Comparing health outcomes and point-of-use water quality in two rural indigenous communities of Baja California, Mexico before and after receiving new potable water infrastructure

Paula Stigler-Granados, Penelope J. E. Quintana, Richard Gersberg,
María Luisa Zúñiga and Thomas Novotny

ABSTRACT

One of the United Nations Millennium Development Goals is to reduce the global proportion of people who do not have access to safe drinking water. In the past, the typical strategy to reach this goal has been the use of investment-intensive centralized infrastructure development for water supplies. However, there is increasing evidence suggesting that improving water quality at the source does not guarantee safe water at point-of-use. This study examined water quality, waterborne disease incidence and water system use over time in two small rural indigenous communities of Baja California, Mexico, before and after drinking-water infrastructure improvements. Community *Promotoras* collected data on the incidence of gastrointestinal illness through face-to-face surveys. Concurrently, water samples from the old and new water sources and household water storage containers were analyzed for fecal coliforms. Although source water quality was significantly improved in both communities ($p < 0.05$), neither community had a significant decrease in the level of contaminated drinking water sampled at the household level. No significant decrease in gastrointestinal illness was found after the improvements to the source water supply. These results indicate that point-of-use contamination and acceptance of the new sources may be a critical point for intervention when attempting to assure access to safe water, especially in rural communities.

Key words | health outcomes, indigenous community, Mexico, point-of-use, pre- and post-evaluation, rural water systems

Paula Stigler-Granados (corresponding author)
Penelope J. E. Quintana
Richard Gersberg
Thomas Novotny
San Diego State University,
Graduate School of Public Health, 5250 Campanile Dr. San Diego,
CA 92182
E-mail: *paula.stigler@gmail.com*

María Luisa Zúñiga
San Diego State University,
School of Social Work, 5500 Campanile Dr. San Diego,
CA 92182

INTRODUCTION

In developing countries, adverse health effects from poor sanitation and lack of access to safe drinking water are common. Many vulnerable populations, especially children, experience substantial preventable morbidity and mortality related to poor water quality throughout the world (Thompson *et al.* 2003; Prüss-Üstün *et al.* 2008). Previous studies have shown that improved access to potable drinking water and sanitation services are associated with lower mortality for children <5 years of age (Shi 2000; Wright *et al.* 2004; Cutler *et al.* 2006; Schmidt *et al.* 2009).

One of the United Nations Millennium Development Goals for 2015 is to halve the proportion of the world's population that lacks sustainable access to safe drinking water and sanitation (Hutten & Haller 2004; Gundry *et al.* 2006; United Nations 2013). A major strategy used in reaching this goal typically involves heavy investment into

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centralized water infrastructures such as the installation of protected sources (e.g. wells, water treatment plants, distribution systems, etc.) to provide better quality sources of drinking water (Jagals *et al.* 1999; Fewtrell & Colford 2005). However, one growing concern is that access to an improved central water source may not always ensure the use and consumption of safe clean water at the household level and that these infrastructure improvements also may be out of reach for many rural communities (Mintz *et al.* 2001).

Increased attention is now focused on potential water contamination between the central source and point-of-use. The microbiological quality of water supplies in household storage containers has been shown to be worse than that measured at the original water source, even if the source has been improved (Jagals *et al.* 1999; Clasen & Bastable 2003; Hunter 2009; Hunter *et al.* 2009). This suggests that contamination may actually be widespread during water collection, transport, and storage (Van Zijl 1966; Lindskog & Lindskog 1988; World Health Organization [WHO] 2011). Wright *et al.* (2004) reviewed several studies and observed variations in contamination in different settings from the source to point-of-use. Their study demonstrated that the decline in water quality between the source and point-of-use was often proportionately greater in places where the source water is mostly uncontaminated or came from an improved source.

Contamination occurring between improved water sources and the water at the point-of-use may reduce considerably the benefits and cost-effectiveness of water source improvements for communities (Wright *et al.* 2004; Rufener *et al.* 2010). There is growing evidence that suggests expensive investments that improve water sources in rural communities should be examined as to whether these investments significantly improve the quality of the water that the recipients are actually using (Clasen *et al.* 2009). Also, the acceptability of new systems comes into question as communities may continue to drink from contaminated sources regardless of improvements. Therefore, it is important to learn how improving water systems at the source can also be better integrated with point-of-use safety to accomplish reductions in waterborne illness incidence.

In Baja California, Mexico, indigenous communities tend to be some of the poorest and most isolated populations of the region. They have historically had little or no access to clean drinking water (Kilpatrick *et al.* 1997). The source of water for most community members has traditionally been untreated and contaminated surface water from springs or shallow hand-dug wells (Coates-Hedberg & Gersberg 2004; Wilken-Robertson 2004). Little information has been available on water resources, water quality, and water infrastructure needs in these remote communities.

In 2004, two of these indigenous communities' health and water resources were studied. Data on water quality, health outcomes such as gastrointestinal and respiratory illness, and water transportation and storage practices were gathered through multiple assessments. In 2006, as a direct result of these assessments, the United States Environmental Protection Agency (U.S. EPA), in collaboration with the Mexican government, funded the construction of two new large-scale drinking-water infrastructure systems for each of the two communities. These systems included a new community well, storage tank, and distribution system that connected water lines to the individual households. In September 2007, the same health and water resource study was repeated to better understand the overall impact the new systems had on both communities.

METHODOLOGY

Communities studied

Both are communities of indigenous peoples, located in Baja California, Mexico. The majority of the residents speak Spanish as well as their native language. At the time of the study, houses in the community were equipped with basic electricity but none had indoor plumbing. Prior to the installation of the new water systems, one community obtained drinking water from natural springs and transported it via PVC pipes and hoses to small, leaking concrete storage reservoirs. It was then distributed to the community via barrels in trucks or garden hoses. The other community mainly used hand-dug wells and transported water via hand-carried buckets. In 2006 and 2007, both communities received a 35-meter deep well installed in the center of their communities along with a large capacity cement storage tank and household connections from the tank. These connections consisted of an outdoor 1 inch PVC line with a spigot that was located outside the home, usually within 100 feet of the house. The total cost, including construction and materials for each new potable water infrastructure system (here-on referred to as 'water system') cost an estimated $250,000 USD, serving approximately 185 people or 66 households in Community 1 and 90 people or 50 households in Community 2.

Study design, survey and sample collection

This was a pre-test/post-test study to evaluate the efficacy of a water system that was implemented to increase access to potable water in two communities. Understanding that households may use water from various sources (both new and old), water samples were collected before and after installation of the new water systems from all available water sources. WHO guidelines for representative sampling from various locations in each community were used (World Health Organization 2011). Samples were taken every two weeks from March 2004 through August 2004 and September 2007 through May 2008. Based on availability, sample sites were selected from household storage containers in various homes throughout the community, uniformly distributed points along the distribution system and from the sources, both the original and improved sources.

Survey data were collected every two weeks from each household in both communities by trained community *Promotoras* from March 2004 through August 2004 and again from September 2007 through May 2008. A *Promotora* is a person who, with or without compensation, provides a service to communities through activities that may include providing patient education, making referrals to health and social services, conducting needs assessments, distributing surveys, and making home visits (Ramos *et al.* 2001). There were two *Promotoras* in each community and each received 16 hours of training in survey administration. The 32-item questionnaires, administered in Spanish or translated into the resident's native language *in situ*, were mainly administered to the female head-of-household at each residence in the community. The survey contained topics relating to usage of drinking water sources, water transportation, storage, and disinfection practices, health and illness data, as well as general household sanitation questions. *Promotoras* also conducted observations and short interviews with each household during each interview. Approval for human subjects research was obtained through the San Diego State University Institutional Review Board and Universidad de Xochicalco in Mexico.

Analysis of water samples

Physicochemical parameters (i.e. temperature, conductivity, total dissolved solids, pH and nitrate) were measured *in situ* when water samples were collected. In order to assess fecal contamination, additional water samples were collected and transported to a laboratory in San Diego, California, for bacteriological analysis. All samples were kept on ice and were processed within 12 hours of collection. Samples were analyzed for *Escherichia coli* and total coliforms (i.e. commonly used bacterial indicator of contamination of foods and water) using the IDEXX Colilert® method to determine the Most Probable Number (MPN) of coliforms per 100 ml (IDEXX 2005). MPN is the standard unit of measure used for quantifying levels of bacterial indicators in water samples using this method. WHO, Mexico and U.S. water quality standards have all set the acceptable limit of *E. coli* in drinking water at 0 MPN per 100 ml (Eriksson & Raben 2004; U.S. EPA 2009; World Health Organization 2011).

Statistical analysis

The primary outcomes of this study were pre/post-change in disease incidence rate for gastrointestinal (GI) illness, report of at least one household GI illness (vomiting, diarrhea) in the last 2 weeks, and pre/post-change in point-of-use water quality. GI illness rates were calculated as the product of new GI illnesses and the total number of samplings completed, divided by the average number of measurements for each community (5 for both communities) and then multiplied by the time period for each measurement (2 weeks). This then expressed the weekly incidence of GI illness within the community per 100 households. Households that reported one or more family member who suffered a GI-related symptom in the last 2 weeks were identified as positive for GI incidence during the survey period (households with no GI reports were identified as negative). To compare post-infrastructure GI illness among the same communities from the baseline pre-infrastructure data (2004), only data from the same months (March, April and May) was used to account for any seasonal fluctuations. Paired *t*-test, the Mann–Whitney test and chi-square statistics were used to assess pre/post water infrastructure differences in water quality, health characteristics, water storage practices and other hygiene related activities, and to evaluate differences in diarrheal disease in each of the communities between pre-infrastructure (2004) and post (2008). Availability of resources dictated the time period of these measures. All survey data and water quality data were analyzed using SPSS statistical software (version 16.0).

Table 1 | Demographic characteristics of households surveyed for water quality, gastrointestinal illness incidence, water storage practices, and point-of-use practices in two indigenous communities, Mexico, 2004 and 2008

	Study Areas			
	Community 1 $n = 183$, 66 total households		**Community 2 $n = 89$, 50 total households**	
Age Group (in Years)	**Male**	**Female**	**Male**	**Female**
>18	48 (26.2%)	51 (27.9%)	25 (28.1%)	27 (30.3%)
10 to 18	19 (10.4%)	21 (11.5%)	12 (13.5%)	12 (13.5%)
4 to 9	12 (6.5%)	13 (7.1%)	3 (3.4%)	5 (5.6%)
0 to 3	9 (4.9%)	10 (5.5%)	2 (2.2%)	3 (3.5%)
Total	88 (48.1%)	95 (51.9%)	42 (47.2%)	47 (52.8%)

RESULTS

The communities were similar with respect to age and gender and share a cultural connection in terms of language and familial ties (Table 1). For each survey period, the number of participating households ranged from 40 to 66 in Community 1 and 31 to 50 in Community 2.

Both communities' original sources of water tested positive for coliforms for almost all samples before receiving new drinking water infrastructure (Table 2). The new main water sources in both communities were significantly less contaminated following the infrastructure improvements ($p < 0.01$). However, water samples taken at the point-of-use (household storage containers) did not

Table 2 | Water contamination as measured by Coliform counts, pre- and post-central water source improvements, two indigenous communities, Mexico, 2004 and 2007/8[a]

	Community 1		**Community 2**	
Water Source	**Pre-infrastructure (2004) (*E. coli*, MPN/100 ml[b])**	**Post-Infrastructure (2007/8)[a] (*E. coli*, MPN/100 ml[b])**	**Pre-infrastructure (2004) (*E. coli*, MPN/100 ml[b])**	**Post-infrastructure (2007/8)[a] (*E. coli*, MPN/100 ml[b])**
System				
GM[c]	6.1[d]	< 1*	18.2[d]	< 1*
Range	< 1–52	all <1	< 1–727	all <1
n	6	10	7	14
Household storage container				
GM[c]	6.5[d]	50.5[d]	12.2[d]	4.5[d]
Range	2–31	5–613	2–317	< 1–387
n	6	6	10	18
Purchased water				
GM[c]	1.1[d]	1.3[d]	<1	1[d]
Range	<1–23	<1–44	<1	<1–3
n	8	12	4	4

*Significant at $p < 0.05$, pre and post-infrastructure comparison for each individual community.

[a] Water samples were collected from September 2007 through May 2008 for the post-infrastructure analysis, see Methods.

[b] MPN most probable number of coliforms per 100 ml of water.

[c] GM is the geometric mean of all samples.

[d] Exceeds Mexican and U.S. safe drinking water standards.

Table 3 | Drinking water sources used, two indigenous communities pre- and post-improvements in central water sources, Mexico, 2004 and 2008

	Community 1			**Community 2**		
	Pre-infrastructure May 2004	**Post-infrastructure May 2008**	***P*-value**	**Pre-infrastructure May 2004**	**Post-infrastructure May 2008**	***P*-value**
Number of households surveyed	40	44		32	31	
Old system	90.0%	18.2%		87.5%	0.0%	
Purchased water	10.0%	59.1%		12.5%	6.5%	
New system	N/A	6.8%	< 0.01*	N/A	93.6%	< 0.01*
Other (e.g. unknown, friend or relative provided)	0.0%	18.2%		0.0%	0.0%	

*Significant at $p < 0.05$, when comparing each of the communities to their previous results.

show improvements in quality, with significant contamination observed before and after central water source improvements.

At the beginning of 2007, the communities had not yet started using the new systems, since they were not completely working at every household. By 2008, each community showed a significant change in the types of sources of water they were using ($p < 0.01$) (Table 3). Community 1 showed an increase in utilization of purchased water (e.g. water purchased from a delivery or truck or water purchased from a local store or market), while Community 2 reported using their new system 94% of the time at the end of the study (Table 3).

By 2008 GI incidence did not significantly decrease after the improved sources were installed. There was no significant difference in the mean weekly incidence of reported gastrointestinal illness rates between the communities from 2004 to 2008 (Table 4) ($p > 0.05$). The incidence rate of GI illness in Community 1 increased from 4.3 to 8.7 per 100 households per week and Community 2 decreased from 8.8 to 5.2 per 100 households per week (Table 4).

In 2008, Community 1 was significantly more likely to use a purchased water container (5 gallon small-mouthed container commonly called a *garafón*) to transport and store water than in 2004 (Table 5). Community 2 had a significant decrease in using 5-gallon buckets to store and transport their water. Both communities showed significant increases in storing their water on furniture, the recommended practice, as opposed to on the floor, by the end of the study.

DISCUSSION

This study showed that the U.S. EPA- and Mexican government-funded development did provide improved water source to two rural indigenous communities in Mexico and significantly reduced bacteriological contamination of

Table 4 | Weekly mean reported GI illness incidence before and after improved water source availability, two indigenous communities, Mexico, March–May 2004 and 2008

	Community 1		**Community 2**	
	Pre-infrastructure March–May 2004	**Post-infrastructure March–May 2008**	**Pre-infrastructure March–May 2004**	**Post-infrastructure March–May 2008**
n^a	69	188	199	105
GI incidence/100 households^b Mean (SD)	4.3 (4.3)	8.7 (2.8)	8.8 (5.7)	5.2 (3.0)
Mean difference [95% C.I.^{c}]	– 4.3 [−17.7, 9.0]		3.6 [−13.7, 20.9]	

[a] Total number of households surveyed during the 3 months.

[b] Mean incidence of GI illness for each survey over the length of the study, expressed as mean number of households reporting any incidence of GI illness per week normalized to 100 households.

[c] Confidence interval.

Table 5 | Water storage and transportation practices, before and after central water source improvements in two indigenous communities, Mexico, 2004 and 2008

	Community 1			**Community 2**		
	Pre-infrastructure May 2004	**Post-infrastructure May 2008**	***P*-value**	**Pre-infrastructure May 2004**	**Post-infrastructure May 2008**	***P*-value**
n^a	41	44		33	31	
Container type used to transport water						
50 gallon barrel	19.5%	11.4%	< 0.001*	3.0%	3.2%	NS
5 gallon bucket	19.5%	0.0%		81.9%	48.4%	
Supply near house (water piped via hose, spigot or line)	58.5%	20.4%		12.1%	29.7%	
Did not transport water (used water from spigot or line)	2.4%	9.1%		3.0%	12.2%	
Purchased water container	0.0%	59.1%		0.0%	6.5%	
Container type used to store water						
50 gallon barrel	29.3%	6.8%	< 0.001*	12.1%	3.2%	< 0.001*
5 gallon bucket	46.3%	6.8%		87.9%	38.7%	
Did not store water (used water from spigot or line)	12.2%	27.3%		0.0%	51.6%	
Purchased water container	12.2%	59.1%		0.0%	6.5%	
Used the same transport container to store water	29.2%	45.5%		48.5%	77.5%	
Location and condition of storage container						
Storage container covered	85.4%	100.0%	0.008*	90.9%	100%	NS
If inside: not elevated off floor	39.0%	16.0%	0.03	24.2%	6.4%	NS
If inside: elevated off floor	61.0%	84.0%		75.8%	93.6%	
Outside home	17.1%	11.4%	NS	18.2%	3.2%	NS
Cleaned storage container in the last two weeks	75.6%	93.2%	0.02	94.0%	87.1%	NS

[a] Total number of households surveyed.

*Significant at $p < 0.05$, when comparing each community pre- and post-infrastructure.

the source water. Most studies on household water quality and disease incidence reduction after improving water sources have been conducted in Africa and Asia. To the best of our knowledge, the current study is the first to look at the impacts of improved water infrastructure among rural communities of Northern Baja California, Mexico.

According to Mexican potable water quality standards, total coliforms cannot exceed 2 MPN/100 ml and fecal coliforms should not be detectable (*E. coli* is used as the indicator for fecal coliforms) (México – Secretaría de Salud 1994; Rompre *et al.* 2002; Eriksson & Raben 2004). The U.S. EPA and World Health Organization (WHO) have also set drinking water guidelines or standards for total coliform and *E. coli* at 0 MPN/100 ml (U.S. EPA 2009; World Health Organization 2011). Both study communities' previous water systems or sources exceeded both Mexican and WHO potable drinking water standards, while the new improved central sources would be considered safe and potable. However, despite this improvement in the water supply there was no significant change in reported incidence of GI illness in either community. One explanation for this is that household stored water (point-of-use) was still significantly contaminated, as demonstrated by the presence of *E. coli* in these water samples at WHO risk levels ranging from low to high both before and after infrastructure improvements (1–10 MPN *E. coli* per 100 ml is low risk, 10–100 per 100 ml is intermediate risk, 100–1,000 per 100 ml is high risk, and >1,000 per 100 ml is very high risk) (WHO 2011). Community 1 had *E. coli* levels in their household containers as high as 613 MPN/100 ml after improvements in the system, which is considered to be high risk for illness.

In comparison to 2004, there was a 15–29% increase in the proportion of households using the same containers to both transport and store water in 2008, which could allow for fewer points of contamination (Jensen *et al.* 2002; Thompson *et al.* 2003; Wright *et al.* 2004). Families also ceased storing their water outside and were more likely to cover and elevate the storage containers. Community 1 had a nearly 50% increase in purchasing water. This may have resulted from community members perceptions that the new system either was not functioning properly or that the water did not taste good to them. When conducting the surveys, *Promotoras* did provide education about water storage practices to the families in the hope of improving storage practices. Despite these improvements and changes, there was no decrease in fecal contamination at point-of-use, including from the water that had been purchased.

Studies on point-of-use water supplies demonstrate that contamination is common at the household level in both improved and unimproved systems (Wright *et al.* 2004; Jagals 2006; deWilde *et al.* 2008). This can be due to the types of containers being used (i.e. large mouth versus small mouth containers) or as a result of family members putting their hands or dirty utensils into the containers (Jensen *et al.* 2002; Wright *et al.* 2004; Cairncross *et al.* 2010). A study in rural Sierra Leone tested household water in areas where residents collected water from improved water sources. The majority of the samples (93%) were contaminated with fecal coliforms at levels higher than those found in source water samples (Clasen & Bastable 2003). In a study of 24 low-income households in South Africa and Zimbabwe (Wright *et al.* 2006), more than 40% of water samples from storage containers contained >10 MPN/100 ml of *E. coli* even though the water had come from improved water sources. Our results are similar to those from Africa, finding that water quality often deteriorates after transporting from the central source. In this study, moderate improvements in storage and transportation practices had little impact on the quality of water at point-of-use.

The Mexican government has responded to the sanitation needs of these rural communities by providing them with access to clean drinking water sources (Eriksson & Raben 2004). Illnesses related to water quality, however, remain a problem (Lang *et al.* 2006). Additional education on household water storage practices or adding water treatment procedures at the point-of-use could prove helpful in reducing exposure to contaminated water at the household level. The evidence for the implementation of household water treatment and storage (HWTS) is growing, especially with the advent of new and cheaper technologies (Mintz *et al.* 2001; Quick *et al.* 2002; Cairncross *et al.* 2010). Several HWTS interventions such as chlorination and filtration have been suggested as alternatives to large-scale infrastructure projects in Mexico (Lang *et al.* 2006). However, HWTS interventions are recommended as a last resort when no other clean sources of water are readily available. These new systems did not include chlorination at the source because of the communities' resistance to chemically treating their water. This may have been a cultural barrier or a lack of education regarding water treatment. Regardless, it is important to consider the need for more integrated interventions when seeking to improve water sources. This may include HWTS along with larger scale infrastructure improvements.

Cultural practices and beliefs also have been shown to affect attitudes to water use and storage (Jackson 2005, 2006). Although both communities appeared similar in demographics, language, and cultural practices, they each had very different original sources of water prior to infrastructure improvements (Stigler *et al.* 2013a). This difference may have played a role in the use of the improved infrastructure.

Limitations

Limitations of this study include the lack of resources available to sample every household water container in each community. Also, diarrheal incidence was self-reported, and there was little access to a local clinic for testing. The sample sizes for this study were small, and associations may have occurred by chance. In addition, although most surveys were conducted in Spanish, it is possible that those that were translated to the resident's native language may have been understood differently.

CONCLUSION

Household water quality and incidence of gastrointestinal illness did not improve after receiving access to an improved water source in these two communities. Costly investments in infrastructure could have been augmented with a more extensive intervention at the household level. Efforts to engage communities in infrastructure development projects prior to undertaking costly changes should be implemented; while community-based participation in design and planning for improved infrastructure could also play an important role in strengthening the feasibility and acceptance of such projects (Stigler *et al.* 2013b). By focusing on water use practices and tailoring interventions to affected communities, a more effective use of investments in water quality improvement can be achieved.

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