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Evaluation of neighborhood treatment systems for potable water supply

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Piped water is available in Ciudad Juárez, Chihuahua, México, but residual disinfectant is not reliably found in the public drinking water supply. Lack of confidence in the public supply leads many residents to rely on bottled water. To provide consistent disinfection, two health clinics were equipped with ultraviolet disinfection systems, and neighboring households were encouraged to obtain their drinking water from the treatment systems. Use of the treated water declined from 62% of self-selected study participants at the time of the first visit to 40% at the second visit. During the first visit, diarrhea prevalence was similar among households using treated water and other water sources yet diarrhea prevalence was higher among households using the treated water during the second visit. Microbiological quality of the treated water in the homes was not demonstrably superior to that of other sources.

Keywords: drinking water; domestic built environment; diarrhea

Introduction

The need for potable water is growing more urgent worldwide and is perhaps greatest in developing countries, where both infrastructure and investments are severely lacking (WHO 2000). In many instances, the lack of potable water is compounded by a lack of water health awareness, often resulting in serious negative health outcomes. This is evident in the border community of Ciudad Juárez, Chihuahua, México, where 16% of the population (200,000 out of 1.2 million) live under extreme poverty and lack basic infrastructure for water and sanitation (Castañón 2003). Although considerable investments have been made in improving the water supply infrastructure in the region, residents of some outlying neighborhoods still lack basic services, such as water and sewerage (Graham et al. 2004, 2005) and suffer from high rates of intestinal parasites (Redlinger et al. 2002).

In-home water disinfection has been proposed as a means to provide safe drinking water in areas lacking a safe public supply. While there are many examples of successful in-home treatment programs (Sobsey 2002), this approach leaves a vital

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engineering process (drinking water disinfection) in the hands of non-professionals. Both consistent use of the treatment methods and accurate disinfectant dosing have been found to be problematic (Gurian et al. 2006). Given these concerns, the use of a neighborhood-level treatment process may offer an alternative way to provide better quality control for drinking water treatment than can be achieved with in-home treatment methods. Such neighborhood treatment systems may avoid the need for large financial investments in piped distribution systems by providing safe water close enough to people's homes that they can transport it to their houses. The widespread use of bottled water in both developed and developing countries suggests that, at least to some extent, individuals are willing to transport water that they believe to be of high quality from neighborhood distribution centers to their homes. However, bottled water is unnecessarily expensive as it is usually shipped from remote sources when local sources can usually be readily and affordably treated to potable quality, and packaging accounts for a large portion of the cost.

This project evaluated two such neighborhood-level water treatment systems which were installed in Ciudad Juárez, Chihuahua, México. These systems were installed as part of an actual interventional effort, not a controlled trial of the intervention designed by the authors. The study described here observed the course of the intervention, including obtaining and analyzing data on water quality, water use, and health status of neighborhood residents. Both water treatment systems were located at neighborhood health clinics, and provided ultraviolet (UV) disinfection of water. The water was available without charge to neighborhood residents who transported the water to their homes in their own containers. The specific objectives of the study were: (i) to identify the extent to which neighborhood families obtained and used the treated water as well as potential barriers for using this water source; (ii) to determine the performance of the water treatment systems based on water quality analyses; and (iii) evaluate the human health impact associated with using this water source. While there are reports of such neighborhood-level, clinic-based systems being used in a number of developing countries (see for example, LWFW 2007), there is a need for more systematic evaluation of this strategy of drinking water provision.

Materials and methods

The two drinking water systems were installed in October 2002 at neighborhood community centers, called "*Oratorios*", located in 16 de Septiembre and Nueva Galeana, two neighborhoods located on the western outskirts of Ciudad Juárez (Figure 1). The community of 16 de Septiembre was established in the mid-1980s, and the community of Nueva Galeana in the 1990s. The community centers are affiliated with the Catholic Church through the worldwide Salesian organization, and serve as centers for religious services and a variety of other activities, such as a kindergarten school, vocational school, sports facilities, and medical (preventive health) care at their clinics. The municipal drinking water supply of Ciudad Juarez, a low-turbidity groundwater, was used as the source water for the treatment units.

The water treatment units (UVWaterworks^{TM}, Water Health International, Irvine, CA, USA, http://www.waterhealth.com) offer a high throughput, ultraviolet (UV) disinfection technology. Two staff members from each *Oratorio* received training on the use and care of the systems during the installations. An owner's

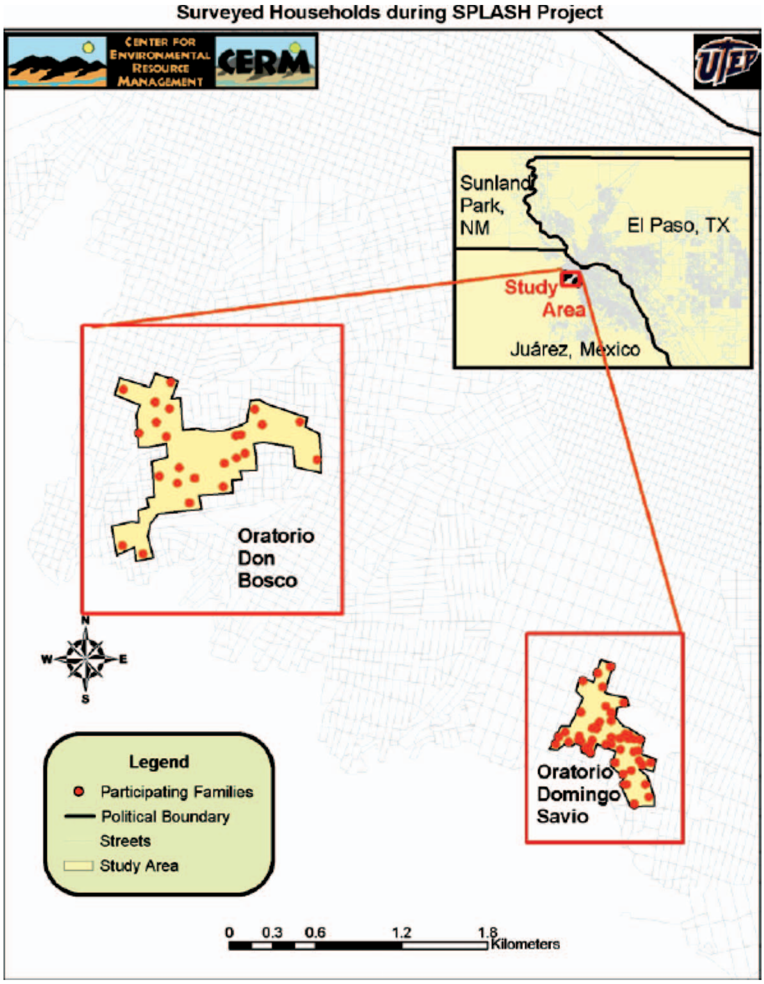

Figure 1. Study area.

manual in Spanish developed by Water Health International (WHI) was provided to each of the *Oratorios* at that time. Regular maintenance of the systems was performed every two months as recommended by WHI. Maintenance consists of emptying the storage container on the roof, cleaning the filter containers with water, soap, and chlorine, and changing the filters. During the summer months, when the consumption rates for electricity increase, the systems experienced issues related to the insufficient electrical power to the *Oratorios*. An electrician was hired to perform appropriate modifications to the power connections in order to support the additional electrical demand due to the water purification systems.

Institutional Review Board approval was obtained for the participation of human subjects in this research. A colorful illustrated brochure was designed and distributed to promote the use of the potable water sources among the communities. Targeted to families who rely on drinking water delivered by trucks or serviced by intermittent tap water, the brochure explains the important relationship between water and health and explains that odorless, filtered, UV-purified drinking water is available to them at the clinics. The brochure was distributed to the residents while on their way to school, while visiting the medical doctor, or while attending a class. Poster announcements and health fairs also served as promotional events for the program. A self-selected convenience sample was used consisting of 60 households (30 at each clinic) who volunteered to use the treated water and 30 households (15 near each clinic) who indicated they did not intend to use the water. Households not using the clinic water relied on a variety of sources including indoor taps, outdoor taps (this term is used for taps located on residential lots and generally used only by the occupants of the lot), and store-bought water. The goal was to visit each participating household twice, once in the spring and once in the summer of 2003. At each visit a survey regarding water source and health status (diarrhea incidence) was administered and samples of source water were collected. Water samples were taken at the household, either from the tap reported to be the source of drinking water or from whatever container was used to store drinking water. Water quality was measured with three indicator variables: chlorine residual, total coliforms, and *Escherichia coli*. Chlorine residual was analyzed with a HACH field kit (Loveland, Colorado). Total coliform and *E. coli* analyses were conducted using the IDEXX® method (Westbrook, Maine, USA).

Data from the surveys and the laboratory analyses were entered into SPSS statistical software (Chicago, IL, USA) and used to evaluate the performance of the water treatment systems from three perspectives:

(i) *Adoption*: were the intervention participants using the treated water supply?
(ii) *Water quality*: was the water provided by the treatment system of better microbiological quality than that of other sources?
(iii) *Health*: were the subjects using the treated water healthier than those using other sources?

Chi-squared tests were used as a general non-parametric measure of association between the following categorical variables: visit (first or second), source of water (UV-treated vs. other), diarrhea, and *E. coli* (presence vs. absence). The *E. coli* data were analyzed based not on estimated numbers of *E. coli* but on the basis of presence/absence, because the reported concentration data, which consist mostly of non-detects with a few highly variable detectable concentrations, are highly positively skewed making it difficult to apply standard parametric statistical methods. Total coliform levels were less skewed, and *t*-tests were used to compare coliform levels among different water sources. Statistical tests with *p*-values of less than 0.05 were considered significant.

Results and discussion

Eighty-six of the 90 households enrolled initially completed the surveys as part of the first home visits. Transportation of water samples across the US-México border posed a logistical problem, and in a minority of cases either appropriate supplies were not available in time to collect the sample, or samples were not received within allowable holding times, resulting in a loss of some data. Overall water samples were successfully analyzed for 62 of the households. Completing all of the second visits within the timeframe provided by the available resources was not feasible. For the second visit, completed survey forms were obtained for 69 of the households. At this point the logistical problems had largely been addressed and water quality samples were obtained for all 69 of these households.

Table 1(a) summarizes information on the source of drinking water for participants in the intervention group, while Table 1(b) summarizes this information for the control group. The percentages using each source total more than 100%, indicating that some households reported using more than one source of drinking water. The percentage of the intervention group obtaining their water from the health clinic dropped from 62% on the first visit to 40% on the second visit. This drop is statistically significant ($p = 0.03$, two-tailed Z-test of proportions) and appears to result mostly from households switching from the clinic to an outdoor faucet (the proportion of households using an outdoor faucet increased from 5–26%). There was also an increase from the first to the second visit in households that reported drinking water purchased at the store, although this difference was not statistically significant.

The decline in use of the UV-treated water is even more dramatic if one considers the households which reported using only water from the clinic. At the first visit 57% reported drinking water treated at the clinic exclusively, but this declined to 24% by the second visit. By the second visit, even among households still using the water, the water from the clinic was often supplemented with water from another source. Participants gave a number of reasons for not using the water from the health clinic, with the most common responses being the distance to the clinic, the lack of a vehicle, the time required, the lack of a suitable container, and the weight of the water. The results suggest that, at least in areas with a piped water supply, interventions such as this will reach only a limited proportion of the population, because of the large amount of effort involved in hauling water from the treatment site to the home. The control group (Table 1b) showed much less use of the water from the clinic. While controls were not encouraged to drink water from the clinic,

Table 1. (a) Source of household drinking water for intervention group.

	1st visit ($n = 58$)	2nd visit ($n = 42$)
Health clinic	62%	40%
Water truck	0%	0%
Store	16%	24%
Indoor faucet	21%	26%
Outdoor faucet	5%	26%
Other	3.4%	2.4%
Total	107%	119%

Table 1. (b) Source of household drinking water for control group.

	1st visit ($n = 28$)	2nd visit ($n = 27$)
Health clinic	7.1%	3.6%
Water truck	3.6%	0%
Store	32%	26%
Indoor faucet	54%	52%
Outdoor faucet	7.1%	15%
Other	3.6%	3.7%
Total	107%	100%

they were not barred from using this water either. Although this was not a rigorously controlled study, the separation into intervention and control groups did succeed in producing two groups with substantially different water consumption patterns. In particular, the control group relied more on tap water than the intervention group. The percentage of treated water use may be biased high, because the intervention group consists of self-selected households who were initially interested in using the treated water.

Water quality was measured with three indicator variables: chlorine residual, total coliforms, and *E. coli*. Chlorine residual protects the water from contamination during the distribution process. Although it is not mandated by the US EPA, it is a common practice in the US to supply water containing a chlorine residual, usually in the range of 0.5–1 mg/l. The State of Texas requires a chlorine residual of at least 0.2 mg/l. However, the health benefits of maintaining a residual are not definitively established, and the practice is less common in Europe. The water sampled as part of this study generally contained little or no residual chlorine, regardless of source (tap, store-bought, or UV-treated). Eighty-three percent of all samples from the first visit and 91% from the second visit contained no chlorine. The observed lack of residual indicates that the water is not protected against recontamination during distribution. Note, however, that 17% and 9% of the water samples did reflect a measurable chlorine residual during the first and second visits, respectively.

Table 2 summarizes the total coliform results by visit and by type of drinking water source. For the first visit, the total coliform levels were lower in the treated water from the health clinic than water purchased from the store or obtained from an indoor tap. Water from outdoor taps had the lowest coliform levels, but this is based on only five samples. None of these differences are statistically significant. On the second visit, the situation changed with the water from the health clinic having the highest coliform levels. As with the results from the first visit, the differences between the health clinic water and the other sources are not statistically significant. Coliform levels increased, but not by statistically significant amounts, from the first visit to the second visit for both the clinic water ($p = 0.07$, one-tailed t-test of means) and in store-bought water ($p = 0.33$). This may reflect the influence of higher

Table 2. Average and range of total coliforms and *E. coli* (MPN/100ml) detected in water samples obtained from households*.

Water sources as measured in the home	1st visit		2nd visit	
	TC (MPN/100 ml)	*E. coli* (MPN/100 ml)	TC (MPN/100 ml)	*E. coli* (MPN/ 100 ml)
Health clinic	73 (<1.0 – 2,419.2) 48% (14/29)**	0 (0 – 0) 0% (0/29)	494 (<1.0 – >2,419.2) 55% (6/11)	0.3 (0 – 1) 27% (3/11)
Store	134 (<1.0 – >2,419.2) 78% (7/9)	0 (0 – 0) 0% (0/9)	491 (<1.0 – >2,419.2) 80% (4/5)	5.5 (0 – 28) 20% (1/5)
Indoor faucet	273 (<1.0 – 1986.3) 58% (11/19)	0.5 (0 – 5.2) 16% (3/19)	258 (<1.0 – >2,419.2) 48% (13/27)	0.2 (0 – 5.2) 7.4% (2/27)
Outdoor faucet	0.2 (<1.0 – 17.5) 20% (1/5)	0 (0 – 0) 0% (0/5)	18 (<1.0 – 238.2) 46% (12/26)	0 (0 – 0) 0% (0/26)

*Using IDEXX Quanti-Tray®/2000 System (Westbrook, Maine); **Percent positive out of total samples assayed. Samples taken at the health clinic had an average of 162 total coliforms (MPN/100 ml) before treatment (i.e. influent) and 97 total coliforms (MPN/100 ml) after treatment (i.e. effluent).

temperature, as the first visits were conducted in the winter and early spring and second visits in the late spring and summer. Total coliforms are not a definitive sign of sewage contamination but do indicate that there was some opportunity for microorganisms to enter the water after disinfection. It is likely that the water became contaminated by the receiving vessel, during transport, or during storage (Jensen et al. 2002; Graham and VanDerslice 2007). Overall, the total coliform results do not suggest any advantage for the clinic water, and in fact the clinic water may even have higher coliform levels due to the need to transport and store the water.

Samples with positive total coliform results were also analyzed for *E. coli*. Positive results for *E. coli* were much less frequent than for total coliforms (Table 2). Both store-bought water and water from the *Oratorio* were susceptible to contamination during storage, and tap water can be contaminated at the faucet. There is some suggestion in the data that outdoor taps might actually provide higher quality water. An outdoor tap is less convenient than an indoor tap and may be used less frequently. Thus, outdoor taps may have fewer opportunities for contamination and more time between usages for contaminating bacteria to die off. However, if this water is then stored inside the house before use, there would be subsequent opportunities for contamination that would probably negate any health benefits of using an outdoor tap. The differences in *E. coli* levels may simply be due to random variation. For example, one cannot reject the hypothesis that the outdoor tap and clinic water had equal probabilities of *E. coli* contamination ($p = 0.19$, one-tailed Fisher's exact test).

The *E. coli* contamination observed here in the samples taken at residences could result from: (i) improper treatment of contaminated source water, (ii) contamination of the tap from which treated water was dispensed, or (iii) transport to and storage in the home. While this study cannot definitely apportion the extent of contamination among these routes, alternative (i) appears unlikely. The disinfection system was installed by a manufacturer's technician and certified as operational. In addition, no positive *E. coli* samples were found even in the untreated source water out of 20 samples taken. At least some of the contamination does appear to have resulted from contamination of the common tap. Out of 44 samples taken, one was positive for *E. coli* (MPN of 1/100 ml). This route is particularly of concern as it provides a mechanism for contamination across households (i.e. among individuals not normally exposed to each other).

During the home visits, participants were asked to report if anyone in the household had recently suffered from diarrhea. The data were analyzed by preparing contingency tables of water use and diarrhea and using a Chi-squared test to evaluate the statistical significance of any association between water source and diarrhea. The analysis was conducted at the household level, because transmission between family members may lead to clustering of cases within households. Table 3 shows the contingency table for diarrhea and water source for the first visit. The percentage of households reporting diarrhea is almost exactly the same among families that used the clinic water and those that did not; however, household members using clinic water also reported using water from other sources.

Table 3 also shows the same analysis at the time of the second visit. At this point, the percentage of households reporting cases of diarrhea is much higher among those using the water from the health clinic than among those using other sources of water (44.4% vs. 11.8%). This difference is statistically significant ($p = 0.008$, Chi-squared

Table 3. Percentage of households with at least one diarrhea case* by water source during the first and second visits.

Water sources	Percentage of households with and without diarrhea during 1st visit		Percentage of households with and without diarrhea during 2nd visit	
	No	Yes	No	Yes
Health clinic	86.8% $n = 33$	13.1% $n = 5$	55.6% $n = 10$	44.4% $n = 8$
Other	87.5% $n = 42$	12.5% $n = 6$	88.2% $n = 45$	11.8% $n = 6$

*Refers to at least one person in the household reporting having diarrhea during the previous week.

test) but not necessarily causal. The relationship may result from households that are more prone to diarrhea being more likely to make the effort to use the water from the clinic, which they may believe to be safer. Forty percent of households reporting diarrhea at the time of the first home visit used the water from the clinic at the time of the second visit, while only 24% of other households used the water from the clinic. While these differences are not statistically significant, the results suggest that homes more prone to diarrhea persisted in using the clinic water.

The occurrence of diarrhea is typically high among community members and an increase in diarrhea incidence among households from the first visit (13% reporting diarrhea within the home) to the second visit (20%) was observed. This may reflect seasonal trends in diarrhea incidence since the second visits occurred in the summer.

Conclusions

The intervention evaluated here failed to improve health outcomes and it is unclear from this study if drinking water quality at the clinics improved. The failure to improve water quality can be attributed to recontamination of the water during transport or storage. Future interventions should provide a residual disinfectant and include an education component for consumers. In addition, future studies should evaluate the role water storage containers may play in microbial contamination. A finding of particular interest to entities wanting to implement such programs that enhance drinking water access within communities is that, after the first visit, only a minority of households used the water provided by this intervention. Specifically, only 40% of the members of the intervention group reported using the clinic water during the second visit as compared to 62% during the first visit. In addition, more of the households stated experiencing diarrhea during the second visit as compared to the number reporting diarrhea during the first visit (13%). Interestingly, the higher diarrhea rates were most pronounced among those using the clinic (UV-treated) water. This increase in reported diarrhea may be a seasonal effect, or it may be random fluctuation as the difference is not statistically significant ($p = 0.21$ for a Chi-squared test).

Transportation of the water from the treatment system to the home appears to be a major barrier to the use of the treated water. Barriers, such as this, need to be identified and addressed prior to program implementation. In areas with a piped water supply, in-home water treatment methods avoid the need to haul treated water, which may result in higher adoption rates. However, as noted in the introduction, there are concerns over the quality of in-home treatment, particularly related to training non-professionals to appropriately measure chlorine doses (Gurian et al. 2006).

Roughly a quarter to a third of participants reported drinking store-bought water. The prevalence of store-bought water even in a low-income neighborhood probably reflects a lack of confidence in the piped public water supply. It is not clear from this study whether this represents a wise use of resources. Because store-bought water lacks a residual disinfectant, it is vulnerable to contamination in the home, and it showed levels of microbiological contamination similar to those of the other water sources. While water from the clinic-based treatment system was not superior to other sources, it was less expensive than store-bought water. Displacing store-bought water with a locally-produced, inexpensive water source may be a reasonable goal of interventional efforts such as this. To protect against disease reliably, the participants would need to obtain all their drinking water from high quality sources. However, even partially displacing store-bought water offers some economic benefits to the population, and this should be easier to achieve than completely displacing the use of tap water, since both store-bought water and the centrally treated water have to be hauled to the home.

While centralized, neighborhood-level water treatment systems offer economies of scale over household treatment options and allow for trained personnel to operate the water treatment system, this study raises questions as to whether they effectively improve drinking water quality. In particular, two findings from our study should be considered in the development of any program designed to provide community access to drinking water. First, as mentioned above, this intervention was limited by the willingness of participants to use the treated water that was made available to them. Most residents in the neighborhoods of Ciudad Juárez that received the treatment systems have access to piped water supplies. While confidence in the public supply is generally low, only a minority of participants were willing to haul the water from a centrally located treatment system. Second, the treatment system did not produce clearly superior water based on a set of common water quality indicators. In general, water quality was similar to that of purchased water, which also lacks residual chlorine and must be stored in the home. While participants drinking the water from the health clinic were more likely to report cases of diarrhea at the time of the second visit, this appears to result from selection bias, rather than from an actual increase in health risk due to the consumption of the treated water.

The high rates of diarrhea found in this study and by previous researchers (Redlinger et al. 2002) suggest that there is a serious problem with fecal-oral transmission of disease in peri-urban Ciudad Juárez. However, it is not clear that drinking water is a major route of infection. Other possibilities include food and person-to-person or fomite-mediated transmission. The role drinking water plays compared to other transmission pathways needs to be further explored so that effective interventions can be developed.

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