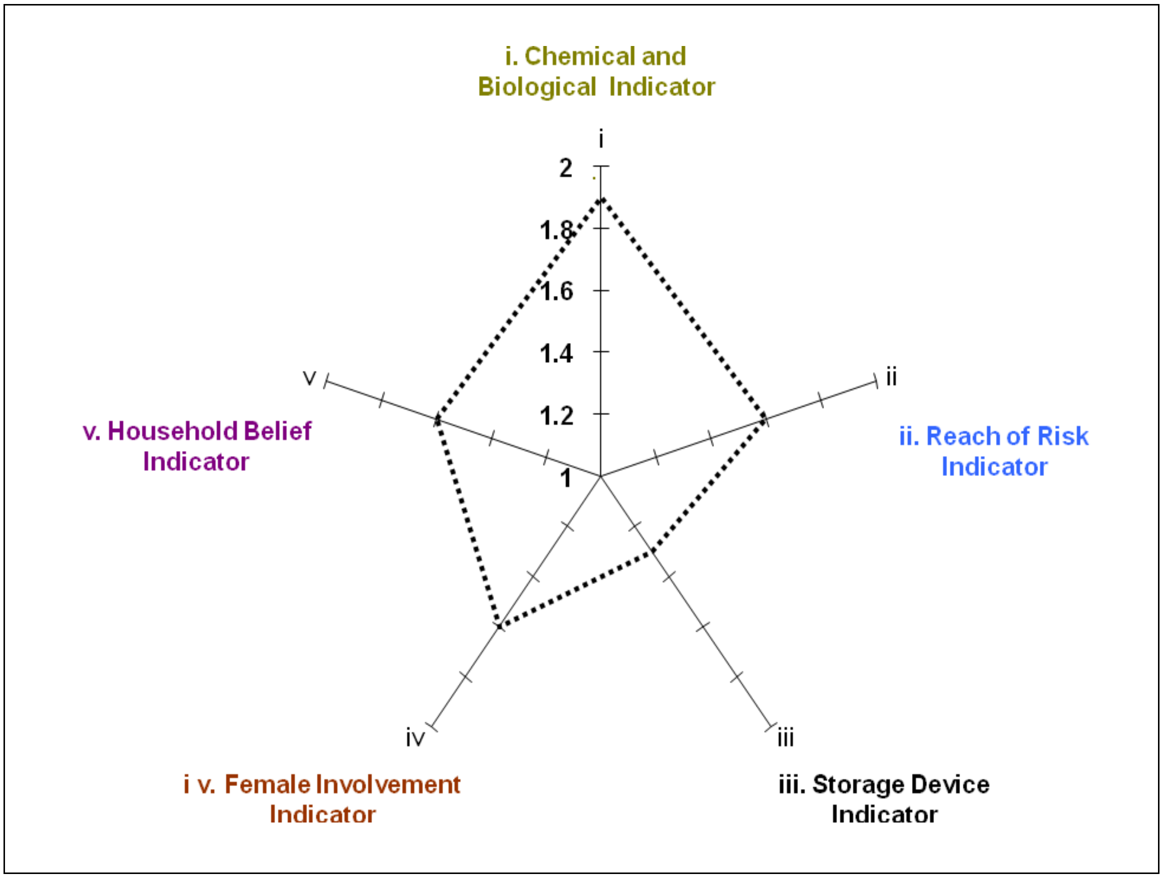

Figure 7.7 Target plot of risk indicators for Villa Litoral, Bolivia.

7.3 Summary

Target plotting provides a means for visual comparisons of risk indicators that can impact environmental health with regards to household water storage and treatment. In the case of the Guyana field site, the greatest risk factor seen for all three sub-groups and the field site as a whole was poor water quality, followed by household beliefs. Variations were seen in the impact values for the three sub-groups particularly regarding female involvement and household beliefs. While female heads of households in Mon Repos were heavily involved in the storage device responsibilities, there was less involvement among households in Greater Georgetown. It was also seen that households in Mon Repos knew more about water-related issues than households in Mocha and Greater Georgetown. These observations may not have been captured otherwise.

Table 7.4 Comparison of risks levels for field sites in Guyana, Trinidad and Tobago, and Bolivia.

		Impact Values		
Indicator	Indicator Name	Region 4 Subset, Guyana	Siparia, Trinidad and Tobago	Villa Litoral, Bolivia
i	Chemical & Biological Indicator	1.7	1.8	1.9
ii	Reach of Risk Indicator	1.4	1.5	1.6
iii	Storage Device Indicator	1.3	1.3	1.3
iv	Female Involvement Indicator	1.5	1.6	1.6
v	Household Belief Indicator	1.6	1.4	1.6

Table 7.4 compares risk levels for the three field sites. Poor water quality was the highest risk factor for each of the three field sites. This was evident by the high microbial contamination, heavy metal concentrations, and turbidity levels. Female involvement in the responsibilities of the household water devices is seen as a moderate to high risk factor. In many households, the female head of the

household was responsible for collecting water from the water storage device, while the cleaning and filling responsibilities were left to the male head of the house or other household member. This may be due to the cultural norms or practical reasons stemming from the size and capacity of the water storage device. This becomes a risk issue when the female head is unaware of what hygienic practices were used during the cleaning and filling and thus uses the water for household purposes, not knowing that the water source may have been further contaminated. As the traditional homemaker and primary caregiver for the household, if the female head is not involved in the water responsibility, there is potential risk for the rest of the household to be exposed to contaminated water sources and subsequent illnesses. In Chapter 2, it was stated that one of the main risks associated with the use of jerry cans and other small containers is that they are not exclusively used for water storage but may be used for multiple purposes. As such, it is all the more important that there is assurance that the container was properly cleaned and/or disinfected.

Within all three communities, the storage device indicator had the lowest impact value and was the lowest risk factor. This was attributed to the fact that the water storage devices all had a sturdy covering and most of the storage devices were relatively new, being under 3 years. Nevertheless, other indicators such as cleaning frequencies and storage capacity still proved to be of concern.

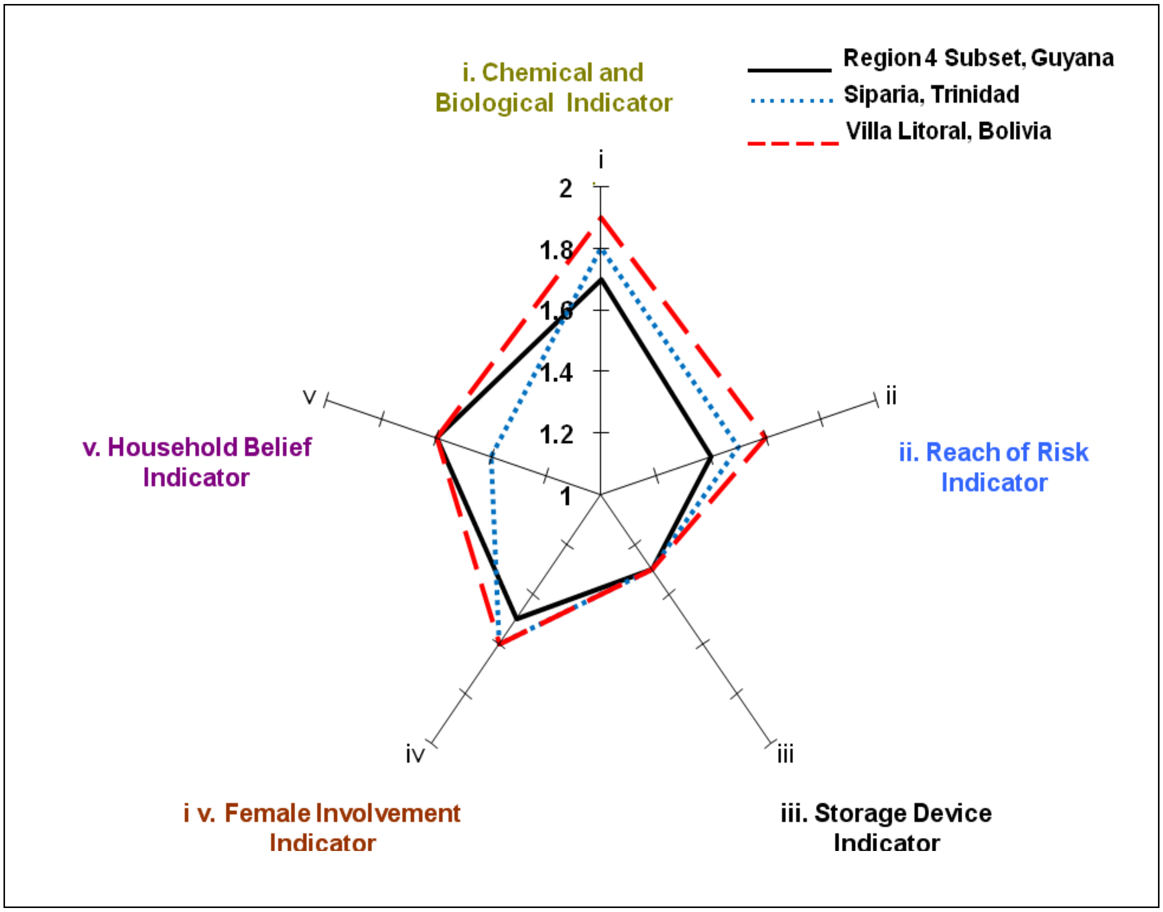

Figure 7.8 Target plot for Siparia, Trinidad and Tobago; Region 4 Subset, Guyana; and Villa Litoral, Bolivia.

Among the field sites, variations were seen with regards to the impact levels and subsequent risk factors of the remaining indicators, as shown in Figure 7.8. While household beliefs were seen as a great risk in field sites in Guyana and Bolivia, this was not the case in Siparia, Trinidad and Tobago. Of the three communities, Siparia had the least amount of microbial contamination and reported waterborne illnesses. Additionally, the community had the highest proportions of households reporting a moderate to high confidence in the safety of the water sources and the security of the water storage device. The reach of risk indicator was a moderate to high risk factor in Siparia and Villa Litoral, while being a low risk factor in the Guyana field site. Among the Guyana households surveyed, larger proportions did not drink the stored water but relied on bottled water. Additionally, the majority of households kept water sources outside of the reach of children. While using different indicators may provide insight to other indicators, the target plots that were constructed showed that there was a linkage between water quality and community perception and health in the three field sites. While other indicators may have had lower impact levels, none had a score of 1. Thus, these other indicators are still of concern with regards to environmental health. Intervention strategies can thus be made according to the indicators where the impact levels were the greatest and risks the highest.

CHAPTER 8: CONCLUSION

8.1 Summary of Findings

In Chapter 1, several research questions were established prior to the commencement of this research. These research questions were:

1) Will potable water quality vary due to the source of water, type of household water storage device used, and community?
2) Will household activities (cleaning of tanks, covering of tanks, treatment of water) improve the water quality of water reaching the household tap?
3) Does a simple approach exists that will capture and present how household understanding of water quality, household practices, gender roles, and household location influence vulnerability to waterborne/water-based/water-related illnesses?

The first research question was addressed in that water quality variations were seen among the various household devices and sources of water. Even while maintaining water sources in water storage devices, the potential for microbial and chemical contamination still exists. Microbial contamination was seen among households in Siparia, Region 4 Subset, and Villa Litoral. In each of the communities, tanks had the highest proportion of overall contamination among the different types of devices used. Water samples from Villa Litoral had the highest percentage of contamination, with 85% of all samples testing positive for fecal coliform and 100% for total coliform. In Region 4 Subset, fecal coliform contamination was greater among piped water sources (71%), while total coliform contamination was greater among rain water sources (44%). In Villa Litoral 42% of piped water sources tested positive for fecal coliform. Turbidity levels were found to be high in each of the three communities, with minimum turbidity levels in Region 4 Subset and Villa Litoral being twice as high as the WHO guideline value of 5 NTU. In Villa Litoral, piped water sources had TDS levels between 800-900 mg/L, almost to the point of being unpalatable by WHO guidelines.

High heavy metal concentrations were seen among the three communities, often exceeding the WHO guidelines. Overall, higher proportions of samples with over-the-limit metal concentrations were seen among samples taken from tank devices and piped water sources. Villa Litoral had the least proportion of samples with over-the-limit concentrations.

The second research question, which asked whether household activities improve water supply, was also addressed. While water storage devices do provide additional and constant water supplies, it was evident that water quality can be compromised without adequate device maintenance and water treatment at the point of use. As most households have multiple water storage devices- several of which may have a capacity over 400 gallons-, it becomes exceedingly difficult to clean these storage devices. The problem of infrequent cleanings is compounded with inadequate water disinfection. In Siparia and Region 4 Subset, household water disinfection is practiced, but the chlorine dosage and mixing time are inadequate to provide optimal disinfection. While many households had connections to the main, water access was often limited to half a day or a few hours a day. Even though residents paid to receive piped water, issues with water aesthetics, taste, and pressure forced many households to purchase bottled water as an alternative drinking water source, as was the case in Siparia and Region 4 Subset.

In Chapter 5, survey results showed that households in Region 4 Subset cleaned their devices and disinfected their water much more frequently than those in Siparia or Villa Litoral. As such, one would expect the water quality analyses to reflect lower microbial contamination levels, turbidity, and heavy metal concentrations within Region 4 Subset. However, this was not the case. Lower microbial levels were seen in Siparia while lower over-the-limits metal concentrations were seen in Villa Litoral. This may be indicative that good household storage and treatment practices can still be thwarted by external factors such as industrial activities, geological variations, water treatment and distribution differences, and overall need for increased disinfection dosage/residency in water sources.

The third research question was answered in that an approach does exist that could capture how household beliefs, practices, and gender roles influence vulnerability to waterborne illnesses. This hypothesis was proven true. In Chapter 7, five indicators were developed while 25 component questions were taken from the household survey and water quality assessments. The indicators developed were physical and biological; risk of reach, storage device, female involvement, and household belief. Using responses and findings from the survey and water quality analyses, target plots were constructed to assess the associated risks with each of the indicators for each of the three filed sites. Poor water quality was the highest risk factor for each of the three field sites. This was evident by the microbial contamination, heavy metal concentrations, and other elevated water parameters that were discussed in Chapter 6.

Lack of female involvement in the responsibilities of the household water devices was seen as a moderate to high risk factor. In many households, the female head of the household was responsible for collecting water from the water storage device, while the cleaning and filling responsibilities were left to the male head of the house or other household member. However, as the primary homemaker and caregiver in the house, the less involved the female head is in the water responsibilities, the greater the potential for increased reach of risk and exposure to the entire household.

High risks were associated with household beliefs in Region 4 Subset and Villa Litoral, as opposed to Siparia. Although relatively lower proportions of households surveyed in Siparia reported regular handwashing or access to water-related media, households in Siparia reported higher confidence in water sources and storage devices and almost no cases of recent waterborne illnesses. In addition, Siparia water sources had the lease microbial contamination of the three field sites. Participants who felt confident in their water sources reported reasons such as adequate treatment at the municipal water plant/pump, regular household water treatment, no reported cases of waterborne illnesses or advisories, and perception that rainwater was free of contaminants. Reasons for lack of confidence included aesthetic aversion (color, smell, and taste), perceived risk, previous advisories, and distrust of the local governmental agency in charge of water provision.

While other indicators may have had lower impact levels, none had a score of 1. Thus, these other indicators are still of concern with regards to environmental health. Intervention strategies can thus be made according to the indicators where the impact levels were the greatest and risks the highest.

As a result of household practices and water distribution issues, many households have experienced water-related illnesses with varying symptoms. In Siparia, only one household reported having a recent water-related illness, in which case the individual experienced headaches following consumption of the water. In contrast, 15 % of households in Region 4 Subset, Guyana and 40.4% of households in Villa Litoral reported recent illnesses. Among those households reporting illnesses, the most common symptom was diarrhea among households in Region 4 Subset (50%) and Villa Litoral (32%). Other symptoms reported included stomach pains/cramps, skin rash, fever, nausea, and loss of appetite. In spite of the various symptoms presented, none of the individuals who had a waterborne illness in Siparia or Region 4 Subset had the illness medically diagnosed, while only half of those in Villa Litoral had the illness diagnosed.

The prevalence of diarrheal episodes following consumption of water sources poses a great threat to the welfare and development of the communities. One of the most acute effects of diarrhea is dehydration due to the loss of electrolytes (sodium, chloride, potassium, and bicarbonate) and water. Fatality can occur when the body reaches a fluid loss of 10%. Even if fatality does not occur, dehydration can make one more susceptible to infections. This is of particular concern for those with children.

It is thus necessary to build increased awareness on proper household water storage practices, particularly among those responsible for the collection of water sources and the cleaning of storage devices. While water advisories have been distributed in the communities, there is sometimes a misunderstanding as to whether the disinfection should take place in a separate, smaller container or in the storage device itself. As such, it is also important to provide accurate information of chemical disinfection of household water sources as there are various device shapes and capacities present within the communities.

8.2 Impact of Findings

Formally documented and tested knowledge of the environmental engineering and public health issues associated with water resources in the Caribbean are severely sparse. It is the aim that the research conducted would be of benefit to the residents of Trinidad and Tobago, Guyana, and Bolivia, along with those living in areas with limited access to clean, potable water. Thus, it was imperative to provide a community technical report to each of the respective communities detailing the findings of the study (Appendix F). In doing so, the communities would then be able to share the findings with the residents, along with use it for the procurement of funding to further address the environmental needs and issues present. Health and environmental issues related to poor water infrastructures are problems that the residents deal with everyday

In addition, this research will provide the basis for further research in the areas of environmental science, engineering, public health, and epidemiology. Further engineering research can take place in which various types of water treatment methods and models can be assessed in order to determine relevancy and whether it will be appropriate for use in the Caribbean. Upon deciding on models that promote best available technology, research can be done to evaluate its efficiency and benefit to the communities and perhaps change to the next best-available technology that is practical for Guyana.

Engineering research can also look at ways to improve or reconstruct the outdated water infrastructures that are currently in place (Semenza, 1998; LeChevallier, 2003). Epidemiological studies can take place in which individuals who reside and utilize the water can participate in cohort and case studies in which researchers screen and monitor their lifestyles, health, and activities both past, present and future to determine the health risks associated with the contaminants in the water and to assess if the overall public health improved as a result of the new technologies that are put in place (Checkley, 2004; Strauss, 2001; Tornheim, 2009; Brown, 2008; VanDerslice, 1994). Overall the goal is to improve water quality, water infrastructures, and public health awareness so as to ensure the environmental health of the community and provide better insight on their needs.

8.3 Recommendations

Several recommendations can be made in an effort to improve efforts taken to achieve MDG-7 and improve water access and water quality. More interventions are needed that are gender sensitive with regards to environmental issues along with water and sanitation. It is often the women who are in charge of the cooking, household care, and water storage and retrieval. As such, many household environmental health issues can be mitigated by training women in proper storage and handling of water, ways to decrease indoor air pollution during cooking, and other sustainable measures (Elmendorf, 1982). While several campaigns are currently in place to combat malaria and dengue in the region, collaborations can be made with those campaigns where proper water storage techniques can be incorporated.

Additional education initiatives can play an important role in ensuring environmental sustainability. Doria (2010) reports that education implementation provides the opportunity for awareness and improved communication with experts. Doria goes on to state that water perception is developed at an early age, it is thus necessary to begin implementing water education from the start of formal education. Water and sanitation issues along with sustainability topics can be implemented into the education system. Lessons can be made to fit into the current science, civic and/or health curriculum. As students are taught about these issues and measures, they can share their new knowledge with friends and family, thus providing an effective measure of information distribution. In many parts of the region, particularly in the rural area, literacy may be an issue. As such, brochures and written documents may not be as effective. One source of intervention is the usage of Performance Theater. These interventions involve informative performances that incorporate culture and entertainment with an underlying message. Performance allows for interaction between the performers and community members in a less formal atmosphere. In tying with an underlying theme of environmental sustainability or water/sanitation, the audience is able to receive the message while the performers are able to modify the performances to better fit the culture and age level of the audience (Conquergood, 1988). Various sustainability initiatives can be taken at the governmental level. These include 1) transference of expenditures to water resources and the health sector, 2) better waste management practices, 3) use of local and natural resources for water treatment and energy generation, and 4) international collaboration and cooperation.

The disparities seen within the Latin American and Caribbean region are much more pronounced than those seen in other regions, and as such the targets are too general. Additionally, meeting the MDG targets in both the urban and rural areas prove to be quite daunting as a result of the disparities and lack of representation in data collection. In many areas of the region, there is a lack of formally documented data and information regarding to environmental issues. In addition, there are reporting discrepancies in many of the reported data. This is due to variations in reporting units, descriptions, and other limitations. With regards to water and sanitation, while many more individuals have access to improved water sources, these sources may not always provide improved water quality. This is seen in areas where there are 1) breaches in the distribution system, 2) contamination occurring at the household level as a result of improper water storage and handling, or 3) proximity of sanitation facilities to drinking water sources.

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APPENDICES

Appendix A. Water Quality Limits and Standards

Table A.1 Water quality limits for chemicals. (UNICEF, 2008).

Chemical	WHO GV		EU MAC		USEPA MCL		Discussed in Section
Aluminium	0.1-0.2	(A)	0.2	(A)	0.05-0.2	(A)	2.4
Antimony	0.020		0.005		0.006		2.3.4
Arsenic	0.01	(P)	0.01		0.01		2.3.1
Asbestos	--	(X)	--		7 MFL		2.3.4
Barium	0.7		--		2		2.3.1
Beryllium	--	(X)	--		0.004		2.3.2
Boron	0.5	(T)	1		--		2.3.1
Bromate	0.01	(Q, T)	0.01		0.01		2.3.4
Cadmium	0.003		0.005		0.005		2.3.2
Chlorine (as Cl_2)	5	(C)	--		4		2.3.4
Chloramines (as Cl_2)	3	(1)	--		4		2.3.4
Chlorine dioxide (as Cl_2)	--	(X)	--		0.8		2.3.4
Chromium	0.05	(P)	0.05		0.1		2.3.1
Copper	2		2		1.3	(TT)	2.3.4
Cyanide	0.07		0.05		0.2		2.3.2
Fluoride	1.5		1.5		4		2.3.1
Iron	0.3	(A)	0.2	(A)	0.3	(A)	2.4
Lead	0.01		0.01		0.015	(TT)	2.3.4
Manganese	0.4	(C)	0.05	(A)	0.05	(A)	2.3.1
Mercury	0.006	(M)	0.001		0.002		2.3.2
Chemical	**WHO GV**		**EU MAC**		**USEPA MCL**		**Discussed in Section**
Molybdenum	0.07		--		--		2.3.1
Nickel	0.07		0.02		--		2.3.4
Nitrate (as NO_3^-)	50		50		44.3		2.3.3
Nitrite (as NO_2^-)	3	(S)	0.5		3.3		2.3.3
	0.2	(L, P)					
Selenium	0.01		0.01		0.05		2.3.1
Silver	--	(X)	--		0.1	(A)	2.3.4
Sulfate	250	(A)	250	(A)	250	(A)	2.4
Thallium	--		--		0.002		2.3.2
Uranium	0.015	(P, T)	--		0.03		2.3.1
Zinc	3	(A)	--		5	(A)	2.4

Notes

A: Based on aesthetic concerns, not health impacts. WHO does not set GVs based on aesthetic concerns, but does note concentrations which may cause complaints.

1: For monochloramine alone. Data are insufficient to set GVs for dichloramine or trichloramine.

C: Concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, causing consumer complaints.

L: for long-term exposure

M: for inorganic mercury

P: Provisional guideline: evidence of a potential hazard, but the available information on health effects is limited.

Q: Because calculated guideline value is below the practical quantification level

S: For short-term exposure

T: Guideline value is set at the practical treatment limit, rather than a lower value based solely on health effects.

X: Excluded from guideline value because of a lack of evidence that ingestion causes adverse health effects, or unlikely to occur in drinking water.

TT: Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps.

Appendix B. Global Drinking Water and Sanitation Coverage

Table B.1 Drinking water and sanitation by means of supply. (UN, 2008)

Drinking water and sanitation coverage: regional estimates by type of drinking water and sanitation facilities (1990 and 2006)

Drinking water coverage (%)

MDG regions and the world	Year	Population: Total (thousands)	Population: Urban (%)	Urban				Rural				Total				% of population that gained coverage (1990-2006) with respect to median population (Year 1998)
				Improved	Piped into dwelling, yard or plot	Other improved	Unimproved	Improved	Piped into dwelling, yard or plot	Other improved	Unimproved	Improved	Piped into dwelling, yard or plot	Other improved	Unimproved	
Sub-Saharan Africa	1990	519,388	28	**82**	46	36	18	**35**	4	31	65	**49**	16	33	51	**37**
	2006	788,214	36	**81**	35	46	19	**46**	5	41	54	**58**	16	42	42	
Northern Africa	1990	118,032	49	**95**	83	12	5	**82**	34	48	18	**88**	58	30	12	**35**
	2006	155,087	54	**96**	91	5	4	**87**	63	24	13	**92**	78	14	8	
Eastern Asia	1990	1,220,373	30	**97**	82	15	3	**55**	37	18	45	**68**	51	17	32	**33**
	2006	1,402,837	43	**98**	87	11	2	**81**	62	19	19	**88**	73	15	12	
Southern Asia	1990	1,192,558	26	**91**	55	36	9	**68**	8	60	32	**74**	20	54	26	**39**
	2006	1,612,840	30	**95**	51	44	5	**84**	10	74	16	**87**	22	65	13	
South-eastern Asia	1990	440,574	32	**92**	41	51	8	**64**	4	60	36	**73**	16	57	27	**36**
	2006	565,105	45	**92**	53	39	8	**81**	14	67	19	**86**	32	54	14	
Western Asia	1990	137,541	62	**95**	82	13	5	**70**	50	20	30	**86**	69	17	14	**54**
	2006	200,205	66	**95**	93	2	5	**80**	57	23	20	**90**	80	10	10	
Oceania	1990	6,449	23	**92**	-	-	8	**39**	7	32	61	**51**	-	-	49	**15**
	2006	9,175	24	**91**	-	-	9	**37**	6	31	63	**50**	-	-	50	
Latin America & Caribbean	1990	444,277	71	**94**	84	10	6	**61**	25	36	39	**84**	67	17	16	**26**
	2006	565,049	78	**97**	90	7	3	**73**	48	25	27	**92**	80	12	8	
Commonwealth of Independent States	1990	281,428	65	**97**	86	11	3	**84**	42	42	16	**93**	71	22	7	**12**
	2006	278,295	64	**99**	90	9	1	**86**	42	44	14	**94**	73	21	6	
Developed regions	1990	934,265	71	**100**	98	2	0	**95**	73	22	5	**98**	91	7	2	**15**
	2006	1,016,093	75	**100**	98	2	0	**97**	78	19	3	**99**	93	6	1	
Developing regions	1990	4,079,192	35	**93**	69	24	7	**59**	19	40	41	**71**	36	35	29	**35**
	2006	5,298,512	43	**94**	70	24	6	**76**	27	49	24	**84**	46	38	16	
World	1990	5,294,885	43	**95**	79	16	5	**63**	24	39	37	**77**	48	29	23	**31**
	2006	6,592,900	49	**96**	78	18	4	**78**	31	47	22	**87**	54	33	13	

Sanitation coverage (%)

MDG regions and the world	Year	Urban				Rural				Total				% of population that gained coverage (1990-2006) with respect to median population (Year 1998)
		Improved	Shared	Unimproved	Open defecation	Improved	Shared	Unimproved	Open defecation	Improved	Shared	Unimproved	Open defecation	
Sub-Saharan Africa	1990	**40**	27	22	11	**20**	9	25	46	**26**	14	24	36	**19**
	2006	**42**	31	19	8	**24**	11	26	39	**31**	18	23	28	
Northern Africa	1990	**82**	6	10	2	**44**	5	21	30	**62**	5	17	16	**32**
	2006	**90**	6	4	0	**59**	7	25	9	**76**	6	14	4	
Eastern Asia	1990	**61**	12	24	3	**43**	1	51	5	**48**	4	44	4	**25**
	2006	**74**	15	7	4	**59**	1	38	2	**65**	7	25	3	
Southern Asia	1990	**53**	17	6	24	**10**	2	7	81	**21**	6	8	65	**19**
	2006	**57**	20	8	15	**23**	6	8	63	**33**	10	9	48	
South-eastern Asia	1990	**74**	8	6	12	**40**	4	21	35	**50**	5	17	28	**36**
	2006	**78**	8	4	10	**58**	5	13	24	**67**	7	8	18	
Western Asia	1990	**93**	6	1	0	**56**	2	24	18	**79**	4	10	7	**63**
	2006	**94**	6	0	0	**64**	4	18	14	**84**	6	5	5	
Oceania	1990	**80**	-	20	-	**44**	1	34	21	**52**	-	48	-	**17**
	2006	**80**	-	20	-	**43**	1	36	20	**52**	-	48	-	
Latin America & Caribbean	1990	**81**	6	7	6	**35**	3	19	43	**68**	5	10	17	**25**
	2006	**86**	6	6	2	**52**	4	21	23	**79**	6	8	7	
Commonwealth of Independent States	1990	**95**	-	5	-	**81**	-	19	-	**90**	-	10	-	**10**
	2006	**94**	-	6	-	**81**	3	16	-	**89**	-	11	-	
Developed regions	1990	**100**	-	0	0	**96**	-	4	-	**99**	-	1	-	**12**
	2006	**100**	-	0	0	**96**	-	4	-	**99**	-	1	-	
Developing regions	1990	**66**	12	12	10	**28**	3	27	42	**41**	6	22	31	**25**
	2006	**71**	15	7	7	**39**	5	21	35	**53**	9	15	23	
World	1990	**78**	8	8	6	**36**	3	24	37	**54**	5	17	24	**22**
	2006	**79**	11	5	5	**45**	5	19	31	**62**	8	12	18	

1 *The figures for Bangladesh have been adjusted for arsenic contamination levels based on the national surveys conducted and approved by the Government.*

2 *Countries with a negative growth rate, reflected in the columns titled '% of population that gained coverage (1990-2006) with respect to median population (Year 1998)'.*

3 *Figures have been estimated by JMP to ensure compatibility, thus they are not necessarily the official statistics of the concerned country, area or territory, which may use alternative rigorous methods.*

Appendix C. Household Survey Tools

USF
UNIVERSITY OF SOUTH FLORIDA

Information to Consider Before Taking Part in this Research Study

Researchers at the University of South Florida (USF) study many topics. To do this, we need the help of people who agree to take part in a research study. We are asking you to take part in a research study that is called Environmental Health in the Caribbean: Water Storage & Water Quality.

The purpose of this study is to better understand the relationship that exists between your community, water storage, and public health. We'd also like to obtain firsthand information on the effects and practices of community residents regarding water collection, storage, and usage, and thus be able to integrate the findings and data into a dissertation.

If you take part in this study, you will be asked to complete a questionnaire regarding your household's water storage containers, along with your beliefs and habits relating to water quality and health. The questionnaire will be done in your home or a local business on a one time basis. The questionnaire will take a few minutes to complete.

The potential benefits to you are:

- Increased knowledge of the environmental health needs of you and your community
- Participation in research where your opinion and experiences matter
- Potential for changes in regulations and practices relating to water
- Increased education and awareness on the importance of maintaining clean water storage containers and health benefits to you

This research is considered to be minimal or no risk. That means that the risks associated with this study are the same as what you face every day.

We must keep your study records as confidential as possible. No personal identification (name, address, etc.) is required for this study. You questionnaire is only identified by a number. Individuals who provide oversight on this study may look over the questionnaires to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights and your safety. We may publish what we learn from this study, but we will not publish anything else that would let people know who you are.

If you have any questions, concerns or complaints about this study, call Dr. Maya Trotz at 1-813-974-3172. If you have questions about your rights as a participant in this study, general questions, or have complaints, concerns or issues you want to discuss with someone outside the research, call the Division of Research Integrity and Compliance of the University of South Florida at (813) 974-9343.

Appendix C. (Continued)

Survey Number: City, Country: Date:

Environmental Health in the Caribbean: Water Storage & Water Quality
Community Survey Questionnaire

<u>Personal Information</u>

1. What is your gender?
    a. Male
    b. Female
2. What is your age range?
    a. 18-35
    b. 36-50
    c. 50-65
    d. Over 65
3. How many persons are living in your household?
    a. 1-3
    b. 4-7
    c. More than 8
4. How many adults (aged 18 and above)?
    a. 1-3
    b. 4-7
    c. More than 8
5. How many children (under 18 years)?
    a. 1-3
    b. 4-7
    c. More than 8
6. What is the age range of children?
    a. Under 5 years
    b. 5-10 years
    c. 11-15 years
    d. 15- 18 years

Appendix C. (Continued)

<u>About Water Storage Tank</u>

7. What is the color of your tank?
    a. Black
    b. Green
    c. Blue
    d. White
    e. Brown
    f. Other ______________________________
8. What material is your tank made of?
    a. Plastic
    b. Metal (aluminum, tin)
    c. Ceramic
    d. Other ___________________________
9. Do you have a reservoir (black tank, drum, etc.) to store the receiving water (from pipe or rainfall)?
    a. Yes
    b. No
10. What is the age of the tank?
    a. 0-3 years
    b. 4-10 years
    c. 11-15 years
    d. 16-20 years
    e. Older than 20 years
11. What is the tank capacity of your unit in gallons? _______________________
12. Where is the water tank located?
    a. On top of an embankment
    b. On the ground
    c. Other ______________________
13. Is there a cover on your drinking water storage container?
    a. Yes
    b. No
14. If yes, what do you cover it with? _______________________
15. Is the water stored in the tank used for drinking water?
    a. Yes
    b. No

16. Is the water stored in the tank boiled prior to drinking?
    a. Yes
    b. No
17. Is the water stored in the tank filtered prior to drinking?
    a. Yes
    b. No
18. If yes to #17, what filtering methods or materials do you use?_________________
19. How frequently do you and your household utilize bottled water?
    a. Daily
    b. Weekly
    c. Rarely
    d. Not at all
20. What is the source of the water used to fill the storage tank?
    a. Municipal water from pipe
    b. Surface water carried by individual to storage tank
    c. Rainwater
    d. Other _________________________
21. Was water within the storage tank topped within two weeks prior to sample collection?
    a. Yes
    b. No
22. Is the water storage tank disinfected?
    a. Yes
    b. No
23. If yes to disinfection, how frequently is the tank disinfected?
    a. Daily
    b. Weekly
    c. Monthly
    d. Every few months
    e. Annually
    f. Rarely
24. If yes to disinfection, when was the last time of disinfection?
    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year

Appendix C. (Continued)

25. If yes to disinfection, how much bleach do you add to the container?
    a. 2 drops
    b. 1 teaspoon
    c. 1 tablespoon
    d. 1 cork-full
26. After treating water with bleach, how long do you leave it to mix/dissolve before consuming?
    a. Less than 10 minutes
    b. 10 – 15 minutes
    c. 15 - 30 minutes
    d. Overnight
    e. Other___________________________
27. Is the tank cleaned?
    a. Yes
    b. No
28. If yes to cleaning, how frequently?
    a. Daily
    b. Weekly
    c. Monthly
    d. Every few months
    e. Annually
    f. Rarely
29. If yes to cleaning, when was the last time of cleaning
    a. Within the last two weeks
    b. Within the last month
    c. Within the last six months
    d. Within the last year

Household Practice & Water Quality Beliefs

30. How frequently do you have access to running pipe water?
    a. All day
    b. Half a day (only evenings or only daytime)
    c. A few hours a day
31. Are you connected to the municipal water system?
    a. Yes
    b. No

32. f you are NOT connected to municipal water system, how far do you travel for water?
    a. Less than 0.5 mile
    b. 0.5-1 mile
    c. More than 1 mile
    d. Other ______________________
33. If you are NOT connected to municipal water system, where do you obtain water from?
    a. Neighbor pipe
    b. Canal
    c. Rainfall
    d. Other ___________________
34. If you are connected to municipal water system, how do you classify the supplied water?
    a. Brown
    b. Smelly
    c. Yellow
    d. Turbid
    e. Clear
35. If you are connected to municipal water system, what is your water pressure like?
    a. Good
    b. Average
    c. Bad
36. If you pay for any of the above sources of drinking water, how much do you pay?
    a. Less than $500
    b. $500-$1000
    c. More than $1000
37. How long does this water last for drinking?
    a. 1 week
    b. 1-3 weeks
    c. More than 3 weeks

38. What container do you use to collect drinking water from the storage tank?
    a. Bucket
    b. Pot
    c. Bottle
    d. Other ______________________
39. Do you cover the container when transporting water?
    a. Yes
    b. No
    c. If yes, what do you cover it with? __________________________
40. Do you keep drinking water within reach of young children?
    a. Yes
    b. No
41. If yes, do they normally put hands or objects in the water?
    a. Yes
    b. No
    c. Sometimes
42. Who is responsible for cleaning/disinfecting the water storage tank?
    a. Male head of house
    b. Female head of house
    c. Child
    d. Other_________________________
43. Who is responsible for filling the water storage tank?
    a. Male head of house
    b. Female head of house
    c. Child
    d. Other_________________________
44. Who is responsible for collecting water from the storage tank for use?
    a. Male head of house
    b. Female head of house
    c. Child
    d. Other_________________________
45. In the past year, have you seen or received any information (brochure, flyer, TV or radio announcement) about keeping your water safe or about handwashing?
    a. Yes
    b. No

Appendix C. (Continued)

46. Is handwashing always practiced prior to filling water storage tank or dispensing water from water storage tank?
    a. Yes
    b. No
    c. Sometimes
47. How confident are you that the water stored in the tank is safe for drinking?
    a. Very confident
    b. Somewhat confident
    c. Not confident
48. How confident are you that using a water storage tank will reduce your risk to water-related illnesses?
    a. Very confident
    b. Somewhat confident
    c. Not confident
49. Have you recently experienced an illness resulting from drinking the water in your storage container?
    a. Yes
    b. No
50. If yes to the illness, was it medically diagnosed?
    a. Yes
    b. No
51. If yes to the illness, what symptoms did you have?
    a. Diarrhea b. Stomach pains/cramps c. Fever
    d. Nausea e. Skin rash/infection f. Loss of appetite
    g. Other______________________

Appendix C. (Continued)

Study Information Sheet for Survey Participants: Trinidad and Tobago
Name of person conducting survey:____________________ Date:______________

You have taken part in a survey for a research study described here.

STUDY TITLE: Environmental Health in the Caribbean: Correlation between Use of Water Storage Containers, Water Quality, & Community Perception

PERSON IN CHARGE: Dr. Maya Trotz **PHONE NUMBER:** 1-813-974-3172
EMAIL: matrotz@eng.usf.edu

LOCAL CONTACT in Trinidad and Tobago: Dr. Maria Byron 1-868-662-2002, EXT 3403

PURPOSE: The purpose of this research is to understand how households use water storage tanks and determine the effect of these tanks and the individual practices on water quality.

RISKS, BENEFITS, AND ALTERNATIVES: There are no known risks or benefits to participation in this study. You have the alternative to choose not to participate. Your participation is voluntary. You may withdraw at any time without penalty.

CONFIDENTIALITY: We have not collected any information about you that could identify you. The information we have collected will be combined with information from other sources to meet the study goals. Results of the study may be published, but will not contain any personally identifiable information about you.

CONSENT: A verbal consent process was used for your participation in this study. If you decide at any time that you want your information to be excluded from this research study, please use the contact phone number above and provide your survey number (in the top right corner of the information sheet) so that your information can be removed from the study.

QUESTIONS OR COMPLAINTS:
If you have any concerns, do not hesitate to call the numbers listed above.
If you have questions about your rights, general questions, complaints, or issues as a person taking part in this study, call the Division of Research Integrity and Compliance of the University of South Florida at 1-813-974-9343.

Appendix C. (Continued)

Study Information Sheet for Survey Participants: Guyana
Name of person conducting survey:_____________________ Date:_______________

You have taken part in a survey for a research study described here.

STUDY TITLE: Environmental Health in the Caribbean: Correlation between Use of Water Storage Containers, Water Quality, & Community Perception

PERSON IN CHARGE: Dr. Maya Trotz **PHONE NUMBER:** 1-813-974-3172
EMAIL: matrotz@eng.usf.edu

LOCAL CONTACT in Guyana: c/o Dr. Rupert Roopnarine (Guyana Citizen's Initiative)
PHONE NUMBER: (592) 227-5523/24

PURPOSE: The purpose of this research is to understand how households use water storage tanks and determine the effect of these tanks and the individual practices on water quality.

RISKS, BENEFITS, AND ALTERNATIVES: There are no known risks or benefits to participation in this study. You have the alternative to choose not to participate. Your participation is voluntary. You may withdraw at any time without penalty.

CONFIDENTIALITY: We have not collected any information about you that could identify you. The information we have collected will be combined with information from other sources to meet the study goals. Results of the study may be published, but will not contain any personally identifiable information about you.

CONSENT: A verbal consent process was used for your participation in this study. If you decide at any time that you want your information to be excluded from this research study, please use the contact phone number above and provide your survey number (in the top right corner of the information sheet) so that your information can be removed from the study.

QUESTIONS OR COMPLAINTS:
If you have any concerns, do not hesitate to call the numbers listed above.
If you have questions about your rights, general questions, complaints, or issues as a person taking part in this study, call the Division of Research Integrity and Compliance of the University of South Florida at 1-813-974-9343.

Appendix C. (Continued)

WATER, SANITATION AND HYGEINE

- **If you use tap water for drinking purposes do one of the following:**
    - Pour one teaspoon (5 ml) of bleach into 20-25 litres of water and mix well, wait for 30 minutes (half Hour).
    - Boil the water. Let the water bubble for one min, to make it clean and safe.
- **Keep your toilet clean**
    - Clean the entire toilet with soap and water to keep it safe and clean from germs
    - Always keep toilet seat down
    - Keep toilet door closed
    - Do not throw waste in the toilet
- **Keep your water storage containers safe**
    - Always keep your water container clean
    - Always keep water container closed
    - Always use a clean jar when scooping water from the container
- **Why is hand washing so important?**
    - Around four billion cases of diarrhoea are recorded worldwide each year.
    - Diarrhoeal diseases claim the lives of nearly two million children every year.
    - Human waste (faeces) is the source of most diarrhoeal pathogens or germs.
    - One gram of faeces can contain 10 million viruses, 1 million bacteria, 1000 parasite cysts and 100 worm eggs.
    - Adequate sanitation can reduce the incidence of diarrhoeal diseases by up to 40%.
    - Hand washing with soap can reduce the incidence of diarrhoeal diseases by 42-46%.
    - Worldwide, hand washing with soap could save a million lives each year.
- **Diarrhoea**

Germs from human waste (faeces) cause diarrhoea, including cholera.
Wash your hands (with soap or ash and safe water) before you eat or prepare food, or after you have been to the toilet.
If you get sick with diarrhoea (runny tummy) or start vomiting go to your clinic for help.

FOR MORE INFORMATION PLEASE CONTACT YOUR LOCAL MINISTRY OF HEALTH

No de Encuesta: Ciudad, País: Fecha:

Salud Ambiental en El Caribe: Almacenamiento de Agua y Calidad de Agua
Encuesta Comunitaria

<u>Información Personal</u>

1. Cuales su genero?
    a. Masculino
    b. Femenino
2. Cual es su edad?
    a. 18-35
    b. 36-50
    c. 50-65
    d. Mayor que 65
3. Cuantas personas viven en su vivienda?
    a. 1-3
    b. 4-7
    c. Mas que 8
4. Cuantos mayores de edad (18 o mayor)?
    a. 1-3
    b. 4-7
    c. Mas que 8
5. Cuantos menores de edad (menor que 18 años) viven en casa?
    a. 1-3
    b. 4-7
    c. Mas que 8
6. Cual es el rango de las edades de los niños?
    a. Menor que 5 años
    b. 5-10 años
    c. 11-15 años
    d. 15- 18 años

Appendix C. (Continued)

<u>Sobre El Tanque/Envase de Almacenamiento de Agua</u>

7. Cual es el color del tanque/envase?
    a. Negro
    b. Verde
    c. Azul
    d. Blanco
    e. Marrón
    f. Otro color:______________________
8. De que material esta hecho el tanque/el envase?
    a. Plástico
    b. Metal (aluminio, hierro)
    c. Ceramico
    d. Metal con capa de concreto
    e. Otro_________________________
9. Tiene un contenedor (tanque, tinaco, etcétera) para almacenar el agua recibida (de tubería o la lluvia)?
    a. Si
    b. No
10. Cuantos años tiene el tanque en este función?
    a. 0-3 años
    b. 4-10 años
    c. 11-15 años
    d. 16-20 años
    e. Mas que 20 años
11. Que es la capacidad del tanque en galones? ______________________
12. Donde esta ubicado el tanque?
    a. En sima de una barraquilla
    b. En el piso
    c. Otro lugar _____________________
13. Usan una tapa para el envase/tanque?
    a. Si
    b. No
14. Con que lo tapan? ______________________
15. Beben el agua del tanque?
    a. Si
    b. No

Appendix C. (Continued)

16. El agua del tanque esta hervida antes de bebérsela?
    a. Si
    b. No
17. El agua del tanque esta filtrada antes de bebérsela?
    a. Si
    b. No
18. Si respondió afirmativo a #17, cuales la metodología de filtrar el agua o cuales materiales usa?_______________________
19. Con que frecuencia usan Usted y los de mas en su casa, agua embotellada?
    a. Diario
    b. Semanalmente
    c. Infrecuentemente
    d. Nunca
20. Cual es el fuente de agua usada en el tanque?
    a. De una red de tubería
    b. Agua superficial traída por individuos al tanque.
    c. De Lluvia
    d. Malacate/Bomba
    e. Otro _________________________
21. El tanque ha sido tapado en las dos ultimas semanas antes de colectar la muestra?
    a. Si
    b. No
22. Desinfectan el tanque?
    a. Si
    b. No
23. Si lo desinfectan, con que frecuencia?
    a. Diariamente
    b. Semanalmente
    c. Mensualmente
    d. Cada dos meses
    e. Anualmente
    f. Infrecuente

Appendix C. (Continued)

24. Si lo desinfectan, cuando fue la ultima vez que lo desinfectaron el tanque?
    a. Entre las dos ultimas semanas
    b. Entre el ultimo mes
    c. Entre los últimos 6 meses
    d. Entre el ultimo año
25. Si los desinfectan, que cantidad de cloro echan al contenedor?
    a. 2 gotas
    b. 1 cucharita
    c. 1 cuchara
    d. 1 tapita llena
26. Desprez de tratar con cloro cuanto tiempo lo dejan mezclar o disolver antes de consumir?
    a. Menos que 10 minutos
    b. 10 – 15 minutos
    c. 15 - 30 minutos
    d. Que pasa la noche
    e. Otro____________________________
27. Limpian el tanque?
    a. Si
    b. No
28. Si lo limpian, con que frecuencia?
    a. Diariamente
    b. Semanalmente
    c. Mensualmente
    d. Cada dos meses
    e. Anualmente
    f. Infrecuente
29. Si lo limpian, cuando fue la ultima vez
    a. Entre la ultimas dos semanas
    b. Entre el ultimo mes
    c. Entre los últimos 6 meses
    d. Entre el ultimo año

Appendix C. (Continued)

Comportamiento Casero y Creencia de Calidad de Agua

30. Con que frecuencia tiene acceso a agua de tubería/red de distribución?
    a. Toda el día
    b. La mitad del día (solo en la tarde o solo durante del día)
    c. Algunas horas del día
31. Están conectados al sistema de agua de la municipalidad?
    a. Si
    b. No
32. Si NO están conectados al sistema, que distancia caminan para buscar el agua.
    a. Menos que media milla
    b. 0.5-1 milla
    c. Mas que 1 milla
    d. Otra distancia___________
33. Si NO están conectados al sistema, de donde obtienen su agua?
    a. Tubería del vecino
    b. Canal
    c. Lluvia
    d. Otro fuente___________
34. Si están conectados al sistema municipal, como clasificaría el agua dotada?
    a. Sucia
    b. Hedionda
    c. Amarilla
    d. Turbia
    e. Clara
35. Si están conectados al sistema municipal, cual es la presión en su conexión?
    a. Buena
    b. Regular
    c. Mala
36. Si pagan para el servicio de agua potable, cuanto pagan?
    a. Menos que 7Bs
    b. 7Bs-10Bs
    c. Mas que 10Bs

37. Cuanto tiempo dura el agua?
    a. 1 semana
    b. 1-3 semana
    c. Mas que 3 semanas
38. Cual contenedor usan para recoger el agua de beber del tanque?
    a. Un balde
    b. Hoyo
    c. Botella
    d. Otro ___________________
39. Cuando transportan el agua lo tapan?
    a. Si
    b. No
    c. Si lo tapan, que es lo que usan?_________________________
40. El agua es almacenada dentro del alcance de niños?
    a. Si
    b. No
41. Si es, ellos normalmente ponen sus manos o objetos en el agua?
    a. Si
    b. No
    c. A veces
42. Quien es responsable para la limpieza y desinfección del tanque?
    a. Hombre cabeza de la casa
    b. Mujer cabeza de la casa
    c. Nino
    d. Otro________________________
43. Quien es responsable para llenar el tanque con agua?
    a. Hombre cabeza de la casa
    b. Mujer cabeza de la casa
    c. Nino
    d. Otro________________________
44. Quien es responsable para recoger el agua del tanque?
    a. Hombre cabeza de la casa
    b. Mujer cabeza de la casa
    c. Nino
    d. Otro________________________

45. En el ultimo año, ha visto o recibo alguna información (folleto, volante, anuncio de televisión o radio) sobre como proteger el agua o lavarse las manos?
    a. Si
    b. No
46. Siempre lavan las manos antes de llenar el tanque con agua o dispensar agua del tanque?
    a. Si
    b. No
    c. A veces
47. Que nivel de confianza tiene de que el agua almacenada es segura de beber?
    a. Mucho confianza
    b. Poco confianza
    c. No confianza
48. Que nivel de confianza tiene que usando un tanque de almacenar su agua reducirá el riesgo de enfermedades relacionadas con el agua?
    a. Muy confianza
    b. Poco confianza
    c. No confianza
49. Últimamente, ha tenido usted una enfermedad como resulto de beber agua del envase de almacenamiento?
    a. Si
    b. No
50. Si ha tenido una enfermedad, la enfermedad fue diagnosticada por un medico?
    a. Si
    b. No
51. Si ha tenido una enfermedad, cuales eran las síntomas que tuvo?
    a. Diarrea b. Dolor del estómago c. Fiebre
    d. Nausea e. erupción/infección del la piel f. Perdida de apetito
    g. Otra síntoma________________________

Appendix C. (Continued)

Formulario de Información para Los Participantes en la Encuesta del Estudio: Bolivia
Nombre y Apellido de la persona ejecutando la encuesta:__________________________
Fecha:_________________

Usted ha participado en una encuesta para la investigación explicada abajo.

EL TITULO DE LA INVESTIGACION: Ambiental en el Caribe: Correlación entre el Uso de Envases de Agua, Calidad de Agua, y Percepción Comunitario.

LA ENCARGADA: Doctora Maya Trotz **TELEFONO:** 1-813-974-3172
CORREO ELECTRONICO: matrotz@eng.usf.edu

EL CONTACTO LOCAL en Bolivia: Nathan Reents **TELEFONO:** 591-227-8665

EL OBJECTIVO: El objetivo de esta investigación es entender como los menajes usan diferentes envases de almacenamiento de agua y determinar el efecto de estos envases y los comportamientos individuales sobre la calidad del agua.

LOS RIESGOS, BENEFICIOS, Y ALTERNATIVOS: No existe un riesgo ni beneficio conocido de participar en esta encuesta. Usted tiene el alternativo de no participar. Su participación es voluntaria. Usted puede retirar en cualquier momento sin ninguna consecuencia.

LA CONFIDENCIALIDAD: No hemos colectado información sobre usted que podría ser utilizado para identificarle. La información que hemos recogido será agregada a otros datos de otras fuentes para llevar a cabo los dichos objetivos. Los resultados de este estudio podrían ser publicados, pero no contendría información que podría ser utilizada para identificar o distinguir usted.

EL PERMISO: Un proceso de permiso verbal ha sido utilizado para su participación en esta encuesta. Si usted decide en cual quiere momento que no quiera que su información fuera incluida en esta investigación, favor de contactarnos al número de teléfono listado. Si desea saquemos sus datos del estudio.

CUESTIONES O QUEJAS:
Si usted tiene alguna preocupación, por favor no hesite en llamar el número de teléfono listado. Si usted tiene preguntas sobres sus derechos, preguntas generales, quejas, o asuntos como participante en este estudio, llame la División de Integridad en Investigaciones y Cumplimiento de la Universidad de Florida- Sur a 1-813-974-9343.

Appendix C. (Continued)

AGUA, SANAMIENTO, E HIGIENE

- **Si Usted bebe agua de la llave, use una de la siguientes metodologías para disinfectar el agua:**
    - Eche una cuchara (5 mili-litros) de cloro a 20-25 litros de agua y agítela bien, espere 30 minutos para bebérsela
    - Hierve el agua. Deje que el agua hierve un minuto para que sea desinfectada.
- **Mantener su inodoro o letrina limpio/a**
    - Lave la bacinilla completa con jabón y agua para mantener libre de gérmenes
    - Siempre mantenga la bacinilla tapada
    - Mantener cerrada, la puerta del baño
    - No tire basura en la bacinilla
- **Mantener sus envases de agua seguros**
    - Siempre mantener sus envases limpios
    - Siempre mantener su envases tapados
    - Siempre use un implemento limpio para sacar agua del envase
- **Porque lavarse las manos es importante?**
    - Mas que 4 billones de casos de diarrea ocurren en el mundo cada año
    - Enfermedades de diarrea causan la muerte de casi 2 millones de niños cada año
    - Materia fecal es el fuente de la mayoría de patógenos o gérmenes que causan diarrea
    - Un solo grama de material fecal contiene 10 millones de virus, 1 millón bacteria, 1000 quistes parasito y 100 huevos de guísanos.
    - Saneamiento adecuado puede reducir la incidencia de enfermedades de diarrea por hasta 40%.
    - Lavarse las manos con jabón puede reducir la incidencia de enfermedades de diarrea por 42-46%.
    - Mundial, lavarse las manos con jabón podría salvar la vida de 1 millón de personas cada año.
- **Diarrea**
    - Gérmenes de material fecal de ser humano causa diarrea, y cólera.
    - Lávese las manos (con jabón y ceniza y agua limpia) antes de comer o preparar comida y después de usar el baño. .
    - Si se enferma con diarrea o empieza vomitando vaya al clínica para ayuda.

PARA MAS INFORMACION POR FAVOR CONTACTE SU MINISERIO DE SALUD Y DEPORTES

Appendix D. Field Observations

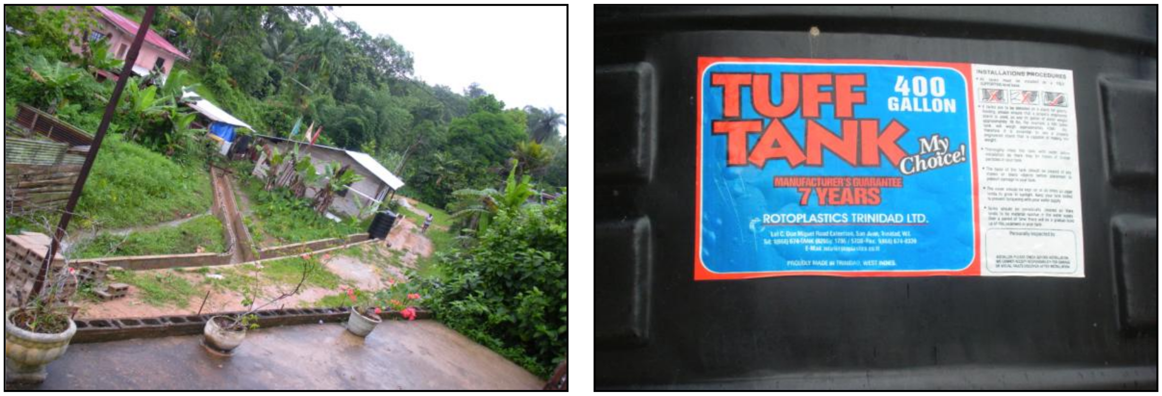


Figure D.1 Community within Siparia, Trinidad and Tobago.

Figure D.2 Household water storage tanks in Siparia, Trinidad and Tobago.

Figure D.3 Household water storage drum in Siparia, Trinidad and Tobago. Left, exterior and right, interior.

Appendix D. (Continued)

Figure D.4 Pictures from Water and Sewerage Authority of Trinidad and Tobago (WASA), Penal Plant.

Appendix D. (Continued)

Figure D.5 Infrastructures at the Water and Sewerage Authority of Trinidad and Tobago (WASA), Penal Plant.

Appendix D. (Continued)

Figure D.6 Processes at the Water and Sewerage Authority of Trinidad and Tobago (WASA), Penal Plant.

Appendix D. (Continued)

Figure D.7 Water storage devices and interior of water storage tank in Mocha-Arcadia Neighborhood Democratic Community, Guyana.

Appendix D. (Continued)

Figure D.8 Pictures from a Guyana Water Inc (GWI) treatment plant in Georgetown, Guyana.

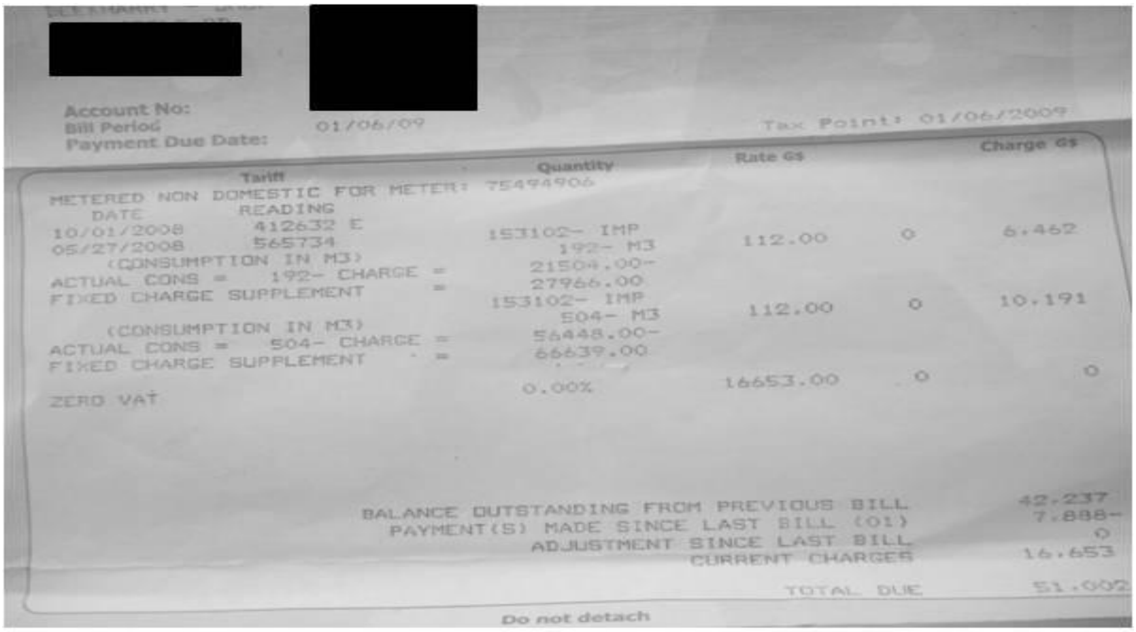
Appendix D. (Continued)

Figure D.9 Residential homes and sources of water seen throughout Georgetown, Guyana.

Appendix D. (Continued)

Figure D.10 Various water storage tank elevations seen in Georgetown, Guyana.

Appendix D. (Continued)


[redacted] [redacted]

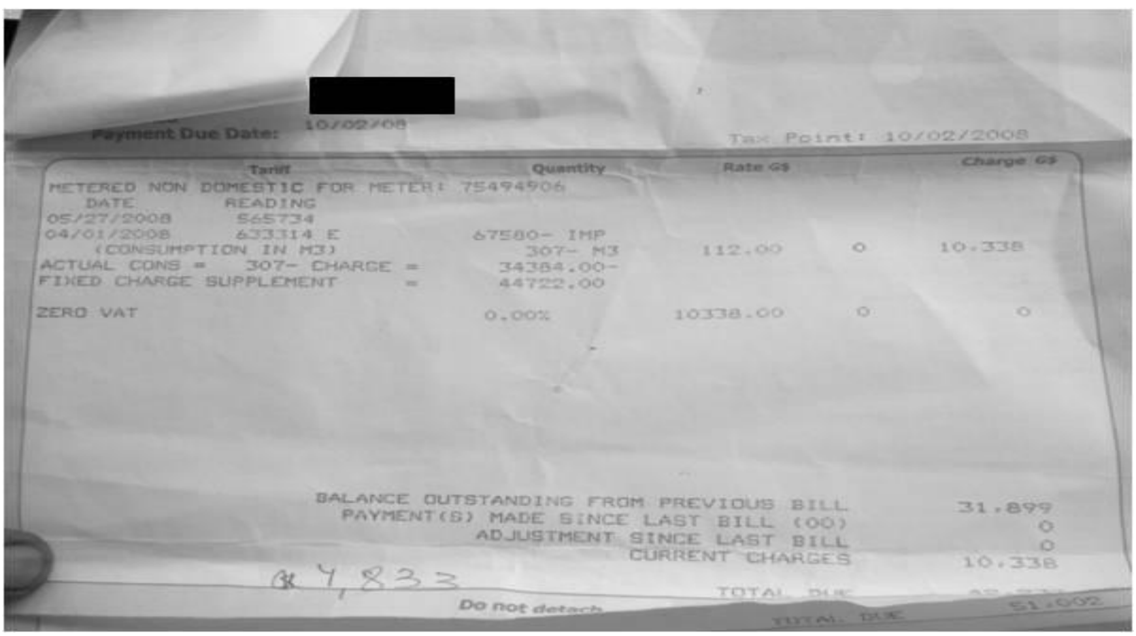
Account No:
Bill Period
Payment Due Date: 01/06/09

Tax Point: 01/06/2009

Tariff	Quantity	Rate G$		Charge G$
METERED NON DOMESTIC FOR METER: 75494906				
DATE READING				
10/01/2008 412632 E	153102- IMP			
05/27/2008 565734	192- M3	112.00	0	6.462
(CONSUMPTION IN M3)				
ACTUAL CONS = 192- CHARGE =	21504.00-			
FIXED CHARGE SUPPLEMENT =	27966.00			
	153102- IMP			
(CONSUMPTION IN M3)	504- M3	112.00	0	10.191
ACTUAL CONS = 504- CHARGE =	56448.00-			
FIXED CHARGE SUPPLEMENT =	66639.00			
ZERO VAT	0.00%	16653.00	0	0

BALANCE OUTSTANDING FROM PREVIOUS BILL	42.237
PAYMENT(S) MADE SINCE LAST BILL (01)	7.888-
ADJUSTMENT SINCE LAST BILL	0
CURRENT CHARGES	16.653
TOTAL DUE	51.002

Do not detach


[redacted]

Payment Due Date: 10/02/08

Tax Point: 10/02/2008

Tariff	Quantity	Rate G$		Charge G$
METERED NON DOMESTIC FOR METER: 75494906				
DATE READING				
05/27/2008 565734				
04/01/2008 633314 E	67580- IMP			
(CONSUMPTION IN M3)	307- M3	112.00	0	10.338
ACTUAL CONS = 307- CHARGE =	34384.00-			
FIXED CHARGE SUPPLEMENT =	44722.00			
ZERO VAT	0.00%	10338.00	0	0

BALANCE OUTSTANDING FROM PREVIOUS BILL	31.899
PAYMENT(S) MADE SINCE LAST BILL (00)	0
ADJUSTMENT SINCE LAST BILL	0
CURRENT CHARGES	10.338
TOTAL DUE	

4,833

Do not detach

TOTAL DUE 51.002

Figure D.11 Typical water bill received from Guyana Water Inc in Georgetown, Guyana.

Appendix D. (Continued)

Figure D.12 Entrance to Villa Litoral community, Bolivia.

Figure D.13 Water sources in Villa Litoral, Bolivia. Left, dug well and right, stand pipe.

Appendix D. (Continued)

Figure D.14 Community pump and water source in Villa Litoral, Bolivia.

Appendix D. (Continued)

Figure D.15 Household cement water storage tanks in Villa Litoral, Bolivia.

Figure D.16 Elevated black water storage tanks in Villa Litoral, Bolivia.

Appendix D. (Continued)

Figure D.17 Plastic water storage containers used in Villa Litoral, Bolivia.

Figure D.18 The community of Villa Litoral, Bolivia.

Appendix D. (Continued)

Figure D.19 Housing within Villa Litoral, Bolivia.

Figure D.20 Community health center for Villa Litoral, Bolivia.

Appendix D. (Continued)

Figure D.21 Public meeting regarding state of community water source and sanitation.

Figure D.22 National campaign on preventing the spread of Dengue in Villa Litoral, Bolivia.

Appendix E. Box Plots for Heavy Metal Concentrations

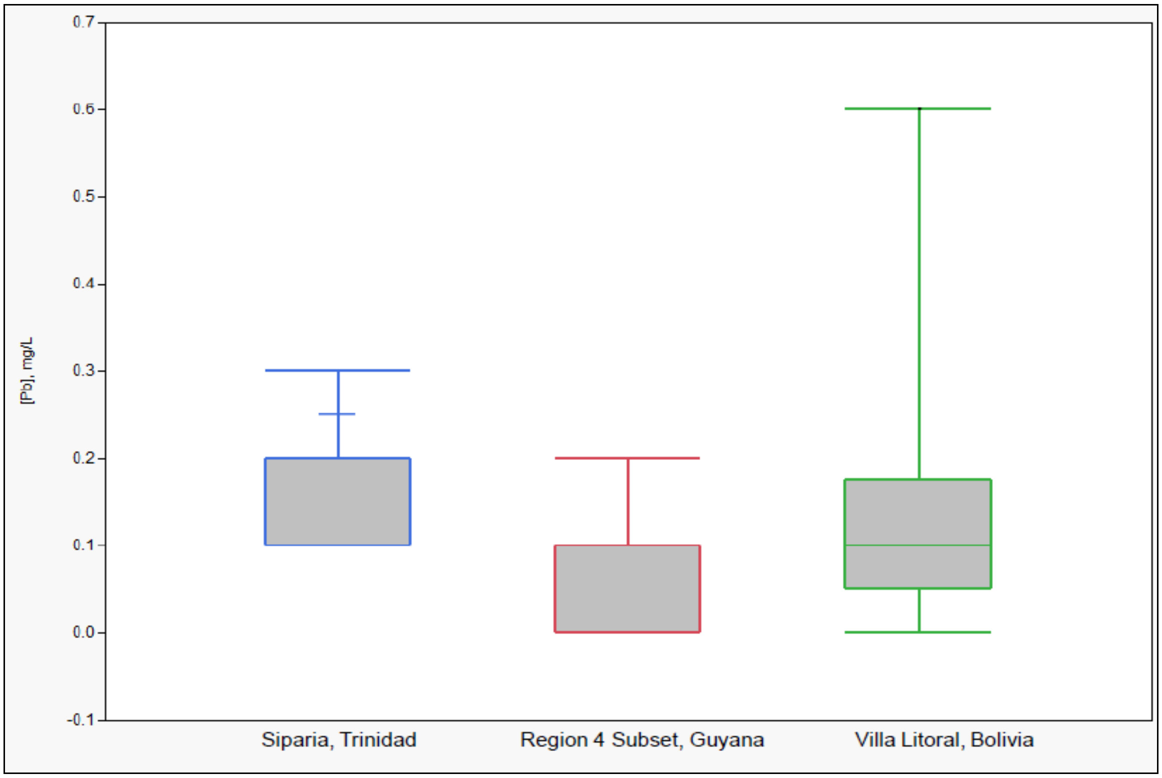


Figure E.1 Comparison of lead concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix E. (Continued)

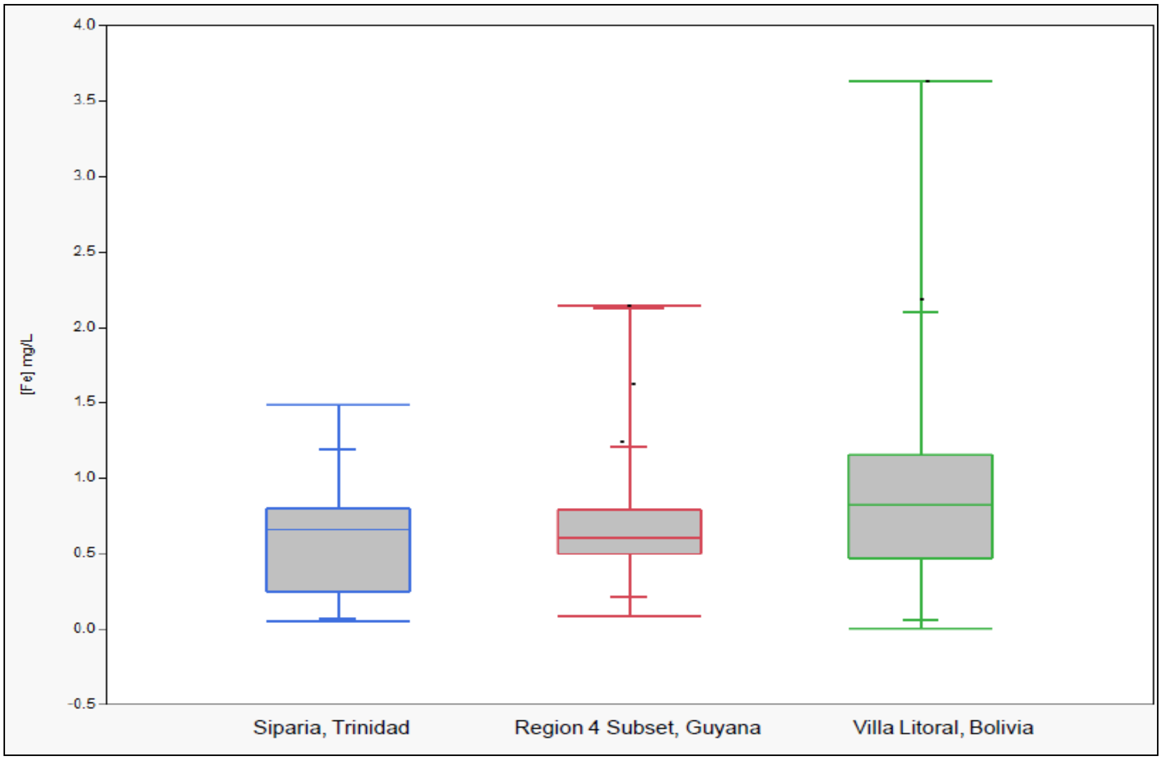


Figure E.2 Comparison of iron concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix E. (Continued)

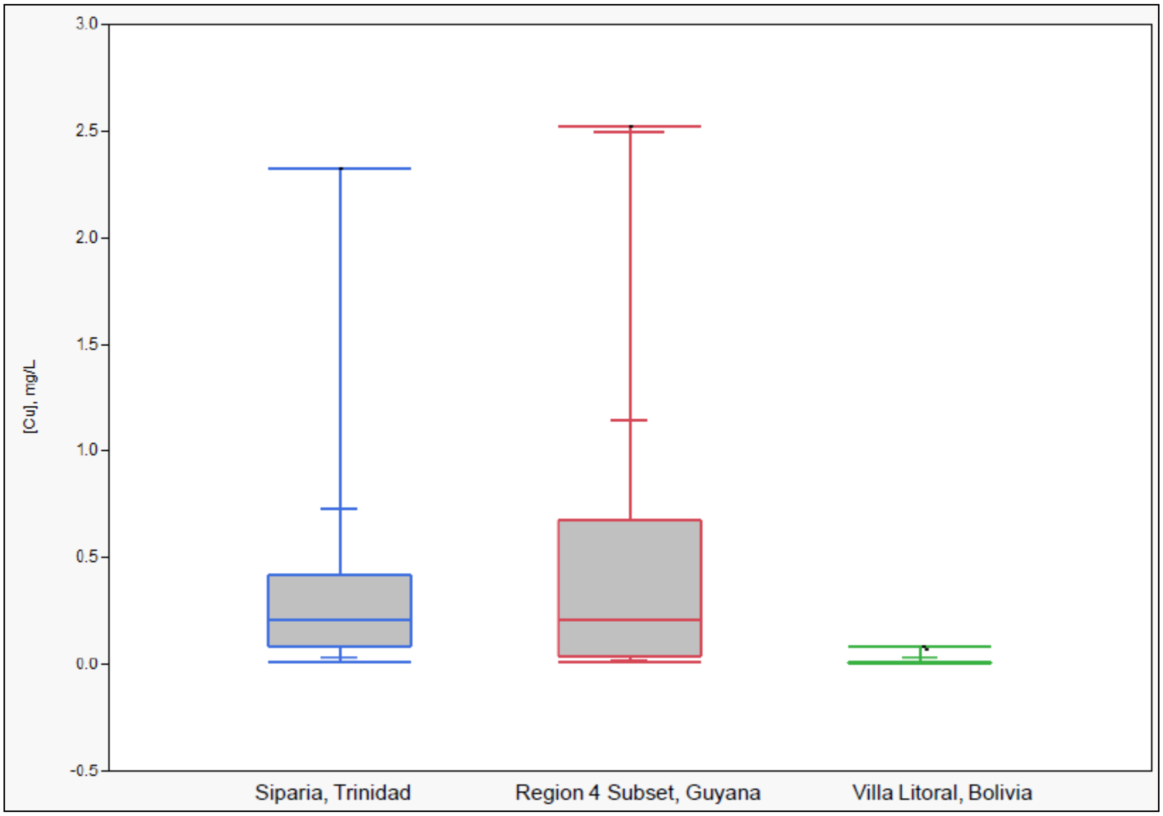


Figure E.3 Comparison of copper concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix E. (Continued)

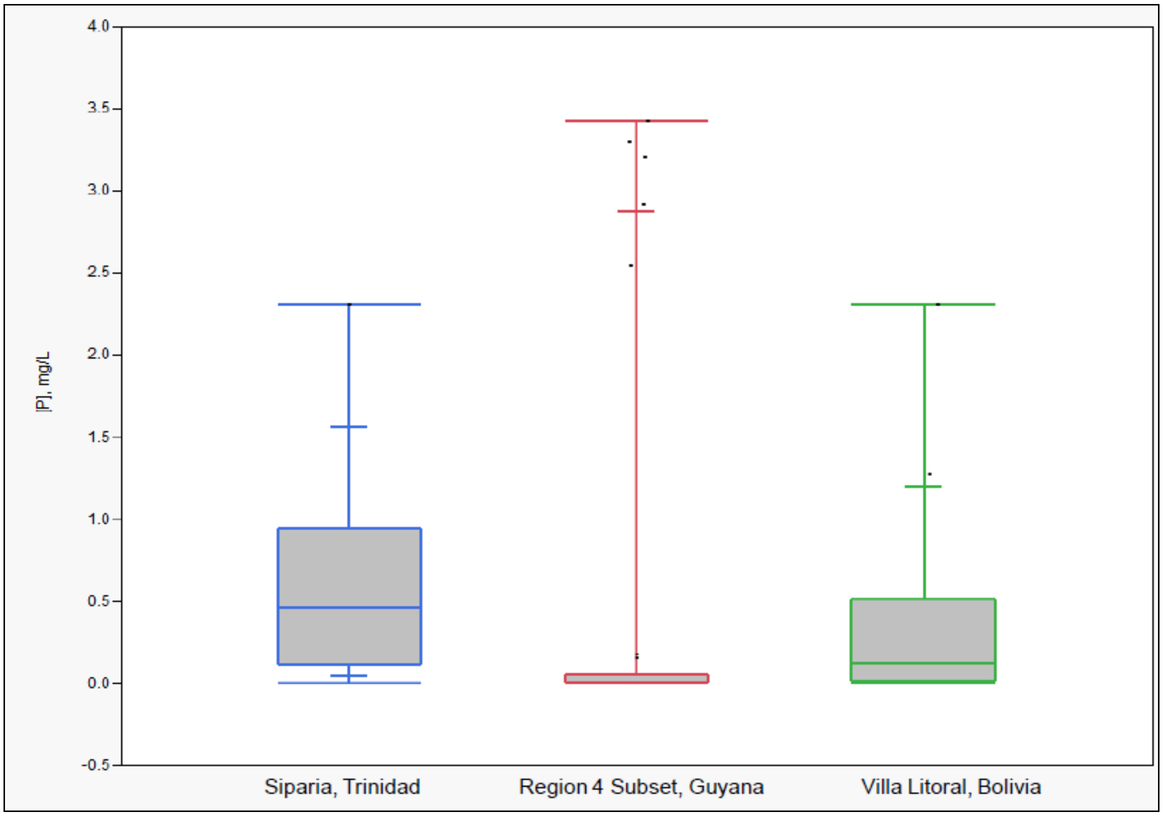


Figure E.4 Comparison of phosphorus concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix E. (Continued)

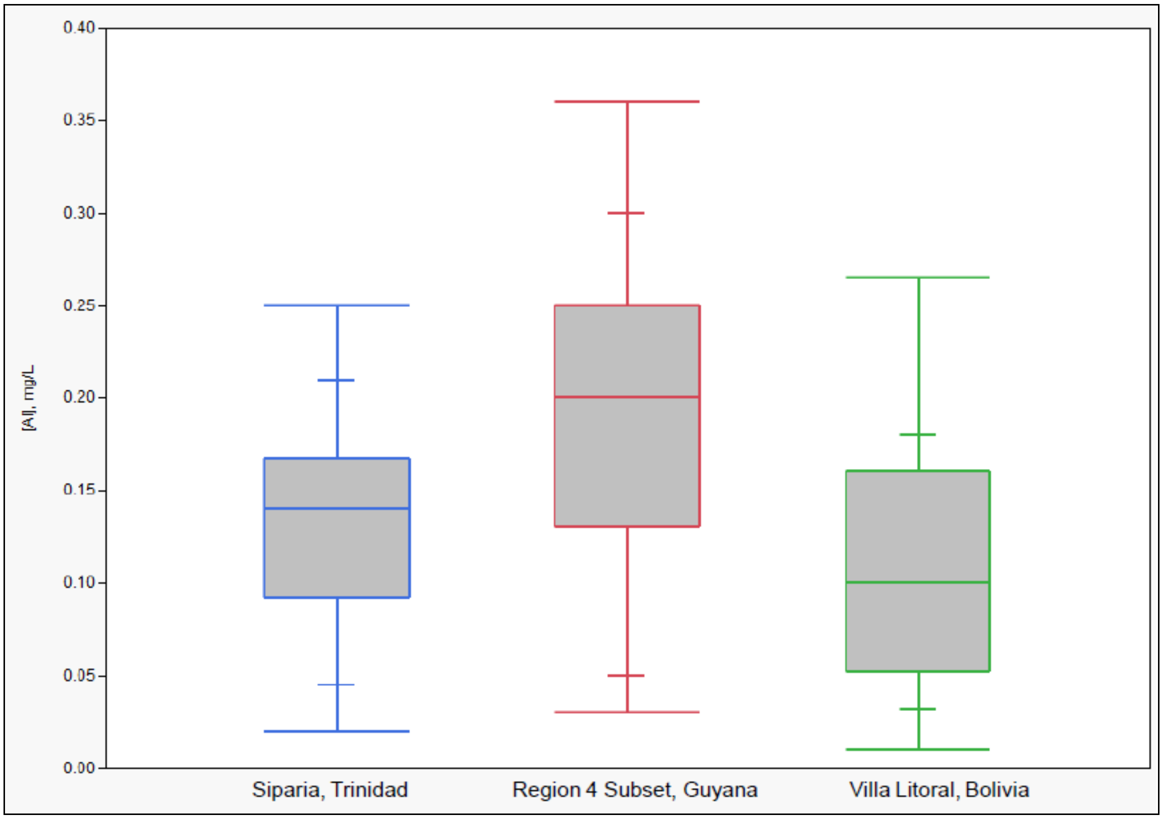


Figure E.5 Comparison of aluminum concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix E. (Continued)

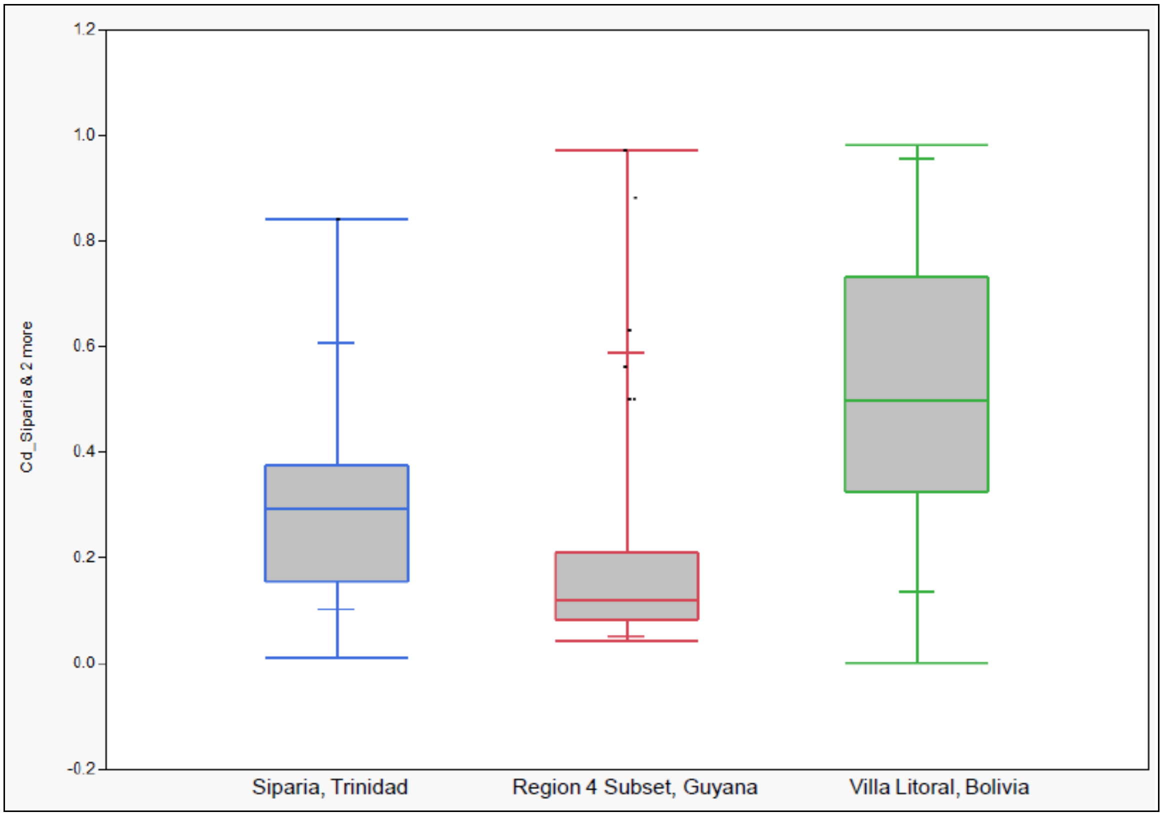


Figure E.6 Comparison of cadmium concentrations present in water sources within households in the Latin American and Caribbean region. Number of samples: Siparia, Trinidad and Tobago (24), Region 4 Subset, Guyana (40), Villa Litoral, Bolivia (26).

Appendix F. Technical Reports

Technical Report on Findings from Environmental Health and Household Water Storage in Trinidad and Tobago

Prepared by Erlande Omisca, MPH, CPH

Introduction

In March 2009, research was conducted within the community of Siparia, Trinidad and Tobago by University of South Florida (Tampa, Florida USA) graduate students. The research consisted of conducting a household survey and collecting water samples from household water sources for analysis. Thirty-nine household surveys were conducted and twenty-four water samples collected. The results are explained below.

Household Water Treatment & Device Maintenance

Ninety- two percent of households in Siparia used their water storage device for drinking. While water boiling is one of the universal methods of water treatment at the household level, the majority of the households surveyed in Siparia (71.8%) did not practice it. In the households where it was practiced, filtration was achieved through the use of a cloth or a sieve. Several participants surveyed in Siparia commented that they allowed the water to "stand" prior to usage so that any sediment or particles present could settle to the bottom. The frequency of bottled water usage was assessed among the communities surveyed. A third of households surveyed in Siparia used bottled water for drinking on a daily or weekly basis.

The frequency of the disinfection was also assessed. Fifty-nine percent of households who reported disinfecting the water within their storage device did so every few months, while 25% reported doing so on a monthly basis. Eight percent of households disinfected their water weekly or annually. Various reasons were given by all households surveyed for not disinfecting, such as not liking the taste of the disinfected water, not being able to access the disinfection materials, and inconvenience.

The majority of households in Siparia (92.3%) reported cleaning their respective storage devices. Households in Siparia were three times more likely to clean their storage devices than to disinfect their water. Participants were more apt to clean their storage device as no additional materials were needed and they did not have to remember correct dosages. Several residents said they left the tops of their tanks and devices open so that rainwater could flush out the interior of the device thereby cleaning it. Some residents also used this approach to fill their storage devices.

Households were then asked to report the time of the most recent chemical disinfection and the type of disinfection practice used. In Siparia, chemical disinfection of water storage devices had occurred within a

1

month of the survey. Dosages varied among the households, as shown in Table 1. In Siparia, 83% of households who disinfected used a cork-full of bleach in water storage devices. Others reported using a tablespoon or a teaspoon of bleach to disinfect water storage devices.

Bleach mix time also varied among the households, as shown in Table 1. In Siparia, 33.3% of households who disinfected allowed the treated water to mix for roughly 15 minutes before use, while 25% of households allowed 30 minutes. Other residents allowed the water to mix for less than 10 minutes (16.7%) or overnight (25%).

While chemical disinfection holds several benefits, it is only effective when the adequate dosage is used and adequate chlorine retention time is allowed. In several of the households, chlorine was being used to disinfect various volumes of water such as a water jug, a gallon jug, a pitcher, or an entire water storage tank/device. Even when the correct dosage is used, the chlorine is not allowed to sit for an adequate amount of time. In such cases, inadequate mixing time results in an inadequate residual in the water, which increases the potential for microbial re-growth in water sources.

Various factors may impact the frequency at which household water storage devices were cleaned. Many of the households surveyed either owned water storage devices with capacities above 400 gallons, had devices which were elevated well above ground level, or were connected to pipes leading into the kitchen and bathrooms. It is likely that these attributes make it difficult to clean the storage devices as frequently as one would wish or is needed, though guidelines for cleaning water storage devices in the regions studied are non-existent. As was previously mentioned, flushing the storage tanks with rainwater was used to clean tanks in some places. Hence, household members coordinate device cleaning with rain episodes. This could explain why many households clean their tanks on a quarterly, annual, or even rare basis.

Community residents were asked to describe the water quality that they received from the municipal water source. The majority of the households in Siparia, Trinidad and Tobago (74%) reported the water source as being brown. Oftentimes, residents would let the water settle or utilize filtration mechanisms prior to drinking. The brown color could be attributed to several factors. The majority of the households received water access in the morning, when the pumps would be turned on. As a result, all the sediment build-up within the pipes from the previous day was also brought in with the water source. A second factor could be high iron and/or manganese content in the water.

Household Practices

Household water responsibilities were assessed for Siparia. In terms of filling the storage devices and ensuring there were no leaks, the duty was performed primarily by the male head of the house (53.8%), followed by the female head (30.8%), a child of the homeowner (17.9%) or other persons (17.9%). Five

2

Figure F.1 Preliminary technical report for Trinidad and Tobago.

Appendix F. (Continued)

percent reported that no one takes filling responsibilities for the storage devices, as they simply allow the rain to fill them. Additionally, the male head is primarily responsible for cleaning the devices in 64.1% of households, compared to the female head (30.8%) and child (23.1%). The responsibility of collecting water from the storage device is primarily that of the male head (51.3%) or the female head (46.2%).

Health

Survey participants were asked whether they had received waterborne advisories or information through various sources of media (TV, radio, flyers, etc.) in the past year. Only a third of the households surveyed in Siparia reported receiving any information or advisories within the past year. The frequency of handwashing prior to water handling was assessed. Roughly forty-four percent of households in Siparia reported frequent handwashing.

When asked about their confidence in the potability and security of their drinking water sources, the majority of households surveyed in Siparia (84.6%) were either very confident or somewhat confident that their water sources were safe for consumption, When asked about their confidence in the water storage systems to keep their water safe, the majority of households surveyed in Siparia (76.9%) were either very confident or somewhat confident that their water sources was safe for consumption,

Participants were asked whether there were any recent waterborne illnesses among those living within the respective home. In Siparia, only one household reported having a recent waterborne illness, in which case the individual experienced headaches following consumption of the water.

Bacterial Contamination

The World Health Organization (WHO) guidelines for microbial measurements state that drinking water should be free of both fecal and total coliform. In Siparia, only one household sampled tested positive for fecal coliform while 25% of households tested positive for total coliform. All of the fecal positive samples came from water piped from the main distribution line, while 83% of samples testing positive for total coliform came from the piped water source.

The presence of coliform in the water could be attributed to several factors, such as increased rain levels, unsanitary handling of water, inadequate disinfection both at the distributing plant and in the household. At the WASA treatment plant, chlorine disinfection is used so as to ensure a residual of 0.2 mg Cl- in the effluent water, which is necessary to prevent microbial re-growth. Additional treatment of the water is also implemented, such as the use of lime and aeration.

With regards to the total coliform levels, the coliform are common in the environment and do not necessarily indicate pathogenic or harmful contamination. However it does indicate that there is a

3

breakdown in the distribution system with the pipes and water treatment. The number of total coliforms is typically worse in the dry season as opposed to the rainy season.

Water Quality

While the water samples collected in Siparia had an average pH of 7.53, almost all of the water samples from Siparia met the WHO guideline of 6.5 - 8. Preliminary research conducted in Siparia indicated that water hardness is prevalent among household water sources. In order to address this, lime softening is used in the water treatment process.

As many of the water storage systems were situated under direct sunlight, it was important to record the temperature of the sources. The average temperature recorded was 27.84°C, about 2.1 degrees higher than the ambient temperature of 26.7°C. Siparia households surveyed reported stored water lasting at least a week, thus allowing a longer residence time for potential microbial growth or for chemical contamination to occur. While only four percent of households tested positive for fecal coliform, it is possible for further contamination if proper maintenance is not taken.

While WHO guidelines have a recommended turbidity level of ≤5 NTU, high levels were seen in several households. During the survey, residents in Siparia largely reported water sources as being brown. High turbidity levels may be attributable to sediment buildup in the distribution pipes during periods of water intermittence and/or sediment levels present in the bottom of the water storage devices. High turbidity levels can be indicative of sediment and hinders the chlorination and disinfection process.

Table 1 shows the ranges of the dissolved heavy metals found in the water samples were measured against the limits set by the World Health Organization (WHO), the US Environmental Protection Agency (USEPA), and the European Union (EU). High levels of lead, iron, and aluminum, and cadmium were found within the community.

Table 1. Range of dissolved metals (as mg/L) present in household drinking water supplies within Siparia, Trinidad and Tobago. Standards from the World Health Organization (WHO), U.S. Environmental Protection Agency (USEPA), and the European Union (EU) are shown.

	Siparia, Trinidad and Tobago	WHO GV	USEPA MCL	EU MAC
Pb (mg/L)	0.1 - 0.3	0.01	0.015	0.01
Fe (mg/L)	0.05 - 1.48	0.3	0.3	0.2
Cu (mg/L)	0.01 - 2.32	2	1.3	3
Al (mg/L)	0.02 - 0.25	0.1 - 0.2	0.05 - 0.2	0.2
Cd (mg/L)	0.01 - 0.84	0.003	0.005	0.005

Elevated levels of heavy metals have been known to cause adverse health effects, such as neurological defects, renal failure, and developmental delays. The average lead concentration of water samples tested

4

Figure F.1 (Continued)

Appendix F. (Continued)

in Siparia was 0.15 mg/L, ten times the maximum level recommended by WHO and USEPA. The high lead levels could be caused by the pipes used in the household plumping or distribution system, or from other lead levels present in the sediment.

Distribution of heavy metal concentrations exceeding WHO guideline levels were assessed by type of water storage device, water source. Lead, iron, and cadmium concentrations were found to exceed WHO guideline values in water supplies stored in both the tanks and water drum. Lead concentrations exceeded WHO guidelines in all of the samples tested. Iron and cadmium levels exceeded WHO guidelines in the water drum, but not in all of the tanks. High aluminum and copper were not seen in samples taken from the water drum, while less than 10% of the water samples from the tanks had exceeded values for both. As there was only one water drum, comparisons could not be made as to the significance of metal concentration by type of device.

In terms of water sources, exceeding iron levels were found in 68% of samples taken from piped water sources. Aluminum levels exceeding WHO guidelines were found in 50% of mixed rain water samples, compared to roughly 5% of the piped water samples. Zinc and aluminum are often used to construct rooftops, which may end up leaching into rainwater sources as water is collected into the storage device.

Summary

While water storage devices do provide additional and constant water supplies, it is evident that water quality can be compromised without adequate device maintenance and water treatment at the point of use. As most households have multiple water storage devices- several of which may have a capacity over 400 gallons-, it becomes exceedingly difficult to clean these storage devices. As such, many households relegate device cleanings to coincide with rainfall episodes, where rainwater can flush out the storage devices. The problem of infrequent cleanings is compounded with inadequate water disinfection. In Siparia, household water disinfection is practiced, but the chlorine dosage and mixing time are inadequate to provide optimal disinfection.

Even though residents paid to receive piped water, issues with water aesthetics, taste, and pressure forced many households to purchase bottled water as an alternative drinking water source. It is thus necessary to build increased awareness on proper household water storage practices, particularly among those responsible for the collection of water sources and the cleaning of storage devices. It is also important to provide accurate information of chemical disinfection of household water sources as there are various device shapes and capacities present within the communities.

In Table 2, proper chlorine dosage measurements are shown with corresponding volumes. For each of the dosage measurements shown, the treated water should be allowed to sit for at least 30 minutes to ensure adequate disinfection.

5

Table 2. Dosage measurements for chlorine disinfection of water sources. Taken from EPA Emergency Disinfection of Water http://water.epa.gov/drink/emerprep/emergencydisinfection.cfm, access on 5/13/2010. Marvex and Trin Chloro information taken from http://www.gina.gov.gy/ads/fullpage-healthadvisories-jan%2018.pdf, accessed 10/1/10.

Chlorine Method	Dosage
1% free chlorine liquid	10 drops per quart of water 10 drops per liter of water 40 drops per gallon of water
4-6% free chlorine liquid	2 drops per quart of water 2 drops per liter of water 8 drops per gallon (1/8 teaspoon) of water 1 cork-full per 5 gallons (for Chloro-sol) of water
7-10% free chlorine liquid	1 drop per quart of water 1 drop per liter of water 4 drops per gallon of water
Prepared calcium hypochlorite	1 part chlorine to 100 parts water ½ liter to 50 liters of water
Chlorine tablets	1 tablet per quart of water I tablet per liter of water
Marvex or Trin Chloro bleach*	½ teaspoon to 5 gallons of water 1 cup to a 400 gallon water tank

*Marvex and Trin Chloro are the main bleach brands in Guyana and Trinidad and Tobago and Tobago.

The information in Table 3 provides an estimate of the frequency with which the tanks would be refilled for domestic purposes. One can use these numbers to estimate the frequency of disinfection required assuming inadequate disinfection residual reached the household yard from the main. Based on the data from Tables 2 and Table 3, if a household of four in Trinidad and Tobago utilizes 200 gal/day and has one 400-gallon tank, one cup of bleach would need to be added to the tank each time the tank is filled. This equates to a minimum of 3.5 cups of bleach on a weekly basis just to maintain adequate chlorine residual.

Table 3. Daily household usage rate of water and number of refills required per week depending on storage device size assuming a 50 gal/day requirement per person.

# people/house	gal/day/house	# refills/week 50 gal	# refills/week 400 gal	# refills/week 1000 gal
1-3	50-150	7-21	0.9-2.7	0.35-1
4-7	200-350	28-49	3.5-6.2	1.4
8	400	56	7	2.8

6

Figure F.1 (Continued)

Technical Report on Findings from Environmental Health and Household Water Storage in Guyana

Prepared by Erlande Omisca, MPH, CPH

Introduction

In March 2009, research was conducted within the communities of Georgetown, Mocha, and Mons Repo by University of South Florida (Tampa, Florida USA) graduate students. The areas where the research was conducted are collectively referred to as Region 4 Subset within the report. The goal of the research was to assess household water storage and treatment while also assessing drinking water quality. The research consisted of conducting a household survey and collecting water samples from household water sources for analysis. Forty household surveys were conducted and forty water samples collected. The results are explained below.

Household Water Treatment & Device Maintenance

Ninety-percent of households surveyed reported that their storage devices had a covering, usually the covering that came with the device. Older HDPE tanks in Guyana featured a lid that was of similar diameter to the bottom; however, all of the tanks surveyed in Guyana had a smaller diameter lid which has implications for access to clean. The water storage systems were elevated on a trestle or some form of embankment in the majority of households surveyed (71.8%). The other water storage systems (ex. water drums) were located on the ground.

While water boiling is one of the most universal methods of household point of use water treatment, the majority of households (97.5%) did not practice it. Water filtration was even less widespread, with only 5% of households practicing it. In the households where it was practiced, filtration was achieved through the use of a cloth or a sieve.

The frequency of bottled water usage was assessed among the communities surveyed. Three-fourths of households surveyed used bottled water for drinking on a daily or weekly basis. The 25% of households who rarely or never used bottled water were also the same 25% who used the water from the storage device for drinking.

Water Quality

Of the 40 water samples taken, close to 18% of the samples tested positive for fecal coliform and 45% tested positive for total coliform. Of the seven water samples that tested positive for fecal coliform, 71% were derived from water piped from the main distribution system. Fifty percent of the eighteen water

1

samples that tested positive for total coliform were derived from piped water sources, with the remainder derived from rain water sources (44%) and mixed rain water sources (6%).

In terms of water storage, 89% of samples that tested positive for total coliform were from tank storage, whereas 100% of samples that tested for fecal coliform were from tank storage. None of the samples taken from the municipal water treatment plants of Guyana Water Incorporated (GWI) tested positive for either fecal or total coliform. This is an indication that the contamination is taking place either along the distribution line or at the household point-of-use, as was mentioned in other studies.

Roughly 53% of water samples taken had pH levels below 6.5 while 25% had pH levels above 8.0. High acidity can lead to metal corrosion while high alkalinity can lead to pipe scaling and taste problems.

The average temperature of the samples was 30.83°C, about 4.3 degrees higher than the ambient temperature of 26.8°C. All of the samples taken were above the ambient temperature, with temperatures reaching 15 degrees above the ambient temperature. While a significant correlation was not seen between the temperature of the water samples and the presence of fecal coliform, the increase temperatures may pose as a factor for other contaminants not tested (ex. *Legionella* spp., biofilm, organics) or during other temporal periods (ex. rainy season).

Table 1 shows the ranges of the dissolved metals found in the water samples were measured against the limits set by the World Health Organization (WHO), the US Environmental Protection Agency (USEPA), and the European Union (EU). High levels of lead, iron, and aluminum, and cadmium were found within the water samples collected.

Table 4 Range of dissolved metals (as mg/L) present in household drinking water supplies within communities in Trinidad and Tobago, Guyana, and Bolivia. Standards from the World Health Organization (WHO), U.S. Environmental Protection Agency (USEPA), and the European Union (EU) are shown.

	Region 4 Subset, Guyana	WHO GV	USEPA MCL	EU MAC
Pb (mg/L)	0 - 0.2	0.01	0.015	0.01
Fe (mg/L)	0.08 - 2.13	0.3	0.3	0.2
Cu (mg/L)	0.01 - 2.52	2	1.3	3
Al (mg/L)	0.03 - 0.36	0.1 - 0.2	0.05 - 0.2	0.2
Cd (mg/L)	0.04 - 0.97	0.003	0.005	0.005

Elevated lead levels have been known to cause adverse health effects, such as neurological defects, renal failure, and developmental delays. Lead levels were found in high concentrations. The average lead concentration was 0.07 mg/L, almost five times the guideline value set by WHO. In Guyana, while PVC pipes were used in many homes to connect the tanks to the interior of the home, some households stated that lead pipes were still being used in the homes.

2

Figure F.2 Preliminary technical report for Guyana.

Appendix F. (Continued)

High heavy metal concentrations were found among the water samples, although copper concentrations stayed below WHO guideline levels. Rain water samples had the least percentage of metal concentrations exceeding guideline views with only 7.7% of samples each having exceeded guideline values for lead, iron, and cadmium. In piped water sources, which are the predominant source of household water, guideline values were exceeded among concentrations of lead (70.8%), aluminum (37.5%), and (91.7%). High levels of iron, aluminum, and cadmium was seen in the mixed rain water source. While piped water appears to have greater proportion of metal concentrations exceeding WHO guideline values and rain water the lowest proportions, it cannot be determined whether having mixed rain water would produce safer water, as only one mixed water sample was taken. Overall, higher proportions of samples with over-the-limit metal concentrations were seen among samples taken from tank water and piped water samples.

Survey results showed that households cleaned their devices and disinfected their water frequently. As such, one would expect the water quality analyses to reflect lower microbial contamination levels, turbidity, and heavy metal concentrations. This may be indicative of industrial activities, geological variations, water treatment and distribution differences, and overall need for increased disinfection dosage/residency in water sources,

Summary

While water storage devices do provide additional and constant water supplies, it is evident that water quality can be compromised without adequate device maintenance and water treatment at the point of use. As most households have multiple water storage devices- several of which may have a capacity over 400 gallons-, it becomes exceedingly difficult to clean these storage devices. As such, many households relegate device cleanings to coincide with rainfall episodes, where rainwater can flush out the storage devices. The problem of infrequent cleanings is compounded with inadequate water disinfection. Household water disinfection is practiced, but the chlorine dosage and mixing time are inadequate to provide optimal disinfection.

Even though residents paid to receive piped water, issues with water aesthetics, taste, and pressure forced many households to purchase bottled water as an alternative drinking water source. It is thus necessary to build increased awareness on proper household water storage practices, particularly among those responsible for the collection of water sources and the cleaning of storage devices. It is also important to provide accurate information of chemical disinfection of household water sources as there are various device shapes and capacities present within the communities.

In Table 2, proper chlorine dosage measurements are shown with corresponding volumes. For each of the dosage measurements shown, the treated water should be allowed to sit for at least 30 minutes to ensure adequate disinfection.

3

Table 5 Dosage measurements for chlorine disinfection of water sources. Taken from EPA Emergency Disinfection of Water http://water.epa.gov/drink/emerprep/emergencydisinfection.cfm, access on 5/13/2010. Marvex and Trin Chloro information taken from http://www.gina.gov.gy/ads/fullpage-healthadvisories-jan%2018.pdf, accessed 10/1/10.

Chlorine Method	Dosage
1% free chlorine liquid	10 drops per quart of water 10 drops per liter of water 40 drops per gallon of water
4-6% free chlorine liquid	2 drops per quart of water 2 drops per liter of water 8 drops per gallon (1/8 teaspoon) of water 1 cork-full per 5 gallons (for Chloro-sol) of water
7-10% free chlorine liquid	1 drop per quart of water 1 drop per liter of water 4 drops per gallon of water
Prepared calcium hypochlorite	1 part chlorine to 100 parts water ½ liter to 50 liters of water
Chlorine tablets	1 tablet per quart of water I tablet per liter of water
Marvex or Trin Chloro bleach*	½ teaspoon to 5 gallons of water 1 cup to a 400 gallon water tank

*Marvex and Trin Chloro are the main bleach brands in Guyana and Trinidad and Tobago and Tobago.

The information in Table 3 provides an estimate of the frequency with which the tanks would be refilled for domestic purposes. One can use these numbers to estimate the frequency of disinfection required assuming inadequate disinfection residual reached the household yard from the main. Based on the data from Tables 2 and Table 3, if a household of four in Guyana uses 200 gal/day and has one 400-gallon tank, one cup of bleach would need to be added to the tank each time the tank is filled. This equates to a minimum of 3.5 cups of bleach on a weekly basis to maintain adequate disinfection.

Table 6 Daily household usage rate of water and number of refills required per week depending on storage device size assuming a 50 gal/day requirement per person.

# people/house	gal/day/house	# refills/week 50 gal	# refills/week 400 gal	# refills/week 1000 gal
1-3	50-150	7-21	0.9-2.7	0.35-1
4-7	200-350	28-49	3.5-6.2	1.4
8	400	56	7	2.8

4

Figure F.2 (Continued)

Appendix F. (Continued)

Technical Report on Findings from Environmental Health and Household Water Storage in Bolivia

Prepared by Erlande Omisca, MPH, CPH

Introduction

In June 2009, research was conducted within the communities of Villa Litoral by University of South Florida (Tampa, Florida USA) graduate students. The goal of the research was to assess household water storage and treatment while also assessing drinking water quality. The research consisted of conducting a household survey and collecting water samples from household water sources for analysis. Fifty-seven surveys were conducted and forty water samples collected. The results are explained below.

Household Water Treatment & Device Maintenance

Within Villa Litoral, water storage devices varied from 18.9-liter (5 gallons) plastic jerry cans to water storage drums to 10,0000-liter (2645.5 gallons) cement tanks. Roughly 25% of households utilize the cement tanks. The majority of these devices are less than three years old. Ninety-percent of households surveyed reported that their storage devices had a covering, usually the covering that came with the device. While roughly 5% of households in Villa Litoral elevated their water storage devices, the rest of households had their water storage systems on the ground. This ground-level group consisted predominantly of water drums, jerry cans, and cement tanks.
As water boiling is one of the most universal methods of household point of use water treatment, the majority of households (75.4%) did practice it. However, water filtration was less widespread, with only 26.3% of households practicing it. In the households where it was practiced, filtration was achieved through the use of a cloth or a sieve.

The frequency of bottled water usage was assessed among the communities surveyed. Over 68% of households reported to never using bottled water. Three-fourths of households surveyed used bottled water for drinking on a daily or weekly basis. The percentage of households who did use bottled water did so on a weekly basis or on rare occasions.

The majority of households in Villa Litoral (87.7%) reported cleaning their respective storage devices. Households surveyed in Villa Litoral were four times more likely to clean their storage devices than to disinfect their water. This is because no expensive chemicals or materials were needed and they did not have to remember correct dosages for cleaning like they would for disinfection. Many of the households surveyed owned water storage devices with large capacities (e.g. cement tanks), which made it difficult to clean on a frequent basis. Flushing the storage tanks with rainwater was used as a cleaning method in many households. Hence, household members coordinate device cleaning with rain episodes. This could

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explain why many households with cement tanks on an annual basis, compared to those have smaller containers and clean them on a daily or weekly basis.

Community residents were asked to describe water access and the water quality that they received from the municipal water source. Close to 16% of households in Villa Litoral reported not having access to any piped water at all and thus relied solely on rain water or river water. For the majority of the population with piped connections, access to water occurred when a member of the local water committee went to turn on the water pump. Additionally, water access alternated between the sides of the main street with each side getting access for a few hours. While 72% of residents described the piped water as being clear, 39% described the water as being salty. While many of the residents were concerned that the taste of the water sources was an indicator of poor water quality they felt that there was little that could be done at the local level to help resolve this.

Health

Survey participants were asked whether they had received waterborne advisories or information through various sources of media (TV, radio, flyers, etc.) in the past year. More than 73% of households had received information or advisories. Close to two- thirds of the households surveyed in Villa Litoral reported frequent handwashing.

When asked about their confidence in the potability and security of their drinking water sources, the majority households surveyed in Villa Litoral (52.6%) were not confident that their water sources were safe for consumption, When asked about their confidence in the water storage systems to keep their water safe, the majority of households surveyed in Siparia (57.9%) were not confident that their water sources was safe for consumption because of the storage that was used.

Participants were asked whether there were any recent waterborne illnesses among those living within the respective home. About 40.4% of households reported at least one member having a recent waterborne illness, in which case the individual experienced headaches following consumption of the water.

Bacterial Contamination

The World Health Organization (WHO) guidelines for microbial measurements state that drinking water should be free of both fecal and total coliform. Of the twenty-six water samples taken In Villa Litoral, fecal coliform was found to be present in 85% of samples, while total coliform was present in 100% of the samples. Fifty-four percent and 42% of water samples that were derived from piped water tested for total coliform and fecal coliform, respectively. Thirty-eight percent of samples taken from water storage tanks tested positive for fecal coliform compared to samples taken from water drums (12%) and other storage

2

Figure F.3 Preliminary technical report for Bolivia.

Appendix F. (Continued)

containers such as jerry cans, buckets, and pots (27%). The same trend was observed for total coliform contamination, as the highest percentage of contamination was seen in water storage tanks (42%), other containers (38%), and water drums (12%). It appears that households with storage tanks had a higher risk for microbial contamination due to their relative larger size and difficulty in cleaning tank systems.

With regards to the total coliform levels, the coliform are common in the environment and do not necessarily indicate pathogenic or harmful contamination. However it does indicate that there is a breakdown in the distribution system with the pipes and water treatment. The number of total coliforms is typically worse in the dry season as opposed to the rainy season.

Water Quality

Water quality parameters were assessed for the community. Drinking water should have a pH between 6.5 and 8. About 53.8%% of water samples taken had pH levels below 6.5. High acidity can lead to metal corrosion. The average temperature of the samples was 24.88°C, about 2.88 degrees higher than the ambient temperature of 22°C. All of the water samples taken had temperatures that surpassed the ambient temperature by 0.82 - 9.84 degrees. Higher temperatures were found among samples taken from the tank compared to those from smaller vessels such as buckets and jerry cans. While households with tanks had an equal percentage of fecal coliform contamination as those using smaller vessels there is an increased risk for microbial growth (e.g. biofilm) as a result of the increased temperature and dark environment presented within the containers

During the survey, many households reported the water sources as being salty, sometimes to the point of being undrinkable. A clear increase in conductivity levels was seen between the samples taken from piped water sources and samples taken from rainwater sources. While the conductivity levels of the rain water sources ranged from 0.001 - 0.239 mS/cm, the piped water sources had conductivity levels of 1286 – 1318 mS/cm. The total dissolved solids (TDS) data showed the same pattern, with levels among the rain water sources ranging from 0 – 200 mg/L while piped water sources ranged from 800 – 900 mg/L. The World Health Organization states that while water with TDS levels less than 600 mg/L are safe to drink, the water becomes less drinkable once it reaches TDS levels of 1000 mg/L. The water salinity may be due to saltwater intrusion and/or other hydrogeological and industrial factors.

Table 1 shows the ranges of the dissolved metals found in the water samples were measured against the limits set by the World Health Organization (WHO), the U.S. Environmental Protection Agency (USEPA), and the European Union (EU). High levels of lead, iron, and aluminum, and cadmium were found within water samples taken in Villa Litoral.

3

Table 7 Range of dissolved metals (as mg/L) present in household drinking water supplies within communities in Trinidad and Tobago, Guyana, and Bolivia. Standards from the World Health Organization (WHO), U.S. Environmental Protection Agency (USEPA), and the European Union (EU) are shown.

	Villa Litoral, Bolivia	USEPA MCL	WHO GV	EU MAC
Pb (mg/L)	0 - 0.6	0.015	0.01	0.01
Fe (mg/L)	0- 3.62	0.3	0.3	0.2
Cu (mg/L)	0 – 0.08	1.3	2	3
Al (mg/L)	0.01 - 0.27	0.05 - 0.2	0.1 - 0.2	0.2
Cd (mg/L)	0 - 0.98	0.005	0.003	0.005

Elevated lead levels have been known to cause adverse health effects, such as neurological defects, renal failure, and developmental delays. Lead levels were found in high concentrations. The average lead concentration was 0.07 mg/L, almost five times the guideline value set by WHO. This may be due to lead present in the water distribution pipes and in the groundwater as well. In Guyana, while PVC pipes were used in many homes to connect the tanks to the interior of the home, some households stated that lead pipes were still being used in the homes. In Villa Litoral, iron concentrations were as high as 3.62 mg/L, twelve times the WHO guideline value. In many of the communities where water is connected, galvanized pipes are used to connect to the main distribution pump or used in faucets and indoor plumbing. As such, there is a risk for pipe materials to leach out over time. While a strong correlation could not be made, higher concentrations of iron were seen in water samples with lower pH levels.

High heavy metal concentrations were found among the water samples, although copper concentrations stayed below WHO guideline levels. Rain water samples had the least percentage of metal concentrations exceeding guideline views with only 7.7% of samples each having exceeded guideline values for lead, iron, and cadmium. In piped water sources, which are the predominant source of household water, guideline values were exceeded among concentrations of lead (70.8%), aluminum (37.5%), and (91.7%). High levels of iron, aluminum, and cadmium was seen in the mixed rain water source. While piped water appears to have greater proportion of metal concentrations exceeding WHO guideline values and rain water the lowest proportions, it cannot be determined whether having mixed rain water would produce safer water, as only one mixed water sample was taken. Overall, higher proportions of samples with over-the-limit metal concentrations were seen among samples taken from tank water and piped water samples.

Survey results showed that households cleaned their devices and disinfected their water frequently. As such, one would expect the water quality analyses to reflect lower microbial contamination levels, turbidity, and heavy metal concentrations. This may be indicative of industrial activities, geological variations, water treatment and distribution differences, and overall need for increased disinfection dosage/residency in water sources,

4

Figure F.3 (Continued)

Table 8 Dosage measurements for chlorine disinfection of water sources. Taken from EPA Emergency Disinfection of Water http://water.epa.gov/drink/emerprep/emergencydisinfection.cfm, access on 5/13/2010. Marvex and Trin Chloro information taken from http://www.gina.gov.gy/ads/fullpage-healthadvisories-jan%2018.pdf, accessed 10/1/10.

Chlorine Method	Dosage
1% free chlorine liquid	10 drops per quart of water 10 drops per liter of water 40 drops per gallon of water
4-6% free chlorine liquid	2 drops per quart of water 2 drops per liter of water 8 drops per gallon (1/8 teaspoon) of water 1 cork-full per 5 gallons (for Chloro-sol) of water
7-10% free chlorine liquid	1 drop per quart of water 1 drop per liter of water 4 drops per gallon of water
Prepared calcium hypochlorite	1 part chlorine to 100 parts water ½ liter to 50 liters of water
Chlorine tablets	1 tablet per quart of water I tablet per liter of water

The information in Table 3 provides an estimate of the frequency with which the tanks would be refilled for domestic purposes. One can use these numbers to estimate the frequency of disinfection required assuming inadequate disinfection residual reached the household yard from the main.

Table 9 Daily household usage rate of water and number of refills required per week depending on storage device size assuming a 50 gal/day requirement per person.

# people/house	gal/day/house	# refills/week 50 gal	# refills/week 400 gal	# refills/week 1000 gal
1-3	50-150	7-21	0.9-2.7	0.35-1
4-7	200-350	28-49	3.5-6.2	1.4
8	400	56	7	2.8

6

Summary

While water storage devices do provide additional and constant water supplies, it is evident that water quality can be compromised without adequate device maintenance and water treatment at the point of use. Most households have multiple water storage devices- several of which have a capacity under 189 liters (50 gallons) – and it is important that these devices are cleaned regularly. However, this may be difficult for those who have larger cement tanks, where the capacity is 10,000 liters (2645.5 liters). As such, many households relegate device cleanings to coincide with rainfall episodes, where rainwater can flush out the storage devices. The problem of infrequent cleanings is compounded with inadequate water disinfection, as chlorination was not reported as being common.

Even though residents paid to receive piped water, issues with water aesthetics, taste, and pressure forced many households to purchase bottled water as an alternative drinking water source. It is thus necessary to build increased awareness on proper household water storage practices, particularly among those responsible for the collection of water sources and the cleaning of storage devices. It is also important to provide accurate information of chemical disinfection of household water sources as there are various device shapes and capacities present within the communities. One suggestion for those who have large tanks or water piped directly into the homes is to have a smaller container that is designated solely for drinking. Having this smaller container will provide ease in regular disinfection, as cleaning and disinfection would take place when the container needs to be refilled. This also makes it easier to remember the correct dosage levels.

In Table 2, proper chlorine dosage measurements are shown with corresponding volumes. For each of the dosage measurements shown, the treated water should be allowed to sit for at least 30 minutes to ensure adequate disinfection.

5

Figure F.3 (Continued)

ABOUT THE AUTHOR

Erlande Omisca is a native of Miami, Florida. Erlande received her Bachelor of Science in Environmental Science and Policy in 2002 and a Master of Public Health (Environmental Health) in 2004 from the University of South Florida. Her research interests include environmental health, water quality, global health, environmental justice, and sustainability issues. Her doctoral research involved looking at the environmental health implications between community perception, water quality, and household water storage/treatment within the Latin American and Caribbean region. To date, Erlande's research and studies have taken her throughout the world, including Tanzania, Ecuador, Trinidad and Tobago, Guyana, Bolivia, and Mexico. In addition to her research endeavors, Erlande has been awarded various grants and fellowships, including the U.S. Public Health Traineeship, the NSF LSAMP Bridge to the Doctorate Fellowship, the McKnight Doctoral Fellowship, and the Alfred P. Sloan fellowship.