Research Paper

Household-level drinking water quality, access, and management practices within an informal community: a case study at Rio das Pedras, Rio de Janeiro

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ABSTRACT

Inter-household patterns in drinking water access, consumption, perception, and quality among residents can vary in Rio das Pedras (RdP), a large favela in Rio de Janeiro, Brazil. While unreliable water quality can influence residents to diversify their drinking water supply, household drinking water management practices are not generally known for this community. Household surveys, and indoor tap, piped water before entering the home, filtered, or bottled dispenser water samples were collected. Respondents reported storing water (91%) and near-daily access to piped water (78%). A majority of households reported cleaning water storage tanks at least once every 6 months. Also, residents rely on bottled water and a considerable proportion supplemented their water supply with at-home filtered water. The quality and safety of these sources are not necessarily superior to indoor tap water, especially under conditions of appropriate water storage tank cleaning. Higher prevalence of total coliform detections was found in indoor tap, filtered, and bottled water. Household characteristics such as home ownership, residence type, and residence time exhibited a positive association with improved tank cleaning. Community health practitioners could evaluate practices in water storage, at-home filtration maintenance, and bottled water dispenser systems using household characteristics to promote protective actions.

Key words | drinking water, households, informal communities, urban health, water access, water storage

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INTRODUCTION

Urban systems warrant attention within informal communities, which are home to more than one billion people globally (United Nations Habitat 2014). These residential environments (for which many labels such as slum, favela, or peri-urban are used) typically do not follow standards set forth by urban planning authorities (e.g., house construction materials or street and sidewalk networks) and may have reduced access to essential public services (e.g., solid waste collection, improved sanitation, centralized drinking water systems). Residents of informal settlements tend to also experience increased health burdens compared to formal, urban environments (Riley *et al.* 2007; Snyder *et al.* 2014; Unger *et al.* 2015). Despite incremental strides made to improve public infrastructure and services, its overall

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effects on households within informal communities are under-studied.

Drinking water distribution in informal communities has particular implications for the daily lives and health of urban residents. Limited access to safe drinking water can negatively impact community health and result in continuous exposure to harmful contaminants and pathogens (Alderman *et al.* 2012). Even in areas where piped drinking water connections are available, suggesting an improved infrastructure, enhancements may be needed to ensure a reliable and safe water supply system. Some findings have suggested that water storage among households located within informal communities is susceptible to microbial contamination (Dasgupta 2008; Copeland *et al.* 2009). Copeland *et al.* (2009) found that water storage increased risks of diarrhea disease in Brazilian favelas through direct measures of *Cryptosporidium* oocytes, a known fecally derived waterborne pathogen. Exposure to contaminated water can itself result in a range of health challenges including gastroenteritis, cholera, and lower respiratory infections. Water storage and sanitation practices also affect community vulnerability to vector-borne illnesses such as dengue fever, leptospirosis, and Zika (Paz & Semenza 2016).

Household determinants such as poverty, education, family size, and home ownership are associated with water access and health risks within informal communities (Snyder *et al.* 2014; Adams *et al.* 2016). In addition to such sociodemographic and housing-related factors, household behaviors and practices related to water consumption can influence water access, quality, and sources (Dasgupta 2008). At-home treatment and water storage practices have been associated with differences in perceived water quality through household surveys (Boateng *et al.* 2013; Miner *et al.* 2015), perhaps because the perception of water quality motivates households to seek alternative sources for consumption, including purchased water, or to filter or otherwise treat water before use. There remain gaps in using collected household-level survey data to compare traditional socio-demographic factors with drinking water-related behaviors such as consumption, perception, and practices.

While contrasts between informal communities and other urban areas have been documented, limited work has been done to characterize variation in improved drinking water access across households within a given informal community. Over 22% of residents of Rio de Janeiro live in informal settlements (Snyder *et al.* 2014), and in recent years (and with increasing global attention during planning for the 2014 World Cup and the 2016 Summer Olympics Games) the state and municipal governments have sought to expand public services into these communities (Baena 2011; Watts 2013).

We present a feasibility scale effort to explore measurement and water consumption patterns relevant to variation in water quality in an informal community in Rio de Janeiro, Brazil. In 2015, we collected household-level data relevant to the drinking water supply and related perceptions and management practices within the Rio das Pedras (RdP) community, an area with an official population estimate of 63,500 and located in the West Zone of Rio de Janeiro, Brazil (Brazilian Institute of Geography and Statistics 2012). We used questionnaire survey data, and water samples' analysis from participating households to explore local variation in: (1) access, supply, and storage of potable water; (2) perceived drinking water quality; (3) household water consumption practices and behaviors; and (4) microbial water quality. This case study builds on prior work assessing the health needs of informal communities in Rio de Janeiro (Carvalho *et al.* 2016) and offers insights to guide future data collection and potential avenues for policy action.

METHODS

Study setting in a large informal community, Rio das Pedras, in Rio de Janeiro, Brazil

According to the Brazilian Institute of Geography and Statistics (IBGE), a favela or 'subnormal agglomeration' is defined as an illegal occupation of at least 51 housing units (Brazilian Institute of Geography and Statistics 2012). Construction and maintenance of buildings and systems within informal settlements of Rio de Janeiro have involved informal para-state authorities, community associations, and collaborations with nonprofit organizations, with limited involvement of the official municipal government (Rufin 2016). More recently, residents have witnessed transitional changes such as formalized piped drinking water distribution, structural development, and other physical infrastructure improvements driven by investments made by state utilities.

Rio das Pedras is bounded by a lagoon and mangrove to the south and west, respectively, and steep hills to the north. The built environment is composed of multistorey buildings with a higher density of persons per square kilometer than is typical of formal neighborhoods in the same city (Snyder *et al.* 2014; Zulaika *et al.* 2016). Most residential buildings consist of concrete block buildings and are incrementally constructed to accommodate housing demand and to keep pace with a growing influx of new residents.

Municipal drinking water is provided and distributed by Companhia Estadual de Águas e Esgotos (CEDAE; State Water and Sewage Company), a historically state-run water utility service based in Rio de Janeiro (Bloomberg L.P. 2017; Mannarino 2017 personal communication). The Guandu River supplies raw water for drinking consumption and is treated at the Guandu Water Treatment Plant. Historically, household drinking water sources are from unofficial connections to distribution lines provided by CEDAE, and, often, piped into household rooftop storage tanks for domestic and potable use (Rufín 2015).

Spatial sampling of households and inclusion criteria

Recruitment of study participants relied on a systematic sampling approach that selected households using a uniform spatial grid to ensure distribution across selected neighborhoods in the Areinha neighborhood in the southwest of RdP, an area chosen to capture variation between the main commercial street and the lagoon. Trained resident data collectors working in pairs attempted recruitment from each of the buildings nearest to a selected grid point. One hundred and eight households were contacted and all household members were enumerated. A randomly selected adult from each household, meeting the study's inclusion criteria (i.e., aged 18–70, able to walk independently, having lived in RdP for at least 6 months), was invited to participate in the initial questionnaire and drinking water sampling, and also invited to participate in other data collection modules, including semi-structured qualitative interviews (Castiglione *et al.* 2018), global positioning system mobility logging (Eniola 2016), and saliva specimen collection.

All study procedures were reviewed and approved by Columbia University Medical Center (IRB-AAA8810) and the National School of Public Health (Escola Nacional de Saúde Publica, ENSP) at the Oswaldo Cruz Foundation (Fundação Oswaldo Cruz) (protocol No. 1.852.162). Individual participants provided written informed consent. The team returned to participants to provide notice if water quality parameters raised potential safety concerns; in addition, a pamphlet with descriptive information based on our data collection and recommendations for protecting the household water supply was made available to participants and other area residents approximately 6 months after data collection.

Questionnaire data on water perception, behaviors related to drinking water, and demographics

Individual questionnaires were administered either at the time of the initial household enumeration or at a later date, if needed, to reach the randomly selected adult. Questions included household sociodemographic and residential characteristics (e.g., employment, housing tenure) as well as household-level drinking water management practices and behaviors. Specific items were adapted from a previous investigation at an informal community in Manguinhos, also in Rio de Janeiro (Carvalho *et al.* 2016). Response categories for several items were dichotomized for analyses, as shown in Table 1. For example, ordinal categories for water quality perception (e.g., very poor, poor, fair, good, and very good) were broken into *good or very good* versus other categories. We note that there may be more households reporting *good (boa,* Brazilian-Portuguese translation*)* water quality than would be expected in many English-speaking contexts. Due to cultural and language differences, good is a common response even when the respondent has some concerns about water quality. We dichotomized responses for cleaning frequencies for water storage containers using *at least once every six months or more* versus *less often* frequencies. This cutoff is based on recommended guidelines (ANVISA 2016). *Never cleaned* and *don't know* responses were included within the category *less than once every six months*.

Table 1 | Summary statistics from selected questionnaire survey data

Question (number of responses)	Mean (standard deviation) or %
Residence and household factors	
Residence time at Rio das Pedras, in years ($n = 101$)	5.3 (6.2)
Monthly income, R$ ($n = 67$)	1,666 (748)[a]
Single-family households ($n = 103$)	94%
Home ownership ($n = 103$)	44%
Living in apartments ($n = 103$)	63%
Water access	
Daily supplied water ($n = 103$)	78%
Stores water for future consumption ($n = 102$)	91%
Water storage practices[b]	
Used water storage approaches ($n = 93$):	
Water tanks with a fitted lid	92%
Cleaning frequency of water storage containers, at least once every 6 months ($n = 94$)	62%
Water treatment and perception[b]	
At-home treatment for drinking water ($n = 103$):	
Filtering	36%
Purchasing bottled water	51%
Water quality perception, Good or Very Good[c] ($n = 101$)	61%

[a]The overall monthly income average for sampled households in US dollars is approximately $480 with a standard deviation at $216. Conversions are based on the average annual exchange rate set for 2015 (1 US dollar = 3.468 Brazilian dollars).
[b]Specifically for water storage practices and water treatment-related survey questions, we assumed that missing data could be denoted as a non-affirmation for the selection of a specific storage practice or water treatment method.
[c]Contextual differences in cross cultural communication and self-reporting may have influenced this majority response.

Drinking water assessment

While the indoor tap (usually the kitchen sink) was the most common sampling point, additional samples were obtained, when available, from other points along the drinking water distribution-to-consumption pathway. The distribution network was sampled before entering the household from 22 buildings (23 households). Since households sometimes reported drinking filtered water, we also sampled water at-home treatment systems (i.e., filtered) from 43 households. Household drinking water filtration systems are designed to improve drinking water quality by removing suspended particles, dissolved contaminants and pathogens. In addition, filtration promotes the removal of organoleptic compounds that can affect the taste, odor, and appearance. These devices are typically directly attached to an indoor water faucet. Finally, we also sampled drinking water from locally purchased bottled water, and often obtained through water dispenser, for 32 households. Such purchased water sources were commonly noted in a prior Brazilian informal community health investigation (Carvalho *et al.* 2016).

Not every household had all four pathway points available and accessible for sampling. Thus, one to four samples per household were collected by trained field samplers, and subsequently analyzed in the laboratory of the Sanitation and Environmental Health Department of the National School of Public Health, Oswaldo Cruz Foundation, using standard methods described elsewhere (Rice *et al.* 2012). Household samples were retrieved throughout the day to accommodate varying schedules among study participants. The sampling team was provided sample collection and field protocol training by water quality specialists from FIOCRUZ and had direct supervision by colleagues while on the ground. For example, samplers were directed to use aseptic techniques by disinfecting faucets for piped and indoor water using 70% alcohol, and then instructed to allow the water to run for 2–3 minutes before collecting a sample.

Microbial water quality parameters analyzed were total coliform (TC) and *Escherichia coli* (EC). We used Colilert testing kit from IDEXX Laboratories Inc., a standard chromogenic substrate test (Enzyme Substrate Coliform Test: 9223B Enzyme Substrate), to enumerate TC and EC microbial indicators (Rice *et al.* 2012). The detection limit for TC and EC indicators is at less than one most probable number (MPN) of organism per 100 mL. The presence of TC (above the detection limit) can represent inadequate disinfection or ineffective sanitary infrastructure to protect distributed water sources (Fewtrell & Bartram 2001). In addition, the presence of EC (above the detection limit) signals potential recent fecal contamination and the increased likelihood of harmful pathogen exposure. In accordance with Brazilian drinking water thresholds, detection of EC renders drinking water inadequate for human consumption and the detection of TC, an indicator of distribution system integrity, can trigger repeated sample monitoring to verify the extent of contamination. Potable water delivered by public systems should not have detectable EC in order to meet Brazilian drinking water standards, whereas as the detection of TC may be allowed according to regulations, but increased monitoring and resolving the source of the contamination is required. These interpretations for microbial quality are consistent with drinking water guidelines set by the World Health Organization (WHO) (World Health Organization 2011).

Microbial indicator standards for maintaining drinking water quality are established by the Brazilian Health Ministry through Decree No. 2914/2011 (Brazil 2011). It is important to note that only distribution system and indoor tap water samples are directly subject to these standards, whereas at-home treated water, such as filtered water, is not subject to the same enforceable requirements but can provide an incremental improvement in quality. Commercialized bottled water, considered as a food product, is not subject to the same regulatory drinking water requirements but must abide by specific requirements set forth by the National Health Surveillance Agency, a federal regulatory body that oversees food and drug safety (Brazil 2005a, 2005b). In this paper, TC and EC microbiological measurements are reported either as 'present' or 'absent' to assess how measures compare with Brazil's microbiological health standards.

Consistent with the regulations above, we attempted to re-test a subset of samples that demonstrated the positive presence of TC or EC. This approach, while challenging to implement and only feasible in this study for a small subset, is used to determine the likelihood of persistent problems with the integrity of the distribution network and other problems along the pathway to consumption.

Statistical analyses

We present descriptive statistics and unadjusted regression models for this feasibility scale study. Unadjusted logistic regression models were used to explore associations between selected household characteristics and the reported drinking water practices (tank cleaning frequency) and perceived drinking water quality. We used R version 3.3.2 for statistical analyses (R Core Team 2016). All statistical tests were two-tailed and based on an alpha of 0.05.

RESULTS

Residence and household factors

One hundred and three adults participated in individual questionnaires, the majority (91%) of whom also consented to provide a sample of their drinking water sources. Among the participating households, 94% were single-family households with an average residence time in RdP of 5.3 years, ranging from 1 month to 29 years. Over half of residents pay rent at their current residence (56%), and close to 63% of residents live in apartments as a residence type versus a house (Table 1).

Water access, water storage practices, and water perception

Nearly all surveyed households (99%) reported receiving piped water in at least one room at their current residence. Approximately 78% of the households reported that they had a daily supply of water at their residence (ANVISA 2016).

The majority of participants (91%) reported storing water for future consumption. Among residents that stored water for future use, nearly all (92%) used water tanks, with fitted sealable lids. Over one-third of individuals (38%) storing water did not report cleaning their water containers at the minimum frequency (at least once every 6 months) recommended by the Brazilian Sanitary Surveillance Agency (Brazil 2004). Most household water tanks are made of synthetic resin composed of polyethylene or polypropylene. Water tank exposure to direct sunlight was not formally recorded.

With respect to at-home water treatment practices, 36% report that they filtered their drinking water as a form of treatment. Approximately half of participating residents reported regularly purchasing bottled water (51%) as a source of drinking water. The majority of surveyed RdP residents (61%) reported the quality of their water at their residence as *good or very good.*

Water sampling and analyses

Across sampled households ($n = 94$), 95.7% of households had available indoor tap water for water quality analyses, followed by filtered (45.7%), bottled (34.0%), and distribution system (24.5%).

We detected EC in three samples (1.6%), two from bottled water and one at-home filtered water (Table 2). No EC was detected during re-sampling. This absence finding suggests that sampled distributed water and indoor tap water demonstrated attainment with EC standards at the time of sampling. Across each available and sampled source type from all households, TC was detected in 60 samples (32%). Out of the 32 sampled households with available bottled water, 75% of samples had detected TC. Among households with filtered sources, we detected TC in 27% samples, followed by indoor tap (22%), and then distribution system (17%) sources. Among the 60 samples with EC and TC detections, 43 households were re-sampled and tested. Thirty-one counts of TC detection were observed in re-sampled indoor tap (53%), filtered (100%), and bottled (85%) water source types (Table 2). Samples with both initial and re-sampled TC presence totaled 31: indoor sink (29%), filtered (15%), and bottled water (55%) sources. Re-sampling results for indoor tap water at nine households suggests compromised distribution system integrity likely due to biological contamination such as biofilm growth from pipe cross-connections and backflows, or soil intrusion from fractured pipes. Regulatorily, the continued presence of TC requires the continuation of repeated sampling monitoring until the biological contamination is resolved.

Associations among residential and household factors, perceptions, practices and parameters

When examining associations between household factors and surveyed drinking water practices (Table 3), owning a home, or residing in the RdP community for a longer period, was significantly associated with reporting a frequency of cleaning water storage containers that meet recommendations. Water quality perception did not vary significantly with measured household factors in our sampled population (Table 3).

DISCUSSION

This paper demonstrates the feasibility of systematically collecting a range of indicators on household characteristics and drinking water perception and practice, as well as water quality parameters in a Brazilian informal community. The findings of overall access to the drinking water

Table 2 | Results of the microbiological indicators in sampled drinking water at each sampled household by source water type

	Presence, count (%)	Re-sampled presence/total re-sampled[a]	Detection in both initial and re-sampled, count
Total coliform			
Distribution system ($n = 23$)	4 (17%)	0/1	0
Indoor tap ($n = 90$)	20 (22%)	9/17	9
Filtered ($n = 44$)	12 (27%)	5/5	5
Bottled ($n = 32$)	24 (75%)	17/20	17
Escherichia coli			
Distribution system ($n = 23$)	0 (0%)	0/1	0
Indoor tap ($n = 90$)	0 (0%)	0/17	0
Filtered ($n = 44$)	1 (2%)	0/5	0
Bottled ($n = 30$)	2 (7%)	0/20	0

[a]Re-sampling was attempted on the subset of households that had observed growth of TC or EC.

Table 3 | Unadjusted associations of residential and household characteristics with water quality management and perception

	Storage tank cleaning (at least than once every 6 months)	Water quality perception (Good or Very Good)
Number of families	1.11	1.22
Single family (reference) vs multiple families	(0.11, 11.17) $n = 93$	(0.21, 7.00) $n = 101$
Home ownership	4.26*	0.91
Rent (reference) vs own	(1.51, 12.00) $n = 93$	(0.40, 2.05) $n = 101$
Residence type	2.43	0.70
House (reference) vs Apartment	(0.95, 6.20) $n = 93$	(0.30, 1.64) $n = 101$
Time living in RdP	1.13*	0.97
in years, continuous	(1.01, 1.28) $n = 91$	(0.91, 3.22) $n = 99$

Note: Values shown are odds ratios and corresponding to 95% confidence intervals, followed by the number of observations in the corresponding logistic regression analysis. * denote statistically significant values ($p < 0.05$).

distribution network in the community were consistent with the IBGE 2010 census (Brazilian Institute of Geography and Statistics 2012). We also noted variation within the community, and associations that may suggest opportunities to further protect drinking water by encouraging at-home best management practices. Household characteristics, such as home ownership and extended residence time within RdP, were positively associated with reporting recommended household water tank cleaning frequency.

Overall, RdP residents have access to treated water as a primary source for consumption as indicated from IBGE's census. Municipal drinking water from CEDAE is distributed to RdP households, but it is mostly accessed through informal connections. Residents do not typically pay for its services (in our sample, 99% reported that they did not pay a water bill). Despite these circumstances, CEDAE has mostly maintained its water availability and overall quality by implementing system-level controls that are consistent with requirements set forth by the Brazilian Health Ministry (Brazil 2011). These requirements only apply to system distribution and indoor tap water sources, which included filtered water but not bottled water. According to the recommendation of the Brazilian Technical Standards Association for both formal and informal communities, residents should supplement their tap drinking water supply by storing volumes at their building appropriate to the number of residents as a precaution against periodic water cutoffs. As a policy, CEDAE feeds additional chlorine at selected distribution system points to achieve stable free residual chlorine (FRC) concentrations (Mannarino 2017 personal communication). Sampled distribution and tap water in our study exhibited FRC concentrations reaching up to 8 mg/L (Figure 1). This approach attempts to maintain optimal disinfection along the system before reaching consumers (Olivieri *et al.* 1986). This may explain the wide variability and elevated FRC concentrations observed among system distribution and indoor tap water source samples, an observation seen at other Brazilian informal communities (Carvalho *et al.* 2016). As expected, mean FRC concentrations decreased along the distribution-to-consumption sampling points: from highest to lowest, distribution system, indoor tap, filtered, and bottled. This decreasing trend coincides with increasing TC and EC detection percentages across water source types in TC and EC samples.

A large proportion of households in our sample reported drinking filtered (27%) or bottled water (55%). We note that residents may use more than one source. The observation of generally positive quality perceptions juxtaposed with the

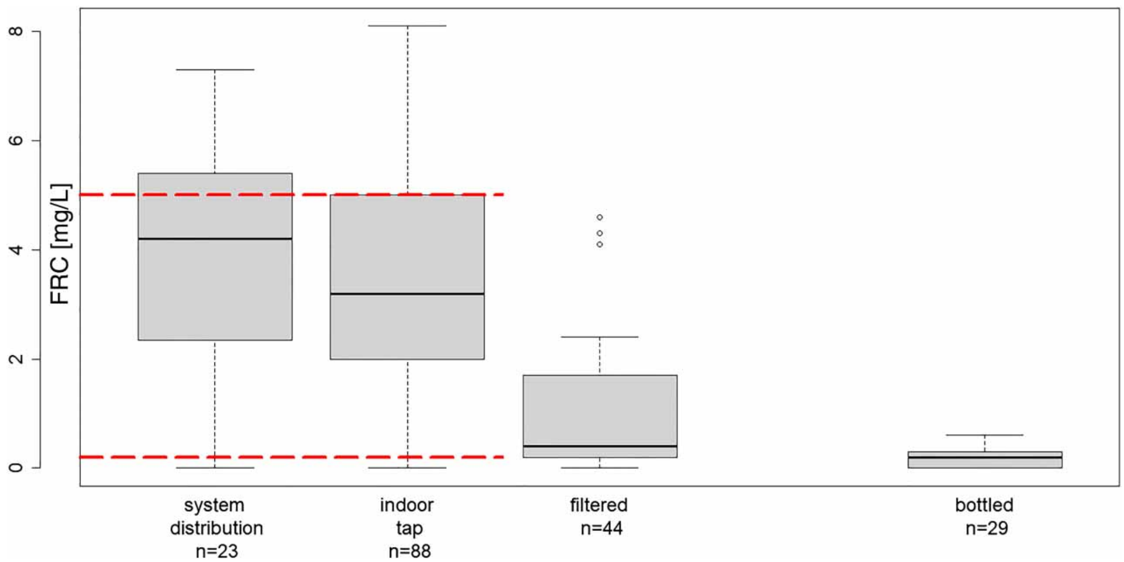

Figure 1 | Free residual chlorine (FRC) concentrations across drinking water source types among sampled households. Side-by-side boxplots of sampled FRC concentrations along the order of the distribution-to-consumption pathway. As indicated by the dashed reference lines for each parameter, only system distribution and indoor tap water sources are subject to drinking water quality requirements set forth by the Brazilian Ministry of Health (0.2 and 5 mg/L for lower and upper thresholds, respectively). Note that bottled water, typically from large dispenser-mounted bottles for in-home use, is considered as a commercial source and not distributed by CEDAE, the local public water utility. At-home filtered water is not subject to enforceable standards or requirements.

reported consumption of alternative drinking water sources suggests that residents' confidence might be lower than suggested by the reported perceptions. Residents may assume that household-level consumption of filtered or purchased water will be sufficient to reduce risks from inadequate water quality (Doria 2006; Rosa & Clasen 2010). While improved water quality is expected in filtered and bottled water samples, EC and TC were detected in filtered water and at elevated rates in bottled water. These detections from post-source measures could pose potential health risks to consumers (Reis *et al.* 2014). Additionally, these sources represent a costly expense among a population that is largely composed of lower-income households (de Queiroz *et al.* 2013). Several residents explained that they chose to purchase bottled water because they believed the local store-bought water had better quality than their piped source. However, prior studies have documented microbiological contamination in commercialized bottled water in Brazil (de Queiroz *et al.* 2013; Reis *et al.* 2014) despite established protection requirements for human consumption (Brazil 2005a, 2005b). These results suggest that bottled water consumption may, under some circumstances, pose a higher health risk than other sources along the distribution-to-consumption pathway.

Future work is needed to monitor water quality from all drinking water sources to inform distribution system improvements and household-level decisions related to storage and at-home treatment and consumption practices. In regions with more prolonged rainy seasons such as Trinidad, rainwater harvesting can be a reliable alternative source for potable water, but not much attention has been paid to its potential health risks (Dean *et al.* 2012). At-home water storage and treatment (e.g., filtration) are not subject to enforceable drinking water requirements, but may, nonetheless, have important health implications. Filtered water is vulnerable to post-treatment microbial contamination. A majority of sampled RdP residents reported storing water in storage tanks for future consumption, but about 38% of respondents reported cleaning frequency consistent with recommendations. These cleaning practices are important to reduce the risk of microbial contamination. More frequent tank cleaning has been associated with reduced EC levels (Schafer & Mihelcic 2012). Therefore, community projects like semi-annual water tank cleaning should be considered to improve the water quality in households reliant on stored water, particularly in informal communities. Waterborne contamination is often attributed to non-sterilized water storage containers or inadequate sterilization practices (Copeland *et al.* 2009). As a result, when disseminating descriptive study results to participants and community residents in collaboration with our partners, we included guidance to inform household practices such as cleaning water storage tanks and dispensers for purchased water to alleviate microbiological growth and risks from infectious diseases.

Water storage, if left uncovered, could also create opportunities for mosquito breeding and habitat, in turn, promoting the transmission of vector-borne diseases such as Zika, dengue, and chikungunya (Wright *et al.* 2004; Morin *et al.* 2013; Paz & Semenza 2016). Questions related to self-reported vector-borne and waterborne diseases and on vector sightings, such as mosquitoes and rats, in and around water storage tanks could be helpful in understanding the extent to which disease transmission could occur at indoor environments within RdP. However, they were not included in this study.

Strengths

Strengths of this study included the use of systematic spatial sampling to increase generalizability to the study area, in a context where household sampling frames via the address or phone number were not available. The survey and water sampling were administered by trained residents and with local academic partners. Involving and training residents was critical in garnering local support for this study. An additional study strength relates to the collection of multiple sampling points along the water distribution to consumption pathway. This sampling strategy is advantageous in pointing to potential strategies to address sources of contamination and curb harmful exposures.

Limitations

This study had limitations that should be noted when interpreting the results. We used a cross-sectional study design, and our sample size for this feasibility scale study was small, limiting our statistical power. In particular, water sampling at points other than indoor tap had smaller sample sizes. Social desirability biases may have led to overestimating the proportion of households meeting recommendations and positive attitudes on water quality perception. Possibilities of selection bias and informative missing data on particular items cannot be excluded. Another study limitation relates to the lack of detail in determining reasons for variability in perceived water quality, including more specific aspects of perception such as smell and taste. Also, our reliance on a single sample for our water analyses meant that we have only indicative, and not representative, information on the quality of the water from each source.

Storage water tanks were not sampled directly in this study. However, tap water is assumed to have been stored in many household tanks.

CONCLUSION

Although previous work has contrasted informal communities with other areas of the same city, we present methods to characterize variation within a given informal community. We note that water quality parameters, as well as perceptions and behaviors, vary by household, and those patterns may be related to household characteristics such as home ownership and length of residence. Indoor tap water, while ubiquitous and accessible, was not commonly reported as the only source of household drinking water. The detection of microbial indicators in bottled water suggests that monitoring of drinking water sources, whether public or private, is crucial to protecting public health. While water distribution infrastructure requires a collective investment, such investments should be informed by evidence and have ongoing monitoring and evaluation to inform further refinements. At-home water management practices are also a potential point of intervention to reduce health risks and inequities.

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