An Evolving Choice in a Diverse Water Market: A Quality Comparison of Sachet Water with Community and Household Water Sources in Ghana

Danice Guzmán^{1*} and Justin Stoler^{2,3}

¹Initiative for Global Development, University of Notre Dame, Notre Dame, Indiana; ²Department of Geography and Regional Studies, University of Miami, Coral Gables, Florida; ³Department of Public Health Sciences, University of Miami, Miami, Florida

Abstract. Packaged water, particularly bagged sachet water, has become an important drinking water source in West Africa as local governments struggle to provide safe drinking water supplies. In Ghana, sachet water has become an important primary water source in urban centers, and a growing literature has explored various dimensions of this industry, including product quality. There is very little data on sachet water quality outside of large urban centers, where smaller markets often mean less producer competition and less government regulation. This study analyzes the microbiological quality of sachet water alongside samples of other common water sources at point-of-collection (POC) and point-of-use (POU) in 42 rural, peri-urban, and small-town Ghanaian communities using the IDEXX Colilert® 18 (Westbrook, ME). Levels of coliform bacteria and *Escherichia coli* detected in sachet water samples were statistically and significantly lower than levels detected in all other water sources at POU, including public taps and standpipes, and statistically similar or significantly lower at POC. In diverse waterscapes where households regularly patch together their water supply from different sources, sachet water appears to be an evolving alternative for safe drinking water despite many caveats, including higher unit costs and limited opportunities to recycle the plastic packaging.

INTRODUCTION

Inadequate drinking water provision in many regions of the world has given rise to a vibrant packaged-water industry that sells water in single-serving sized bottles and plastic bags.¹ In lieu of a piped water connection, low-cost bagged or “sachet” water has been shown around the world to often exhibit the lowest levels of contamination among available drinking water options² and has become a particularly important drinking water source in West Africa.³ The reclassification of high-quality packaged water as an *improved water source* would improve progress toward global drinking water targets,¹ and the World Health Organization (WHO) is slowly incorporating packaged water into its revised drinking water ladder where appropriate.⁴ Some of the highest rates of sachet water consumption are in Ghana, where in 2014, 29% of all households nationally (43% of urban households and 12% of rural households) relied on it as the primary drinking water source.⁵

In Ghana, households must diversify their water sources to meet their consumption needs, a practice long observed throughout sub-Saharan Africa.^{6,7} Diversifying the households' water supply makes sense in areas with unreliable infrastructure, as it provides households a hedge against uncertain availability. A recent study of five regions in Ghana found that more than half of households are collecting water from improved sources,⁸ although they rely on many sources to meet their household water needs. During the rainy season, 76% of households collect rainwater, 24% use public taps, 43% collect from boreholes, and 6% buy sachet water. Because all non-rainwater sources are vended, 46% of households were observed to pay for water in some way.⁸

Although sachet water has been ubiquitous in urban Ghana for more than a decade, it is increasingly becoming a popular drinking water source in rural areas.⁹ The formalization of the packaged-water industry has led to increased competition

in urban centers, and this has been associated with the increase in product quality as large corporate producers replace smaller cottage-industry players in these large markets. Rural Ghanaian communities are often secondary markets with higher distribution costs, thus cottage-industry producers often continue to operate with less competition, and unfortunately, less regulation, and quality control.³ One nationally representative study in Ghana observed that sachet water had a strong protective effect from *Escherichia coli* contamination of drinking water relative to other water sources.⁹ Although the study observed that rural localities were associated with higher contamination rates at the point of consumption in bivariate analysis, urban versus rural disparities were not assessed in multivariable analysis because of multicollinearity between the urban–rural classification and other demographic covariates.

The study of packaged water quality remains dynamic but remains focused primarily in dense urban centers with the largest consumer markets. Recent Ghanaian studies from urban areas have identified traditional indicator bacteria^{10,11} and antibiotic resistance,¹² explored differences between brands,¹³ and evaluated vendor practices.¹⁴ Despite significant growth in the number of sachet water quality studies this decade, just a handful have assessed sachet quality in rural contexts where it is a relatively newer product.³

Packaged water is theorized to confer a public health benefit if consumed in lieu of water stored in the household because of limited opportunity for cross-contamination.^{15,16} The quality of stored water is well known to deteriorate due to improper storage or treatment at home,¹⁷ and recent evidence confirms that sachet water tends to be of better quality at the point of consumption.⁹ But there has been no systematic assessment of how sachet water compares with water from other sources at the point of collection (POC). This approach was piloted in a previous Accra study, where POC and point-of-use (POU) water samples from 15 households were tested along with sachet water samples; a decline in quality was observed from sachet to POC to POU samples.¹⁵

* Address correspondence to Danice Guzmán, Initiative for Global Development, University of Notre Dame, 3150 Jenkins Nanovic Halls, Notre Dame, IN 46556. E-mail: dbrown16@nd.edu

This study compares the microbiological quality of sachet water and other drinking water sources tested across a sample of 42 Ghanaian communities in rural and peri-urban areas and small towns. We specifically compare the quality of sachet water sold in communities with water from other POC in those communities and with water stored in households. We hypothesized that in smaller communities located beyond large urban centers such as Accra, Kumasi, Sekondi-Takoradi, Sunyani, and Tamale, where sachet water producers and distributors can more easily evade regulatory scrutiny,³ sachet water will exhibit lower rates of microbiological contamination than POC water samples, which in turn will exhibit lower rates of contamination than POU water samples. Our findings present a rare opportunity to assess Ghana's evolving sachet water landscape outside of Ghana's major urban centers.

MATERIALS AND METHODS

Study site. Water quality was tested in 42 communities as a part of an end line study that evaluated the impact of Millennium Challenge Corporation's (MCC) water, sanitation, and hygiene (WASH) investment in rural Ghana during their first compact (2007–2012). The WASH activity was concentrated in 137 communities within 30 of Ghana's 170 districts in the Ashanti, Central, Eastern, Northern, and Volta Regions. The Millennium Development Authority (the Ghanaian government branch of MCC) coordinated three different types of water infrastructure improvements (boreholes, pipe extensions, and small-town water systems) depending on the needs of each community.¹⁸ Communities were selected for participation in the water intervention based on a point system that ranked communities based on adequacy of water, presence of guinea worm disease, quality of water, distance to water sources, and community participation (see Supplemental Information).

Figure 1 presents the sampling framework for community selection. From the 137 intervention communities, the National Opinion Research Center (NORC; University of Chicago, Bethesda, MD) selected 50 to be included in the study.

FIGURE 1. Sampling framework yielding 42 study communities where sachet water was analyzed.

National Opinion Research Center paired each of those communities with another community that was eligible to receive the water intervention. The NORC used a nearest neighbor-matching methodology, rating both treatment, and comparison communities on the selection criteria and other factors, including poverty, population, and number of Farmer-Based Organizations.¹⁸ National Opinion Research Center conducted power calculations, which accounted for clustering in the data, and found that a sample size of 12 households per community yielded the statistical power to detect an income change of 10%, and a change in proportions of 20%.

The Notre Dame Initiative for Global Development's research team completed end line data collection in the 100 study communities. Outcomes of interest for the MCC impact evaluation included health, time and distance to collect water, amount of water consumed, price of water, and household welfare. The project added a microbiological water quality component to better understand the relationship between water quality and diarrheal disease incidence, and to learn the quality degradation rate between POC and POU. In 42 of the 100 communities, sachet water was also tested. The 42 communities were selected for water sachet testing based on the availability of sachet water. Water-testing teams were instructed to test all water that was available in the community, and when sachet water was available it was tested as well. To test for bias in this sample, we performed clustered multivariate logistic regression analysis to determine whether these 42 communities differed from the remaining 58 on a variety of community and household level characteristics. Our analysis thus compares the microbiological quality of sachet water with that of other water sources among the subset of 42 communities where sachets were sampled, and separately with water quality metrics for the full sample of 100 communities. Figure 2A presents the district locations of communities sampled for sachet water testing ($N = 42$), and Figure 2B presents the full sample for all water-testing activities ($N = 100$). In both panels the number depicted in each district is the number of communities sampled.

Notre Dame Initiative for Global Development obtained approval to conduct this research from both the University of Notre Dame Institutional Review Board and the University of Ghana Noguchi Memorial Institute for Medical Research.

Study sample. Twelve households were selected in each community to participate in the survey using systematic random sampling from a starting point in the community. Enumerators started at a geo-coded starting point selected by a field manager, and used a code that determined which house was to be visited first. After selecting the first house, enumerators skipped a specific number of houses to locate each subsequent house—the skip pattern varied per community and was calculated as the 2,000 population estimate in the community, divided by average household size in the communities' zone, divided by the number of surveys to be completed. Enumerators followed the same side of the road and did not cross the street.¹⁸

Ten of the 12 households were also chosen for water testing with priority given to more physically accessible households that would facilitate samples reaching the incubator within 6 hours as is specified by the water-testing protocol. A potential limitation of this method of convenience sampling is that it introduces bias into the sample. A multivariate logistical

FIGURE 2. Ghana districts containing (A) the 42 communities where sachet water samples were collected and (B) all 100 study communities.

regression was conducted on the data to investigate if there was selection bias based on any household-level characteristics (see Supplemental Information). Water was tested from the household's main storage container for drinking water, that is, POU. At each household, respondents were asked to provide water that they used for drinking for the water quality test. Enumerators then asked them a few questions about the water, including the source from which they had collected it.

Water was also sampled from all community-level sources that were available. In 42 communities, enumerators included sachet water as a community-level water source and collected a sample, that is, POC (in one community, two sachet water samples were collected). This study analyzes water-testing results both from the 42 communities in which sachet water was tested and the 100 communities where any water sources were tested.

Water quality testing. Four water-testing laboratories were set up in May 2015 to complete testing in 28 days. Laboratory teams were trained on appropriate protocols for collection, transport, and processing of samples. Samples were aseptically poured into a sterile 100-mL specimen container, capped, and labeled. They were then stored in a cooler with ice packs and transported to the laboratory in the field within 6

hours of collection. Depending on the community, sample collectors traveled with the samples by motorcycle, car, bus, or boat. Training on the collection and transport of water samples was conducted by BCAN Consult, Ltd. in collaboration with the IDEXX Laboratories for Ghana and West Africa. Four external supervisors, who served as experts in water testing and data collection, monitored sample collection and reading of results. In the full study, 247 water samples were tested from community-level sources, and 987 samples were collected from households. A few samples were dropped from the dataset because of low frequencies of certain water sources. Table 1 summarizes the water samples tested in the communities that were included in the analysis presented in this paper. In total, 124 samples were collected from community-level water sources and 388 were collected from households. At POU, the most common sources of drinking water tested came from surface water, public taps, or boreholes. At POC (community-level), the most commonly tested sources were sachet water, boreholes, and surface water. Bottled water was not tested at POU or POC.

Water collectors (1–2 individuals in the household who are responsible for collecting water) reported volume of water

TABLE 1
Counts of POU and POC water sources sampled and tested

Water source	POU		POC	
	All study communities	Communities where sachets were collected	All study communities	Communities where sachets were collected
Sachet water	—	—	43 (19.28%)	43 (34.68%)
Public tap/standpipe	166 (17.58%)	73 (21.16%)	28 (12.56%)	14 (11.29%)
Tube well/borehole	353 (37.39%)	100 (28.99%)	69 (30.94%)	28 (22.58%)
Surface water	192 (20.34%)	84 (24.35%)	62 (27.80%)	29 (23.29%)
Unprotected dug well	44 (4.66%)	23 (6.67%)	21 (9.42%)	10 (8.06%)
Piped water into dwelling	34 (3.60%)	16 (4.64%)	—	—
Protected dug well	61 (6.46%)	11 (3.19%)	—	—
Protected spring	9 (0.95%)	8 (2.32%)	—	—
Unprotected spring	33 (3.5%)	17 (4.93%)	—	—
Rainwater collection	35 (3.71%)	13 (3.77%)	—	—
Total	987	388	223	124

POC = point-of-collection; POU = point-of-use. Percentages of total samples in parentheses.

collected in units of containers collected per day per source during the dry season. Containers were measured by enumerators to calculate volume. We then determined the average water quality of water from each source, both at POC and POU.

Water was tested using the IDEXX Colilert 18 Quanti-Tray/2000, an internationally accredited and certified methodology for determining fecal bacterial total coliforms and *E. coli* in drinking water. This test was selected because it is internationally approved, allows for rapid detection, and is cost-effective and suitable for field use. Finally, it allows for simultaneous estimation of both coliforms and *E. coli* to a specificity of 1 colony-forming unit (CFU)/100 mL of water, without the need for further verification. Water quality was measured as coliform and *E. coli* most probable number (MPN) in CFU/100 mL, and classified into the three WHO health risk classifications: “low” where *E. coli* MPN < 10 CFU/100 mL; “intermediate” where *E. coli* MPN = 10–100 CFU/100 mL; and “high” where *E. coli* MPN > 100 CFU/100 mL.

Statistical analyses. First, we calculated summary statistics to provide information on the context of water source choice and use in Ghana. Household choices for water sources are summarized by source and season with the average volume of water collected each day. To assess differences in coliform and *E. coli* levels between sachet water samples and other water sources, we performed pairwise comparison tests of means with a Bonferroni adjustment for the differences in the raw means of logged coliform MPN and logged *E. coli* MPN. Bonferroni adjustments were chosen as a more conservative approach relative to other multiple comparisons adjustments. For all analysis, we reported cluster-robust standard errors at the community level. We performed this multiple-comparison test for the subset of 42 communities where sachet water was tested and then repeated the analysis comparing the quality of sachets and all other water sources for all 100 communities in the study. All analyses were interpreted using $\alpha = 0.05$ as the threshold for statistical significance. All statistical analysis was performed using STATA 14.¹⁹

RESULTS

Distribution of water sources. First, we present the water-seeking behaviors and choices of households included in the

study. As found in prior studies, we observe that households are collecting water from multiple sources of water to satisfy their households’ needs. Table 2 presents the water collection behavior of the sampled population as mean percentages by water source in both the dry and rainy seasons, and mean daily volume collected from each source. Overall, most households collect water from at least one improved water source, but they are still also accessing water from unimproved sources. During the dry season, the most commonly cited sources are boreholes, surface water, and public taps. In rainy season, 81% of the households collect rainwater, and a lower proportion of households collect water from boreholes and surface water sources. In terms of volume, households collect the largest quantities of water from piped or carted sources, boreholes, and surface water. An analysis of household choices found that larger households were more likely to diversify their water source choices during the rainy season; however, no differences were observed in terms of water source choice based on income.⁸ In addition, 9% of households report using bottled or sachet water in the dry season and 8% in the rainy season, well above national estimates of 0.8%.⁵

The MCC evaluation did detect some selection bias toward larger households among the 10 households in each community where water was tested compared with those households excluded from water testing (see Supplemental Information, Supplemental Tables 1 and 2).

Point-of-use. Behavioral issues such as failure to properly store water can cause the deterioration of water quality at POU. Drinking water quality at POU was quite poor. Figure 3 summarizes the percent of drinking water by source categorized into each of the following WHO thresholds for *E. coli* MPN:

- “Low” health Risk: < 10 CFU/100 mL.
- “Intermediate” health Risk: 10–100 CFU/100 mL.
- “High” health Risk: > 100 CFU/100 mL.

Most water tested in households was classified as intermediate or high-risk level in terms of *E. coli* MPN.

Table 3 presents the multiple comparisons analysis between coliform and *E. coli* levels in sachet water and all other water sources at POU. There were higher logged counts of coliforms and *E. coli* CFUs in all water sources compared with sachet water. These differences were all statistically significant ($P < 0.05$) when testing differences of raw means using

TABLE 2

Water sources by season and volume summarized across the study sites in rural Ghana (mean values with 95% confidence intervals in parentheses)

	% Of households using source in dry season	% Of households using source in rainy season	Water volume collected per day by household in dry season (L)
Piped water into dwelling	5.1 (1.6–8.6)	4.0 (1.4–6.6)	76.3 (–38.7–191.4)
Piped water into yard/plot	1.8 (0.1–3.5)	2.0 (0.4–3.6)	49.8 (–6.7–106.3)
Piped into someone else’s yard/plot	4.3 (0.9–7.8)	2.3 (–0.0–4.7)	47.5 (–7.7–102.7)
Public tap/standpipe	26.8 (17.1–36.4)	24.8 (15.6–34.0)	39.4 (25.9–52.9)
Tube well/borehole	46.0 (34.9–57.1)	39.4 (28.8–50.0)	55.6 (15.4–95.9)
Protected dug well	5.0 (1.4–8.5)	4.1 (0.4–7.8)	10.6 (3.7–17.4)
Unprotected dug well	14.7 (5.7–23.7)	15.9 (7.1–24.7)	19.5 (14.5–24.4)
Protected spring	0.3 (–0.3–0.8)	0.3 (–0.4–1.1)	25.7 (25.7–25.7)
Unprotected spring	4.0 (–1.1 to 9.1)	1.6 (0.2–2.9)	17.8 (6.4–29.3)
Rainwater collection	6.2 (1.7–10.6)	81.2 (76.0–86.5)	10.6 (5.8–15.4)
Bottled or sachet water	8.8 (3.8–13.7)	8.3 (3.4–13.1)	10.5 (10.5–10.5)
Cart with small tank/drum	0.9 (–0.1–1.9)	0.0 (0.0–0.0)	18.5 (–2.1–39.2)
Tanker-truck	2.0 (–1.7–5.7)	0.4 (–0.4–1.3)	18.4 (12.7–24.0)
Surface water (river, lake, dam, pond)	46.3 (34.9–57.6)	33.3 (24.0–42.7)	82.8 (–6.9–172.5)

FIGURE 3. *Escherichia coli* levels assessed at point-of-use in communities where sachet water was tested, according to World Health Organization's low/intermediate/high risk classification.

Bonferroni-adjusted degrees of freedom. Although the selection process for testing water in 10 of the 12 households may have suffered from bias, this bias would have to be quite large to affect the results, which are large in magnitude and all statistically significant. When testing for bias between communities the 42 communities where sachet water was tested and the 58 where it was not, we observed no significant differences between the communities where sachet water was tested and those where it was not (see Supplemental Information, Supplemental Table 3). As a robustness check, we repeated the multiple comparisons analysis between sachet water and other water sources with data pooled from all study communities where water was tested. These results confirmed what we observed among the communities in which sachet water was tested: again, sachet water was less contaminated than any other drinking water source stored in the household.

Point-of-collection. Figure 4 summarizes the classification of water at POC according to the same WHO standards.

Water quality varied by source. Most samples taken from public taps, boreholes, and sachet water were classified as low health risk, and most water samples from unprotected dug wells and surface water were classified as high health risk. Among all drinking water sources, sachet water samples had the highest frequency of low-risk categorization.

Table 4 presents the multiple comparisons analysis between coliform and *E. coli* levels in sachet water and all other water sources at POC. All water sources tested contained statistically significantly higher levels of coliforms and *E. coli* than sachet water (unprotected dug wells and surface water, $P < 0.001$; public taps/standpipes $P < 0.05$), except for water from boreholes that exhibited no significant difference in either coliform or *E. coli* MPN. Again, as a robustness check, we performed the same analysis with data pooled from all study communities, and the results were similar to those observed from communities where sachet water was tested.

TABLE 3

Means and robust standard errors from multiple comparisons test of the difference in raw means of log coliform MPN and logged *Escherichia coli* MPN between sachet water samples and all other POU water sources for communities where sachets were tested, and all study communities

POU water source	Communities where sachets were collected		All study communities	
	Log coliform MPN	Log <i>E. coli</i> MPN	Log coliform MPN	Log <i>E. coli</i> MPN
Piped water into dwelling	6.62 (0.15)***	2.91 (0.59)***	6.87 (0.19)***	3.59 (0.48)***
Public tap/standpipe	7.02 (0.15)***	2.90 (0.44)***	7.04 (0.10)***	2.66 (0.27)***
Tube well/borehole	7.09 (0.11)***	3.07 (0.28)***	7.05 (0.09)***	3.36 (0.18)***
Protected dug well	7.20 (0.00)***	3.28 (0.00)***	7.40 (0.13)***	4.15 (0.36)***
Unprotected dug well	7.55 (0.16)***	5.12 (1.28)**	7.55 (0.09)***	4.67 (0.74)***
Protected spring	7.61 (0.00)***	4.95 (0.00)***	7.27 (0.43)***	4.65 (0.38)***
Unprotected spring	7.03 (0.42)***	3.32 (0.13)***	7.08 (0.22)***	3.87 (0.34)***
Rainwater collection	7.20 (0.35)***	2.47 (0.31)***	7.07 (0.26)***	3.17 (0.38)***
Surface water	7.64 (0.06)***	3.95 (0.55)***	7.4 (0.13)***	4.06 (0.39)**
Sachet water†	1.57 (0.33)	1.35 (0.09)	1.57 (0.33)	1.35 (0.09)
N	388	388	986	987

POU = point-of-use.

† Reference Category, * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

FIGURE 4. *Escherichia coli* levels assessed at point-of-collection in communities where sachet water was tested, according to World Health Organization's low/intermediate/high risk classification.

DISCUSSION

This study assessed the microbiological quality of Ghanaian sachet drinking water supplies in rural and peri-urban areas and small towns, relative to other local-drinking water options. As observed in prior studies,^{9,15} we found that sachet water contains fewer microbiological contaminants than other water options at POU within households, and generally appeared to be an important source for household consumption. We expected that water stored in a home would be of lower quality than sachet water, as water from other sources are more likely to have experienced quality degradation due to transport to a household and storage. We thus also expected that water from other sources at POC might compare more favorably to sachet water, given fewer opportunities for cross-contamination. However, we found that even at POC, sachet water is still among the highest quality water sources available. This study adds to the scant literature about sachet water quality outside of major urban centers. These findings are significant as the sachet water industry continues to spread to rural regions and small towns due to robust demand for the product's perceived higher quality and convenience, and

persistent water production shortages among many of Ghana's urban water systems, which limits water service expansion projects for adjacent areas.

In Ghana, water collectors must diversify their sources to have a stable and sufficient household supply. This study highlighted the patchwork of water sources that many households use to meet their needs, with sachet water increasingly becoming an important option. Despite the social injustice of having the second-highest unit cost per volume (after bottled water) among common water sources, it is available in small unit sizes at a cost of approximately US\$.05 per sachet and thus, widely accessible even for households living in extreme poverty. Perhaps no drinking water innovation of the last 20 years has done more to increase drinking water availability in Ghana. But improvements in availability alone do not necessarily translate into improved water security,²⁰ and it is not clear that sachets would confer a long-term health benefit to people who intermittently consumed water from unsafe sources.

As the market for sachet water grows, several important challenges remain: 1) maintenance of sachet quality control by national regulatory bodies in a geographically growing

TABLE 4

Means and robust standard errors from multiple comparisons test of the difference in raw means of log coliform MPN and logged *Escherichia coli* MPN between sachet water samples and all other POC water sources for communities where sachets were tested, and all study communities

POC water source	Communities where sachets collected		All study communities	
	Log coliform MPN	Log <i>E. coli</i> MPN	Log coliform MPN	Log <i>E. coli</i> MPN
Public tap/standpipe	3.94 (0.73)*	1.38 (0.38)*	4.04 (0.53)**	1.51 (0.27)**
Tube-well/borehole	2.90 (0.62)	1.33 (0.48)	2.77 (0.35)	0.75 (0.23)
Unprotected dug well	7.79 (0.00)***	6.37 (0.49)***	7.23 (0.38)***	5.33 (0.48)***
Surface water	7.35 (0.39)***	6.01 (0.46)***	7.50 (0.19)***	6.01 (0.19)***
Sachet water†	1.56 (0.34)	1.35 (0.09)	1.56 (0.34)	1.35 (0.09)
N	122	124	222	224

POC = point-of-collection.

† Reference Category, * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.

market, 2) regularization of transportation corridors for rural areas, and 3) commodification of the plastic waste stream that accompanies increased packaged water consumption. There are still open questions about how sachet water quality is affected by longer storage (with respect to sun, dirt, fecal matter, etc.); and by extended sun exposure during transportation (typically on the back of flatbed trucks); and during the sales process by women vending single sachets from questionably hygienic buckets atop their heads, often filled with ice or other untreated water to cool the sachets.³ The sun, for example, may result in solar disinfection of bags at the top of a pile that receive direct ultraviolet exposure, whereas simultaneously facilitating the growth of bacteria in bags at the bottom of the same pile that only experience the heat. There is also the risk of sun-exposed bags having plastic leachates enter the water. All of these factors may disproportionately affect rural sachet water supplies given the longer supply chain. Two limited studies of storage temperature demonstrated the regrowth of some indicator organisms,²¹ limited growth, or no regrowth of others,²² demonstrating that there is still much to learn about environmental effects on sachet water quality.

The results of this study should be interpreted in the context of several limitations. The data were collected in the context of a larger study of water availability, microbiological quality, and quality and was not intended as a representative assessment of sachet water. The water samples collected at POU incurred some household selection bias due to logistical constraints during data collection, and therefore may not be representative of all available water sources in the communities from which they were taken. In addition, although the selection process for testing water in 10 of the 12 households may have suffered from bias, this bias would have to be quite large to affect the results, which are large in magnitude and all statistically significant. The cross-sectional nature of this study limited generalization of our results to year-round sachet water microbiological quality, especially in light of new research characterizing the seasonal variability of sachet water microbiological quality in Nigeria.²³ Because sachet water originated as an urban phenomenon and the corporate brands are primarily produced in urban regions, there may have been some relationship between relative urbanity and sachet water quality. But the original study communities were not characterized using any rural–urban classification, and because of data privacy constraints, we were only able to reconcile community locations to their district, which prevented us from matching study communities to data from the Ghana Population and Housing Census. The study also did not record additional attributes of the sachet, such as brands, or vending conditions, that have been shown to be associated with sachet water quality.^{11,13} We analyzed the results of water quality testing of sachet water that had already been transported to the communities where it is consumed, and it is unknown if any quality degradation occurred in the supply chain. Future studies should assess sachet water quality after prolonged storage in the home and collect data on other characteristics related to sachet water's production, transport, and storage by distributors.

Although this study was not nationally representative, it contributes to our understanding of the options and relative microbiological quality of drinking water in rural, peri-urban, and small-town communities in Ghana. Despite many trade-offs and in lieu of other POU treatment options in these

communities, sachet water often contains the fewest microbiological contaminants compared with most alternatives, particularly water from other sources stored in the home. Sachet water consumption continues to diffuse hierarchically to these areas from the nation's urban centers, and is increasingly becoming a dependable drinking water source in water-stressed communities. Many caveats, ranging from plastic degradation of the environment, high unit costs, and price instability make sachet water an environmental justice issue for low-income communities and simultaneously help and hinder household water security. The increasing use of sachet water outside of urban areas demonstrates the need to improve the quality and coverage of publicly available water sources, but also presents another option for provision of clean drinking water if sachets can be produced and consumed sustainably. Household water provisioning schemes should consider sachet water as an evolving option for many consumers and work with regulators to ensure proper quality control along the supply chain, plastic waste management solutions that keep the wrappers of the environment, and fair pricing to protect the poor and vulnerable.

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Authors' addresses: Danice Guzmán, Initiative for Global Development, University of Notre Dame, Notre Dame, IN, E-mail: dbrown16@nd.edu. Justin Stoler, Department of Geography and Regional Studies, University of Miami, Coral Gables, FL, E-mail: stoler@miami.edu.

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