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Author
Stigler, Paula E.

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Water, culture and environmental health: understanding community based planning to improve health outcomes in vulnerable populations

A dissertation submitted in partial satisfaction of the requirements for the degree Doctor of Philosophy

in

Public Health (Global Health)

By

Paula E. Stigler

Committee in charge:

University of California, San Diego
Professor Deborah Wingard
Professor María Luisa Zúñiga

San Diego State University
Professor Penelope JE Quintana, Chair
Professor Richard Gersberg
Professor Thomas Novotny
Professor Ramona Perez

2013

The Dissertation of Paula E. Stigler is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

Chair

University of California, San Diego
San Diego State University
2013

DEDICATION

To my partner and best friend Ángel Granados, my inspiration to explore, travel and reach beyond.

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Chapter 2 has been submitted for publication in the *Journal of Water, Sanitation and Hygiene for Development* as Stigler PE, Quintana PJE, Gersberg R, Novotny T, Zúñiga ML. 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. Chapter 3 is being prepared for publication as Stigler PE, Quintana PJE, Gersberg R. Acceptability and cultural barriers of improved drinking water infrastructure: a perspective from two indigenous communities of Baja California, Mexico. Chapter 4 is being prepared for publication as Stigler PE, Quintana PJE, Novotny T. Vulnerability assessment for water supplies in rural communities

Paula E Stigler is the primary author on all three papers.

VITA

Education

1998	BA Geography University of Texas at Austin
2009	MS Environmental Health Sciences San Diego State University
2013	PhD Public Health (Global Health) University of California San Diego / San Diego State University La Jolla/San Diego, California, USA

Professional Positions

2011 - Present	Policy Research Associate: Tobacco waste toolkit and the Cigarette Butt Pollution Project. San Diego State University (P.I. Dr. Tom Novotny)
2011 – Present	Co-PI. Assessing vulnerable populations to climate change. San Diego State University (P.I. Dr. Rick Gersberg)
2010 – 2012	Research Assistant: Health impact of border crossings. San Diego State University (P.I. Dr. Penelope Quintana)
2008– Present	Grant writing and research consultant. Owner of PS Consulting.
2007 - 2010	Tribal Liaison and Environmental Program Manager. The San Diego Foundation.
2007-2009	PI. Water quality as an environmental health indicator. Pan American Health Organization.
2005 – 2009	Project Lead. Border water infrastructure program. Pala Band of Mission Indians.
2005 – 2007	Air Quality Specialist. Pala Band of Mission Indians.
2001 – 2005	Program Coordinator. Environmental health and justice initiative. The San Diego Foundation.

Teaching Experience

Fall 2013 Instructor, HHS 350, Applied International Health and Human Services, College of Health and Human Services, San Diego State University

Fall 2013 Instructor, PH 682, Geographic Information Systems and public Health, Graduate School of Public Health, San Diego State University

Spring 2012 Instructor, HHS350, Applied International Health and Human Services, College of Health and Human Services, San Diego State University

Fall 2012 Instructor, PH 682, Geographic Information Systems and public Health, Graduate School of Public Health, San Diego State University

Publications

Stigler PE, Quintana PJE, Gersberg R, Novotny T, Zúñiga ML, 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. *Journal of Water, Sanitation and Hygiene for Development. (forthcoming 2013)*

ABSTRACT OF THE DISSERTATION

Water, culture and environmental health: understanding community based planning to improve health outcomes in vulnerable populations

by

Paula E. Stigler

Doctor of Philosophy in Public Health (Global Health)

University of California, San Diego, 2013
San Diego State University, 2013

Professor Penelope JE Quintana, Chair

Background: Previous research suggests that rural water infrastructure investments in developing countries may be expensive, culturally inappropriate and do not result in clean water being consumed at the household level. Interventions and planning that incorporate community-based planning approaches with a careful consideration of cultural and historical connections may be the most effective method of implementing successful improved water projects.

Objective: This dissertation examined the outcomes, cultural challenges and successes of water infrastructure projects in two indigenous communities of Baja California, Mexico and developed a low-cost method of assessing rural water systems to improve targeted outcomes of water system improvements.

Methods: Both quantitative and qualitative data from a longitudinal study and focus groups were obtained. Survey data regarding health and water practices, along with water samples in each community were collected before and after new water systems were installed and gastrointestinal illness rates calculated. Transcripts from focus groups conducted after the new infrastructure was implemented were examined for cultural attitudes and beliefs towards water use. Field observations from both communities were used to develop a low-cost assessment tool with a scoring method for determining vulnerabilities in water systems.

Results: After receiving new water infrastructure in both communities, neither saw a reduction in rates of gastrointestinal illness. Household point-of-use water quality was still poor despite new infrastructure. One of the two communities receiving new water systems did not accept their new system. Cultural significance of the previously used water source was likely the most significant reason for non-acceptance. Conducting a thorough assessment of each point of the communities' water systems using the low-cost indicator method developed could have provided a better assessment of vulnerabilities in the systems and a better approach to intervention.

Discussion: This work provides support for incorporating community participation into the planning and implementation of water improvements, and stresses the importance in addition of examining water beliefs and practices.. Poor water quality at point of use underscores the importance of measuring this water quality indicator. Meaningful inclusion of communities can be used to inform approaches to community development that simultaneously take into account community perspectives as well as technical capacity.

CHAPTER 1:

Introduction

Health effects from environmental factors such as poor sanitation and access to clean drinking water are prevalent in developing countries. Many people needlessly die of illnesses related to water quality, such as dehydration caused by diarrhea (World Health Organization (WHO), 2012; Thompson, Sobesy, and Bartram, 2003). Studies have shown that access to potable drinking water and sanitation services are associated with lower child mortality (Shi, 2000; Cutler, Deaton and Lleras-Muney, 2006). Puffer and Serrano (1973) studied infant and child mortality in several Latin American cities and found that households reporting a higher proportion of infant deaths lacked adequate water sources. In a study on child mortality in urban Brazil, it was found that access to piped water in a household, as opposed to little or no access to an in home or near home water source, is likely to provide the most direct benefit in lowering child mortality by reducing exposure to water-borne illnesses, in particular diarrhea (Merrick, 1985).

Access to an improved water source may not always ensure use of clean water. Regardless of the improved source, it has been observed that the microbiological quality of water in household storage containers is frequently lower than that at the source, suggesting that contamination is widespread during collection, transport and storage (Van Zijl 1966; Lindskog & Lindskog 1988). Public health attention has increasingly turned to the issue of water contamination between source and point-of-use. A review of 57 studies conducted in developing countries by Wright et al. (2004) showed that approximately half of the studies identified households had significant contamination after collecting the water. There were no reported instances of water quality improving significantly afterwards. Wright et al. also showed that the decline in water quality between the source and point-of-use in the home is proportionately greater where the source water is mostly uncontaminated. This pattern of contamination has been also reported by a study in rural Sierra Leone where households collecting water from improved water sources had their household water tested. There were 100 homes sampled and 92.9% of the samples were contaminated with fecal coliforms at levels higher than those found in the source water samples (Clasen and Bastable, 2003). In a study carried out in South Africa and Zimbabwe (Gundry et al., 2006), 24 households in low-income communities were surveyed and water samples were taken, finding that more than 40% of samples taken from homes were 'unsafe' (i.e. contained more than 10 cfu / 100 ml of E. coli) even though the water had come from improved sources. These are strong results indicating that access to improved water may not always mean access to 'safe' water. Contamination between an improved source of water and water at point of use may severely lessen the health benefits of water source improvements for communities. Here, I report on the water quality at the source and point of use in two indigenous Mexican communities located near the United States-Mexico border, and diarrheal disease before and after major water improvement projects.

Brief introduction to communities of Baja California, Mexico

The Baja California indigenous communities are among some of the poorest and most isolated populations of the region, and have historically had little or no access to clean drinking water. The usual source of water for most community members has been untreated surface water from springs, shallow hand-dug wells or creeks. Many of these sources are contaminated by natural and anthropogenic source such as: livestock, trash, dead animals, latrines and animal feces (Wilken-Robertson, 2004). Historically, little information has been available on water resources, water quality and water infrastructure needs in these remote communities, however two assessments studies were completed in these communities in 2004 and 2007 that gathered baseline data on their drinking water systems and health.

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 drinking water infrastructure systems in the indigenous communities of San Antonio Necua and San Jose de la Zorra. These systems included new community wells, new storage tanks and new distribution systems that took water lines to the household properties.

Water and Health

Bacteria, viruses, and protozoa are the main microbiological indicators for drinking water quality (DeZuane, 1997). Water treatment technology has greatly improved during the last two centuries, with the realization that water quality and public health are connected. Adequate water systems and proper treatment is not always possible in developing countries because this technology requires significant capital investment with continuing costs for operation and maintenance and enforcement of water quality standards. However, it is possible to assist small communities with simple systems as long as the community members are able to maintain and operate the system.

In the case of these indigenous communities in Baja California, their drinking water previously came from surface and shallow groundwater from hand dug wells and springs. Surface water has the ability to come in contact with a variety of pollutants, mostly anthropogenic in nature. Drinking water treatment may not remove the organic and inorganic chemicals that surface water may contain (DeZuane, 1997). Due to the fact that there was no formal water treatment system previously in place, the communities may have been at risk of exposure to contaminants in their drinking water.

One of the California Safe Drinking Water Act requirements for surface water is that it must undergo filtration if fecal coliforms exceed 20MPN/100mL and if total coliforms exceed 100MPN/100mL in more than 10% of the measurements for the previous 6 months (calculated each month) (California, 2004).

Several physiochemical parameters can affect drinking water quality. The parameters studied in this project were pH, conductivity, nitrate and nitrite, and total dissolved solids (TDS). The Safe Drinking Water Act and WHO guidelines state that drinking water must be in the pH range of 6.5-8.5 to meet drinking water standards (WHO, 2004). Total dissolved solids are comprised of inorganic salts with small concentrations of organic matter (DeZuane, 1997). An acceptable upper limit for TDS is 500mg/L (WHO, 2004). Conductivity measures the ability of water to conduct an electric current. Ionized substances like salts contribute to conductivity. Potable water is usually between 50 to 500micromhos/cm. Nitrates found in water are usually attributed to sources such as fertilizer runoff from agriculture, animal feces or septic systems. Nitrates are reduced to nitrites in the human body and may cause methemoglobinemia, especially in younger children (WHO, 1997). The maximum contaminant level for nitrate and nitrite set by the U.S. EPA in 1991 was 10mg/L for both as a total (DeZuane, 1997).

Bacteriological water quality indicators such as total coliform bacteria and *E coli* can quickly provide a reliable assessment for pathogen presence in drinking water. The U.S. EPA and WHO have set guidelines for total coliform and *E. coli* at 0 MPN/100mL (WHO, 1997; U.S. EPA, 2003). MPN (Most Probable Number) is a statistical estimate of the mean number of coliforms in a sample (Rompre et al, 2002). Although not the only indicators, these both provide an effective way for measuring the safety of water.

Overview of main analyses

Chapter 2, "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", explores the question how waterborne diseases and illness is affected by the implementation of new water systems and providing access to clean water. This paper utilizes data collected both before and after each community received new and improved water systems, in which community residents reported incidence of illness, sources of water they were using and other water practices such as storage and transportation of water. Results showed no significant correlation receiving new water systems and reduction in gastrointestinal illness rates. This paper is unique because it illustrates the problems with large-scale infrastructure as well as shows over a long period of time how similar communities have different practices in handling and using water. While we know that access to clean water is important, particularly for children and elderly, the types of systems installed and the intervention that follows may influence the positive or negative outcomes of the communities.

Chapter 3, "Acceptability and cultural barriers of improved drinking water infrastructure: a perspective from two indigenous communities of Baja California, Mexico" illustrates the role that culture and history play in the acceptance of new water systems and ultimately the impact it has on the health outcomes of the community. This analysis uses a qualitative approach from both communities to explain the findings from Chapter 2 that indicated one of the communities did not use their new water system. Themes such as rituals, taste, safety and responsibility were reviewed and provided valuable input into the community's views and perspectives about water. The results of this paper add to evidence demonstrating the need for integrated approaches to water management that simultaneously take into account more variables than just technical capacity. The need for change in how water resources are managed, especially drinking water infrastructure, is becoming increasingly important especially in the areas of participatory management, collaborative decision-making and understanding community specific cultural beliefs.

Chapter 4 “Vulnerability assessment for water supplies in rural communities” provides a new methodology for analyzing water systems from top to bottom without using expensive tests or equipment. In this paper, a cumulative scoring technique is used to observationally assess each portion of a water system, including: source, transport, storage and point-of-use. As each portion of the system is assessed, a vulnerability impact score can be developed to assist the community and planners to work together to address the most vulnerable areas first. Including qualitative questions in this assessment is a unique part of this methodology, which explores cultural and historical ties to the source and practices. By involving the community in every aspect of the assessment and planning process it is expected to improve the overall outcomes of the intervention, including but not limited to reduction in disease.

Access to clean water is a human right that unfortunately not all people enjoy. Understanding how resources can be best utilized and effectively improve the heath of rural and vulnerable populations in developing countries via access to clean water is very important. This body of work contributes to the field of water and sanitation in developing countries by advancing the understanding of the connection between culture, community and water. Results from the three papers will advance the field for future researchers and planners, particularly those who work in rural developing world settings, where the acceptance and access to clean water can be a critical component to sustainability.

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CHAPTER 2:

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

Abstract

Objectives: 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 and water-borne disease incidence in two small rural indigenous communities of Baja California, Mexico, before and after drinking-water infrastructure improvements.

Methods: 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.

Results: 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.

Discussion: These results indicate that point-of-use contamination may be a critical point for intervention when attempting to assure access to safe water, especially in rural communities.

Background and significance

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 (Prüss-Üstün, 2008;Thompson, 2003). Previous studies have shown that improved access to potable drinking water and sanitation services are associated with lower mortality for children $\leq$5 years of age (Shi, 2000; Cutler, 2006; Schmidt, 2009; Wright, 2004).

One of the United Nations Millennium Development Goals (MDGs) for 2015 is to halve the proportion of the world's population that lacks sustainable access to safe drinking water and sanitation (Gundry, 2006; Hutten & Haller, 2004; United Nations 2013). A major strategy used in reaching this goal typically involves heavy investment into 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 (Fewtrell & Colford, 2005; P Jagals, Bokako, & Grabow, 1999). 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 2001; Reiff 1996).

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 the that measured at the original water source, even if the source has been improved (Clasen & Bastable, 2003; Hunter, 2009; Hunter, Pond, Jagals, & Cameron, 2009; P Jagals et al., 1999). This suggests that contamination may actually be widespread during water collection, transport, and storage (Lindskog & Lindskog, 1988; Van Zijl, 1966; World Health Organization 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 (Rufener, Mausezahl, Mosler, & Weingartner, 2010; Wright et al., 2004). 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). It is important to learn how improved water sources can be better integrated with point-of-use safety to accomplish reductions in water-borne 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, Wiken-Robertson, & Connoly, 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 compare both water quality and diarrheal disease incidence in the two indigenous communities before and after infrastructure upgrades were made.

Methods

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. Each new potable water infrastructure system (here-on referred to as “water system”) cost an estimated $250,000 USD.

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. Water samples were collected before and after installation of the new water systems using WHO guidelines for representative sampling from various locations in each community (World Health Organization 2011). Samples were taken every two weeks from March 2004 through August 2004 and September 2007 through May 2008. Sample sites were systematically 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*[1] from March 2004 through August 2004 and again from September 2007 through May 2008. 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 their 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 and storage practices, water disinfection, 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.

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[1] "*Promotora*" broadly defined, 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, May,

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 *E. 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 100mL (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 100ml (Eriksson & Raben, 2004; US 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 least one household GI illness in the last 2 weeks, and pre/post change in point-of-use water quality. GI illness rates were calculated as the product of 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 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).

Results

Table 1 gives the age and gender characteristics of both communities. Each is similar and shares 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 One and 31 to 50 in Community Two.

Both communities' original sources of water tested positive for coliforms for 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 ($p<0.05$). However, water samples taken at the point-of-use (household storage containers) did not 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 One showed an increase in utilization of purchased water, while Community Two 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 One was between 4.3 and 8.7 per 100 households per week and Community Two had a rate of 8.8 to 5.2 per 100 households per week (Table 4).

In 2008, Community One was significantly more likely to use a purchased water container to transport and store water than in 2004 (Table 5). Community Two 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 EPA and Mexico government funded water system development did provide improved water sources to two rural indigenous communities in Mexico and significantly reduced bacteriological contamination of 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 2MPN/100mL and fecal coliforms should not be detectable (*E.coli* is used as the indicator for fecal coliforms) (Eriksson & Raben, 2004; México - Secretaría de Salud 1994; Rompre, Servais, Baudart, de-Roubin, & Laurent, 2002). 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/100mL (US 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. Although diarrheal diseases decreased in Community Two, the sample size was not large enough to detect a significant decrease. Another 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 100mL is low risk, 10-100 per 100mL intermediate risk, 100-1000 per 100mL is high risk, and >1000 per 100mL very high risk (WHO, 2011). Community One had *E.coli* levels in their household containers as high as 613 MPN/100ml after improvements in the system, which is considered to be high risk for illness.

Data suggest that in comparison to 2004, data from 2008 showed a 15-29% increase in proportion of households using the same containers to both transport and store water, 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 One had a nearly 50% increase in purchasing water. This may have been a result of anecdotal reports from community members stating that the new system either was not functioning properly or the water tasted poorly. *Promotoras* did provide education about water storage practices to the families when conducting the surveys in the hope of improving storage practices. Despite these improvements and changes, there was no decrease in the measured 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 (deWilde, Milman, Flores, Salmeron, & Ray, 2008; P. Jagals, 2006; Wright et al., 2004). This can often 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 (Cairncross et al., 2010; Jensen et al., 2002; Wright et al., 2004). 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 the 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 confirm those detailed above from Africa, finding that water quality often deteriorates after the central source, and 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 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, Kaser, Reygadas, Nelson, & Kammen, 2006). Inclusion of additional education on household water storage practices or adding water treatment at the point-of-use could prove to be very helpful in reducing exposure to contaminated water at the household level. The evidence for the implementation of household water treatment (HWT) is growing, especially with the advent of new and cheaper technologies (Cairncross et al., 2010; Mintz, Bartram, Lochery, & Wegelin, 2001; Quick et al., 2002). Several HWT interventions such as solar disinfection (SODIS) and chlorination have been suggested as alternatives to large-scale infrastructure in Mexico (Lang et al., 2006).

Cultural practices and beliefs also have been shown to affect attitudes to water use and storage (Jackson, 2005; Jackson, 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, Quintana, & Gersberg, 2013a). This difference may have played a role in the use of the new improved infrastructure (Stigler et al., 2013a).

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. Although most surveys were given in Spanish, it is possible that those that were translated to their 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, Quintana, & Gersberg, 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 appreciated.

Chapter 2 has been submitted for publication in the *Journal of Water, Sanitation and Hygiene for Development* as Stigler PE, Quintana PJE, Gersberg R, Novotny T, Zúñiga ML. 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 E. Stigler is the primary author on this paper.

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

Age Group (in Years)	*Study Areas*			
	Community One n = 183, 66 total households		*Community Two n=89, 50 total households*	
	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%)*

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 One		Community Two	
Water Source	Pre-infrastructure (2004) *(E.coli, MPN/100ml[b])*	Post-Infrastructure (2007/8)[a] *(E.coli, MPN/100ml[b])*	Pre-infrastructure (2004) *(E.coli, MPN/100ml[b])*	Post-infrastructure (2007/8)[a] *(E.coli, MPN/100ml[b])*
System				
GM[d]	*9.0[c]*	*<1**	*18.1[c]*	*<1**
Range	*2-52*	*all <1*	*2-727*	*all <1*
n	*6*	*10*	*8*	*14*
Household Storage Container				
GM[d]	*6.5[c]*	*50.5[c]*	*12.2[c]*	*4.5[c]*
Range	*2-31*	*5-613*	*2-317*	*<1-387*
n	*6*	*6*	*10*	*18*

*Significant at p<0.01, 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 100ml of water

[c] Exceeds Mexican and U.S. Safe Drinking Water Standards

[d] GM is the geometric mean of all samples

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

	Community One			Community Two		
	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%*	*<0.01**	*87.5%*	*0.0%*	*<0.01**
Purchased Water	*10.0%*	*59.1%*		*12.5%*	*6.5%*	
New System	*N/A*	*6.8%*		*N/A*	*93.6%*	
Other (e.g. unknown, friend or relative provided)	*0.0%*	*18.2%*		*0.0%*	*0.0%*	

*Significant at p<0.01, when comparing each of the communities to previous results

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 One		Community Two	
	Pre-infrastructure Mar-May 2004	Post-infrastructure Mar-May 2008	Pre-infrastructure Mar-May 2004	Post-infrastructure Mar-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.]	*-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

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

	Community One			Community Two		
	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%*	*<0.01**	*3.0%*	*3.2%*	*<0.01**
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%*	*<0.01**	*12.1%*	*3.2%*	*<0.01**
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%*	*<0.01**	*48.5%*	*77.5%*	*<0.01**
Location and condition of storage container						
Storage container covered	*85.4%*	*100.0%*		*90.9%*	*100%*	
If inside: not elevated off floor	*39.0%*	*16.0%*	*<0.01**	*24.2%*	*6.4%*	*<0.01**
If inside: elevated off floor	*61.0%*	*84.0%*		*75.8%*	*93.6%*	
Outside home	*17.1%*	*11.4%*		*18.2%*	*3.2%*	*<0.01**
Cleaned storage container in the last two weeks	*75.6%*	*93.2%*		*94.0%*	*87.1%*	

[a] Total number of households surveyed

* Significant at $p<0.01$, when comparing the community to previous results

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Chapter 3:

Acceptability and cultural barriers of improved drinking water infrastructure: a perspective from two indigenous communities of Baja California, Mexico

Abstract

Background: Programs to implement improved water systems for clean water in rural and indigenous communities are a key component of development and public health activities. However, many water improvement programs fail due to a lack of adequate pre-implementation investigation, community involvement and understanding of community cultural beliefs regarding water and water management practices.

Methods: This study applies a mixed methods approach to describe water practices and beliefs from a cultural perspective in two indigenous communities of Baja California, Mexico. We assess how cultural perspectives and practices surrounding water presented challenges for acceptability of a new drinking water infrastructure.

Results: Indigenous community members who have strong cultural ties to their water sources were found to be less likely to accept new water infrastructure. Community participation in the building of the infrastructure improved acceptability of the new system.

Discussion: Findings fill a research gap on meaningful inclusion of communities in water planning that can be used to inform subsequent integrated approaches to water management that simultaneously take into account community perspectives as well as technical capacity. The need for change in how water resources are managed, especially drinking water infrastructure, is critical. Our study sheds light on the importance of participatory management, collaborative decision-making, and understanding community-specific cultural beliefs.

Background and significance

The World Health Organization (WHO) estimates that more than three million people die each year as a result of waterborne diseases and that 780 million people globally lack access to clean water (Prüss-Üstün, Bos, Gore, & Bartram, 2008). There are many agencies and organizations trying to address this problem by providing support for infrastructure with which to bring clean water and sanitation to communities in need (Clasen et al., 2009; United Nations Development Programme (UNDP) 2013; World Health Organization (WHO) 2012). Despite these efforts, the billions of dollars and resources invested annually in water projects in developing countries are often inefficient and unsustainable (Gomez & Nakat, 2002). Many of these programs failed due to a variety of technical, cultural, and political reasons (UNDP World Bank, 2000).

Water infrastructure projects in developing countries have historically employed a top-down or supply–driven approach (SDA) working with engineers from developed nations to design the new systems (Black, 1998; Cummings, 1997). These projects proved to be mostly unsuccessful in rural and marginalized communities due to a variety of reasons such as a lack of community involvement, insufficient resource allocation to sustain the infrastructure and not considering preferences of the community in terms of technology, siting and costs to maintain (Francis & Jahn, 2001; Gomez & Nakat, 2002). After evidence of the SDA not functioning in rural communities, organizations and agencies began to realize the need for integrated approaches to water management that simultaneously take into account key variables in addition to technical capacity and that involve stakeholders in the entire process (Pahl-Wostl et al., 2007). Changes in how water resources are managed, especially drinking water infrastructure, have recently been advocated by a few researchers. Although each emphasizes different priorities for water management improvements, there is agreement on needs in the areas of participatory management, collaborative decision-making, and consideration of cultural beliefs during the planning process. (Cortner & Moote, 1994; Gleick, 2000; Gomez & Nakat, 2002; Hunter, MacDonald, & Carter, 2010; Pahl-Wostl, 2002).

Trickett (2011) described culture as “a collective concept arising from conditions, shared experiences, and memories that are common to a group of people and transmitted intergenerationally”(p. 59). Many residents in rural communities, especially indigenous populations, may have specific cultural beliefs and rituals surrounding water that have been passed down for many generations (Brewis, Gartin, Wutich, & Young, 2013). These cultural beliefs could express themselves in a variety of ways such as traditions, stories, or celebration. They may also have religious or cultural ties to their water sources that are not documented and may not be considered as having “value” by outside entities (Jackson, 2005, 2006; Trickett, 2011). In the case of Northern territory aboriginal communities in Australia, Jackson (2005) underscored the importance of cultural relevance in community participation in the planning process. However, reliance on technical and physical solutions continues to dominate traditional planning approaches to water management, but these solutions are increasingly difficult to sustain and manage (Gomez & Nakat, 2002). Although planners and community advocates recognize the importance of community engagement for the success of water improvement projects, there is a dearth of studies devoted to understanding indigenous community beliefs and preferences surrounding water resources. This gap in knowledge about failed infrastructure projects, especially in rural and indigenous communities, must be addressed in order to use scarce financial and environmental resources most efficiently in water projects.

The overall goal of this study is to inform the development and sustainability of future water infrastructure projects through community engagement and participation. The objectives of this research are to:

1) Determine the water sources used in two rural indigenous communities in Baja, California, Mexico, before and after a new drinking water infrastructure was installed;
2) Assess community perceptions about water sources; and
3) Identify cultural beliefs associated with barriers to acceptance of new water systems.

Methods

Local knowledge regarding use of, and responses to newly-installed drinking water infrastructure were investigated using a mixed method design in which a qualitative study was conducted after a cross-sectional quantitative study. The qualitative analysis was used to validate the quantitative findings through complementarity or triangulation (Creswell, 2013; Morse, 2003). Approval for human subjects research was obtained through the San Diego State University Institutional Review Board.

Study Population

The two communities studied are indigenous peoples, located in Baja California, Mexico. The majority of the residents speak Spanish as well as their native language. The communities are related through cultural and familial ties and are located on *ejidos*[2] approximately 40 miles from each other. Community One has approximately 66 households (population 165) and Community Two has approximately 50 households (population 115). In 2007, both communities received new drinking water infrastructure as a result of funding provided by the U.S. and Mexican governments. Each new system

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[2] *Ejidos* in Mexico are quasi-communal lands given to rural populations (usually indigenous) to be used for farming or subsistence living, however the government maintains some control and regulation over the lands (Haenn, 2006; Perramond, 2008).

was similar and consisted of 30-35 meter groundwater wells with large capacity concrete storage tanks and underground PVC distribution lines. Both systems were completed by August 2007. Prior to the installation of the new systems, Community One obtained drinking water from natural springs and Community Two mainly used shallow hand-dug wells. Although the U.S. and Mexican governments financed the installation of the new systems, each community was physically and financially responsible for the operation and maintenance of their new systems. Both communities elected community water boards to assist with any issues related to the new systems.

Qualitative Data Collection

The household survey portion of this research was part of a longitudinal study of behavioral and health conditions for water and sanitation among households in the two rural indigenous communities in Baja California, Mexico (more detail in Stigler et al., 2013). Trained community health workers conducted the interviews from March 2004 through August 2004 and again from September 2007 through May 2008 (after the completion of the new system in August 2007). Every household in each of the communities was asked to participate. Female head-of-households in each community were surveyed every two weeks before and after the communities received new drinking water systems. The surveys periodicity allowed for better assessment of changes in health over the study period. For each survey period, the number of participating households ranged from 40 to 66 in Community One and from 31 to 50 in Community Two.

The surveys consisted of two domains, one designed to assess behavior changes and the other to assess health conditions. The surveys were conducted pre and post water system improvements in order to identify changes over time in water use, water and sanitation practices and health conditions. Surveys also included questions on demographics; sources of water used; storage practices; incidence of gastrointestinal illness; and other observations regarding sanitation practices. We also included information on water samples that were collected during the survey periods using WHO guidelines for representative sampling from various locations in each community (World Health Organization 2011) to assess bacteriological contamination and general water quality. For the purposes of this paper, we only present the results from the question that asked each household which water source they used most frequently over the last two weeks. The additional findings can be found in Stigler, et al. (2013).

Qualitative Data Collection from Focus Groups

Results from the household surveys indicated that Community One was not using their new system; therefore, we conducted focus groups to better understand community experiences surrounding the new system. Between July and August 2008, a subset of each community's residents was invited to participate in a focus group to discuss concerns, attitudes and perceptions about the new water systems. Community leaders (both elected and cultural), elected water board officials, and interested residents participated. Each community focus group consisted of both male and female participants and was held in their community meeting places (a schoolhouse and a community room). There were 16 participants present for the focus group in Community One and 15 participants present for Community Two.

Focus groups were conducted in Spanish using a semi-structured interview guide that was developed based on topics identified from the survey data and from previous discussions with community leaders. Participants provided voluntary and informed consent prior to participating, and the sessions were tape-recorded with permission and notes were also taken. Discussion topics focused on how residents felt about their new water systems, concerns about the new system's water quality, issues encountered with operation and maintenance, and specific barriers or successes to using the new system. Participants were also asked to discuss how these barriers or successes had affected their water practices. Each focus group lasted approximately two hours and was moderated by a trained facilitator from a local non-profit organization.

Data analysis

Quantitative data were analyzed by comparing differences in practices between the two communities pre- and post-infrastructure changes with regard to which water sources they used most frequently over the last two weeks. The response rates were averaged from all two-week surveys taken before the new water system was installed and compared to the average response rates from all data collected after the new systems were completed. Associations and differences were evaluated using the Chi-square statistic, with $p < 0.05$ considered as statistically significant associations on bivariate analyses. Survey data were analyzed using SPSS statistical software (version 16).

Focus groups were digitally recorded and transcribed. We applied an inductive process to identify themes in accordance with qualitative research practices (Glaser, Strauss, & Strutzel, 1968). Two members of the study team independently read both transcripts to identify initial themes. The study team members met to achieve consensus on the codes for primary themes and then independently hand-coded both transcripts, noting emerging themes. Coders then met to compare coded transcripts and reach consensus on coding discrepancies and coding of emerging themes. We then tabulated frequency of instances where specific themes were mentioned by different participants. Qualitative results were used to explain and interpret the quantitative analysis using an explanatory design (Creswell, 2013). In particular, the qualitative research was conducted to better understand the results from the quantitative analysis that showed acceptance of the new water systems was a concern. The themes identified from the transcripts were used to understand how acceptance (or non-acceptance) was associated with cultural beliefs surrounding water practices. Excerpts from the coded transcripts were selected for this paper and translated into English to provide a better understanding of the quantitative findings.

Results

We observed a significant difference between Community One and Community Two in the types of water sources they used after the installation of new drinking water infrastructure (Table 1). Prior to new infrastructure, both communities were similar in the water sources being used. However, after infrastructure was installed, Community One reported still using the old water source 37.2% of the time while Community Two reported never using their old water source. Post-infrastructure results show that the communities were significantly different from each other as well as among themselves when compared to pre-infrastructure.

When comparing the average of responses from 2004 versus 2007/2008, only 8.2% of households in Community One used the new system after it was installed, and they also reported a significant increase in purchasing water (11.3% in 2004 to 41.3% in 2007/2008) ($p<0.05$, Figure 1). In Community Two, 95.9% of all households reported using the new system and had completely abandoned using the old system (Figure 1).

Five primary themes emerged from the focus group data:

1) Perceptions and beliefs about water;
2) Perceptions and attitudes about water safety;
3) Responsibility of maintaining the systems;
4) Perceptions of taste; and
5) Purchased water.

Below we describe each theme that allows for greater depth of comparisons between Community One and Community Two.

Perceptions and beliefs about water

When asked about rituals or customs associated with their water sources, focus group participants responded by discussing several interrelated concepts involving beliefs, ritual and practices surrounding water. Although the communities share a common culture, it should be noted that Community One was accustomed to drinking surface-obtained spring water while Community Two did not have a spring and drank groundwater from shallow wells.

Focus group participants from Community One had a stronger connection to the old spring water system with 75% responding positively to associations of rituals and beliefs with their spring and 0% regarding their new water source (Table 2).

> [Community One]
> We have used this water since forever. Our ancestors drank this water and we drink this water. It gives us life…its part of our culture. If its bad for us, its because we have angered the spirits and we need to clean it. Why would we not drink it? We have to drink it or its like we've betrayed our past. We are here because this water is here.
>
> Every year we go up and clean the water. It's a community event…we take the children and the mothers and we all walk up and clean out the spring. We sing songs and make blessings. Its what we do to make them [spirits] happy and to make sure the water is safe to drink.
>
> We found a dead horse in the spring. It was dead because someone in the community made the spirits mad. It was witchcraft and we had to make the situation right. We had to clean and bless the spring. The water from the mountain gets angry sometimes and it's our job to make it happy.

Community Two did not express a strong cultural connection to either water source (13%) (Table 2). They did refer though to the importance of water and the need to have clean water.

> [Community Two]
> Water is everywhere here…it flows underground and below us. We have a responsibility to our families to make sure the water is here and its good to drink. You don't have to dig deep and there's water. That's why we shouldn't throw stuff on the ground that can hurt the water. It's [water] important to us but its not always good to drink.
>
> We have water and we used to have to collect it everyday. Now we can jut turn on the tap and it's at our house. It's better now. God has blessed us with good water.

Perceptions and attitudes about water safety

Both communities had concerns about the safety of their drinking water. The majority of focus group participants in Community One stated their old water source was safe to drink (69%) while only 2% said the new system was safe (Table 2). The participants mentioned they were also concerned with contamination from a neighboring winery that they believed were using and dumping pesticides onto the ground.

> [Community One]
> This water is bad [new system]…its dead. It has no life. The people over there [outside the community] throw chemicals onto the ground and it gets into this water. It [groundwater] has no way to clean itself and might not be safe. The spring cleans itself on the way down the mountain.
>
> We have been drinking this water since the beginning of our time….we are still alive. The water [old system] provides us with what we need and it is safe for us.
>
> Sometimes the vineyard next door [neighboring winery] dumps dirty water onto the ground. It's contaminated with pesticides and junk…this contaminates everyone's water [groundwater].

Community Two was more concerned with the safety of the old system (60%) and had greater confidence in the safety of the new system (80%) (Table 2).

> [Community Two]
> The water we drank [old system] was brown and sometimes had insects. We had to carry it for a long ways sometimes many times a day. When our children got sick, the water just made it worse. The new water comes out clean and we don't have to carry it anymore.
>
> The new water seems safe and clean. At first it had too much air, but now it seems to be working and is right here at the house.

Responsibility of maintaining the systems

Focus group participants from each community had different perspectives on the responsibility of maintaining both the old and new systems. In Community One, 69% responded that it is important for the community to assist in the maintenance of the old water system. However, they reported to be somewhat nervous about maintaining the new system, and believed that outside resources would be important to assist with maintenance and operation (81%) (Table 2).

> [Community One]
> We are all responsible for the spring [old system]. We must respect the spring by cleaning it and caring for it regularly.
>
> This new system was a gift from the government and we need support to help it keep running. Its not running good right now and we don't know what to do. We don't know what’s wrong with it but it only works sometimes. The spring is always running and we know what to do to keep it that way.
>
> It’s expensive to keep this water running [new system]. We don't have enough resources to keep it going, especially if its broken.
>
> It's good to have the government and you [non-profit] helping us…what happens when you leave? Or when the government changes next month [elections]?

Community Two placed more importance on the communal aspect of maintaining the new system (80%), while the old system was mostly maintained by individuals (67%) (Table 2).

> [Community Two]
> Our old wells were not cared for and people forgot to keep the lid on…so bugs and animals got inside. It was our responsibility to keep them up but it just depended on who was using them.
>
> The new system is very important. We have made it a priority to keep it running. We are asking everyone to give a little [money] to help make sure it stays working. I go out everyday to make sure its working. We keep the tank locked so no animals or people who aren’t supposed to be there get in. It is our responsibility.

Perceptions of taste

When asked about the taste of the water, the communities had opposing views. Community One stated the old system tasted good (69%) and the new system tasted bad (63%) (Table 2).

> [Community One]
> The old spring is life giving. It tastes refreshing and I feel good…I drink it and it tastes good. The other [new system] tastes dead. It doesn't taste like anything. Its cold and tastes bad when it comes out…like plastic or something chemical.
>
> We always drink this water [old system]. It tastes like it always has and its not bad. If it needs attention it tastes different, but it usually tastes all right.

The opposite responses were apparent with Community Two as the majority stated the old system tasted bad (53%) and no one reported the new system tasting bad (Table 2).

> [Community Two]
> The new water tastes better than before…it tastes clean. It doesn't have dirt and stuff that made the other water [old system] taste bad. It tastes the same, but better.

Purchased Water

Participants were asked about purchasing water from either local stores or water truck vendors that came to the community. Both communities reported similarly that the purchased water was relatively safe to drink. Community One reported that they purchased water because they were afraid to drink from their water systems (56%) (Table 2).

> [Community One]
> There's a truck that will bring us water and its pretty good. Not too expensive and it tastes ok. I'm not always sure its safe but its not too bad. If there's no water here, then I buy it.
>
> When the doctor came and told us the water wasn't safe to drink, we bought water. They brought us some water too so we drank it. They said our water was contaminated and we should buy water or add chlorine. The water they brought tasted better than adding drops [chlorine].

> Sometimes I'm afraid to drink the water here now [new water system]. Especially when my children or parents are sick. I think its better to buy the water when we can.

Community Two found purchased water to be less affordable and a burden to try and get it in the community (Table 2).

> [Community Two]
> It's too hard and too expensive to buy water. The trucks don't come out this far and it's too much to carry water back when we catch a ride to town. We just have to drink what we have but I might buy water when I can. I don't need to now though as long as this water [new system] keeps working.

Discussion

This study indicates that the majority of households in Community One did not accept their new drinking water system after the new infrastructure was installed, and instead of using their new system they continued using their old system or purchased water. This is in contrast to Community Two, which did accept their new system and completely abandoned their old system. These findings suggest that there were specific barriers or issues in Community One that may not have been present in Community Two. Focus group findings indicated that Community One demonstrated a deep cultural connection to their old water system, which was a spring that they described as part of their history. This is a common notion for many indigenous communities and even some rural non-indigenous communities with close environmental connections to a specific geographic region (Satterfield, Gregory, Klain, Roberts, & Chan, 2013). Community One participants discussed community gatherings and celebrations around the water, cleaning of the water supply, and ancestors and spirits associated with the source. The focus group data also indicated that Community One was distrustful of the new water system and was less inclined to accept it, especially at the cost of abandoning the old system. Community One was most likely not accustomed to drinking groundwater, unlike

Community 2 who collected their water from groundwater wells. Spring water has a higher mineral content that often tastes very different from groundwater, which may have contribute to the “dead” taste participants discussed. Although the water was not tested for chemical contamination, some of the residents believed the new water system to possibly be contaminated. Exploring further the intrinsic meaning of springs versus groundwater in terms of cultural relevance could be an important next step. These could be examples of deep cultural beliefs and rituals colliding with and maybe even undermining underlying assumptions that a new and expensive engineering solution could change the behaviors of the community and convince them that science trumps tradition (Gomez & Nakat, 2002; Hopkins, Lauria, & Kolb, 2003; Trickett, 2011).

Another factor determining acceptance may be community involvement in planning and implementation (Gomez & Nakat, 2002). In the planning and design of the new system in Community One, the residents were not very involved, nor did they participate significantly in the construction of the new system. The government contracted an outside crew to build the new system. However for Community Two, the husband of one of the residents was contracted to build the system and he hired residents to assist with the construction. Although Community Two may not have been very involved in the consultation of the type of system to be built, by actively participating in the construction, community residents may have gained a greater confidence in the new system. Previous research has shown that participation can help to facilitate empowerment and capacity building while encouraging the community to take ownership and assist with maintaining the new system, as was what appeared to have happened in this case (Cummings, 1997). Focus group data revealed that Community One residents had problems with the new system functioning properly and that it was difficult to find the resources to fix the problem. By not participating in the construction, there may have been less of a sense of ownership of the new system as well as a lack of knowledge on how to maintain the system appropriately (Black, 1998; Cummings, 1997; Dongier et al., 2003; Gomez & Nakat, 2002).

Professional engineers, as is common in these projects, used an evidence-based practice to provide safe drinking water for the communities. Although the government had a relatively large budget to spend on the new systems, they had a short timeline to implement the intervention and were concerned that spending too much time on community consultation would result in a loss of the funding. As community based participation and planning can be a lengthy process, outside implementation of the water infrastructure process did not allow for enough time to involve the residents in the process; therefore possibly contributing to the community's non-acceptance of the system.

This study was limited in that there were only two focus groups held after the new systems were installed and that all community members were not interviewed. Further investigation and personal interviews with community leaders would have enhanced this study and should be considered in subsequent studies. It is also possible that gender dynamics or power dynamics played a role in the ability of participants to feel that they were able to speak freely during focus groups. Although all participants spoke Spanish, it is possible that some participants may have felt more comfortable speaking their native language; therefore, their opinion and perspectives may not have been included.

Overall, the results provide valuable evidence for the importance of understanding community perceptions and beliefs regarding their water as a method for providing accepted and sustainable infrastructure, the survey findings alone did not explain why the communities did not use their new system. Based on the beliefs associated with water in Community One, perhaps other types of water systems should have been explored rather than the well provided, such as a visible pipe system into the community leading from the old spring.

Conclusion

Investigation into community beliefs about water provided some explanation as to why a large and expensive infrastructure project failed to be used by Community One. There is a need to research and understand cross-cultural approaches to engage and involve communities in decision-making about development. Such approaches can build a better understanding of community perceptions and in turn improve the use of improved water sources. By engaging the community in the process, a stronger foundation for sustainable improvements can be built and possibly improve the final health outcomes for the community. This same involvement is also critical after building a system or making improvements, in order to properly maintain and operate the system according to what works best for the community. Many communities are very limited in resources therefore creating a system that is simple and understandable on their terms is vital to longevity of use of improved water and community health.

Chapter 3 is being prepared for publication as Stigler PE, Quintana PJE, Gersberg R. Acceptability and cultural barriers of improved drinking water infrastructure: a perspective from two indigenous communities of Baja California, Mexico. Paula Stigler was the primary author on this paper.

Table 1. Comparison of differences in drinking water sources used, pre- and post-improvements in central water sources, two indigenous communities, Mexico, 2004 and 2007/2008.

	Community One	Community Two	*P-value**	Community One	*P-value†*	Community Two	*P-value††*	*P-value**
	Pre-infrastructure March – August 2004			*Post-infrastructure September 2007 – May 2008*				
Average number of households surveyed	*40*	*32*		*44*		*31*		
Old System	*85.9%*	*95.8%*		*37.2%*		*0.0%*		
Purchased Water	*11.3%*	*4.1%*		*41.3%*		*4.1%*		
New System	*N/A*	*N/A*	*NS*	*8.2%*	*<0.01*	*95.9%*	*<0.01*	*<0.01*
Other (e.g. unknown, friend or relative provided)	*2.8%*	*0.0%*		*13.3%*		*0.0%*		

*****P-value based on chi-square test comparing the communities to each other
NS – not significant at p<0.01
† P-value based on chi-square test, comparing Community One to itself, pre and post-infrastructure improvements
†† P-value based on chi-square test, comparing Community Two to itself, pre and post-infrastructure improvements

Table 2. Perceptions and beliefs regarding water sources from focus groups after water infrastructure improvements, two indigenous communities, Mexico, 2008

	Community One *n=16*	Community Two *n=15*
Demographics		
Male	8 (50%)	7 (47%)
Female	8 (50%)	8 (53%)
Elected official (i.e. community leader, water board member)	9 (56%)	8 (53%)
Resident (non-elected official)	7 (44%)	7 (47%)
Themes	Frequency (%)	Frequency (%)
Old water system		
Rituals or customs associated with water source	12 (75%)	2 (13%)
Yes	0 (0%)	8 (53%)
No		
Part of our culture and our past	13 (81%)	5 (33%)
Safe to drink	11 (69%)	0 (0%)
Not safe to drink	4 (25%)	9 (60%)
Maintenance of system is important for community	11 (69%)	2 (13%)
Maintenance of system is an individuals responsibility	4 (25%)	10 (67%)
Outside resources are needed to maintain and operate the system (e.g. govt. assistance, funding, technical support)	8 (50%)	2 (13%)
Taste is good	11 (69%)	2 (13%)
Taste is bad	2 (13%)	8 (53%)
New water system		
Rituals or customs associated with water source	0 (0%)	2 (13%)
Yes	10 (63%)	5 (33%)
No		
Part of our culture and our past	0 (0%)	6 (38%)
Safe to drink	2 (13%)	12 (80%)
Not safe to drink	9 (56%)	0 (0%)
Maintenance of system is important for community	5 (31%)	12 (80%)
Maintenance of system is an individuals responsibility	2 (13%)	3 (20%)
Outside resources are needed to maintain and operate the system	13 (81%)	2 (13%)
Taste is good	2 (13%)	10 (67%)
Taste is bad	10 (63%)	0 (0%)
Purchased water		
Safe to drink	9 (56%)	8 (53%)
Not safe to drink	2 (13%)	3 (20%)
Taste is good	4 (25%)	6 (38%)
Taste is bad	2 (13%)	0 (0%)
Affordable	4 (25%)	0 (0%)
Unaffordable	6 (38%)	9 (60%)
Afraid of drinking community water	9 (56%)	2 (13%)

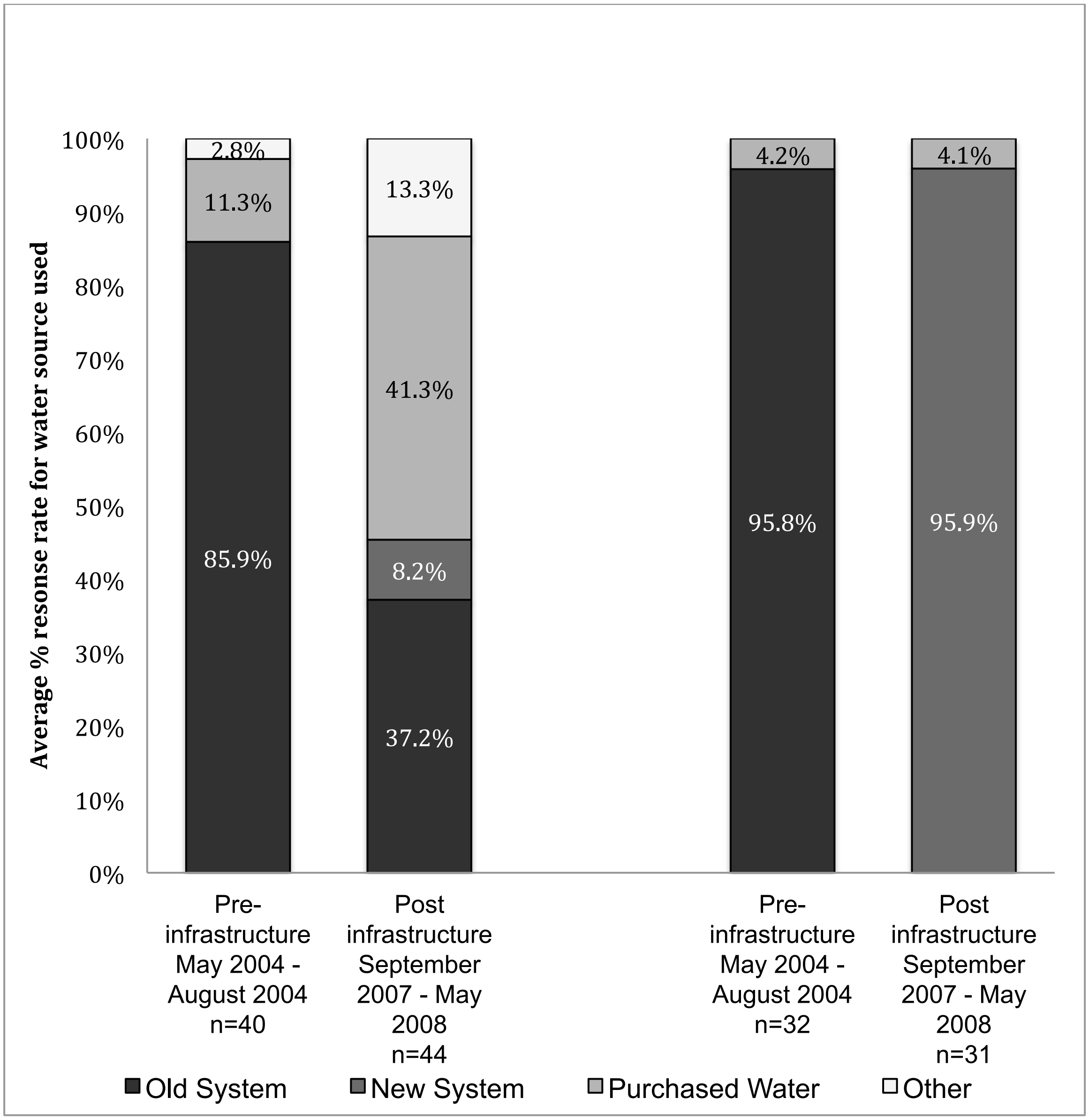

Figure 1. Distribution of drinking water sources used in two indigenous communities pre and post water infrastructure improvements, Mexico, 2004 and 2008

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Chapter 4:

Vulnerability assessment for water supplies in rural communities

Abstract

Background: Drinking water infrastructure development may alleviate some of the disease burden of water-borne diseases. In developing countries, there are limited resources to improve drinking water infrastructure and the responsibility for providing solutions for these challenges often falls to small, non-profit organizations or poorly funded local governments. Hence, there is a need for cost-effective methods to assess vulnerabilities of community water systems, especially in rural areas.

Methods: We developed a low cost tool to assess vulnerability of the system to contamination in rural water systems at the major points within these systems using a novel scoring system. This tool also takes into account communities' historical and cultural connections to their water systems. The practicality of the approach is demonstrated by a technical assessment of two systems in Mexico: 1) an improved water source consisting of above and below-ground piped distribution lines with public and private connections that are fed by spring water; and 2) an unimproved source consisting of shallow hand-dug, unlined wells.

Results: The improved source overall was less vulnerable to contamination than the unimproved source, scoring a 2.8 on a scale of 5 possible points, with 1indicating the lowest level of vulnerability. The unimproved source scored a 4.4 out 5; however both systems had the same poor vulnerability scores at the household level (4.0 for point-of-use).

Discussion: This simple assessment tool provides rapid insight into the overall vulnerability of the system to contamination as well as for the individual components. Each part of a water system may have a weak point, which requires a specific

intervention. It is important to understand the weakest points in order to focus time and energy on areas of highest vulnerability. This tool is meant to be used by communities and development organizations as a more culturally and technically focused approach to improving water system infrastructure.

Background and significance

Globally, diarrheal diseases are one of the leading causes of morbidity and mortality. Providing access to clean water is one of the most cost-effective solutions to lessening the disease burden of water-borne illness (Clasen, Haller, Walker, Bartram, & Cairncross, 2007). One of the United Nations' Millennium Development Goals is to halve the number of people globally without access to safe drinking water by the year 2015 (Hutton & Bartram, 2008; Onda, LoBuglio, & Bartram, 2012; United Nations 2013). Although progress is being made in attaining this goal, access to safe drinking water is still a major problem in small rural communities in low and middle-income countries (LMIC). Drinking water in these settings is often impaired by poor sanitation and lack of resources to maintain water systems (Cameron, 2011; Gundry, 2006). Residents in these communities are thus more vulnerable to water-borne illnesses, which in turn adversely impacts their economic and social stability (Hunter, Zmirou-Navier, & Hartemann, 2009). Expensive centralized water infrastructure improvements are not always the solution for poor communities due to their inability to maintain them (Stigler, Quintana, & Gersberg, 2013) Thus, cost-effective, community-oriented approaches to water system infrastructure improvements may present greater long-term success.

Because large-scale infrastructure improvements may not be the best solution to provide clean water to rural communities in LMICs providing clean water in these areas is becoming more and more the responsibility of small non-profit organizations or poorly-funded local governments (Hopkins, Lauria, & Kolb, 2003; Mintz, Bartram, Lochery, & Wegelin, 2001). To optimize scarce resources, low or no-cost methodologies to assess the vulnerabilities of rural water systems can assist communities, organizations, or governments in focusing interventions on the most deficient points in the systems. Thus, there is a need for a practical tool or guidelines for conducting an assessment of rural water system vulnerabilities in LMICs.

Vulnerability assessment

A "vulnerability assessment" for a water system can be broadly defined as the identification of weaknesses in the system, focusing on defined risks that could compromise its ability to provide safe water (Adger, 2006; Cutter, 1996). Vulnerability assessments can help communities evaluate susceptibility of their source, or systems, to potential hazards and identify corrective actions that can reduce or mitigate the risk of disease. Such an assessment for a water system takes into account the vulnerability of the water supply (both ground and surface water), transportation, treatment (if any), and storage. An effective vulnerability assessment can serve as a guide to the community, organization, or government agency by demonstrating priorities for targeted upgrades, modifications of operational procedures, and/or behavioral changes to mitigate the risks and vulnerabilities in the system (Hashimoto, Stedinger, & Loucks, 1982). The assessment method described in this paper focuses on the following major areas of rural water systems: water source, reservoir, transportation, storage, point-of-use, and human behaviors. A vulnerability assessment can be a starting point for communities to determine where to focus resources.

Causal connections between environment and health

There have been several models or frameworks developed to define indicators and the causal connections between the environment and health, taking into account the complexities of the environment. One of these models is the World Health Organizations (WHO) "Driving Forces-Pressures-State-Exposure-Effects-Action (DPSEEA) framework" (World Health Organization 1999). This model identifies causal pathways for determining how driving forces interact with each other and how these driving forces consequently affect health. The model provides a basis for researching possible actions or policies on improving the health of vulnerable populations. This theoretical framework specifies various criteria for what is a good indicator, provides that an indicator must provide a meaningful understanding of the conditions of interest, be scientifically sound, and be cost-effective, sensitive, and specific for actual changes that may be made in the measured conditions.

The most commonly used indicators for water quality are bacterial counts (e.g., total coliforms) (Rompre, Servais, Baudart, de-Roubin, & Laurent, 2002; Wright, Gundry, & Conroy, 2004). These bacteriological indicators can quickly provide a reliable assessment of fecal contamination in drinking water. However, in rural communities' capability for using these indicators is not always adequate. Although relatively inexpensive, these tests generally require some training and access to specialized equipment (e.g., incubators) to ensure quality and timely results. However, pathogen contamination is not the only concern when assessing drinking water systems, though it is the main indicator for risk of illness caused by water system failures (Zwane & Kremer, 2007).

Several global health agencies and organizations have developed comprehensive frameworks with which to evaluate water systems. However, most of these frameworks or methods have been developed for large-scale, improved infrastructure water systems. Rural communities with small or unimproved systems do not have the financial resources, skilled personnel, or abilities to monitor water quality using coliform counts or other technical approaches. When water testing is not a viable option for assessing the quality or vulnerability of a water system, it may be possible to use proxy indicators for vulnerability of the system to contamination. These types of indicators may be used to measure specific aspects of a system and thus provide an assessment of wider system quality (Songsore et al., 1998). Proxy indicators can be low-cost, observational, qualitative, or quantitative and may serve as substitutes for more expensive or less accessible indicators. Organizations, communities, and government agencies may be interested in using such low-cost indicators to assist in identifying and prioritizing problems areas for improvement in their water systems. In addition, an assessment of a broader range of determinants of water use practices that extend beyond the traditional water monitoring and assessment processes is best obtained through community participation in household surveys and interviews.

The assessment method described in this paper focuses on the following major areas of rural water systems: water source, reservoir, transportation, storage, point-of-use, and human behaviors.

Methods

Communities assessed

Source water may come from an "improved" or an "unimproved" water source. Types of improved sources may include: piped water into a home or yard; public tap or connection; protected spring; protected well; or a rainwater collection. Types of unimproved sources may include: unprotected well; unprotected spring; cart with small tank or drum; surface water (river, dam, lake, pond, stream, canal, irrigation channel) (World Health Organization 2012).

The assessment was tested in two indigenous communities in Baja California, Mexico, in May of 2004. Community One has approximately 66 households (population 165) and at the time of the assessment had an "improved" spring fed water system. Community Two has approximately 50 households (population 115) and at the time of the assessment used hand-dug wells or an "unimproved" water system.

Analysis of water samples

We obtained water samples and used fecal coliform counts to verify the results of the assessment tool. Water samples were collected from the source, as well as from the household storage containers in both communities. All samples were kept on ice and were processed within 12 hours of collection at a laboratory in San Diego, California. Samples were analyzed for *E. coli* (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 100mL (IDEXX, 2005). Risk levels for E.coli above 0 are as follows: 1-10 MPN E. Coli per 100mL is low risk, 10-100 per 100mL intermediate risk, 100-1000 per 100mL is high risk, and >1000 per 100mL very high risk (Eriksson & Raben, 2004; US EPA 2009; World Health Organization 2011).

Assessment development

Figure 1 depicts water system vulnerabilities to contamination. Our tool is designed to measure weaknesses at every point in the water system and produce an index of vulnerability. The tool described here has been explicitly designed to be low cost, rapid, locally managed, and participatory in nature. It is understood that not every system is the same and that the method will need to be modified to accommodate different types and kinds of systems. Indicators for the assessment of several different components of a rural water system were adapted from both field observations and other assessments developed for large scale systems (Jujnovsky, Gonzalez-Martinez, Cantoral-Uriza, & Almeida-Lenero, 2012; Songsore et al., 1998; World Health Organization 2012) Figure 1.

Having identified a set of proposed indicators, the next steps were to develop a weighting mechanism for the data, and then to combine the indicators into an overall index. Each indicator within each component was assigned a point across a scale of one to five points, and the average of the entire component was determined. After all components were assessed, the average of all components combined were then calculated to determine the overall systems' vulnerability score. The scales for each component were determined from adapting water system risk assessments used in larger scale or urban community assessments (Jujnovsky, Gonzalez-Martinez, Cantoral-Uriza, & Almeida-Lenero, 2012; Songsore et al., 1998; World Health Organization 2012). The proposed indicators were then tested in two indigenous communities in Baja California, Mexico.

The assessment methodology involved two sets of instruments. For community level indicators (water source, reservoir), structured observations were used. For household level indicators, the following were used: structured observation; discussion/interviews with residents/community leaders/community health providers, and focus group discussions with residents in charge of the water system or simply interested in the issue. When conducting the assessment at the household level, all survey responses were tabulated and combined over the entire set of surveys. The most common response(s) were then selected as the main indicator for that component of the assessment. For example, when surveying one of the communities in this research, 80% of the households responded that they stored their water inside the home, on the floor, and uncovered. Approximately 20% of the other households responded with various other methods for storing their water. The assessment therefore took the 80% response as the main indicator for that component of the assessment. There may be several indicators receiving equal or similar rates of response, if needed, more than one indicator can be included.

Source water indicators

Table 1 lists several potential indicators for both improved and unimproved water sources and ranks (indicated by the “x”) the risk level according to low, medium and high risks of vulnerability.

Reservoir indicators

Reservoirs may or may not be used in a water system. An example of a reservoir in a small community system may be a springbox or weir (small damn) used to retain or hold water before it enters a distribution system or it is collected for transport. Table 2 suggests several indicators for assessing the vulnerability of a reservoir if it is being used.

Transportation indicators

Some improved water systems may use distribution systems that include pipes or hoses which may be above or below ground and that lead to a community standpipe or individual properties. Other systems that are unimproved may not have a single method for transporting water, and thus it must be collected and transported by hand or truck. Table 3 lists several indicators for both methods of transportation or distribution of the water.

Household storage or tap indicators

Some households with improved water sources may have a tap or spigot attached to a distribution system. Other household systems may store water in or near their homes after collecting and transporting the water. Table 4 lists several indicators for assessing the household storage system or tap being used by residents.

Point-of-use indicators

Each household may have a different method for dispensing water in their home, creating different vulnerability scenarios. Table 5 list indicators to assess these vulnerabilities at the point-of-use, however there may be additional indicators added as needed.

Behavioral assessment

We developed questions for assessing behaviors, practices, and beliefs about community water in order to assess the probability of acceptance of a new water system (Table 6). These are suggested topics to include in an assessment as a way to better understand the types of systems that might work best in the community.

Results

Community One

Community One used an “improved” source of water that originated from a spring. The overall score for the entire system for this community was a 3.0 with the highest vulnerability being at the point-of-use (4.0) (Table 7).

Community Two

Community Two used an unimproved source of water, sourced from hand-dug wells. The overall score for the entire system was a 4.4 with all components individually scoring 4 or higher, indicating high vulnerability at every point in their system (Table 8).

Comparing the assessments in the two communities (Table 9), using an improved water source may improve the overall systems vulnerability. However, the vulnerability of the different components of the system may be higher or the same as unimproved sources at different points within the system.

Both communities, on average, had higher contamination at their sources when compared to the household storage containers (Table 10). Community Two had the highest levels of contamination. Data for Table 10 was part of larger study, see Stigler, Quintana, Gersberg, Zúñiga, and Novotny (2013) for more details.

Discussion

The water system vulnerability indicators developed in this project were used to conduct an assessment of contamination risks in two different types of rural water systems. Both communities scored the same for the point-of use risks (4.0) indicating a relatively high risk for contamination. This may indicate that regardless of the improvements made to systems at the source, the household practices and behaviors impact the safety of the water at the point of consumption (Gunther & Schipper, 2013; Jagals, 2006; Stigler, Quintana, Gersberg, et al., 2013). Community Two was almost twice as contaminated with fecal coliforms as Community One. Although point-of-use practices are a strong determinant of vulnerability, the source being unimproved appears to be the most important factor (Hunter, 2009; Wright et al., 2004). Therefore, we recommend improving the source of the water as a long-term solution when possible and focusing on point-of-use as a short-term solution.

Water quality testing was used to verify the vulnerability assessment. International water quality standards have set the acceptable limit of *E.coli* in drinking water at 0 MPN per 100mL. Both communities exceeded this level, but Community One was at a low risk and Community Two was at an intermediate risk for water contamination, thus validating the results of the vulnerability assessment. Both communities had lower coliform counts in their household storage container after the water system improvements. These findings were not surprising, as Wright et al. (2004) explains that when there is significant contamination at the source, it is not uncommon to have less contamination at the household level, possibly due to bacteria dying off.

A limitation of this study is that the actual behavioral or practice components of the assessment were not directly observed at the time of this assessment; nevertheless, this simple assessment tool appears to suggest a practical approach to assessing water system vulnerabilities without more detailed field research. It was, in fact, used in a later study after new systems had been installed in each of the communities described here (Stigler, Quintana, & Gersberg, 2013). It was found in that study that one of the communities did not accept their new system due to cultural practices and beliefs surrounding their old system. The behavioral component to this assessment is thus strongly recommended in order to gain deeper knowledge about the systems being used and to understand the community's perceptions, feelings, and practices surrounding their water systems (Dolnicar & Hurlimann, 2009; Jackson, 2006). We also recommend possibly adding in additional questions that focus on the political economy of the community (e.g. trust between the community and the government) and health beliefs (e.g. water as a source of illness). This is also important because technical changes or improvements may be made to the system and may not be fully applied or could negatively alter the social structures in the community, thus creating additional problems or concerns about water system improvements (Gomez & Nakat, 2002). This study was only tested in two communities and should undergo further testing.

This study did not take into account other factors that are important to the operation and maintenance of rural water systems such as economic viability and technical capacity. It is also limited in that we do not present an entire list of possible indicators for every type of a system. Nonetheless, this tool may assist organizations, government agencies, and communities to conduct a rapid assessment of water system vulnerabilities using community input and observations as a starting point in the system improvement process.

Conclusions

Assessing the various components for vulnerabilities in a community water system is an important task in the pursuit safe water and sanitation in LMICs.

Understanding vulnerabilities within the system and focusing efforts on specific risk areas could more effectively allocate scarce development resources. This research has provided a guide or template for communities, organizations, and government agencies in order to assist them to rapidly assess the areas of greatest need in a community water system. It is recommended to include questions about the cultural beliefs, rituals surrounding water or other practices to gain a deeper understanding of how infrastructure changes may impact the community and guide planners in improving acceptability of new systems.

Chapter 4 is being prepared for publication as Stigler PE, Quintana PJE, Novotny T. Vulnerability assessment for water supplies in rural communities Paula E. Stigler is the primary author on this paper.

Table 1. Indicators to assess vulnerability of source water in rural community water systems

	Risk Level		
Indicator	Low (1 Point)	Medium (3 points)	High (5 points)
Improved source			
Not disinfected		x	
Protection is in poor condition (e.g. lid is not closed or present on well, leaking casing)			x
Source runs above ground before entering system (e.g. rainwater runs through open gutter; spring is above ground before entering springbox)			x
Trash or debris located nearby	x		
Latrines or septic located nearby		x	
Not fenced in or protected with barrier	x		
Animal feces present		x	
Unimproved source			
Not disinfected			x
Uncovered or unprotected			x
Unfiltered (especially if from a spring, lake or pond)			x
Trash or debris located nearby		x	
Latrines or septic located nearby			x
Not fenced in or protected with barrier		x	
Animal feces present			x

Table 2. Indicators to assess vulnerability of reservoirs in rural community water systems

	Risk Level		
Indicator	Low (1 Point)	Medium (3 points)	High (5 points)
Small leaks of cracks		x	
Large leaks or cracks			x
Open or no lid that seals			x
Debris, sediment or algae present		x	
Trash or debris located nearby	x		
Latrines or septic located nearby		x	
Not fenced in or protected with barrier	x		
Spigot or line out not sealed or no backflow device		x	

Table 3. Indicators to assess vulnerability of water transportation components of rural community water systems

	Risk Level		
Indicator	Low (1 Point)	Medium (3 Points)	High (5 Points)
Line or hose is cracked or leaking small amount		x	
Line or hose is broken			x
Buckets or large mouth containers used to transport			x
Transportation container is dirty			x
Transportation container is a used container previously containing oil or chemicals			x
Water truck delivers water to central locations		x	
Transportation is a small mouthed container with a lid	x		
Spigot near house, water transported a short distance	x		

Table 4. Indicators to assess vulnerability of household storage or household tap sources in rural community water systems

	Risk Level		
Indicator	Low (1 Point)	Medium (3 Points)	High (5 Points)
Spigot or tap is located outside, no backflow device		x	
Spigot or tap is located outside, no backflow device and connected to a hose			x
Spigot or tap is located inside, no backflow device	x		
Spigot or tap is located outside, has backflow device	x		
Large mouthed container			x
Small mouthed container		x	
Uncovered container located on the floor			x
Covered container located on the floor		x	
Uncovered container located outside			x
Covered container located outside		x	
Container located inside, covered and off the ground	x		

Table 5. Indicators to assess vulnerability of water at the point-of-use in rural community water systems

	Risk Level		
Indicator	Low (1 Point)	Medium (3 Points)	High (5 Points)
Ladle, spoon or cup inside container		x	
Children have access to storage container			x
Animals or pets have access to storage container			x
No obvious place for hand washing			x
Hand washing station nearby	x		
Unsanitary household conditions		x	
Water is not boiled or disinfected at point-of-use		x	
Water is covered with towel or lid	x		

Table 6. Questions to assess community behaviors, practices, and beliefs about water systems

Indicator	Yes	No
New system will cause a dramatic shift in water collection responsibilities		
Community or residents have a cultural connection to the source of water used (e.g. is it used in rituals, connected to a creation story, etc.)		
Reluctant or unwilling to drink water from another source		
Does not believe in disinfection or does not think it is important		
Feels that operation and maintenance of a water system is the responsibility of the entire community or a special group selected from within the community		
Feels that operation and maintenance of a water system is the responsibility of an outside agency or group		

Table 7. Vulnerability assessment of an improved rural water system, Mexico, 2004

Indicator	Score
Source water	
Not disinfected	3
Protection is in poor condition (e.g. lid is not closed, leaking)	5
Source runs above ground before entering system (e.g. spring is above ground before entering springbox)	5
Trash or debris located nearby	1
Latrines or septic located nearby	0
Not fenced in or protected with barrier	1
Animal feces present	3
Total Score	18
Average Total Score	2.6
Reservoir/Springbox	
Leaking or cracked	3
Open or no lid that seals	5
Debris, sediment or algae present	3
Trash or debris located nearby	1
Latrines or septic located nearby	0
Not fenced in or protected with barrier	1
Spigot or line out not sealed or no backflow device	3
Total Score	16
Average Total Score	2.3
Transportation	
Line or hose is broken, cracked or leaking	3
Small mouth containers used to transport	1
Total Score	4
Average Total Score	2
Household storage/tap	
Spigot or tap is located outside, no backflow device	3
Covered container located on the floor	3
Total Score	6
Average Total Score	3
Point-of-use	
Ladle, spoon or cup inside container	3
Children have access to storage container	5
Animals or pets have access to storage container	5
Water is not boiled or disinfected at point-of-use	3
Total Score	16
Average Total Score	4
Overall Average of System	2.8

Table 8. Vulnerability assessment of an unimproved rural water system, Mexico, 2004

Indicator	Score
Source water	
Not disinfected	5
Uncovered or unprotected	5
Unfiltered (especially if from a spring, lake or pond)	5
Trash or debris located nearby	3
Latrines or septic located nearby	5
Not fenced in or protected with barrier	3
Animal feces present	5
Total Score	31
Average Total Score	4.4
Reservoir/Springbox not present	
Transportation	
Buckets or large mouth containers used to transport	5
Transportation container is dirty	5
Total Score	10
Average Total Score	5
Household storage/tap	
Large mouthed container	5
Uncovered container located on the floor	5
Covered container located outside	3
Total Score	13
Average Total Score	4.3
Point-of-use	
Ladle, spoon or cup inside container	3
Children have access to storage container	5
Animals or pets have access to storage container	5
Water is not boiled or disinfected at point-of-use	3
Total Score	16
Average Total Score	4
Overall Average of System	4.4

Table 9. Comparing vulnerability scores of two water systems in rural indigenous communities, Mexico, 2004

Component	Community 1 Vulnerability Assessment Score	Community 2 Vulnerability Assessment Score
Source	2.6	4.4
Reservoir	2.3	--
Transportation	2.0	5.0
Household storage/tap	3.0	4.3
Point-of-use	4.0	4.0
Overall System Score	2.8	4.4

Table 10. Water contamination as measured by coliform counts, two indigenous communities, Mexico, 2004

	Community One	Community Two
Sample Location	2004[a] *(E.coli, MPN/100ml[b])*	2004[a] *(E.coli, MPN/100ml[b])*
Source		
GM[d]	*9.0[c]*	*18.1[c]*
Range	*2-52*	*2-727*
n	*6*	*8*
Household storage containers		
GM[d]	*6.5[c]*	*12.2[c]*
Range	*2-31*	*2-317*
n	*6*	*10*

[a] Water samples were collected from March through August 2004
[b] MPN most probable number of coliforms per 100ml of water
[c] Exceeds WHO Safe Drinking Water Standards
[d] GM is the geometric mean of all samples

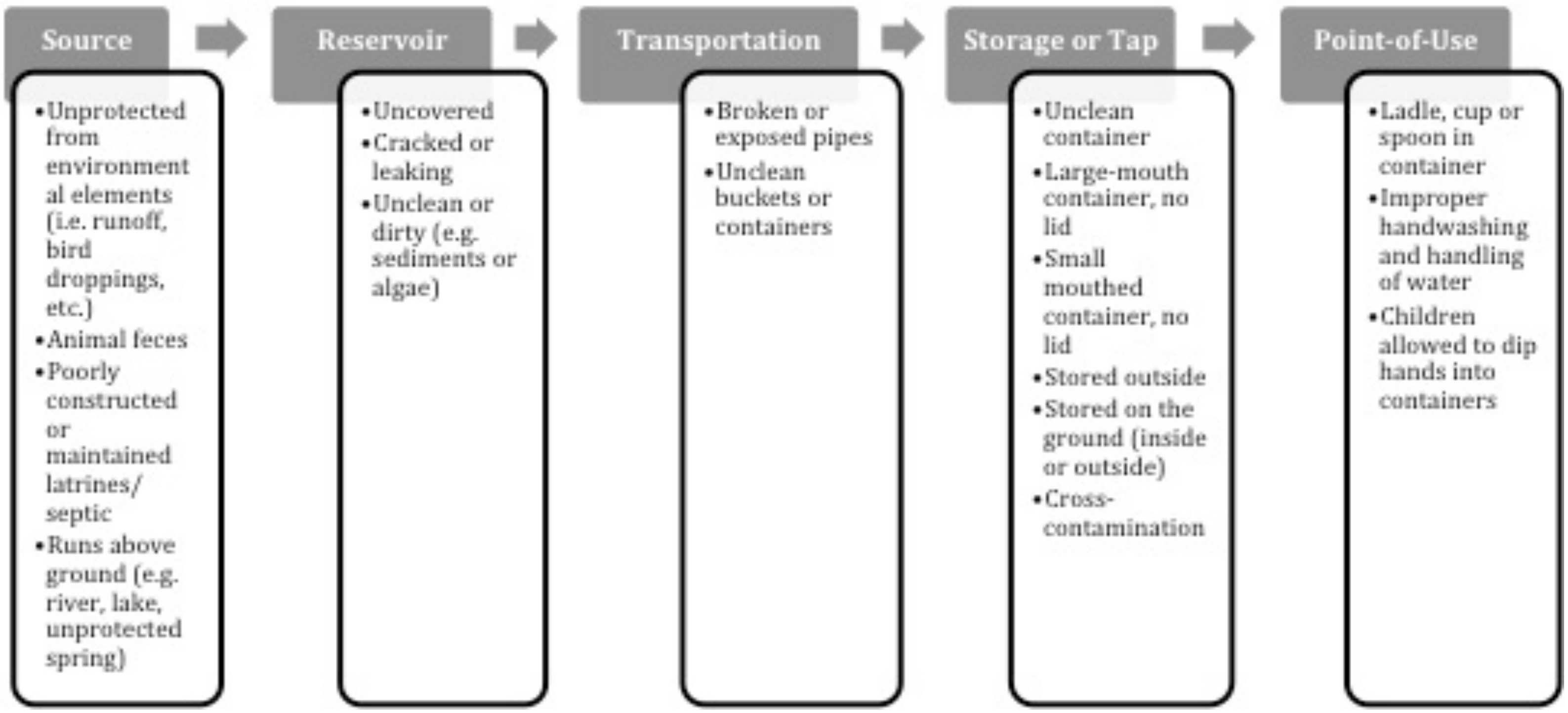

Figure 1. Flow diagram of potential contamination points or risks within a rural community drinking water system.

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CHAPTER 5:

Overview of findings

These communities have a long history of living on this land and have used this same water for thousands of years. In Community One the water comes from a source that is said to come from the hills of their ancestors. Every year, many community members make a trip up the mountain to clean out the old spring and to "renew" their life giving water. Although their new drinking water system comes from the groundwater found locally, it is a new source for them and may not have the same life-giving characteristics that they believe the other spring source may have. Not only did this community's new water system not work properly, the community itself was reluctant to use it as well. Many residents stated that the new water tasted "dead" and that the old water was alive with minerals and salts that the body needed to survive. It was important to understand why the community may have chosen not to drink from the new system.

Cultural beliefs and practice surrounding water may play a significant role in how a community views their source of water and therefore influence the acceptability of a new system. It may not be immediately obvious to planners or even the communities themselves that their beliefs may affect their acceptability of change. It may take lengthy discussions and the right questions to gather this information, however the outcomes could greatly improve if such measures are undertaken.

Although it is critical to improve a community's source water used for drinking, there are other key areas that deserve adequate attention in order to truly improve the health of the community. When changing the infrastructure within a community, it is important to have the community's involvement in order to ensure the system is usable and functional.

Another important area in planning a new system is taking into consideration already in place infrastructure such as septic systems or latrines in order to prevent contamination and plan for the possibility of improved sanitation systems that may be able to utilize the new water system. Household plumbing, or the lack thereof, should also be considered when installing a new system as some families may plan on installing plumbing once potable water is located near their home.

As this study proves, proper household storage containers and good behaviors at the point-of-use are critical to reducing contamination and possible exposures to pathogens. The prevention of hands, utensils, animals and insects from entering the storage container may prove significantly helpful in reducing contamination.

Learning about the most vulnerable components of a water system can enhance a community's capacity to create a sustainable solution to improving their water sources. In areas where it is not possible to make more significant investments in the infrastructure of the water system, simple fixes like chlorine disinfection solution may serve as a temporary measure to reduce illness. This is an area however that requires further research as some illnesses may be the result of food-borne pathogens, zoonosis, and other factors not directly related to the water supply.

Future directions

The intent of this research was to show the impact that access to safe drinking water had on vulnerable populations. It was found that although the new drinking water sources were no longer contaminated, the old contaminated sources were sometimes still being utilized and the water at the point of consumption was still contaminated. It is recommended that not only both communities begin to disinfect the water in their new and old systems but they also monitor the levels of residual chlorine or disinfectant. Each household should also receive a closed storage container with a spigot or suitable container for water storage purposes in order to prevent contamination at the household level. Additional outreach and education on the importance of proper household storage of drinking water and sanitation should also be implemented in the communities. It is recommended that the community model continue to be used in these communities as well.

Cultural beliefs and practices should not be overlooked when determining which outreach materials and technology would best serve rural populations. Many researchers in public health categorize indigenous people into single groups, however often times each community possesses unique characteristics and customs that are not replicated in other communities. Developing native language based education programs in public and environmental health with tribal life-ways figured into the equation would make for a more integrated approach to assisting these unique communities in protecting the health of their people. This idea can also be developed further for non-indigenous rural communities as well.