© IWA Publishing 2020
374
Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

Drinking water quality and consumer perceptions at the point-of-use in San Rafael Las Flores, Guatemala

C. E. Marcillo[a,*], G. García Prado[b], N. Copeland[c] and L. H. Krometis[a]

[a] Department of Biological Systems Engineering, Virginia Polytechnic Institute and State University, Seitz Hall Rm. 200, 155 Ag Quad Lane, Blacksburg, VA, 24061, USA

[b] Centro de Estudios Conservacionistas (CECON), Universidad de San Carlos de Guatemala, Avenida 11, Guatemala City, 01012, Guatemala

[c] Department of Sociology, Virginia Polytechnic Institute and State University, 225 Stanger Street, Blacksburg, VA, 24061, USA

*Corresponding author. E-mail: cem101@vt.edu

Abstract

Limited information is available describing point-of-use (POU) water quality in rural Guatemala. Source water quality in eastern Guatemala is of concern given underlying volcanic geology that can leach arsenic and the presence of large-scale mining, which can potentially exacerbate exposure. On-premise piped POU water in the rural community of San Rafael las Flores was sampled in 31 households to characterize a suite of metallic ions and *E. coli*, along with a survey of water uses and perceptions. Samples were analyzed via standard laboratory methods in the United States and an arsenic quick kit in the field. Fourteen household samples contained arsenic >9 μg/L and 13% of households exceeded at least one Guatemalan and US health-based water quality standard. Survey results revealed widespread dissatisfaction with water quality and service: most participants did not drink their POU water, fearing illness, and instead purchased bottled water or collected from untreated springs. Ideally, establishment of baseline water quality and an understanding of local concerns will facilitate collaborative partnerships and interventions that build community trust in appropriate water infrastructure while identifying surrounding land use impacts. This work represents the first Guatemalan study that quantifies POU contamination while concurrently examining user perceptions, preferences, and concerns.

Key words: arsenic, bacterial contamination, drinking water, Guatemala, metals, point-of-use

INTRODUCTION

In 2015, the United Nations and World Health Organization's (WHO) Joint Monitoring Program estimated that 95% of communities in Latin America and the Caribbean have access to improved drinking water sources (UNICEF & WHO 2015). Sources are characterized as improved based on water quantity and ease of availability, but do not necessarily meet local or WHO contaminant guidelines for human consumption at the point-of-use (POU). Therefore, although this region has made considerable progress in water access over the last several decades, it is imperative to examine the quality of water provided to communities at the POU to continue to safeguard public health.

Within the nation of Guatemala, an estimated 93% of citizens have access to improved water sources, with 85% of citizens served by on-premise piped water (UNICEF & WHO 2015). Despite this, significant gaps in the consistency and quality service exist in rural communities, which are relatively much poorer and often significantly comprised of indigenous populations in comparison to urban areas (World Bank 2018). There is considerable interest in the impact of underlying volcanic geology in this region, which can result in naturally elevated levels of arsenic in local groundwater (Bundschuh *et al.* 2012a; Cortina

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

et al. 2016). Moreover, there is local and international concern that heavy investment in extractive industries, such as mining, may exacerbate potential exposure by facilitating metal and salt movement into drinking water sources (Basu & Hu 2010; Bundschuh *et al.* 2012a).

Despite the unique challenges of the local landscape, only a very limited number of peer-reviewed household or POU water quality studies are available for Guatemalan communities. Gallardo *et al.* (2013) sampled water from 30 households served by artesian wells in the Monterrico community and 26 in the Candelaria community of Taxisco in the Santa Rosa municipality, about 90 miles from San Rafael Las Flores. Roughly one-fourth (23%) of samples from Monterrico and over half (53%) from Candelaria did not meet national standards for fecal coliform (i.e. 0 MPN/100 mL). This was not necessarily surprising, as contamination by fecal indicator bacteria is a common issue at the POU in developing countries (Bain *et al.* 2014).

In a study targeting the impacts of volcanic geology, Lotter *et al.* (2014) sampled 42 households at the POU to assess arsenic exposure in the Municipality of Chimaltenango. Though only one location in this study yielded samples above the WHO recommended arsenic standard (range: 46.0–47.6 μg/L) the authors recommended further sampling, given that tertiary volcanic rocks in the Cerro Alto area were a likely source of arsenic. In 2016, the faculty of the San Carlos University of Guatemala (USAC) studied dissolved arsenic in zones of the Municipality of Guatemala, much of which is served by treated drinking water, and reported that 25% of samples exceeded national water quality standards, but methodological details (e.g. participant selection, analytical techniques) were unspecified (Prado *et al.* 2016).

Arsenic contamination of drinking water is of increasing concern globally. In 2011, the WHO lowered its arsenic drinking water guideline to 10.0 μg/L, due to increasing evidence that chronic exposure can lead to cancer of the skin, bladder, kidney, and lungs, as well as dermal lesions in as little as five years (WHO 2017). Ongoing study suggests that adverse health effects, such as cardiovascular system impacts in children, are possible with exposure below the WHO guideline. However, the 10.0 μg/L guideline has been retained to accommodate reasonably achievable 'treatment performance … with the provision that every effort should be made to keep concentrations as low as possible' (WHO 2017).

The present study aimed to describe typical POU household water quality in San Rafael Las Flores, located in the department of Santa Rosa in eastern Guatemala. Local community concern over POU water quality has increased with the introduction and operation of the Escobal Silver Mine (property of the Pan American Silver Corp) in the area (CECON 2019). In order to characterize household tap water quality in San Rafael Las Flores, samples were collected from 31 households in tandem with an accompanying survey of water quality and service perceptions by users. Completion of this work permitted: (1) determination of the incidence of a suite of metallic ions, *E. coli*, and basic water chemistry parameters in household water; (2) comparison of the accuracy of field arsenic test kits to standard laboratory methods; and (3) assessment of community household water consumption and quality perceptions. Interventions and collaborative partnerships that build community trust in appropriate water infrastructure and identify land use impacts can be facilitated through establishment of a baseline water quality profile, confirmation of arsenic field kit potential, and an understanding of water quality concerns. Although this work is inherently local in its immediate focus, identification of key contaminants of concern and patterns of household use may prove useful to other groups in Latin America examining potential environmental health issues related to drinking water quality.

METHODS

Site description

The municipality of San Rafael Las Flores is located in the eastern department of Santa Rosa in Guatemala. Within the 85.2 km^2 municipal area, 71% of the population is described as rural and 84% of

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

laborers work in agriculture (SEGEPLAN 2010). The municipality is divided into five microregions, a geographic unit used in rural planning: the four rural regions of Las Nueces, Media Cuesta, San Rafaelito, and San Juan Bosco, and the urban center, also called San Rafael Las Flores (SEGEPLAN 2010). The most recent Guatemalan census reports a population of 12,641, of which 23.4% are indigenous Xinka, living in 3,111 households in the San Rafael Las Flores municipality, with 77.3% of households served by on-premise potable water (Guatemalan National Institute of Statistics 2019). The 2018 census also documented 3,610 individuals living in the urban center (Guatemalan National Institute of Statistics 2019). The urban center is further subdivided into 10 neighborhoods: Central, Colonia San Francisco, Las Colonias, Las Piedronas, Las Piscinas, Linda Vista, Oriental, San Antonio, Norte, and El Borbollón.

Households in the urban center are served on-premise piped water by three sources: a municipal drinking water treatment plant (MDWTP), the Cuevitas community spring box distribution tank, and the Morales community spring box distribution tank. All sources are overseen by the municipality and consumers pay for service. Through personal communication with the San Rafael Las Flores municipal authority, the MDWTP was found to employ pre-oxidation of arsenite through chlorine disinfection using a hypochlorite liquid, followed by coagulation/filtration using a system of adsorbent filters with iron chloride, Greensand adsorbent, and industrial grade silica of various sizes. Operation of the Cuevitas and Morales spring box distribution tank is carried out by a community member appointed to the local Water Committee, which is part of the local Community Development Council (COCODE). Though water directly sourced from the Cuevitas and Morales springs are not formally treated, volunteers who maintain the tanks indicated that the Morales tank is chlorinated once a month by a community volunteer. Households outside the urban center are generally served either by spring box distribution tanks, private on-residence springs, or artesian wells. The Cuevitas spring box and private, rural springs are untreated sources.

Participant recruitment and selection

Because San Rafael Las Flores is the epicenter of a protracted socio-environmental conflict over the Escobal Mine (Solano 2015; CECON 2019), trust building through collaboration with community partners was essential to recruiting study participants. The Diocesan Commission for the Defense of Nature (CODIDENA) is a well-known organization in the community that has been involved in water quality monitoring efforts as well as academic study with the Center for Conservation Studies (CECON) at the University of San Carlos of Guatemala (CECON 2019), making them an appropriate, and indeed necessary, choice for partnership. Households were recruited based on two main factors: (1) their spatial distribution allowed for analysis across sources and neighborhoods, particularly in the urban center of San Rafael Las Flores, and (2) they were willing to participate anonymously. Socio-environmental conflict in San Rafael Las Flores, and in many locations in Guatemala, has made study involvement a risk that could prevent participation, even anonymously. Households were initially contacted through a local representative of CODIDENA, though not all households recruited were part of this organization. At the time of sampling, participants were not asked if they were involved in CODIDENA, to maintain anonymity. The CODIDENA representative who helped recruit participants visited each household with researchers to make introductions, and after training, aided in POU sampling. Participants from 31 households were intentionally recruited to spatially represent two of the rural microregions, San Juan Bosco and Las Nueces, and all 10 urban neighborhoods (Figure 1). Participating households in the urban center were served by one of the three sources listed previously. Those in the rural microregions were served by private on-residence springs.

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

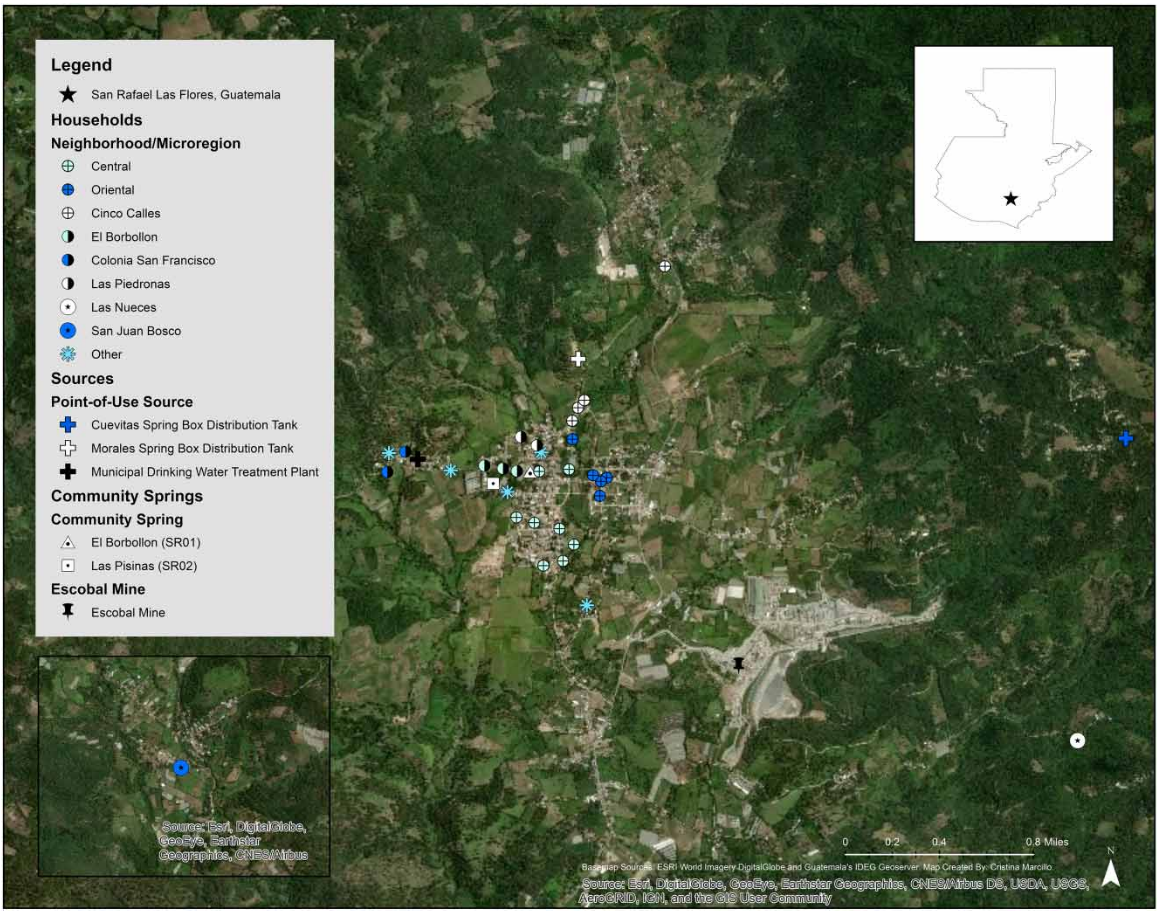

Figure 1 | Map of San Rafael Las Flores households, community springs, and water sources involved in this study. *Note*: Neighborhoods with only one household participant are grouped in the 'Other' category.

Household surveys

During the first household visit, an eleven-question survey in Spanish was verbally administered, to the head-of-household or available adult, by two of the authors who are fluent in Spanish. Informed study consent was obtained verbally from each participant prior to beginning the survey. The study protocol, including survey design, collection, and analysis, were approved by the Institutional Review Board of Virginia Tech (VA, USA, IRB#18-386, approved on 05/06/2018). Surveys did not record participant names, affiliation with CODIDENA, or any demographic information in order to ensure complete anonymity. The survey consisted of a mixture of multiple-choice and short answer questions characterizing water use, service satisfaction, and perceptions of quality (Supplementary Table 1). Pictures were used to demonstrate certain water quality conditions (e.g. particulates or staining) to ensure consistent communication (Supplementary Figure 2).

Water sampling campaign

Household POU tap water samples were collected over a 3-day period in December 2018, which corresponds to the Guatemalan dry season. All samples were collected in pre-sterilized and acid-washed 125 mL polypropylene bottles. During the first household visit, three 125 mL grab samples were collected at the POU and tested in-home for physicochemical parameters, *E. coli*, and arsenic via a quick test (methodology in the subsequent section). An additional 125 mL grab sample was immediately wax-sealed for transport to the United States for laboratory ICP-IMS metals testing. A final

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

125 mL sample bottle was left with each household participant for collection and pick-up the following day, to be immediately wax-sealed upon receipt for transport to the US for ICP-IMS analysis via standard methods. Twenty-seven of the 31 participating households returned the follow-up grab sample: household 2 declined to provide a second sample, household 6 did not have tap water service for the following two days, and households 30 and 31 were too remote to visit a second time. Additionally, household 30 used two different private springs: one for drinking and one for all other uses. One sample was taken from each of household 30's two private springs. This resulted in a total of 59 household samples: 27 households with two samples one day apart, 2 households with only one sample from the first household visit, and 1 household with two samples from the first visit from two different private springs (Supplementary Figure 1).

During the household surveys accompanying this sampling campaign, participants identified two community springs (i.e. not piped into homes) in the urban center that were common alternate drinking water sources. 'El Borbollón' (SR01) is an unprotected roadside spring while 'Las Piscinas' (SR02) is located in a gated public park (Figure 1). Both community springs are named after their respective adjacent urban neighborhood. At each community spring, three 125 mL grab samples were collected and tested on-site for physicochemical parameters, *E. coli*, and arsenic and an additional 125 mL grab sample was collected and immediately wax-sealed for transport to the US for ICP-IMS analysis, the same as the household POU samples. This resulted in a total of two community spring samples: one from each community spring from the first and only visit. Because water samples were collected at the community spring source, results for SR01 and SR02 represent drinking water that is consumed at the source or very shortly after collection, and does not quantify risks associated with community spring water storage in the household.

Field water quality analysis

Upon the first visit to households and community springs, one of the 125 mL grab samples was analyzed on-site for water conductivity, total dissolved solids (TDS), pH, and temperature using a HANNA Instruments Low Range Probe HI98129 (Smithfield, RI, USA). The two additional 125 mL grab samples were analyzed either immediately in the household or within 10 hours of collection (i.e. promptly upon return to study base after household surveys) for *E. coli* using the Aquagenx Compartment Bag Test (Chapel Hill, NC, USA) and for arsenic using the Industrial Test Systems, Inc. Quick Arsenic Econo Test II Kit (Rock Hill, SC, USA; Part No. 481304). Both tests require no electricity or specialized equipment to complete. A demonstration of these field tests to household participants was used as an opportunity to educate individuals on these water quality parameters. The *E. coli* test follows a classic most probable number analysis, with a colorimetric change (yellow to blue) used to identify positive sample wells. Results from the *E. coli* test are available within two days given incubation at room temperature (21–25 °C) and range from 0 to >100 MPN/100 mL. The arsenic Quick Test measures inorganic (III and V) arsenic using a colorimetric strip test. It has a detection limit of '<2 μg/L' and distinct colors are given for 3, 5, 7, 8, 9, 10, 12, and 16 μg/L. Should a sample result be above 16 μg/L, the Quick Test provides instructions on dilution so that the scale provided can be used. Results from the Quick Test are available within 20 minutes. For this purpose, if the colorimetric change was deemed 'in between' two color blocks, a duplicate sample was analyzed and recorded. More detail on the Arsenic Quick Test can be found in Supplementary Figure 3.

Laboratory water quality analysis

A total of 61 grab samples (59 from households and two from community springs) were wax-sealed and transported to Virginia Tech for laboratory metals analysis via ICP-IMS. Samples were analyzed within two weeks of sample collection (US Environmental Protection Agency 2016). Upon arrival in

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

the US laboratory, all samples were acid digested with nitric acid (2%) for a minimum of 24 hours prior to inorganic metal analysis via ICP-IMS according to Standard Methods 3030D and 3125B (APHA/AWWA/WEF 1998).

Statistical analysis

Survey results were qualitatively evaluated through a tally of most common close-ended responses and a categorization of short answer responses based on common themes. ICP-IMS laboratory results were analyzed for differences by source using Kruskal-Wallis, a non-parametric method to assess median differences, and a post-hoc Dunn's test. Non-parametric tests were most appropriate as non-normality persisted despite multiple data transformation attempts. All households that had two ICP-IMS results from the same POU tap (i.e. first and second day samples from households 1, 3–5, and 7–29) were averaged before use in statistical analysis. Field Quick Tests and laboratory ICP-IMS arsenic quantification were compared using a Pearson correlation coefficient and a paired-sample Wilcoxon rank sum test to assess median differences by method. Statistical significance was defined at a p-value of 0.05. Contaminant levels were compared to Guatemalan COGUANOR NTG 29001 (Congress of the Republic of Guatemala 2011) maximum permissible limits (LMPs: 'límite máximo permisible'), US National Primary Drinking Water Regulations (i.e. MCLs: maximum contaminant levels and TTs: treatment techniques) (US Environmental Protection Agency 1974), and WHO (2017) drinking water guidelines. Secondary standards include Guatemalan maximum acceptable limits (LMAs: 'límite máximo aceptable') and US secondary maximum contaminant levels (SMCLs). Associated drinking water limits are detailed in Supplementary Table 2. All analyses were conducted in R Studio version 3.4.4 (R Studio Team 2017).

RESULTS AND DISCUSSION

Household survey of water perceptions

Household surveys identified a widespread lack of trust and dissatisfaction with POU water. A summary of primary survey results is presented in Table 1; complete responses, including full short answers, are provided in Supplementary Table 1 (translations completed directly by the authors). Overall, 23 households were served by the MDWTP, six by the spring box distributions tanks, and two by private springs (Table 1). This study provided the first household tap water quality information almost all (94%) participating households had ever received. More than 90% of participants bathe and brush teeth with their POU water, but only 52% and 23% use it for cooking and drinking, respectively. Of participants that use alternate drinking water sources, 61% prefer to rely on bottled water, though this represents an additional household expense. One household specifically mentioned a financial concern associated with reliance on bottled water. Nearly a third (32%) of households prefer to drink from the untreated community springs (i.e. SR01 'El Borbollón' and SR02 'Las Piscinas') sampled in this study.

The majority (84%) of households also identified at least one, but usually more, consistent aesthetic issues with their tap water, most often relating to color, odor, or particulate matter. Specific aesthetic issues mentioned ranged from 'tastes a lot like chlorine' to 'smells of pure rust' to 'feels greasy or oily' to general observations that 'it is dirty and smells bad' (Supplementary Table 1). Aesthetics play a critical role in a consumer's choice of drinking water, as many consumers use smell, taste, and appearance to judge water quality and gauge risk (Levallois *et al.* 1999; Anadu & Harding 2000).

Given the noted aesthetic concerns, it is perhaps unsurprising that the majority of households (77%) perceived their tap water as unsafe to drink. Households that did not believe their POU

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

Table 1 | Top responses from household survey ($n = 31$), translated from Spanish by the authors

What is the source of your in-home tap drinking water? 74% Municipal drinking water treatment plant 19% Spring box distribution tank 7% Private spring		**For what do you use your tap water?** 100% Clean (i.e. floors, counter space) 100% Wash (i.e. dishes, clothes) 97% Bathe 94% Brush teeth 52% Cook 23% Drink		
Does your tap water:				
have an unpleasant taste? 68% No 13% Chlorine 10% Metallic 3% Salty	**have an unpleasant odor?** 65% No 16% Chemical 10% Sulfur 7% Musty	**have an unnatural color?** 36% No 52% Muddy 13% Yellow 3% White	**stain?** 74% No 26% Rust/brown 3% Black/grey	**have particles?** 45% No 39% Sediment 13% Black specks 7% Red/orange slime
Do you perceive your in-home tap water to be safe for drinking? 23% Yes 77% No		**What concerns do you have?** *(of the 24 that said 'No')* Concerns related to self or family's health −32% Concerns of perceived contamination −40% Ecological concerns −16% Financial concerns −4% Other −8%		
Do you use alternate sources of drinking water? 87% Yes 13% No		**What alternate sources of drinking water do you use?** 13% None 61% Bottled water 32% Community spring		
Do you have continuous (all day and night) in-home tap water service? 26% Yes 74% No		**How many hours per day do you have in-home water available?** *(of the 23 that said 'No')* 30% 5–7 hours 26%14–16 hours 22% 11–13 hours		
Within the last year, have you ever experienced an unplanned or no-notice service interruption? 26% Yes 74% No		**How many times?** *(of the 8 that said 'Yes')* 63% 2–3 times 25% 6–8 times	**Approximately how long did each last?** *(of the 8 that said 'Yes')* 13% Half day 50% 1 day 38% 2 days	
Has your household tap water quality ever been tested? 6% Yes 94% No			**Who tested your tap water?** *(of the 2 that said 'Yes')* 100% The municipality	

Values may not total to 100% due to rounding or additional responses listed fully in Supplementary Table 1.

water was safe to drink were most concerned with potential illnesses related to the consumption of poor-quality water. In the 40% of households concerned with perceived contamination, participants specifically mentioned arsenic, bacteria, sediment, and chlorine as contaminants of concern. Perception of water contamination often stemmed from the observation that water was 'always dirty'. Health concerns for individuals and their families, noted by 32% of participants, included rashes, hair loss, and allergies, most of which participants attributed to perceived metals and/or microbial contamination. A small number of participants identified local mining and new source waters at the MDWTP as the cause of contamination and illness, although these claims cannot be corroborated given the absence of prior POU water quality results. These survey questions did not ask about seasonality of perceived contamination, a limitation worth mentioning.

Stated dissatisfaction with household water was also likely related to intermittent service. Only 25% of households noted having continuous tap water service, with most others having running water for only 5–7 or 14–16 hours per day. The only participant from the San Antonio neighborhood had service every two days. One household specifically stated that they were willing to sacrifice water quality

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

for continuous POU service. About one quarter of households also reported that they had experienced no-notice service interruptions, aside from already scheduled intermittent service, which forced them to turn to alternate water sources. A portion of households (16%) also expressed concern that ecological concerns, regarding future droughts or water scarcity, would completely cut off or further reduce already non-continuous tap water service.

Arsenic

Results suggested that arsenic was the contaminant of most immediate health concern in the samples collected. Two households (sources: MDWTP and a private spring) provided at least one ICP-IMS sample that exceeded Guatemalan, US, and WHO arsenic drinking water standards (Table 2). It is important to note that samples from 12 additional households (sources: MDWTP and Cuevitas spring box), were within 1.0 μg/L of the limit, via ICP-IMS analysis. Arsenic toxicity is well established, with adverse health impacts recorded even below the recommended standard (WHO 2017). Arsenic significantly differed by POU source (Kruskal Wallis: $\chi^2 = 11.387$, $p < 0.01$), with the MDWTP having a significantly higher median value than the Morales spring box (Dunn's: $p < 0.05$). This finding is surprising, given that the San Rafael Las Flores MDWTP is the only sampled source with treatment specifically designed to remove arsenic, via pre-oxidation of arsenite through chlorine disinfection, followed by coagulation/filtration (personal communication with the municipal authority). Further study into the source of this arsenic, including an investigation of local geology, potential impacts of surrounding land use, and water system operation is warranted.

The arsenic Quick Test kit employed in the field identified seven households at or above the arsenic primary standard and an additional six households within 1.0 μg/L of the standard, which is notably higher than that indicated via ICP-IMS (Table 2). Quick Test results were within 1.0 μg/L of ICP-IMS results for 45.2% of households, with an additional 41.0% of samples within 5 μg/L, and the final 12.9% of Quick Test results within 10 μg/L of ICP-IMS results. The two methods did not have significantly different medians ($p < 0.05$, paired-sample Wilcoxon rank sum test) and were moderately strongly correlated (Pearson's coefficient = 0.73). Ideally, the arsenic Quick Test should be employed as an early indicator, with follow up via standard methods for concerning samples. While the use of

Table 2 | Results of ICP-IMS and Quick Test arsenic analysis in sampled households (HH) ($n = 31$) and community springs (SR) ($n = 2$)

Sampling site		HH01	HH02	HH03	HH04	HH05	HH06	HH07	HH08	HH09	HH10	HH11
ICP-IMS (μg/L)	Sample 1	7.90	7.80	8.89	9.41	7.78	9.86	8.68	2.75	10.39	8.19	9.88
	Sample 2	7.82	–	9.91	8.59	7.78	–	8.44	4.55	8.35	9.32	9.10
	Average	7.86	7.80	9.40	9.00	7.78	9.86	8.56	3.65	9.37	8.76	9.49
Quick Test (μg/L)		7	5	9	12	10	9	8	7	9	8	9

Sampling site		HH12	HH13	HH14	HH15	HH16	HH17	HH18	HH19	HH20	HH21	HH22
ICP-IMS (μg/L)	Sample 1	9.88	4.02	9.68	9.65	1.03	9.47	1.05	1.20	0.93	0.88	1.55
	Sample 2	9.68	5.30	8.08	9.04	1.11	8.89	1.15	1.08	0.95	0.90	1.52
	Average	9.78	4.66	8.88	9.34	1.07	9.18	1.10	1.14	0.94	0.89	1.54
Quick Test (μg/L)		8	5	9	9	10	<2	<2	<2	<2	<2	5

Sampling site		HH23	HH24	HH25	HH26	HH27	HH28	HH29	HH30	HH31	SR01	SR02
ICP-IMS (μg/L)	Sample 1	1.60	8.81	7.99	9.51	8.34	8.57	4.76	8.21[a]	1.58	2.81	1.07
	Sample 2	1.55	8.28	9.15	7.85	7.39	9.77	2.98	17.87[b]	–	–	–
	Average	1.57	8.54	8.57	8.68	7.86	9.17	3.87	–	1.58	2.81	1.07
Quick Test (μg/L)		<2	5	10	10	12	5	5	10[a];16[b]	<2	3	3

[a,b]HH30 provided one sample for two different private springs: a is the spring used for drinking; b is the spring for all other uses. – = no such standard.
Note: The Quick Test arsenic kit has a minimum detection limit of '<2' μg/L.

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

this field kit allowed for heightened community participation as participants could assist in Quick Test analysis in their own homes, appropriate training and communication of the potential uncertainty surrounding results is critical to minimize unnecessary distress.

It is important to note that the presence of arsenic at the POU does not necessarily equate to exposure, as daily drinking water quality can vary and the majority of households in this study relied on alternative sources for drinking water. Previous studies have indicated that soaking, preparing, and cooking foods with arsenic contaminated water may be a critically understudied source of exposure in Latin America (Bundschuh *et al.* 2012b). Given that half of the households in this study did cook with their POU water, further investigation of potential daily arsenic intake via food is recommended.

Other health-based contaminants

Four households (sources: MDWTP, the Morales spring box, and a private spring) provided *E. coli*-positive samples, with significantly higher median values (KW: $\chi^2 = 11.84$, $p < 0.01$) for samples from systems dependent on the Morales spring box (Dunn's: $p < 0.05$) as compared to the MDWTP, despite the fact that both sources chlorinated. This could be due to on-site contamination, as free-roaming chickens were often seen in outdoor patios and yards, where POU sinks were located. Although boiling water concentrates metals (Bundschuh *et al.* 2012b), it is a recommended household intervention for *E. coli* contamination, which can cause gastrointestinal issues such as diarrhea. The success of such interventions is highly dependent on consistent hygiene practices in the home, as contamination can be easily reintroduced. Recent studies have shown that in-home treatment via chlorination or boiling water had no effect on reducing diarrhea incidence among children in Guatemalan households (Vásquez & Aksan 2015; Trudeau *et al.* 2018).

One household sample, served by the MDWTP, resulted above Guatemalan, US, and WHO primary lead standards, at 32.8 μg/L (Table 3). Additionally, seven households had at least one sample (sources: MDWTP, the Cuevitas spring box, and a private spring) above the primary Guatemalan aluminum standard, with significantly higher median values (KW: $\chi^2 = 14.40$, $p < 0.01$) in the MDWTP (Dunn's: $p < 0.01$) and the Cuevitas spring box (Dunn's: $p < 0.01$) than the Morales spring box. Twenty-four households (representing all sources) had at least one sample above the more stringent US SMCL for aluminum. Given that both metal and bacteriological health-based contaminants were found in San Rafael Las Flores POU water, household interventions must counterbalance their treatment considerations.

Aesthetic contaminants

The majority of households surpassed secondary aesthetic guidelines for aluminum (which is a primary standard in Guatemala), iron, sodium, and/or manganese, which was unsurprising given that 84% of participants noted that their POU water had a strange color, odor, or particulates. Twenty-five households (representing all sources) yielded at least one sample above the US sodium recommendation, with values ranging from 9.23 to 62.1 mg/L. One household had at least one sample that resulted above the US manganese SMCL (source: MDWTP). The MDWTP had significantly higher (KW: Na $\chi^2 = 14.85$, $p < 0.01$; Mn $\chi^2 = 15.28$, $p < 0.01$) sodium and manganese values than both the Morales spring box (Dunn's: Na $p < 0.05$; Mn $p < 0.01$) and private springs (Dunn's: Na and Mn $p < 0.05$). Six households had at least one sample (sources: MDWTP and the Cuevitas spring box) that resulted above the Guatemalan LMA and US SMCL for iron, with the MDWTP and Cuevitas spring box having significantly higher values (KW: $\chi^2 = 15.05$, $p < 0.01$; Dunn's: MDWTP and Cuevitas $p < 0.05$) than the Morales spring box. Though these contaminants do not represent health-based concerns, aesthetic issues can reduce consumer water use and trust in the utility.

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

Table 3 | Households ($n = 31$) with at least one sample exceeding Guatemalan, US, and/or WHO primary drinking water standards, with maximum and minimum (μg/L) values

	% Households above primary standard			ICP-IMS (μg/L)	
Parameter	**US**	**WHO**	**Guatemala**	**Minimum**	**Maximum**
Sodium	80.6[a]	–	–	9,228.52	62,116.79
Magnesium	–	–	0	427.39	15,894.83
Aluminum	77.4[a]	–	22.6	1.46	3,602.60
Calcium	–	–	0	5,397.19	65,487.81
Chromium	0	0	0	0.07	1.41
Iron	19.4[a]	–	19.4[a]	ND	889.30
Manganese	3.2[a]	–	0	0.15	65.95
Nickel	–	0	–	0.26	34.61
Copper	0	0	0	0.19	677.53
Zinc	0[a]	–	0	4.99	2,470.64
Arsenic	6.5	6.5	6.5	0.88	17.87
Selenium	0	0	0	ND	2.13
Silver	0[a]	–	–	ND	0.06
Cadmium	0	0	0	ND	0.03
Barium	0	0	0	2.68	273.91
Lead	3.2	3.2	3.2	ND	32.80
Uranium	0	0	–	0.01	0.30
E. coli	12.9	12.9	12.9	ND	100 MPN

[a]Secondary standard, if there is no primary, or the recommended level, in the case of US sodium. ND = not detected. MPN = Most probable number per 100 mL. – = no such standard.

Community spring water quality

Two community springs, El Borbollón (SR01) and Las Piscinas (SR02), were identified through initial household surveys as highly valued alternate drinking water sources. These community springs were the primary source of drinking water for almost a third (32%) of participants and were perceived by this subset as safer than their household POU water. Water quality results indicated that water from these community springs contained markedly lower arsenic (1.07–2.81 μg/L via ICP-IMS) and were *E. coli* negative. Samples from both community springs exceeded the Guatemalan primary standard and US SMCL for aluminum. However, it is unclear whether these values would be applicable beyond the lower flows associated with the Guatemalan dry season during the December sampling period. This presents an opportunity for community engagement through a citizen science water monitoring campaign to better characterize community spring water quality. To be effective, this effort would require committed technical partners to assist in quality assurance, documentation, and interpretation of resultant data.

Study limitations

Introduction through local stakeholders was essential to gain access and build trust with this previously little studied rural community. Conflict surrounding the local mine and general water rights in San Rafael Las Flores made participant recruitment especially difficult (Copeland 2019). The decision to partner with CODIDENA, an organization by name dedicated to ecological stewardship, may have led to the selection of study participants biased towards similar views. However, CODIDENA's successful completion of prior academic surveys (CECON 2019) in this region made them the best partner available. Although demographic information was not collected in the survey, not all

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

participants were affiliated with CODIDENA and there was a wide range of views regarding land use and environmental issues. This study does not spatially represent the entire municipality, instead focusing on the urban center. Water sampling spanned three days in December 2018 during the Guatemalan dry season, where the lower ambient temperature of bacterial incubation may have impacted study results, and therefore cannot be extrapolated beyond that seasonal time frame. Additionally, this study does not have information on the raw source water quality from the MDWTP or either spring box, and does not have relevant network distribution information (i.e. pipe materials) that likely influenced the water quality exhibited in household POUs.

CONCLUSION

Although the majority of homes in San Rafael Las Flores, Guatemala, have in-home piped water, participants in this study expressed dissatisfaction with the quantity and quality of water provided. Very few households used their in-home tap water for drinking. Samples from 13% of households exceeded at least one US and Guatemalan health-based water quality standard, including 14 homes which provided samples with arsenic ranging from 9 to 18 μg/L. This is significant, given that arsenic toxicity is well-established, with adverse health impacts recorded even below recommended guidelines. The impacts of long-term exposure near the recommended arsenic limit, through both drinking and cooking, should be explored further in this community. Although the source of this arsenic is not known, underlying volcanic geology may leach arsenic into groundwater, and it is possible for local mining and other anthropogenic land-uses to exacerbate this natural source. Arsenic Quick Test field kits were found to be moderately well correlated and not significantly different from standard ICP-IMS analysis, though high level samples should be confirmed with standard methods. Given notable aesthetic concerns, improvement of water infrastructure in San Rafael Las Flores will likely require both system rehabilitation and increased community participation to improve perceptions and use of tap water service. Long term monitoring of household POU taps and valued community springs in conjunction with surveys on typical water use and concerns is recommended to better understand community exposures to drinking water contaminants.

ACKNOWLEDGEMENTS

The authors would like to thank the George Washington Carver Research Assistantship (Virginia Tech College of Agriculture and Life Sciences), the Pratt Scholarship (Virginia Tech Biological Systems Engineering Department), and Virginia Tech's Center for Peace Studies and Violence Protection for supporting this research effort. These funding sources had no involvement in the study design, collection, analysis and interpretation of data, or the writing and submission of this article for publication. The authors would also like to thank our community partners, including CODIDENA and Alfonso Solórzano, for their help in conducting fieldwork.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/wpt.2020.025.

REFERENCES

American Public Health Association/American Water Works Association/Water Environment Federation. 1998 *Standard Methods for Examination of Water and Wastewater*, 20th edn. APHA/AWWA/WEF, Washington, DC, USA.

Water Practice & Technology Vol 15 No 2
doi: 10.2166/wpt.2020.025

Anadu, E. C. & Harding, A. K. 2000 Risk perception and bottled water use. *Journal of the American Water Works Association.* **92**(11), 82–92. https://doi.org/10.1002/j.1551-8833.2000.tb09051.x.

Bain, R., Cronk, R., Hossain, R., Bonjour, S., Onda, K., Wright, J., Yang, H., Slaymaker, T., Hunter, P., Prüss-Ustün, A. & Bartram, J. 2014 Global assessment of exposure to faecal contamination through drinking water based on systematic review. *Tropical Medicine and International Health* **19**(8), 917–927. doi:10.1111/tmi.12334.

Basu, N. & Hu, H. 2010 *Toxic Metals and Indigenous Peoples Near the Marlin Mine in Western Guatemala: Potential Exposures and Impacts on Health*. Report for Physicians for Human Rights, Cambridge, MA, USA.

Bundschuh, J., Litter, M. I., Parves, F., Román-Ross, G., Nicolli, H. B., Jean, J., Liu, C., López, D., Armienta, M. A., Guilherme, L. R. G., Gomez Cuevas, A., Cornejo, L., Cumbal, L. & Toujaguez, R. 2012a One century of arsenic exposure in Latin America: a review of history and occurrence from 14 countries. *Science of the Total Environment* **429**, 2–35. doi:10.1016/j.scitotenv.2011.06.024.

Bundschuh, J., Nath, B., Bhattacharya, P., Liu, C. W., Armienta, M. A., Moreno López, M. V., Jean, J. S., Cornejo, L., Lauer Macedo, L. F. & Filho, A. T. 2012b Arsenic in the food chain of Latin America's population. *Science of the Total Environment.* **429**, 92–106. doi:10.1016/j.scitotenv.2011.09.069.

Center for Conservation Studies at the University of San Carlos of Guatemala (USAC CECON) 2019 *Desigualdad, Extractivismo y Desarrollo en Santa Rosa y Jalapa (Inequality, Extractivism and Development in Santa Rosa and Jalapa)*. Report for Oxfam Guatemala, Guatemala City, Guatemala.

Congress of the Republic of Guatemala 2011 Norma Técnica Guatemalteca No. 29001: Agua para consumo humano (Technical Guatemalan Norms No. 29001: Water for human consumption). In *La Comisión Guatemalteca de Normas (COGUANOR)*, Guatemala City, Guatemala.

Copeland, N. 2019 Defending consultation: indigenous resistance against the Escobal Mine in Guatemala. In *Article for the North American Congress on Latin America*.

Cortina, J. L., Litter, M. I., Gibert, O., Valderrama, C., Sanchez, A. M., Garrido, S. & Ciminelli, V. S. T. 2016 Latin American experiences in arsenic removal from drinking water and mining effluents. In: *Innovative Materials and Methods for Water Treatment: Solutions for Arsenic and Chromium Removal*, 1st edn (Bryjak, M., ed.). CRC Press, London, UK, pp. 391–416.

Gallardo, V., Albanés, E., Rivera, D., Flores, C., Vásquez, O., Ruano, M., Alvarado, E., Muñoz, A., Chiguaque, A., Recinos, B., Díaz, A., Ortiz, D. & Arroyo, G. 2013 Estado de salud de los habitantes de las aldeas Monterrico y La Candelaria, Taxisco, Santa Rosa, Guatemala (Health status of the villagers of Monterrico and Candelaria, Taxisco, Santa Rosa, Guatemala). *Revista Científica de la Facultad de Ciencias Químicas y Farmacia* **23**(1), 54–67.

Guatemala Nacional Institute of Statistics 2019 *Censos Nacionales XII de Población y VII de Habitación de 2018 (XII Population and VII Housing National Census)*. Serviprensa, Republic of Guatemala, Guatemala City, Guatemala.

Levallois, P., Grondin, J. & Gingras, S. 1999 Evaluation of consumer attitudes on taste and tap water alternatives in Quebec. *Water Science and Technology.* **40**(6), 135–139. https://doi.org/10.1016/S0273-1223(99)00549-1.

Lotter, J. T., Lacey, S. E., Lopez, R., Socoy Set, G., Khodadoust, A. P. & Erdal, S. 2014 Groundwater arsenic in Chimaltenango, Guatemala. *Journal of Water and Health* **12**(3), 533–542. https://doi.org/10.2166/wh.2013.100.

Prado, F., González, M. E., Hernández, M., Guzmán, C., Chaulon, M. G., Cóbar, S., Donis, M. & Rivera, C. 2016 Preliminary study of total levels of dissolved arsenic in drinking water of different zones of the Municipality of Guatemala, Department of Guatemala. *Toxicology Letters* **259S**, S122. http://dx.doi.org/10.1016/j.toxlet.2016.07.313.

R Studio Team 2017 RStudio: Integrated Development for R. RStudio, Inc., Boston, MA. http://www.rstudio.com/

SEGEPLAN (Guatemalan Secretariat for Planning and Programming of the Presidency) 2010 *Plan de desarrollo: San Rafael Las Flores, Santa Rosa (Development Plan for San Rafael Las Flores, Santa Rosa)*. Serviprensa, Republic of Guatemala, Guatemala City, Guatemala.

Solano, L. 2015 *Under Siege: Peaceful Resistance to Tahoe Resources and Militarization in Guatemala*. Report for The International Platform Against Impunity in Central America, MiningWatch Canada, and the Network in Solidarity with the People of Guatemala, Guatemala City, Guatemala.

Trudeau, J., Aksan, A. M. & Vásquez, W. F. 2018 Water system unreliability and diarrhea incidence among children in Guatemala. *International Journal of Public Health* **63**, 241–250. https://doi.org/10.1007/s00038-017-1054-6.

UNICEF and WHO 2015 *Progress on Sanitation and Drinking Water – 2015 Update and MDG Assessment*. New York, New York, USA. Available from: https://www.unicef.org/publications/index_82419.html (accessed 31 August 2019).

United States Environmental Protection Agency 1974 *Code of Federal Regulation Title 42: The Safe Drinking Water Act (1974)*. The Government Publishing Office, Washington, DC, USA.

United States Environmental Protection Agency 2016 *Quick Guide to Drinking Water Sample Collection*, 2nd edn. The Government Publishing Office, Golden, CO, USA.

Vásquez, W. F. & Aksan, A. M. 2015 Water, sanitation, and diarrhea incidence among children: evidence from Guatemala. *Water Policy* **17**(5), 932–945. doi:10.2166/wp.2015.211.

World Bank 2018 *Guatemala's Water Supply, Sanitation, and Hygiene Poverty Diagnostic: Challenges and Opportunities*. WASH Poverty Diagnostic, Washington, DC, USA.

World Health Organization 2017 *Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum*. Water Sanitation and Health Programme, WHO, Geneva, Switzerland.