The effectiveness of large household water storage tanks for protecting the quality of drinking water

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ABSTRACT

Many communities along the US-México border remain without infrastructure for water and sewage. Residents in these communities often collect and store their water in open 55-gallon drums. This study evaluated changes in drinking water quality resulting from an intervention that provided large closed water storage tanks (2,500-gallons) to individual homes lacking a piped water supply. After the intervention, many of the households did not change the source of their drinking water to the large storage tanks. Therefore, water quality results were first compared based on the source of the household's drinking water: store or vending machine, large tank, or collected from a public supply and transported by the household. Of the households that used the large storage tank as their drinking water supply, drinking water quality was generally of poorer quality. Fifty-four percent of samples collected prior to intervention had detectable levels of total coliforms, while 82% of samples were positive nine months after the intervention ($p < 0.05$). Exploratory analyses were also carried out to measure water quality at different points between collection by water delivery trucks and delivery to the household's large storage tank. Thirty percent of the samples taken immediately after water was delivered to the home had high total coliforms ($>10 \, CFU/100 \, ml$). Mean free chlorine levels dropped from 0.43 mg/l, where the trucks filled their tanks, to 0.20 mg/l inside the household's tank immediately after delivery. Results of this study have implications for interventions that focus on safe water treatment and storage in the home, and for guidelines regarding the level of free chlorine required in water delivered by water delivery trucks.

Key words | water quality, water storage, water transport

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INTRODUCTION

A significant proportion of the world's population must collect, transport and store their own water for drinking, cooking and personal and home hygiene (Kindhauser 2003). Research indicates that improving the source of water for these individuals does not always ensure safe water at the point-of-use, as quality often deteriorates subsequent to collection (Jensen et al. 2002). Additionally, post-source contamination has been associated with increased rates of diarrheal disease (Musa et al. 1999; Gundry et al. 2004).

In El Paso County, Texas, there are an estimated 3,500 people living in *colonias* (unincorporated neighborhoods) who do not have a piped water supply (Crowder 2003). The neighborhoods are characterized by substandard housing and poor living conditions, with the median annual income for households ranging between $7,000 to $11,000, and the number of individuals in each household consisting of typically five to six residents (Ward 1999). *Colonia* residents either collect their own water, using available receptacles or rely on water delivery trucks to fill large open containers

outside the home, such as discarded 55-gallon drums. This lack of services represents not only an inconvenience to the residents, but also poses real health risks.

The number of people globally who rely on water delivery trucks is not well documented, however, it is an option that many cities rely on for servicing residents who are not connected to the public distribution system. For example, in Ciudad Juárez, México, across the border from El Paso, Texas, the water and sanitation utility, Junta Municipal de Agua y Saneamiento (JMAS), estimates 50,000 residents receive water via water trucks (personal communication with JMAS). The United Nations has estimated that the number of people living in urban slums, 1 billion, will double by 2030, and thus water delivery by trucks will likely remain an important option for cities.

In an effort to improve the water supply available to households in colonias, a local foundation funded a project entitled "When Water Works for Health" that provided 2,500-gallon water storage tanks to homes lacking a piped water supply (Figure 1). The tanks are filled by a water delivery truck, and have pipes connected to the homes in order that each household may have running water.

Most of the households in *colonias* use drinking water that originates from a public distribution system, however, water quality changes during transport and storage are not well documented. In some cases *colonia* residents purchase drinking water, either from a store or from a water vending machine. Numerous studies have found bacteria in both bottled water and vending machine water (Warburton 1993; Schillinger & Du Vall Knorr 2004). There are three aims of this study: 1) evaluate water quality from different drinking water sources used by *colonia* residents; 2) evaluate how the intervention (the installation of the large storage tanks) affected drinking water quality; and 3) study how delivery of water affects water quality at different points during the transport of water from the standpipe, where delivery trucks fill their tanks, to delivery of water to the home.

METHODS

Data collection

Data were collected between September 1998 and December 1999 in four contiguous communities of El Paso County, Texas where a community-based organization had received funding to install 102 2,500-gallon water storage tanks. Data on water collection, use, and storage practices were gathered through face-to-face interviews. The research design called for data to be collected before installation of the large storage tanks (the intervention), one month after the intervention and nine months after the intervention.

Figure 1 | 2500-gallon water storage tank provided in intervention.

Drinking water samples were analyzed for residual chlorine, turbidity, total coliforms, and *Escherichia coli*. A residual chlorine level of 0.2 mg/l is deemed adequate to protect water in most distribution systems, however, water haulers in Texas are required to raise the level of free chlorine residual to a minimum of 0.5 mg/l before delivering water to residents' homes. Turbidity, which has been found to be positively associated with bacteriological quality, was used as an additional indicator of water quality. Turbidity and residual chlorine levels were measured immediately after sample collection using a Hach® portable turbidity meter and chlorine colorimeter, respectively. The coliform test has been considered a reliable indicator of the possible presence of fecal contamination and has been correlated with pathogens (WHO 2004). The World Health Organization Recommended Water Quality Standards call for less than 10 total coliforms per 100 ml (WHO 2004). However, many environmental bacteria can give positive results, thus a positive test does not necessarily indicate the presence of fecal contamination. Other disadvantages of total coliforms include the possibility of regrowth in some environments and they do not often correlate with enteric protozoan and viral levels (Chauret *et al.* 1995).

Water was allowed to run from the faucets prior to the collection of samples for 30 seconds to avoid contamination from the tap. Samples were collected in Whirl-Pak® sample bags containing sodium thiosulfate (i.e. declorination tablets) and were tested within 8 hours of collection for total coliforms and *E. coli* using membrane filtration and m-coli blue 24 (Hach®, Loveland, CO) that allows simultaneous detection of *E. coli* and total coliforms (*Standard Methods* 1998). Samples were incubated for 24 hours at 35°C under aerobic conditions. The negative controls consisted of sampling 100 ml of distilled water (autoclaved in the lab and transported to the field), using the same collection procedures as above. *E. coli* bactrol disks were used as the positive control.

In order to examine the changes in water quality during the short period of time (approximately 30 minutes) between collection and delivery of water by delivery trucks, a series of water samples were collected. Samples were taken from the distribution standpipe where the hauling tanker trucks filled up, the tanker truck once it arrived at the home, and the household's large storage tank before it was filled with water and after being filled. The tanks generally have 100-300 gallons of water remaining from a prior delivery. The same four measures mentioned previously were used to characterize water quality.

Statistical analysis

Descriptive statistics were generated to assess the central tendency and variation in drinking water quality. Mean turbidity and mean residual chlorine levels were compared for different types of water storage containers using non-parametric t-tests. Mean coliform densities were also compared, and categorical measures of coliform density were used as well. T-tests were used to assess the statistical significance of comparisons of continuous measures of water quality, while contingency tables were used to assess the significance of categorical measures of water quality. The study of water quality at different points during the transport of the water from the standpipe to the home is considered exploratory given the limited number of samples analyzed. SPSS 11.0 statistical software (SPSS, Inc., Illinois) was used for the analyses.

RESULTS

Drinking water sample results and questionnaires were completed for 35 households before the intervention, 59 households one month after intervention, and 34 households nine months after intervention. The remaining households participating in the intervention were either not available, did not have water at the time of the visit, opted to not participate, or had not received their tank during the time period of the study. In some cases, tanks were either delivered prior to the study or after the study was completed, thus data were not collected for a large portion of the participating households.

Prior to the installation of the storage tanks, a large number of the households had two different supplies of water, one for drinking and cooking, either purchased or collected from a public source, and one for other purposes, such as personal and home hygiene. After the installation of the tanks, many of the households did not change the source of their drinking water to the large storage tanks.

Therefore, the drinking water quality results were combined from the three collection times (before intervention, 1-month after and 9-months after) and compared based on where the household's drinking water was derived (Table 1). Households generally received their drinking water from three sources: 1) the municipal supply, transported by residents in their own personal containers, usually less than 10 gallons (43 samples); 2) water purchased from stores or from water vending machines (37 samples); and 3) from tanker trucks which obtained water from the municipal piped supply and delivered the water to the large storage tanks (48 samples).

Thirty-seven samples were analyzed from households that purchased their drinking water and stored it in a small container (29 from a vending machine and 8 from a store). All of the samples originating from stores were positive for total coliforms (38% >10 CFU/100 ml) and 59% of the samples from vending machines were positive for total coliforms (38% >10 CFU/100 ml). Forty-three samples came from households that collected drinking water from a municipal supply and stored it in small containers (<10 gal.). Twenty-six (60%) samples from these small containers tested positive for total coliforms (35% >10 CFU/100 ml). Forty-eight samples were from households that received their drinking water from delivery trucks. Seventy-one percent of these samples had total coliform levels greater than 10 CFU/100 ml (Table 1).

To compare pre-intervention and post-intervention drinking water quality, data were compared from 35 households prior to installation of the water storage tanks and 34 households nine months after tank installation. The study time frame did not allow for pre-intervention and 9-month post-intervention samples to be collected from the same households. The percentage of samples with total coliforms was higher for the samples collected at the 9-month follow-up visit, as was the geometric mean of total coliforms (Table 2). The percentage of households with adequate free chlorine was relatively equal between the samples from baseline and the 9-month follow-up visit. The number of samples positive for *E. coli* was three positive samples prior to the intervention and one positive sample after installation of the tanks.

Overall, having adequate residual chlorine generally resulted in very low total coliform levels. Figure 2 shows a plot of free chlorine versus total coliforms for all of the households that stored drinking water in a small container. The figure clearly shows that when high free chlorine exists, no or very few total coliforms are present. Only one of the thirteen drinking water samples, which had adequate chlorine residual also had total coliforms >10 CFU/100 ml. Furthermore, 62 of the 63 drinking water samples with more than 10 CFU/100 ml had residual free chlorine less than 0.2 mg/l. This association was highly significant ($\chi2 = 22.26$, p = 0.001). There were 52 samples which had low chlorine and low total coliform levels, indicating that it is possible to have disinfected water with low or no chlorine residual present.

In order to assess the changes in water quality occurring during transport and delivery by tanker trucks, water samples were taken at different points between collection by the water delivery company and delivery to the household's large water storage tank, including: 1) water distribution standpipe at the time the water delivery company filled their truck; 2) water

Table 1 │ Comparison of drinking water sources by level of free chlorine and total coliforms

Water quality parameter	Store/vending machine (n = 37)	Collected from municipal supply[*](n = 43)	Delivery truck (Tank)[†] (n = 48)	p-value[‡]
Free Chlorine				
(<0.2 mg/l)	94%	77%	98%	0.49
Total Coliforms				
(>10 CFU/100 ml)	38%	35%	71%	0.02

[*]Drinking water collected by household from a public distribution system.
[†]Drinking water collected by delivery truck and delivered to 2,500 gallon water storage tank.
[‡]Chi-square test comparing proportions of positive results among the three sources of drinking water.

Table 2 | Differences in measures of drinking water quality: baseline vs. 9-month follow-up visit

Water quality parameter	Baseline intervention (n = 35)	9-month follow-up (n = 34)
Turbidity		
(% > 1.0 NTU)	11.4%	5.9%
Free chlorine		
(% < 0.2 mg/l)	97.1%	97.1%
Total coliforms (%):		
< 10 CFU/100 ml	68.6%	29.4%
11-100 CFU/100 ml	5.7%	38.2%
> 100 CFU/100 ml	25.7%	32.4%
Total coliforms		
Geometric mean		
(CFU/100 ml)	0.58	1.27
E. coli		
(% positive)	8.6%	2.9%

delivery truck once it arrived at the home; 3) the household 2,500-gallon water storage tank before being filled; and 4) the 2,500-gallon household water storage tank after being filled. Samples were collected between January 1999 and June 1999. Water quality generally worsened as the water was taken from the standpipe and delivered to the storage tanks
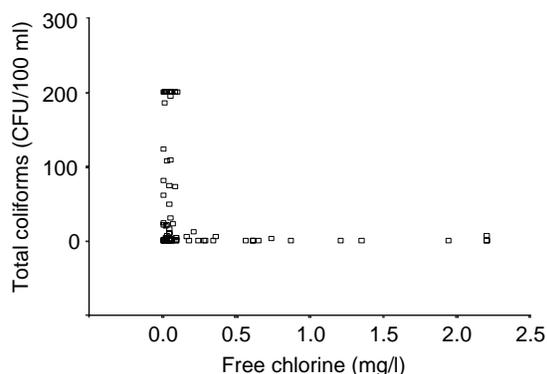
Figure 2 | Scatterplot of free chlorine by total coliform densities.

(Table 3). Although water quality changes were not statistically significant, the differences seem to indicate that water delivery can affect turbidity, total coliforms and chlorine, and that chlorine residual in the tanks declines over time, allowing the persistence or regrowth of the bacteria potentially introduced during the hauling process, from biofilms in the tank or from deposition from air into the tank.

DISCUSSION

Multiple aspects should be considered when assessing the benefits and costs of interventions of this nature. Large water storage tanks, in the case of "When Water Works for Health", reduced the time households spent collecting their own water, and provided more water for non-drinking purposes, such as washing and cleaning. It should be noted that significant reductions in diarrheal diseases have resulted from interventions solely focused on increasing the quantity of water available (Esrey *et al.* 1991).

Water in the large water storage tanks rarely had sufficient chlorine residual and was commonly contaminated with total coliforms. No statistically significant differences in drinking water quality, however, were detected between the time before the installation of the large storage tanks and nine months after.

The large storage tanks allowed for longer storage times, which may potentially increase the risk of contamination and allow chlorine to volatilize. Water, stored by the household, in small containers (i.e., less than 10 gallons) also suffered from low chlorine levels and bacteriological contamination, however, such containers were more likely to have a chlorine residual, and less likely to be contaminated with total coliforms. This may be due to the fact that small containers were often refrigerated and had less headspace, limiting the volatilization of chlorine.

No statistically significant associations were found between the amount of time that water was stored and the quality of the water. This may be due to a number of factors that affect water quality, such as using contaminated containers, or mixing water that has been stored for a long period of time with newly collected water.

As in many community intervention studies, participants were not randomly selected, and although selection bias may

Table 3 │ Water quality measurements at different points between collection by the water delivery truck and delivery to the household's large storage tank

Water quality	Standpipe (n = 16)	Delivery truck (n = 13)	Tank before delivery* (n = 13)	Tank after delivery (n = 14)
Mean turbidity (NTU)	0.40	0.58	0.57	0.65
Mean free chlorine (mg/l)	0.43	0.35	0.04	0.20
Total coliforms (Geometric mean CFU/100 ml)	0.06	0.47	0.68	0.50
Total coliforms >10 CFU/100 ml	13.3%	30.8%	36.4%	30.0%

*"Tank before delivery" consisted of water, usually <300 gallons, leftover from a previous delivery.

be present, qualitative observations by the researchers indicated that those households who chose to participate were not systematically different from those who chose not to participate. Reasons for non-participation varied, but generally were due to no one being home to interview.

Programs, which educate families on safe water treatment (e.g., chlorination) and safe storage in the home, especially for homes not connected to a public water distribution system are recommended. Additionally, the use of small-mouthed containers that provide for easy fill-up and dispensing, and prevent people from contaminating the drinking water during storage should be promoted. A recent analysis of interventions designed to improve water quality at the household level, through in-home treatment and appropriate storage, demonstrated a median reduction in diarrheal disease of 42% versus control groups (Clasen & Cairncross 2004). It is recommended that households not drink water directly from large water storage tanks, unless adequate levels of chorine can be maintained. In situations where water must be delivered by trucks, such as poor urban areas or refugee camps, the amount of chlorine added to water delivered by water delivery trucks should be adjusted to a level that will protect water quality during storage.

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