WATER QUALITY DEGRADATION AFTER WATER STORAGE AT HOUSEHOLD LEVEL IN A PIPED WATER SYSTEM IN RURAL GUATEMALA

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Abstract – In response to a rural community's concern regarding diarrheal disease, particularly among children, a field assessment was performed to determine the concentration of 4 classes of indicator bacteria: aerobic bacteria, total coliform, fecal coliform and *Escherichia coli*. Matched supply tap and storage container samples were taken from 28 households; two additional samples were taken at the main storage tank. Total and free chlorine concentration was also determined for each sample. While nearly all samples taken from household taps were near or below limits of detection, samples from storage containers all showed high densities of indicator bacteria and one was positive for *Salmonella*. All chlorine measurements indicated concentrations of < 0.5 ppm. These data suggest that while the source well water shows indicator bacteria concentrations at or below limits of detection, drinking water becomes significantly more hazardous while in storage containers at the household level, and this reflects insufficient chlorination. An uninterrupted and adequately chlorinated water supply system is planned to eliminate the need for drinking water storage at the household level.

Index Terms – Guatemala, microbial contamination, water quality, water storage

INTRODUCTION

An initial community health assessment identified diarrheal disease, particularly among children, as a primary morbidity concern for a rural community in Guatemala. Informal discussions with several community leaders suggested that 60-90% of children and 3-40 % of adults suffer at least one episode of gastroenteritis per year. Water is available to sectors of the community on a rotating basis, so drinking water must be stored at individual households for 2 to 3 days between re-supply. Several reports have indicated that microbiologically clean sources of drinking water become contaminated after water collection and subsequent storage at the household level and contaminated source water quality declines further with storage.^{i, ii, iii, iv, v, vi}

An assessment strategy utilizing matched water samples from the supply tap and storage container at the household level were collected to determine the concentration of 4 classes of indicator bacteria. These data will help inform an intervention strategy entailing an uninterrupted and adequately chlorinated water distribution system. Also, these data are useful to those concerned with safe drinking water in rural communities in developing countries to anticipate the type, concentration and possible sources of contamination. In addition, the methods used provide an assessment strategy to characterize contamination in similar rural settings. To our knowledge, no published data is available on the quality of well water and stored drinking water in Guatemala.

This work was performed by the Engineers Without Borders Student Chapter at the University of Illinois at Chicago. This multidisciplinary team is comprised of students and faculty mentors from nearly all disciplines of engineering, public health, and urban planning. The composition of this team facilitates learning across professions, and establishes the necessary framework to approach and the skills to solve complex public health problems.

Study location

Cerro Alto and Labor de Falla are small, neighboring rural communities in the mountainous region of Chimaltenango, Guatemala, approximately 30 km west of Guatemala City (Figure 1). The community is comprised of approximately 160 households (approximately 1,400 residents) of predominantly Kaqchikel Mayan decent, and covers 4.5 km² at an elevation of 1,890 m.

FIGURE 1
Project Location

Water distribution system

The system currently in place is six years old; prior to its installation, residents would have had to walk several kilometers to retrieve spring water. In the currently existing system (Figure 2), water is pumped from an approximately 245 m deep well to a main storage tank measuring 9 x 4 x 2 m (total volume of 72 m³) at a regional high point (elevation 1900 m). When the storage tank is nearly full, a series of valves are manually opened and water is gravity fed through a polyvinyl chloride pipe distribution network to individual households; each household has a single water tap.

The distribution network is divided into three area sections with rotating service, such that each section is provided water for 4 to 5 hours once every 2 to 3 days, necessitating water storage for washing, bathing and drinking. Each household has a cement or a wooden frame with plastic liner cistern which is filled from the tap to hold water for washing and bathing (Figure 3). The cisterns are typically 3 x 2 x 1 m (total volume of approximately 6 m³) in size and are uncovered. Separate drinking water storage container(s) are filled from the tap; these are typically 20 or 40 L plastic containers and are usually covered.

FIGURE 2
CURRENTLY EXISTING SYTEM

FIGURE 3
Typical Household Water Storage Containers

The local government had very recently installed a basic chlorination system where the supply line from the well enters the main cistern. A small volume from the supply line to the storage tank is diverted to a mixing cylinder that utilized 3-5 70% calcium hypochlorite tablets, and then plumbed into the main storage tank. The local government provided instructions on how and when to use the chlorine to disinfect the drinking water, but provided only a few tablets for demonstration purposes. The community leadership wanted to spend as little money as possible for disinfection, and subsequently rationed the remaining chlorine using only a third of the minimum recommended dose.

METHODS

Preliminary water testing

Initial limited field sampling with LaMotte© TC-5 Presence/Absence Coliform Bacteria Test kits (Chestertown, MD) determined presence of coliform bacteria in drinking water which prompted a systematic microbiological sampling campaign presented here.

Microbiological sampling

The water distribution system was mapped utilizing a handheld GPS device to identify the spatial location of all major features of the water distribution system and locations of homes in the community; these data were uploaded to ArcGIS and displayed over local topographical maps. Household sample sites were then randomly selected using satellite orthophotographs to attain representative spatial distribution that was reflective of the household density in a given area (Figure 4). To examine possible differences in bacterial contamination between water being supplied to the household supply tap versus drinking water in household storage containers, one sample from the household tap and one sample from the drinking water storage container were obtained from twenty-eight households (approximately 18% of households in the community).

The number of samples collected was limited by the field time available due to terrain and travel time to the laboratory, and budget limitations of our service organization. Since different areas of the village were supplied water only every 2-3 days, each home was visited twice during our two days of sampling: when water was being supplied to collect tap samples, and again to collect samples from the drinking water storage container on the non-delivery days. Samples were collected in 175 ml sterile containers. Drinking water storage container samples were taken at the top of the water line from the center of the storage container, reflective of typical use by the community. For tap samples, water was either already flowing when we arrived at the household (during water delivery) or was permitted to flow approximately 15 seconds before collection. All sampling was conducted over two consecutive mornings. Collected samples were placed on ice in a cooler, and then transported to Guatemala City for analysis at a local commercial laboratory; the longest time between collection of the first sample and delivery to the laboratory was approximately 7 hours.

FIGURE 4
Microbiological and Chlorine Sampling Locations

Wastewater (APHA/AWWA/WWF 1998) and included aerobic bacteria, total coliform, fecal coliform and *Escherichia coli* (*E. coli*) concentration and detection for presence of Salmonella. These 4 indicator bacteria were selected due to their significance for public health. Aerobic bacteria count was determined using the Heterotrophic Plate Count Method 9215. The limits of detection for aerobic bacteria were 10 to 57000 CFU/ml. Total coliform count was determined using the Standard Total Coliform Fermentation Technique 9221B. The most probable number (MPN) of bacterium was determined to estimate the mean density of coliform in the sample. Fecal coliform count was determined using the Fecal Coliform Procedure 9221E. The MPN method was then used to estimate the mean density of coliform in the sample. *E. coli* count was determined using the *Escherichia coli* Procedure 9221F. The MPN method was then used to estimate the mean density of *E. coli*. The limits of detection for total coliform, fecal coliform and *E. coli* were 2 to 1600 MPN/100ml. Samples were analyzed for Salmonella using a qualitative technique as described in Method 9260B.

Chlorine sampling

Total and free chlorine concentration was determined in the field for each supply tap and drinking water storage container at the households where sampling for indicator bacteria was performed. Hach Water Quality Test Strips (Loveland, CO) were utilized, with a detection range of 0 to 10 ppm, scaled at 0.5 ppm increments.

Data analysis

Geometric means for aerobic bacteria, total coliform, fecal coliform and *E. coli* were determined. Lower and upper censored values in the dataset were addressed by using probability plotting to estimate the geometric means without including the censored values.

RESULTS

Microbiological results

Table I shows sample location, sample type (storage container or tap), aerobic bacteria concentration (CFU/ml), and total coliform, fecal coliform and *E. coli* counts (MPN/100ml), and Salmonella presence for each household sampled, along with 2 samples taken at the main storage tank. The aerobic bacteria concentration geometric mean for all tap samples was 17 CFU/ml and the geometric mean for all storage container samples was 28000 CFU/ml. The average total coliform concentration for all tap samples was 5 MPN/100ml and the average for all storage container samples was 171 MPN/100ml. The average fecal coliform concentration for all tap samples was < 2 MPN/100ml and the average for all storage container samples was 17 MPN/100ml. The average *E. coli* concentration for all tap samples was < 2 MPN/100ml and the average for all storage container samples was 6 MPN/100ml. One sample, Household #28, tested positive for salmonella.

TABLE I
MICROBIOLOGICAL RESULTS BY HOUSEHOLD AND SAMPLE TYPE

Household / Location	Sample Type	Aerobic bacteria (CFU/ml)	Total Coliform (MPN/100ml)	Fecal Coliform (MPN/100ml)	E. coli (MPN/100ml)	Salmonella Presence
1	Storage Container	3500	48	17	17	Negative
	Tap	10	<2	<2	<2	Negative
2	Storage Container	22000	23	13	4	Negative
	Tap	2200	1600	40	40	Negative
3	Storage Container	>57000	140	23	8	Negative
	Tap	15	<2	<2	<2	Negative
4	Storage Container	>57000	>1600	7	<2	Negative
	Tap	10	2	<2	<2	Negative
5	Storage Container	>57000	170	8	<2	Negative
	Tap	10	<2	<2	<2	Negative
6	Storage Container	>57000	>1600	9	9	Negative
	Tap	<10	<2	<2	<2	Negative
7	Storage Container	2600	30	23	2	Negative
	Tap	30	<2	<2	<2	Negative
8	Storage Container	6300	2	<2	<2	Negative
	Tap	<10	<2	<2	<2	Negative
9	Storage Container	3200	350	13	2	Negative
	Tap	<10	<2	<2	<2	Negative
10	Storage Container	3200	50	7	<2	Negative
	Tap	70	<2	<2	<2	Negative
11	Storage Container	24000	240	22	9	Negative
	Tap	20	<2	<2	<2	Negative
12	Storage Container	>57000	1600	500	170	Negative
	Tap	50	<2	<2	<2	Negative
13	Storage Container	24000	>1600	>1600	>1600	Negative
	Tap	10	<2	<2	<2	Negative
14	Storage Container	<10	<2	<2	<2	Negative
	Tap	10	<2	<2	<2	Negative
15	Storage Container	6100	23	23	23	Negative
	Tap	20	<2	<2	<2	Negative
16	Storage Container	>57000	80	<2	<2	Negative
	Tap	15	<2	<2	<2	Negative
17	Storage Container	>57000	430	11	11	Negative
	Tap	20	<2	<2	<2	Negative
18	Storage Container	29000	30	7	6	Negative
	Tap	15	<2	<2	<2	Negative
19	Storage Container	19000	80	2	2	Negative
	Tap	10	<2	<2	<2	Negative

20	Storage Container	>57000	>1600	>1600	50	Negative
	Tap	25	<2	<2	<2	Negative
21	Storage Container	28000	1600	300	7	Negative
	Tap	90	<2	<2	<2	Negative
22	Storage Container	24000	34	4	<2	Negative
	Tap	<10	<2	<2	<2	Negative
23	Storage Container	>57000	900	29	29	Negative
	Tap	15	<2	<2	<2	Negative
24	Storage Container	>57000	>1600	>1600	>1600	Negative
	Tap	330	6	4	4	Negative
25	Storage Container	17000	900	13	13	Negative
	Tap	80	<2	<2	<2	Negative
26	Storage Container	>57000	36	32	32	Negative
	Tap	<10	<2	<2	<2	Negative
27	Storage Container	5800	300	110	12	Negative
	Tap	15	<2	<2	<2	Negative
28	Storage Container	>57000	<2	<2	<2	Positive
	Tap	10	<2	<2	<2	Negative
Main Tank	Supply inlet	10	<2	<2	<2	Negative
	Cistern storage	10	<2	<2	<2	Negative

Chlorine results

There was no colorimetric change in any of the field test strips for total and free chlorine concentrations at each household sampled, indicating chlorine concentrations < 0.5 ppm.

DISCUSSION

Samples from the main storage tank indicate aerobic bacteria, total coliform, fecal coliform, and *E. coli* levels were at or below the detection limit, indicating little to no microbiological contamination of the source water. Further, 25 of the 28 samples from the household supply taps exhibited total coliform, fecal coliform, and *E. Coli* below the detection limit; of those 25 samples, the aerobic bacteria concentrations were < 100 CFU/mL, which is not uncommon in well water and does not necessarily indicate a public health hazard.^{vii} Only two households (#2 and #24) showed elevated levels of indicator bacteria. Our data suggests that water from the tap is not contaminated when it reaches the households, and that contamination occurs during storage.

In a pre-intervention baseline sampling of traditional and modified drinking water storage containers in San Juan Sacatepequez, Guatemala, Rangel et al. reported a mean *E. coli* range of 324 to 2,553 MPN.^{viii} In a stored drinking water study of peri-urban households in Lima, Peru, Oswald et al. reported a geometric mean for *E. coli* in principal water storage containers of 16 CFU/100mL.ⁱⁱⁱ In Hyderabad, India, Eshcol et al. found a decrease in total coliform count with increased storage time (though this trend was not statistically significant), reporting a mean of 753 CFU/100mL in samples collected from drinking water in storage containers less than 24 hours, and 228 CFU/100mL in samples collected from drinking water stored over 24 hours.^{iv} In

Kibera, near Nairobi, Chemuliti et al. reported a mean total bacteria count of 47/100mL in tank/standpipe water compared to 818/100mL for in-house drinking water storage containers; these samples were not matched, as in our study.^v Chemuliti also reported a mean fecal coliform count of 93/100mL for tank/standpipe water and 103/100mL for in house drinking water storage containers.^v In Vellore, India, Brick et al. reported *E. coli* counts of 440 to >3600/mL in the municipal water supply; after 1 to 9 days of storage at the household level, 67% of the homes sampled showed increased contamination.^{vi}

The US Environmental Protection Agency (US EPA) recommends a total coliform (fecal coliform and *E. coli*) concentration level of zero, but the enforceable maximum concentration is more complicated. The US EPA requires that less than 5.0% of water samples test positive for total coliform or a maximum of one sample if less than 40 samples were taken in a month; samples that test positive for total coliform must also be tested for fecal coliform or *E. coli*.^{ix} The World Health Organization (WHO) recommends water intended for human consumption contain no indicator organisms, including *E. coli* and fecal coliform.^x More specifically, they recommend no *E. coli* or thermo-tolerant bacteria present in the water entering or in the distribution system and all water directly intended for drinking.^x By comparison to these standards, bacteria counts were above US EPA and WHO limits in most samples collected from the water storage containers of each household, for total coliform, *E. coli* and fecal coliform. While contaminants were present in low levels in some of the tap samples, the elevated geometric means were largely a result of the sample from Household #2. The high contaminant concentration in the tap sample from Household #2 may be the result of gross contamination of the tap or possible sample contamination.

Possible sources of water contamination may be related to hand hygiene and water handling. Most drinking water storage containers had a lid of some sort (from tight-fitting plastic lids, to plastic bags, plywood, and metal plates), but were not always in place at the time of our observations. Many of the storage containers were located outdoors but under an overhead covering. Domestic and farm animals lived and roamed in the household area. One sample from a drinking water storage container was positive for the detection of the presence of Salmonella. The source and species of Salmonella is not known; the storage container could have been contaminated directly or indirectly by an individual who had Salmonella gastroenteritis, or it could have an animal source. It is notable that total coliform, fecal coliform and *E. coli* were below the limit of detection in the sample that tested positive for Salmonella. This demonstrates the limitations of these indicator bacteria as predictors of this pathogen in stored drinking water.

Total and free chlorine levels in the water were < 0.5 ppm, suggesting little to no chlorine content in the water despite the community's recent effort to implement a chlorination system. Given the inadequate chlorination, it is not surprising that coliform bacteria were present in the water storage and distribution system. Providing the community guidance on the proper dosing of chlorine for their system, as well as a sufficient supply of chlorine, is an immediate priority.

Our results are consistent with other studies as we conclude that safer methods for storing drinking water at the household level are needed.^{i-iv,vi,xi} System operations, monitoring, maintenance and decision making must be formalized, addressing the financial, social and behavioral factors that are critical to safe drinking water intervention success.^{xii} Our ultimate goal is to eliminate the need for drinking water storage at the household level by engineering an uninterrupted water supply for this community.^{iv}

CONCLUSIONS

Our data demonstrate that the bacterial contamination in drinking water is substantially worse in the drinking water storage containers used at individual households than in the upstream storage and distribution system. This is consistent with the insufficient chlorination of the supply water, and may also reflect additional contamination that occurs during storage. Although many potential compromised hygiene and sanitation mechanisms exist to contribute to the burden of diarrheal illness in this rural community, the storage of drinking water is likely a major contributor to overall morbidity. Though the community had made recent efforts to chlorinate their drinking water supply, we have demonstrated here that the effort is inadequate; additional resources and training will be needed.

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