Research Paper

Household stored water quality in an intermittent water supply network in Panama

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ABSTRACT

Safe water storage is critical to preserve water quality, especially when intermittent piped drinking water supply creates a need for household storage. This study characterized household storage practices and stored water quality in 94 households ($N = 94$) among four peri-urban neighborhoods in Arraiján, Panama with varying degrees of supply intermittency. We found that 18 (19.1%) households stored drinking water in unsafe containers. Forty-four (47%) samples of household stored drinking water had residual chlorine levels <0.2 mg/L. While 33 (35.1%) samples were positive for total coliform bacteria, only 23 (24.4%) had >10 most probable number (MPN)/100 mL total coliform bacteria. Eight (44%) samples were positive for *Escherichia coli*, whereas only one (1.3%) sample from the safe containers was positive. Twenty-nine (30.9%) samples had >500 MPN/mL heterotrophic plate count bacteria. These findings suggest that longer supply interruptions were associated with longer storage times and lower chlorine residual, which were associated with higher concentrations of indicator bacteria. This is one of the first studies in the Central-American region to show an association between the lack of turnover (replacement with fresh water) and greater contamination during household water storage. Thus, when drinking water supply is not completely continuous and household storage is required, decreasing the time between supply periods can facilitate safer water storage. Public awareness and education are also recommended to increase hygiene practices during water collection and storage.

Key words | chlorine residual, *E. coli*, household drinking water storage, intermittent drinking water supply

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INTRODUCTION

A recent review estimated that 1.8 billion people use a source of drinking water affected by fecal contamination (Bain *et al.* 2014). Excreta can be a source of bacteria, viruses, protozoa, and helminths that cause diseases in humans ranging from mild gastroenteritis to severe cases of dysentery, hepatitis, and typhoid fever (WHO 2011). Several studies have proposed that diarrheal diseases in developing countries can be reduced by implementing improved sources and supply of drinking water, hand washing, improved hygiene, and water treatment at home (Arnold *et al.* 2009; Eshcol *et al.* 2009; Vacs Renwick 2009). After the implementation of the Millennium Development Goals (MDGs), between 1990 and 2015, the percentage of the world's population using improved sources of drinking water increased from 76% to 91%, and the percentage of population receiving piped water supply

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increased from 44% to 58% (WHO 2015). Despite these positive achievements, diarrheal diseases related to water, sanitation, and hygiene still remain a major contributor to the global burden of disease, causing an estimated 829,000 deaths in 2016 (Prüss-Ustüna *et al.* 2019). A multidisciplinary strategy is needed to close this gap for access to piped potable water worldwide.

In many countries of the world, even where piped supply is available it often operates intermittently (Kumpel & Nelson 2016). In places with intermittent or no piped household supply, the water is collected from taps located in the home or at a distance from the home and then stored until it is consumed (Rubino *et al.* 2018). Even if water is of good quality when it arrives at the tap, the storage of drinking water at home can be associated with re-contamination (Matsinhe *et al.* 2014; Heitzinger *et al.* 2015) and regrowth (Coelho *et al.* 2003). The introduction of dirty hands into containers with wide mouths is an important mechanism for household water contamination (Oswald *et al.* 2007; Pickering *et al.* 2010). Consequently, the use of containers that have narrow, well-capped mouths can decrease the likelihood of microbial contamination (Levy *et al.* 2008; Cawst 2009). Levy *et al.* documented an increased risk of infectious diseases transmitted by stored water. Large-mouthed containers were associated with higher levels of enterococci and uncovered containers were associated with higher levels of enterococci and *Escherichia coli* (Levy *et al.* 2008). Other studies have found buckets and other open containers to be more vulnerable to introduction of hands, cups, and ladles that can carry fecal contamination (Oswald *et al.* 2007; Pickering *et al.* 2010; Harris *et al.* 2013). Furthermore, households with an intermittent drinking water supply store water for a larger amount of time. The extended storage time causes the residual chlorine to decay, which in turn makes the water more susceptible to growth of microbial contaminants. In addition, there is more exposure to the introduction of microbial contaminants during longer storage times. Taken all together, poor water storage practices and decay of residual chlorine lead to contamination and microbial after-growth in stored water (Coelho *et al.* 2003).

Good quality drinking water remains vulnerable to contamination when stored within the household. This study aims to describe the quality of drinking water stored in households in four areas of Arraiján, Panama. Our findings reveal bacteriological indicators of contamination in stored drinking water, the factors favoring the deterioration of such water and their association with the use of unsafe containers and supply intermittency.

MATERIALS AND METHODS

Study site

A total of four areas in the district of Arraiján, Panama, located in the western outskirts of Panama City, were selected for this study (Figure 1). The study areas had between 232 and 650 households each. A previous study revealed that water from the pipe network in these areas almost always met drinking water quality standards (Erickson *et al.* 2017). The unplanned urban growth and complex topography, along with high rates of leakage in the distribution network, has led some areas to have intermittent supply, with varying degrees of severity. Area 1 is supplied water directly from a main pipe from one of the water treatment plants. Except for occasional interruptions during the year due to damage to the main pipeline, supply in Area 1 remained constant throughout the study duration. Area 2 receives water from two storage tanks and also from a main pipeline from one of the water treatment plants. When the tanks emptied, which occurred mainly during the weekends, it caused the high parts of this area to lose supply. Area 3 supply is controlled by a valve at the entrance to the area, which was operated with a schedule of being open for 3 days to supply Area 3 and then closed for 3 days to supply another adjacent area. This valve operation schedule was not carried out precisely every week, resulting in some outages occasionally lasting longer than 3 days. In Area 4, the water is supplied by a pump station. This pumping was frequently interrupted due to limited supply of electricity to the pump station, causing most of the area to lose supply.

Household selection and water sampling

Ninety-six households (24 per study area) were randomly selected to be interviewed and sampled between May and

Figure 1 | Location of Arraiján, Panama and the four study areas, 20 km west of the Panama Canal.

August 2015. If no one was home at a randomly selected household, the sampler proceeded to the nearest household until arriving at a household where someone was at home. Households were surveyed and samples of stored water were collected between 9 a.m. and 4 p.m. Supplementary Table S1 shows the number of households sampled each day. One sample was collected at each household from the container where the household stored its drinking water. For logistical reasons, only 95 households were sampled and only 94 of the samples were analyzed, due to loss of one of the samples. The 23–24 households sampled per study area represented 3.7–9.9% of the total population of households in each area.

Survey on piped supply and storage methods

A survey was conducted on household piped supply and drinking water practices. This survey aimed to describe the type of containers that households used for storing drinking water, the volume of water stored for drinking, and the total volume of water stored (for drinking and other uses). The survey also collected information regarding whether the piped supply was currently on or off at the time, how long it had been on or off, and how long the water being sampled had been stored. The survey questions are provided in Supplementary Table S2. Containers were classified as 'safe' or 'unsafe' according to how water was extracted from them. If water was extracted by pouring, the container was classified as 'safe'. If water was extracted by dipping another container (cup, bowl, etc.), the container was classified as 'unsafe'. This definition did not consider whether or not the container was capped or covered.

Water quality analysis

For bacteriological analysis, an average of 120 mL was collected in sterile plastic bottles with screw caps containing a sodium thiosulfate solution to neutralize any chlorine residual in the sample. Two methodologies were used for the collection of samples, depending on the type of container. If the container was narrow-mouthed or had a low storage capacity, it was poured directly into the sterile bottle. Before removing the water from the container, the mouth was disinfected with cotton or tissue (Kimwipes®) moistened with chlorine. When the vessel was larger and wider-mouthed, an aluminum vessel was used to extract the sample and transfer it to the sterile bottle. The aluminum vessels and the bags containing them were pre-sterilized in an autoclave, and the researcher's hands did not come in contact with the portion of the vessel that contacted the water. The collected samples were placed in a cooler with ice or cold packs during transport to the INDICASAT-AIP Laboratories in the City of Knowledge, Panama City. Maximum transit time was 7 h. Negative controls using sterile water were included for each day of sampling.

We determined the most probable number (MPN) of total coliform bacteria and *E. coli* in 100 mL water samples using Colilert reagent and Quanti-Tray®/2000 trays (IDEXX Laboratories, Inc., Westbrook, ME, USA) according to the manufacturer's instructions. Water samples were incubated at 35 °C (range 32–37 °C) and read after 24–25 h of incubation. Heterotrophic plate count (HPC) bacteria in water samples were quantified by diluting the sample in sterile water according to the residual chlorine (100:1 dilution for Cl <0.4 mg/L, and 20:1 dilution for Cl >0.4 mg/L) to achieve a final volume of 100 mL. The MPN of HPC was determined using IDEXX HPC reagent and Quanti-Tray®/2000 trays (IDEXX Laboratories, Inc., Westbrook, ME, USA) according to the manufacturer's instructions. Samples were incubated at 35 °C (range 32–38 °C) and read after 48–72 h of incubation.

Samples for physical, chemical, and microbiological quality parameters were collected in separate glass vials without sodium thiosulfate. Turbidity was measured using a MicroTPW turbidity meter (HF Scientific, Fort Myers, FL, USA), and residual chlorine was measured in the field using the DPD method (Pocket Colorimeter™ II, Hach, Loveland, CO, USA).

Data analysis

Statistical software R (R Core Team 2017) and Microsoft Excel were used for graphing and data analysis. Permutation tests (previously described in Erickson *et al.* were used to test for significance, with a threshold of $p < 0.05$ for significance (Erickson *et al.* 2017). The Coin package for R was used for Permutation tests (Hothorn *et al.* 2015).

RESULTS

Water storage containers varied according to the supply type

Examples of the four most common types of household water storage containers are shown in Figure 2: (A) Large plastic or metal tanks with wide mouths and capacity between 10 and 55 gallons; (B) Buckets, generally plastic and cylindrical, with a wide mouth, and capacity ranging from 2.5 to 10 gallons; (C) Pitchers with a wide mouth and a maximum capacity of 1 gallon; and (D) Plastic or glass bottles with a narrow mouth. As described in the Materials and Methods section, containers were classified as 'safe' (types C and D) or 'unsafe' (types A and B) according to how water was extracted from them. We found a total of 76 (80.8%) of households using safe containers to store water for drinking purposes (Table 1).

Storage practices varied according to the continuous or intermittent supply (Table 1). Area 3 had the most intermittent supply (average of 96 h per week with water supply) (Nelson & Erickson 2016; Erickson *et al.* 2017) and the highest portion of households using unsafe storage containers (56.5%). Area 3 also had the highest average storage capacity for drinking water per household (28 gallons). The more frequent use of unsafe containers in Area 3 was

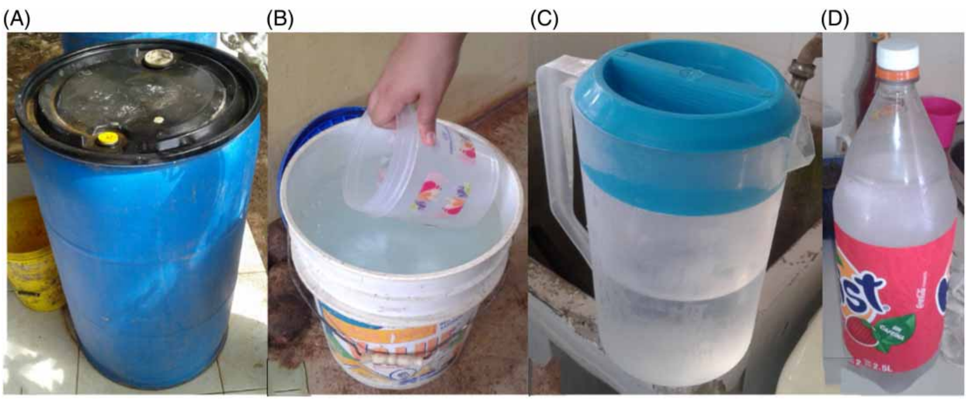

Figure 2 | Examples of common methods of storing drinking water. (A) Tank (unsafe), (B) 5 gallon bucket with extraction by dipping (unsafe); (C) Pitcher (safe), and (D) Bottle (safe).

Table 1 | Summary of storage types by study area

Study area	*n*	Safe container	Unsafe container	Container with lid	Average storage (gallon)[a]	Storage time (h)[b]	Weekly available supply (h)[c]
Area 1	23	23 (100.0%)	0 (0.0%)	18 (78.3%)	1.8	28	166
Area 2	24	24 (100.0%)	0 (0.0%)	19 (79.2%)	3.5	42	139
Area 3	23	10 (43.5%)	13 (56.5%)	22 (95.7%)	27.9	79	96
Area 4	24	19 (79.2%)	5 (20.8%)	22 (91.7%)	12.5	43	146
Total	**94**	**76 (80.8%)**	**18 (19.3%)**	**81 (86.2%)**	**11.4**	**48**	**NA**

[a]Average storage refers to the average capacity that household has to store water for drinking.
[b]Storage time refers to the average time the water spent stored in the containers at households.
[c]Supply time per week (h) is based on continuous pressure monitoring, conducted for 1 year in areas as part of another study (Erickson et al. 2017). Note that the monitoring was only at one point in each area, and the schedule of supply varied within each area.

probably due to households needing to use larger unsafe containers because of the more intermittent supply. In the areas with the continuous supply (Area 1) and with the occasionally intermittent supply (Area 2), all storage containers were safe and had an average storage volume lower than containers in Area 3 and Area 4. Although all households in Area 1 and Area 2 used pour-extraction from water storage containers, they had more frequent use of uncovered containers compared to Area 3 and Area 4 (Table 1). However, 9 of the 10 containers without covers in Area 1 and Area 2 were bottles or pitchers stored in the refrigerator, where low temperatures would likely inhibit bacterial growth (LeChevallier 2003).

Water stored in unsafe containers had a higher prevalence of poor microbiological quality

We found higher prevalence and higher concentrations of indicator bacteria in household drinking water stored in unsafe containers. Thirty-three (35%) of stored water samples were positive for total coliform bacteria, including 23 (25%) of samples with greater than 10 MPN/100 mL. Twenty-one (27.6%) samples of water stored in safe containers were positive for total coliform bacteria. In contrast, a significantly higher portion of samples of water stored in unsafe containers (66.7%) was positive for total coliforms ($p = 0.0019$, two-tailed independence test) (Table 2). Only

Table 2 | Summary of water quality results

Water quality parameters	Safe containers ($n = 76$)	Unsafe containers ($n = 18$)	Area 1 ($n = 23$)	Area 2 ($n = 24$)	Area 3 ($n = 23$)	Area 4 ($n = 24$)	Total ($n = 94$)
Free chlorine							
<0.2 mg/L	38.2%	83.3%	17.4%	29.2%	91.3%	50.0%	46.8%
Turbidity							
>1.0 NTU	1.3%	0.0%	0.0%	0.0%	4.3%	0.0%	1.1%
Total coliforms							
<1 MPN/100 mL	72.4%	33.3%	87.0%	75.0%	30.4%	66.7%	64.9%
1–10 MPN/100 mL	13.2%	0.0%	13.0%	8.3%	13.0%	8.3%	10.6%
11–100 MPN/100 mL	5.3%	0.0%	0.0%	0.0%	0.0%	16.7%	4.3%
>100 MPN/100 mL	9.2%	66.7%	0.0%	16.7%	56.5%	8.3%	20.2%
E. coli							
Positive	1.3%	44.4%	4.3%	0.0%	34.8%	0.0%	9.6%
HPC							
>500 MPN/mL	19.7%	77.8%	4.3%	25.0%	78.3%	16.7%	30.9%

9 (9.6%) of all samples were positive for *E. coli*, one of them from a safe container, and the other eight from unsafe containers. Regarding HPC, samples from unsafe containers had significantly higher concentrations of HPC bacteria than samples from safe containers ($p = 0.000008$, two-tailed test). Twenty percent of samples of water stored in safe containers resulted with HPC concentrations >500 MPN/mL, whereas 78% of samples stored in unsafe containers had >500 MPN/mL (Table 2). Similarly, unsafe containers showed lower levels of residual chlorine ($p = 0.00014$, two-tailed independence test).

Residual chlorine decreased over time in household stored drinking water

It was previously reported that the chlorine residual in 405 samples from the distribution system in our study areas ranged from 0.30 to 1.31 mg/L (Erickson *et al.* 2017). In this study, we observed that nearly half of the household stored drinking water (46.8%) had <0.2 mg/L free chlorine residual. Low levels of residual chlorine were observed more frequently in Area 3 and Area 4, where residual chlorine levels <0.2 mg/L were measured in 91.3% and 50.0% of household stored drinking water samples, respectively (Table 2). Chlorine residuals were significantly lower in Area 3 compared to Areas 1, 2, and 4 ($p < 0.00001$, two-tailed independence test) and were significantly lower in Area 4 compared to Areas 1 and 2 ($p = 0.006$, two-tailed independence test).

Long storage times were associated with lower levels of residual chlorine (Figure 3(a)), with samples stored for longer than 72 h having significantly lower chlorine residual ($p = 0.000002$, two-tailed independence test). Storage times were longer in the more intermittent study areas. Area 3 (intermittent), where 61% of samples were stored for 72 h or longer (Figure 4) and average storage time was 79 h (Table 1), had significantly longer storage times than the other three areas ($p = 0.0009$, two-tailed independence test). In Area 1, which had a continuous supply and significantly

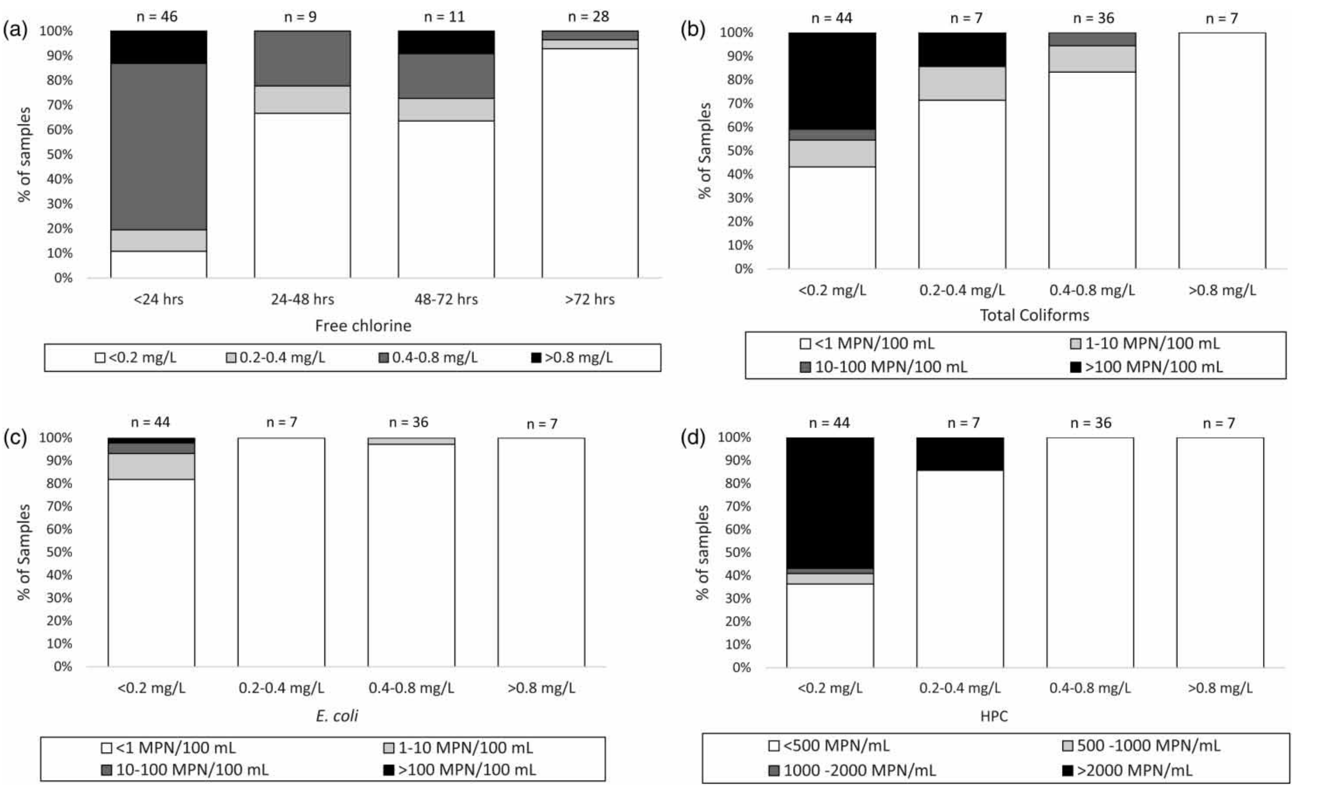

Figure 3 | Water quality sampling results: Free chlorine residual by storage time (a), total coliform concentration by chlorine residual (b), *E. coli* concentration by chlorine residual (c), and heterotrophic plate count (HPC) by chlorine residual (d).

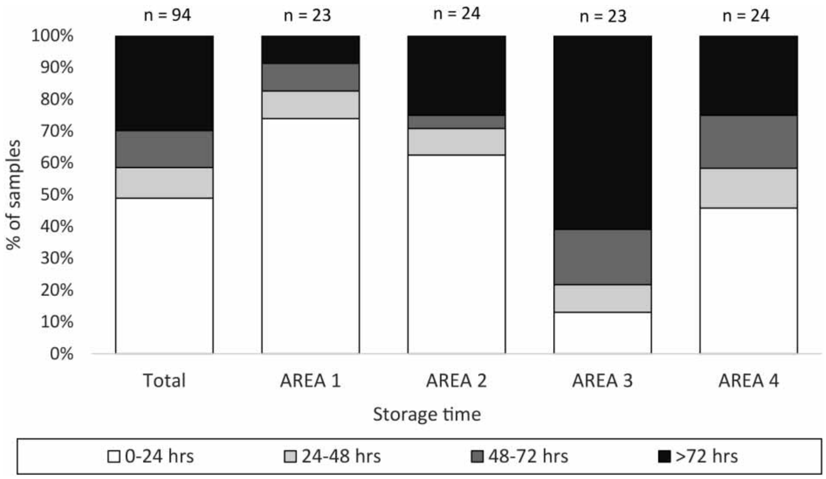

Figure 4 | Storage times by the study area.

lower storage times than the other study areas ($p = 0.003$, two-tailed independence test), 8.7% of containers were stored more than 72 h, and average storage time was 28 h.

In contrast to chlorine residual, turbidity did not appear to be substantially affected by storage and remained at levels below 1.0 Nephelometric Turbidity Units (NTUs) in most household stored drinking water. Only one sample (1.01 NTU from Area 3) had turbidity above the Panamanian standard of 1.0 NTU (COPANIT 1999). The fact that particulate matter may have settled in the larger storage containers and our samples were extracted from the top or middle of the container may explain this observation.

The presence of E. coli, total coliforms, and HPC in household stored drinking water were related to low levels of residual chlorine and more intermittent supply

Higher concentrations of *E. coli* and total coliform bacteria were found in samples with residual chlorine levels <0.2 mg/L ($p = 0.007$ for *E. coli* and $p = 0.000004$ for total coliform bacteria, two-tailed independence tests) (Figure 3(b)–3(d)). Eight (89%) of the nine samples positive for *E. coli* had residual chlorine levels <0.2 mg/L. Of the 33 (35.1%) samples positive for total coliform bacteria, 25 (75.8%) had levels of residual chlorine <0.2 mg/L. In samples with residual chlorine levels <0.2 mg/L, a total of 18 (40.9%) had total coliform concentrations >100 MPN/100 mL (Figure 3(b)). Regarding the type of water supply, we observed significantly higher incidence of *E. coli* in Area 3, the area where supply was most intermittent ($p = 0.0000020$, two-tailed independence test). Eight of the nine (89%) samples positive for *E. coli* were from Area 3 (Table 2).

All areas yielded some household stored drinking water positive for total coliform bacteria (Table 2). Specifically, 16 samples (69.6%) from Area 3 were positive for total coliform bacteria, the highest among our study sites. Interestingly, 13 (56.5%) samples collected in Area 3 had more than 100 MPN/100 mL total coliform bacteria (Table 2). Samples from Area 3 had significantly higher total coliform concentrations than those from the other areas ($p = 0.000006$, two-tailed independence test). In contrast, Area 1 had no samples with total coliform concentrations greater than 10 MPN/100 mL.

The presence of HPC was observed in 77 (81.9%) of all samples analyzed (detection limit was 1.0 or 0.2 MPN/mL depending on dilution). Twenty-nine (30.9%) samples had ≥500 MPN/mL HPC. Area 3 had the highest proportion of samples positive for HPC (95.7%) and the highest portion of samples with ≥500 MPN/mL HPC (78.3%). HPC levels were also higher in household stored drinking water with less residual chlorine ($p = 0.0000000013$, two-tailed independence test). Only 37 (74%) samples with ≥0.2 mg/L residual chlorine were positive for HPC and only one had ≥500 MPN/mL HPC. On the other hand, 28 (63.6%) samples with residual chlorine <0.2 mg/L had ≥500 MPN/mL HPC (Figure 3(d)).

DISCUSSION

Maintaining the quality of household stored drinking water remains a public health challenge. Our study focused on evaluating household water storage practices and their effect on water quality in the context of varying degrees of intermittent piped supply in Arraiján, Panama. In agreement with previous research (Levy *et al.* 2008; Harris *et al.* 2013), we found poorer microbiological quality of stored water to be associated with lower or undetectable residual chlorine concentrations, longer storage time, and storage container types that were more susceptible to contamination. We found all of these risk factors to be associated with areas that had more intermittent and unreliable piped water supply. The highest levels of microbial contamination were found in Area 3, where drinking water supply was most intermittent and risk factors like long household water storage times and unsafe storage were more common. These findings suggest that the manipulation of stored drinking water in households and the reliability and continuity of piped drinking water supply significantly influence household stored drinking water quality.

Fast growing communities demand larger quantities of safe water. Arraiján, our study site, has grown rapidly, quadrupling its population from 1990 to 2014 (INEC 2010a, 2010b). Two drinking water treatment plants supply good quality water to the areas of Arraiján we studied (Erickson *et al.* 2017), but this quality was not reflected in water stored at households. Panama's drinking water quality standards (COPANIT 1999) state that piped drinking water should have residual chlorine between 0.8 and 1.5 mg/L, turbidity <1.0 NTU, 0 MPN/100 mL *E. coli*, and ≤ 3 MPN/100 mL total coliform bacteria. A previous study by our team revealed that water randomly sampled from taps in the Arraiján study area had levels of residual chlorine ranging from 0.30 to 1.31 mg/L (Erickson *et al.* 2017). The same study confirmed very low incidence of *E. coli* and total coliform bacteria in both the continuous and intermittent supply. Panama's biological standards for non-piped water call for 0 MPN/100 mL *E. coli* and ≤ 10 MPN/100 mL total coliform bacteria. We used these standards in our analysis with the exception of residual chlorine, for which we used the World Health Organization (WHO) standard of ≥ 0.2 mg/L (WHO 2011). For HPC, the WHO recommends that piped water have <500 MPN/mL HPC bacteria (WHO *et al.* 2003). It should be noted that our study did not include the measurement of actual pathogens. The indicator bacteria we used are typically used to assess disinfection processes during treatment and post-treatment contamination (total coliform bacteria) and indicate fecal contamination (*E. coli*). With the exception of some *E. coli* strains, the indicator organisms used are not pathogens themselves (Mattioli *et al.* 2013).

Our study had some limitations. All negative controls were negative for total coliform bacteria and *E. coli*. However, 12 (63.2%) of the negative controls for HPC resulted positive. One of these controls was above the detection limit (24.2 MPN/mL HPC). Apart from that sample, all of the negative controls had concentrations of 0.79 MPN/mL HPC or lower. The contamination of the negative controls with HPC bacteria could have occurred during the collection of the controls in the field or in the laboratory. Methodologically, our study showed correlation but not causation. We demonstrated that lower stored water quality was associated with certain practices, but could not show that these storage practices caused changes in water quality. We did not evaluate many other simultaneous factors that could cause deterioration in water quality in order to determine which factor was most important. For instance, Area 3 showed the worst stored water quality, higher frequencies of unsafe storage, and longer storage times, and consisted of a different set of households with unique characteristics. However, data were not collected on educational, behavioral, or socioeconomic conditions, and thus we are unable to identify the key factors associated with poor stored water quality. Further research under controlled and randomized conditions might be able to show causation rather than just association.

Our study noted a higher incidence of unsafe storage in Area 3, where households have to store a larger volume of water because of intermittence in the supply network. The need to store more water could lead to the use of larger containers that are less safe because they are not well covered. The use of larger storage containers also makes it more difficult to extract water in a hygienic manner, increasing the risk of contamination when another potentially contaminated device is introduced to retrieve water from the container. Thus, a more continuous piped water supply could decrease household storage time and prevent the deterioration of water quality. In addition, we speculate that differences in the education or socioeconomic status of the community and household members could affect the use of safe storage containers. The implementation of an educational program might improve knowledge and awareness in these households and promote improvements in water storage methods. Such a program should promote safe storage methods similar to those we found in Areas 1 and 2. The implementation of these storage methods could reduce the risk of water contamination and secure public health. This strategy could be particularly effective if implemented in systems like Arraiján's, where there is a good water quality in the distribution system.

For now, our study provides a baseline understanding of the factors associated with poor quality of drinking water stored within the home. Further research is needed to accurately determine the influence of household storage containers on disinfectant decay rate. Similarly, a controlled study of which storage practices lead to contamination and what conditions or factors motivate households to use safe or unsafe storage practices is needed to define what storage practices should be promoted and how to effectively promote them. Such an approach could be complemented with microbial ecology studies to determine the source of contaminating bacteria (regrowth in storage containers vs. introduction via contaminated hands or utensils) and assess to what extent typical indicator bacteria are reliable indicators for pathogens. Altogether, such research would provide a detailed understanding of bacterial contamination dynamics at the household level.

CONCLUSIONS

The use of unsafe containers for household storage of drinking water in Arraiján makes stored water vulnerable to contamination. Water is typically extracted from these unsafe containers by introducing another container that could be contaminated with pathogens. We found that water stored for a longer time had lower residual chlorine levels and higher concentrations of HPC bacteria. In areas with more intermittent supply, storage times were longer, chlorine residuals were lower, and the use of unsafe containers was more common compared to areas with more continuous supply. All of these factors were associated with higher levels of indicator bacteria. Thus, the type of water supply (intermittent or continuous) can influence household drinking water storage conditions and risk of contamination. We strongly recommend against interruptions of drinking water supply for more than 72 h and recommend the implementation of educational programs to improve household storage practices for drinking water. Together, these strategies will protect public health after the production and distribution of drinking water. By improving public awareness, promoting existing safe storage practices, and re-engineering the current designs of household storage systems in cases where currently available practices are inadequate, the quality of drinking water stored in homes can be improved.

CONFLICTS OF INTEREST

The authors declare no competing interests.

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SUPPLEMENTARY MATERIAL

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