

Sachet water quality and product registration: a cross-sectional study in Accra, Ghana

M. Dzodzomenyo, G. Fink, W. Dotse-Gborgbortsi, N. Wardrop, G. Aryeetey, N. Coleman, A. Hill and J. Wright

ABSTRACT

The study's objectives were to assess the extent to which packaged water producers follow product registration procedures and to assess the relationship between product registration and drinking water quality in Accra, Ghana. Following preliminary analysis of a national water quality survey, 118 packaged sachet water samples were collected by sampling all brands sold by 66 vendors. A sample of vendors was selected from two high-income and two low-income areas of Accra, Ghana. Sachet packaging and labelling details were recorded and compared to a regulatory database to assess product registration. All samples were weighed and tested for faecal indicator bacteria and selected physico-chemical parameters. Product registration numbers and brand names could be matched to regulatory records for 77 of 118 sachets (65.2%). All samples tested were compliant with national water quality standards for faecal indicator bacteria and nitrate. Brand registration was not associated with any of the quality indicators considered. The results of this study suggest that while a substantial proportion of sachet water is sold without formal product registration, the microbial quality of the unlicensed water is consistently high in Accra, Ghana. Further examination of regulatory enforcement and monitoring will be needed to ensure sustained high water quality over time.

Key words | beverages, *Escherichia coli*, government regulation and oversight, potable water, water quality

M. Dzodzomenyo
W. Dotse-Gborgbortsi
G. Aryeetey
N. Coleman
School of Public Health,
University of Ghana,
P.O. Box LG13, Legon, Accra,
Ghana

G. Fink
Swiss Tropical and Public Health Institute and
University of Basel,
Basel,
Switzerland

N. Wardrop
J. Wright (corresponding author)
Geography and Environment,
University of Southampton,
Highfield, Southampton SO17 1BJ,
UK
E-mail: j.a.wright@soton.ac.uk

A. Hill
Social Sciences,
University of Southampton,
Highfield, Southampton SO17 1BJ,
UK

INTRODUCTION

Packaged drinking water consumption is growing rapidly in West Africa and in other low and lower middle income countries (Rodwan 2014). Unlike in high income countries, this growth in packaged water consumption has taken place against a background of partial and interrupted piped water coverage in urban sub-Saharan Africa (Stoler *et al.* 2012a, 2012b). In particular, sachet water, drinking water (typically 500 mL) sold in heat-sealed plastic sleeves, has proved a popular supplement to piped water among

urban consumers in many settings. In Ghana, the percentage of households reporting bottled water or sachets as their main source of drinking water increased from 9.2% to 29.8% (7.9 million people) between 2008 and 2014 (Ghana Statistical Service (GSS) *et al.* 2015). Although the sachet industry is particularly well developed in West Africa, sachet water is also consumed elsewhere in Africa (Sima *et al.* 2013).

Internationally, drinking water standards and guidelines are provided by the Codex Alimentarius Commission of the World Health Organization (WHO) and Food and Agriculture Organization (FAO). These standards differentiate packaged drinking water, typically originating from piped

This is an Open Access article distributed under the terms of the Creative Commons Attribution Licence (CC BY 4.0), which permits copying, adaptation and redistribution, provided the original work is properly cited (<http://creativecommons.org/licenses/by/4.0/>).

systems, from natural mineral water originating from groundwaters and characterised by its mineral constituents (Codex Alimentarius Commission 2001, 2011). In Ghana, standard setting and product certification is the responsibility of the Ghana Standards Authority (GSA), who have separate standards for packaged mineral and packaged drinking waters (Ghana Standards Authority 2005b). Alongside the GSA, the Ghana Food and Drugs Authority (FDA) is responsible for assuring the ongoing safety of products sold to consumers and implementation of relevant standards. Sachet producers certified by the GSA are authorised to use a GSA mark of conformity (kite mark) on packaging, and producers registered with the FDA are authorised to print their registration number on packaging. While certification with the GSA is voluntary, registration with the FDA is compulsory and entails health checks on staff, compliance with safe production, labelling (e.g., a producer address and 'best before' date) and handling practices (Ghana Standards Authority 2005a), and water quality testing of the product. However, given limited resources, regulation of the sachet water industry remains a challenge. In particular, there are concerns about wholesalers and small-scale unregistered producers (Stoler *et al.* 2012b) operating outside this regulatory framework, whose sachets may therefore present a greater contamination and public health risk, particularly in poorer urban Ghanaian neighbourhoods (Stoler *et al.* 2014). Greater exposure to more contaminated drinking water has also been observed among deprived neighbourhoods and households in other countries and supply systems (Yang *et al.* 2013; Delpla *et al.* 2015). More generally, a complex interplay of economic and social factors determines the outcome of diarrhoea for example, with sanitation infrastructure, hygiene behaviours, and community cohesion directly affecting its transmission (Fewtrell *et al.* 2005; Zelner *et al.* 2012). Despite such concerns, a recent nationally representative household survey, the Ghana Living Standards Survey Round 6, found lower rates of detectable *Escherichia coli* in sachet samples compared to point-of-consumption samples from piped systems (Johnston & Amoako-Mensah 2014). Visits to several small-scale sachet production premises in Accra suggested that most were packaging piped water from the municipal system (Stoler *et al.* 2012b). However, packaging of groundwater from boreholes, following treatment via reverse

osmosis, has also been observed for three production facilities in Dodowa, north of Accra (Gronwall & Oduro-Kwarteng 2018).

There is widespread recognition that water safety should be assessed by examining risk management arrangements in addition to water quality monitoring. This approach is embodied, for example, in the water safety plan concept (Davidson *et al.* 2005), but also with greater recognition of 'safely managed' water services in proposals for post-2015 international monitoring of safe water access (World Health Organization and UNICEF 2014, 2015). This is because, for many water sources, contamination events may be sporadic and intermittent quality testing may therefore miss such events (Hrudey *et al.* 2006), even where a contamination pathway exists. Despite this, most studies of sachet water safety and compliance have concentrated on water quality testing (Obiri-Danso *et al.* 2003; Orisakwe *et al.* 2006) rather than risk management and regulatory compliance. Furthermore, while consumer trust in different sachet brands varies (Stoler *et al.* 2014), few studies of packaged drinking water in low and middle income countries have incorporated information about brands, packaging and labelling (Bain *et al.* 2014).

This study therefore aims to assess the extent to which local sachet water producers follow national product registration laws, as well as the degree to which unlicensed water meets national water quality standards in both relatively wealthy and relatively poor neighbourhoods of Accra, Ghana. It also aims to examine the inter-relationship between labelling, packaging quality, price and market penetration on the one hand and sachet water quality and brand registration status on the other.

METHODS

Sampling for primary fieldwork

The sampling strategy was designed to cover the entire spectrum of sachet water brands sold in rich and poor neighbourhoods within Accra. To identify rich versus poor neighbourhoods, we developed a deprivation index for enumeration areas (EAs) in the Accra Metropolitan Area using 2010 population census data. Deprivation was measured via

the first component derived from a principal components analysis (PCA) of selected EA characteristics. Specifically, we analysed the following variables: proportion of illiterate population over 11 years, proportion of active population not working in professional, technical or managerial occupations, proportion of households without access to improved sanitation, piped domestic water to the dwelling, living in overcrowded conditions, lacking solid waste disposal, electric lighting and a computer or phone, renting, squatting or 'perching', and living in houses of inadequate construction.

Based on the PCA score, we classified all EAs into deprivation quintiles, and then selected four EAs from the two most deprived quintiles (deprived neighbourhoods) and eight areas from the two least deprived quintiles (wealthy neighbourhoods, generally with fewer stores) for the study. We reviewed Google Earth satellite imagery from 12 January 2010 and 20 March 2016 to ensure that there had been no major changes to the built environment following the 2010 census at these sites. All water vendors operating from fixed premises, kiosks or shops in and immediately surrounding each EA were mapped. Street hawkers were excluded. In the first phase, 16 sachet vendors were selected from those listed as being closest to a set of randomly selected households with young children participating in a pilot intervention study (Wright *et al.* 2016a). In the second phase, 50 vendors were selected using simple random sampling from the list of eligible vendors.

Data collection

Fieldwork took place in two phases, in February 2015 and September 2016. Fieldwork for the first phase took place in four case study EAs within Accra, Ghana, in the Abeka and Pig Farm areas, two deprived neighbourhoods. In the second phase, sampling was expanded to include a further eight EAs in two wealthy neighbourhoods, East Legon and Roman Ridge areas, and additional EAs in Abeka and Pig Farm.

Power calculations

Based on a national rate of 20% detectable *E. coli* in point-of-sale sachet water in the 2012–13 Ghana Living Standard

Survey (Wright *et al.* 2016b) and assuming a 20% difference in sachet contamination between rich and poor areas, we estimated that 118 samples would be required to detect 10% sachet contamination in least deprived EAs versus 30% contamination in those most deprived (with $\alpha = 0.05$ and 80% power).

Sachet collection and assessment of product registration

After seeking informed consent from vendors, a single sample sachet was collected of each brand on sale and the price paid for it recorded. Primary packaging characteristics were recorded via direct observation, including brands, producer addresses, the presence of a GSA kite mark and FDA registration number. Printed storage and handling instructions, description of treatment processes, minimum durability ('best before') date, and any details of water chemical composition were also recorded. To measure packaging quality, the 'feel' of the packaging was assessed (following Stoler *et al.* 2014), as was the presence of blurred or poor colour quality printing or frayed heat-seals. All 16 vendors in the first phase were also asked about sachet procurement and subsequent storage, with observations made on each brand's storage.

Brand details and FDA registration numbers printed on primary packaging from both phases were then compared with records of products registered with the FDA (Ghana Food and Drugs Authority 2015). Two authors (WDG, JW) undertook this comparison independently, then reconciled any differences thereafter.

Water quality testing and sachet weights

Samples were transported on ice to the Noguchi Memorial Institute laboratory within Accra and processed within 6 hours. The pour plate technique was used to enumerate heterotrophic bacteria in selected samples, following incubation at 22 °C for 72 hours (Phase 1) and 37 °C for 48 hours (Phase 2). After appropriate dilutions of one in ten, hundred and thousand, 1 mL of each of the dilutions were dispensed and aliquots were transferred into petri dishes. Thereafter, 25 mL of the molting media were added at 45–50 °C into petri dishes, swirled and incubated. Plates

containing colonies which were countable were counted and expressed as coliform forming units per millilitre (cfu/mL). Bacterial identification was achieved by using Brilliance *E.coli*/coliform selective agar with undiluted samples. Briefly, after thorough mixing, 100 mL of samples were filtered through a sterile filter paper with 0.45 µm pore diameter and filters removed and placed onto chromogenic agar CM1046 Brilliance *E. coli*/coliform selective agar (Oxoid Hampshire, UK), and incubated at 37 °C for 24 hours. The total number of purple/blue and pink (1–3 mm) colonies were regarded as confirmed total coliforms.

Electrical conductivity was assessed using a portable hand-held water quality meter, model HANNA H1 98129. Nitrate-nitrogen (NO₃-N) levels in each sample were measured using nitrate powder pillows in a direct reading Hach spectrophotometer Model DR 2010. Chloride concentration was determined titrimetrically by the silver nitrate method (Eaton *et al.* 1995).

In the second phase, sachets were also weighed in the laboratory prior to testing, to assess deviations from the stated, standard 500 mL sachet volume. Individual sachet brand weights were measured using a Mettler Toledo (PM 600) weighing scale which was calibrated every six months. Each sample was weighed three times and the mean weight recorded to the nearest 0.01 g. We also weighed a small sample of primary packaging and found it weighed on average 2 g. Assuming a water density of 0.996 g/cm³ at an ambient temperature of 30 °C (Jones & Harris 1992), a 500 mL sachet should weigh 497.8 g + 2 g for packaging or approximately 500 g.

Analysis

We start with descriptive statistics of the number of brands sold by vendors, packaging characteristics, sachet prices and brand registration, and describe water quality test results. We also assess the extent to which vended sachets contained the stated quantity (500 mL) of water. To examine the suggestion that unregistered brands are more likely to be sold cheaply in poorer neighbourhoods (Stoler *et al.* 2014), we examine the relationship between brand registration with the FDA, price and neighbourhood deprivation for the EA at point-of-sale using logistic regression. Through this analysis, we also examine brand registration in relation

to visual indicators of production process problems that are apparent to consumers. These include deviations from the stated sachet weight and signs of poorer quality packaging, such as frayed heat-seals. Finally, we examine the relationship between product registration and brand characteristics that could be perceived as quality indicators by consumers, namely, being part of the leading franchise, market penetration (measured by the proportion of vendors selling a given brand) and labelling on primary packaging. Due to small cell counts, Fisher's exact test was used to examine these brand characteristics relative to FDA registration status.

Secondary data analysis of Ghana Living Standards Survey 6

A recent study in a Nigerian city found evidence of seasonal microbial contamination of sachet water (Kumpel *et al.* 2017). Therefore, to assess whether packaged water in Ghana was also subject to seasonal contamination in response to initial reviews of this study, we examined data from a nationally representative multi-stage cluster survey, the Ghana Living Standards Survey 6 (GLSS6) conducted from October 2012 to October 2013, which included a water quality module (Ghana Statistical Service 2014). The GLSS6 sampled 15 households in each of 1,200 EAs nationally, resulting in 18,000 participating households. Of these, a random sample of three households in each EA was asked for 'a glass of water as though for a child to drink'. Among selected households, 550 were using sachets for drinking water and in these households, the sachet was first poured into a glass prior to sampling. Sampling took place via continuous, parallel survey of each of Ghana's ten regions over the 12-month period. Samples were then tested for *E. coli* and total coliforms, following methods previously described elsewhere (Johnston & Amoako-Mensah 2014; Wright *et al.* 2016b).

To test for seasonal variation in microbiological contamination of sachets, we grouped dates of sample collection into four quarters (Jan–Mar; Apr–Jun; Jul–Sep; and Oct–Dec) since very few samples were collected in June and December. As noted in our previous analysis of the GLSS6 microbiological data (Wright *et al.* 2016b), digit preference and rounding when enumerating *E. coli* gave

rise to unusually large numbers of samples with colony forming unit (cfu) counts such as 10 and 100. To avoid such rounded cfu counts when distinguishing between low, medium and high contamination of sachets, we therefore reclassified the *E. coli* counts as low (<1 cfu/100 mL), medium (1–72 cfu/100 mL) or high (>72 cfu/100 mL). We then cross-tabulated contamination levels against quarter, using the *svy* set of commands in Stata to take account of the survey design and calculating an F-statistic (Rao & Scott 1984) to test for seasonal variation in *E. coli* contamination.

RESULTS

Primary fieldwork

Combining both fieldwork phases, 34 of the 66 sampled vendors sold one brand, 18 sold two brands, nine sold three brands, four sold four brands, and one sold five brands. This gave a total of 118 sachet samples, since one sample was taken of each brand sold per vendor (vendor-brands). Overall, the samples taken from these vendors represented 33 different sachet brands. Sachets with specific brands were however not all produced in the same factory, and some factories produced multiple brands. The most widespread brand was manufactured under franchise, so this one brand was produced at 13 different factories. Furthermore, three factories manufactured two different sachet brands rather than a single brand. Given that product registration with the FDA varied within this franchise, we work hereafter with the 43 unique combination of factory and brand (producer-brands) as the unit of analysis, considering each franchise separately.

Table 1 summarises the packaging quality and prices of vendor-brands. No sachet samples contained visible particles and there were no sachets with a discernibly poorer 'feel' to the plastic. Table 1 also summarises labelling of primary packaging and product registration, for the 43 producer-brands. All packaging samples were labelled with the GSA mark of conformity (kite mark) and manufacturer's address. Most producer-brands printed storage instructions, but only four printed details of water chemical composition as required under the more stringent natural mineral water

Table 1 | Packaging quality characteristics and prices of 118 unique combinations of vendor and sachet brand in Accra, Ghana

Packaging quality	
Blurred print	8 (6.8%)
Seal frayed	5 (4.2%)
Poor colour printing	7 (5.9%)
Total vendor-brands	118
Price per sachet (GHS)	
0.10 (\$0.02)	8 (6.8%)
0.15 (\$0.03)	18 (15.3%)
0.20 (\$0.05)	92 (78.0%)
Total vendor-brands	118
Labelling	
'best before' date	1 (2.3%)
Chemical composition parameters (e.g., nitrate)	4 (9.3%)
Storage instructions	28 (65.1%)
Ghana Standards Authority seal (kite mark)	43 (100%)
Water treatment processes	4 (9.3%)
Total producer-brands	43
Market penetration of brands:	
Sold by one vendor	21 (63.6%)
Sold by two vendors	3 (9.1%)
Sold by three vendors	3 (9.1%)
Sold by four to seven vendors	3 (9.1%)
Sold by 11 vendors	1 (3.0%)
Sold by 20 vendors	1 (3.0%)
Sold by 33 vendors	1 (3.0%)
Total brands	33
Comparison of labelling with Food and Drugs Authority database	
<i>Exact match</i> : Printed FDA registration number and brand name match to FDA records	23 (53.5%)
<i>Partial match</i> : No printed FDA registration number, but brand name listed in FDA database	5 (11.6%)
<i>Partial match</i> : Brand name matches to FDA database, but not FDA registration number printed on sachet packaging	4 (9.3%)
<i>Partial match</i> : Printed FDA registration number is associated with sachet producer, but not brand on which it is printed	3 (7.0%)
<i>No match</i> : no printed FDA registration number; brand name not listed in FDA database	4 (9.3%)
<i>No match</i> : neither brand name nor FDA registration number printed on sachet packaging match to FDA database	4 (9.3%)
Total producer-brands	43

standard (Ghana Standards Authority 2005a). Four producer-brands listed treatment processes on labelling. For the one brand with a printed 'best before' date, this date was in the future.

The two leading brands were sold by 33 (50%) and 20 (30.3%) of the 66 vendors sampled. The majority of the 33 brands sampled (63.6%) were sold by only one of the 66 vendors. A similar pattern is apparent when franchises of the leading brand are considered separately and market penetration of producer-brands is considered: 60.3% of producer-brands are sold by just one vendor. Almost all brands were manufactured within the same region as the point-of-sale (Greater Accra), most within 25 km of the retail outlet. Only one brand, sold at just one outlet, was transported more than 50 km. This came from a different region (Eastern Region), being transported 90 km for sale.

On average, the 16 vendors interviewed in Phase 1 had 27.9 bags of water sachets delivered per week (median = 20.0, range = 5 to 400). Vendors typically received deliveries more than once a week: 33 of 52 brands sold (62.3%) were delivered between two and five times a week. Most vendors stored water sachets indoors, but a minority stored sachets outdoors (11.8%), in direct sunlight (18.7%) or directly on floors (17.7%).

Brands, manufacturer names and addresses, and FDA registration numbers printed on packaging could be matched to the FDA database for 23 out of 43 producer-brands. This represented 65.2% of the 118 vendor-brands sampled. Of the remaining producer-brands, five brand names were listed in FDA records but did not print the FDA registration number on the sachet packaging. Four producer-brands lacking FDA registration numbers on packaging were not listed in FDA records. Four more printed an FDA registration number, but there was no

corresponding record of either the brand name or registration number in the FDA database. Finally, three producers manufacturing two different brands used the same FDA registration number for both of their products.

As shown in Figure 1, despite being labelled as containing 500 mL of water, which should weigh 500 g, sachets from the second round of sampling weighed only 480.3 g on average (standard deviation: 18.9 g; $n = 78$).

Water quality

Six out of 118 samples were mislaid by the processing laboratory and therefore lacked test results and weights. Of the remainder, all samples were <1 cfu per 100 mL and so compliant with national standards for *E. coli* and total coliforms, and also compliant with national standards for heterotrophic plate counts (50 cfu/mL and 500 cfu/mL, respectively, when incubated at 22 °C and 37 °C (Ghana Standards Authority 2009)). Table 2 shows physico-chemical water quality test results for the 112 sachet water samples.

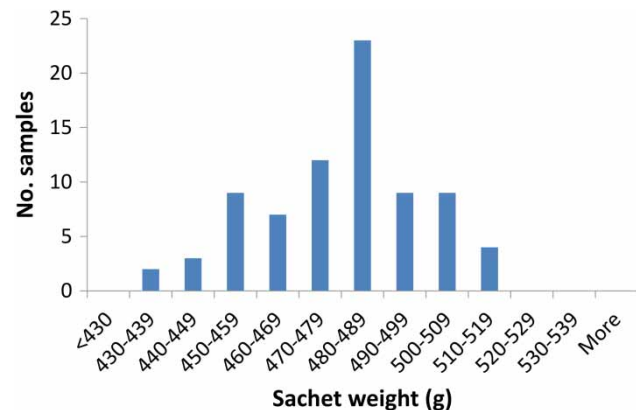


Figure 1 | Distribution of weights for 78 sachet samples labelled as containing 500 mL of water.

Table 2 | Descriptive statistics for water quality parameters from 112 water samples, representing 33 different sachet brands

Parameter	Mean	Minimum	Maximum	Standard deviation	No. samples
Heterotrophic plate count (cfu/1 mL), Phase I (22 °C for 72 hrs)	15.6	0	35	10.7	34
Heterotrophic plate count (cfu/1 mL), Phase II (37 °C for 48 hrs)	63.5	0	443	107.0	78
Nitrate as nitrogen (mg/L)	0.5	0.0	2.8	0.5	112
Chloride (mg/L)	3.1	0.0	16.1	3.2	112
Electroconductivity (μ S/cm)	34.3	0	222.0	32.4	112

These were all compliant with national standards for nitrate. When electro-conductivity was converted to total dissolved solids, all sample values were well below 300 mg/L, the threshold above which panels of water tasters begin to detect a salty taste (World Health Organization 2003).

Sachet and brand characteristics associated with registration with the FDA

Table 3 summarises the brand characteristics associated with an exact match of brand name and product registration number with FDA records, based on Fisher's exact test. None of the labelling characteristics were associated with brand registration with the FDA. Brand registration was not associated with a producer-brand being sold at a single store. However, being part of the franchise for the leading brand approached significance as a predictor of being FDA-registered.

Table 4 summarises the relationship between individual sachet characteristics and brand registration status with the FDA. Only the absolute difference between a sachet weight and 502 grams (representing the weight of 500 mL of water plus 2 g of packaging) was significantly related to brand registration, although poor print colour approached significance in predicting non-registration of brands.

Secondary data analysis of Ghana Living Standards Survey 6

Table 5 shows the pattern of *E. coli* contamination in the GLSS6 by quarter. Although a slightly greater proportion of samples had detectable *E. coli* in Oct–Dec, this difference

Table 3 | Relationship between product labelling, franchising and market penetration with brand registration with the Food and Drugs Authority for 43 producer-brands sold in four neighbourhoods of Accra

Characteristic	P-value
Franchised production	0.054
Chemical composition printed on packaging	0.610
Water treatment processes listed on packaging	0.610
Storage instructions listed on packaging	1.00
Product sold at only one retail outlet	0.233 ^a

^aChi square test.

Table 4 | Relationship between sachet weight, price, neighbourhood deprivation for point-of-sale, and packaging quality with brand registration with the Food and Drugs Authority for 118 sachet samples from four neighbourhoods of Accra

Characteristic	Odds ratio (95% confidence intervals)	P-value
Neighbourhood deprivation ^a	1.124 (0.842–1.501)	0.430
Absolute difference in sachet weight from 500 g ^b	0.959 (0.925–0.995)	0.028
Price (GHS)	0.936 (0.813–1.08)	0.355
Poor print colour	0.192 (0.036–1.038)	0.055
Blurred labelling	0.292 (0.066–1.290)	0.104
Frayed seal	2.192 (0.237–20.28)	0.489

^aWith robust estimation to account for clustering of observations within enumeration areas.

^bFor 55 out of 118 sachets.

Table 5 | *E. coli* contamination versus season of sampling for 550 point-of-use sachet water samples from the Ghana Living Standards Survey 6, 2012–13

Quarter	< 1 cfu/100 mL	1–72 cfu/100 mL	> 73 cfu/100 mL	No. of samples (n)
Jan–Mar	76.9%	21.9%	1.3%	160
Apr–Jun	80.1%	16.6%	3.3%	123
Jul–Sep	80.9%	16.5%	2.7%	168
Oct–Dec	60.8%	37.0%	2.2%	99

was not statistically significant (Rao & Scott (1984) F statistic = 1.60; $p = 0.16$). Primary fieldwork therefore did not explicitly sample both wet and dry seasons.

DISCUSSION

A recent systematic review (Bain *et al.* 2014) noted low rates of microbial contamination in sachet water, with three out of four included studies having detectable faecal indicator bacteria in less than 10% of samples. Since no samples had faecal indicator bacteria levels exceeding national standards, our results accord with this finding and confirm other recent studies of sachet water in Ghana (Johnston & Amoako-Mensah 2014; Stoler *et al.* 2014), which suggest that rates of detectable *E. coli* in vended sachet water are low. We also find no evidence that those in more deprived neighbourhoods were more likely to consume faecally

contaminated sachet water. In contrast to a recent study of a city in Nigeria (Kumpel *et al.* 2017), our analysis of the nationally representative GLSS6 found no evidence of significant seasonal variation in point-of-use microbial contamination of sachets in Ghana. Electro-conductivity in our samples (Table 2) was generally lower than values reported for untreated borehole water in the Densu Basin that contains Accra (Fianko *et al.* 2010). These measurements are thus consistent either with producers packaging groundwater treated via reverse osmosis (which reduces total dissolved solids and thereby electro-conductivity) or packaging of piped water.

In addition, by cross-checking packaging details against lists of manufacturers registered with the FDA, our study provides some further reassurance about the safety of the sachets on sale in these case study neighbourhoods, over and above water quality testing. Not only were the sachets compliant with national standards for faecal indicator bacteria and nitrate, but the majority of brands on sale also had packaging details consistent with FDA records of registered products. However, while the FDA registration entails inspection of processing and packaging facilities (Ghana Standards Authority 2005a), correspondence of packaging labelling with the FDA database does not conclusively demonstrate that such inspections have taken place. Nonetheless, this approach would be applicable in other countries with widespread sachet water consumption. For example, the equivalent regulatory body in Nigeria, the National Agency for Food and Drug Administration and Control (NAFDAC), also holds a registered producer database (National Agency for Food and Drug Administration and Control 2015).

The recent systematic review by Bain *et al.* (2014) excluded studies that did not differentiate between brands and sampled less than ten brands. By recording and sampling a range of brands, our study both meets the review inclusion criteria and confirms the general trend in this wider pool of studies. However, our study also suggests that there is a complex relationship between sachet production and branding. Production of a leading sachet brand is franchised to multiple producers, while a single factory may produce more than one brand. This suggests that where such details are available, production addresses as well as brands should be recorded in market surveillance of packaged water quality.

In keeping with another study of water packaging in Africa, our study identified some aspects of packaged water that were not compliant with legislation. A Nigerian study of 92 sachet water samples found no samples had printed 'best before' dates and 7% of sampled sachets lacked manufacturer addresses and NAFDAC registration numbers (Olaoye & Onilude 2009). However, while printed 'best before' dates required by the FDA were rare both in this study and our own data, it seems unlikely that bulky, low margin goods such as sachets would be stored for long periods by either retailers, wholesalers or manufacturers given the costs associated with doing so. Vendor questionnaire responses also support this, with deliveries on a weekly basis, or more frequently, for most vendor-brand combinations (Table 1), suggesting this is not a significant public health concern. The majority of sachets we sampled were also under the labelled volume (Figure 1), although again this does not in itself raise public health concerns.

Storage methods were appropriate in the majority of cases, although three vendors (17.65%; Table 1) reported storing water sachets on the floor, which may result in absorption into sachet water of detergents and other chemicals. In addition, two vendors (12.50%) reported that sachets were sometimes exposed to direct sunlight, which may promote bacterial growth and can result in contaminant release from the plastic packaging or packaging deterioration, increasing overall contamination risks. Most producers were within 25 km of the retail outlets they supplied, confirming suggestions (Dzodzomenyo *et al.* 2017) that sachets are transported short distances to reduce delivery costs. Although this reduces the energy costs and carbon dioxide emissions from sachet transportation, it does not mitigate the air quality-related public health impacts of sachet delivery trucks in urban Greater Accra.

Our study is subject to several limitations. The proportion of sachet samples contaminated with *E. coli* was lower than we estimated in our sample size calculation, preventing us from comparing sachet contamination in more versus less deprived neighbourhoods as originally intended. Similarly, the sample was not designed to be representative of the city of Accra and larger numbers of samples per brand would be required to be confident of the compliance of individual sachet brands (Ghana Standards Authority 2009). While it is encouraging that for most sachet brands, details

on packaging matched with regulatory records, it is conceivable that packaging details had been counterfeited and copied exactly, although this would mean that the counterfeiter would potentially lose business by not having their own contact details printed on packaging. We also did not assess the robustness of the FDA's regulatory procedures, such as product testing and production facility inspection, underpinning the brand registration numbers that we examined. Even though the heat-sealed plastic sachet packaging is likely to reduce recontamination commonly found with other forms of household stored water (Wright *et al.* 2004; Fisher *et al.* 2015), by sampling at the point of sale rather than at the point of consumption, our study may underestimate consumers' exposure to contaminated sachet water. This may occur, for example, if sachet water is transferred to other containers prior to consumption. There are also difficulties with some aspects of our study protocol. For example, our findings are dependent on the currency, accuracy and completeness of the FDA database of registered products, and record linkage will be affected by changes of address by registered manufacturers. There is also scope for further refinement to our sampling protocol, for example, in recording whether sachets are labelled as mineral water on packaging. Finally, growing sachet consumption suggests that Ghana's sachet industry is evolving rapidly and our findings should be interpreted within this context.

CONCLUSIONS

This study suggested that in both low and high deprivation neighbourhoods of Accra, water sachets were compliant for water quality parameters tested, and most brand details printed on packaging matched to regulatory records of registered producers. These results provide further evidence of the comparative safety of sachet water in Ghana, although issues such as the extent and frequency of regulatory inspection of producers' premises and franchising of production require further investigation. The methodology used should be applicable to other West African countries, enabling assessment of packaged water brand registration in addition to water quality testing.

ACKNOWLEDGEMENTS

This research was funded by the UK Medical Research Council and Department for International Development under the Public Health Intervention Development programme (ref: MR/M008940/1). The funders had no role in the study design or collection, analysis, and interpretation of data. Data supporting this study are openly available from the University of Southampton repository at <https://doi.org/10.5258/SOTON/D0204> and from <http://www.ilo.org/surveydata/index.php/catalog/466/study-description>. Free and informed consent of the participants or their legal representatives was obtained and the study protocol was approved by the appropriate Committees for the Protection of Human Participants [Noguchi Memorial Institute For Medical Research Institutional Review Board; Faculty of Social, Human and Mathematical Sciences Ethics Committee, by the University of Ghana, Greater Accra, Ghana, ref: 006/14-15 and 3 Sept 2014; University of Southampton, Hampshire, UK, ref: 12241, and 23 Sept 2014]. The Steering Committee for this project included representation from the National Association for Sachet and Packaged Water Products. No financial or in kind contributions were received, and the steering committee played no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

REFERENCES

- Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T. & Bartram, J. 2014 *Fecal contamination of drinking-water in low- and middle-income countries: a systematic review and meta-analysis*. *Plos Medicine* **11** (5): e1001644.
- Codex Alimentarius Commission 2001 *Code of Hygienic Practice for Bottled/Packaged Drinking Waters (Other Than Natural Mineral Waters)*. Codex Alimentarius Commission, Rome, Italy.
- Codex Alimentarius Commission 2011 *Code of Hygienic Practice for Collecting, Processing and Marketing of Natural Mineral Waters*. Codex Alimentarius Commission, Rome, Italy.
- Davidson, A., Howard, G., Stevens, M., Callan, P., Fewtrell, L., Deere, D. & Bartram, J. 2005 *Water Safety Plans: Managing Drinking-Water Quality from Catchment to Consumer*. World Health Organization, Geneva, Switzerland.

- Delpa, I., Benmarhnia, T., Lebel, A., Levallois, P. & Rodriguez, M. J. 2015 Investigating social inequalities in exposure to drinking water contaminants in rural areas. *Environmental Pollution* **207**, 88–96.
- Dzodzomenyo, M., Dotse-Gborgbortsi, W., Lapworth, D. J., Wardrop, N. & Wright, J. 2017 Geographic distribution of registered packaged water production in Ghana: implications for piped supplies, groundwater management and product transportation. *Water* **9** (2), 142.
- Eaton, A., Clesceri, L., Greenberg, A. & Franson, A. 1995 *Standard Methods for the Examination of Waste and Wastewater*. American Public Health Association, Washington, DC, USA.
- Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L. & Colford, J. M. 2005 Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *Lancet Infectious Diseases* **5**, 42–52.
- Fianko, J. R., Adomako, D., Osa, S., Ganyaglo, S., Kortatsi, B. K., Tay, C. & Gliver, E. T. 2010 The hydrochemistry of groundwater in the Densu River Basin, Ghana. *Environmental Monitoring and Assessment* **167**, 663–674.
- Fisher, M. B., Williams, A. R., Jalloh, M. F., Saquee, G., Bain, R. E. S. & Bartram, J. K. 2015 Microbiological and chemical quality of packaged sachet water and household stored drinking water in Freetown, Sierra Leone. *PLoS ONE* **10** (7), e0131772.
- Ghana Food and Drugs Authority. 2015 *Registered Products [Online]*. Ghana Food and Drugs Authority, Accra, Ghana. Available: http://www.fdaghana.gov.gh/index.php?option=com_fdasearch&Itemid=36 (accessed 10 November 2015).
- Ghana Standards Authority 2005a *Code of Hygienic Practices for the Collection, Processing, and Marketing of Potable Water*. Ghana Standards Authority, Accra, Ghana.
- Ghana Standards Authority 2005b *Water Quality – Specification for Natural Mineral Water*, 2nd edn. Ghana Standards Authority, Accra, Ghana.
- Ghana Standards Authority 2009 *Water Quality – Specification for Drinking-Water*. Ghana Standards Authority, Accra, Ghana.
- Ghana Statistical Service 2014 *Ghana Living Standards Survey Round 6 Main Report*. Accra, Ghana.
- Ghana Statistical Service (GSS), Ghana Health Service (GHS) & ICF International 2015 *Ghana Demographic and Health Survey 2014*. Rockville, MD, USA.
- Gronwall, J. & Oduro-Kwarteng, S. 2018 Groundwater as a strategic resource for improved resilience: a case study from peri-urban Accra. *Environmental Earth Sciences* **77**, 6.
- Hrudey, S. E., Hrudey, E. J. & Pollard, S. J. T. 2006 Risk management for assuring safe drinking water. *Environment International* **32**, 948–957.
- Johnston, R. & Amoako-Mensah, S. 2014 *Water Quality Module of the Ghana Living Standards Survey VI: Monitoring Household Drinking Water Quality Through a Household Survey*. *Water and Health – Where Science Meets Policy*. University of North Carolina, Chapel Hill, NC, USA.
- Jones, F. & Harris, G. 1992 ITS-90 density of water formulation for volumetric standards calibration. *Journal of the National Institute of Standards and Technology* **97**, 335–340.
- Kumpel, E., Cocci-Esteb, A., Duret, M., De Waal, D. & Khush, R. 2017 Seasonal variation in drinking and domestic water sources and quality in Port Harcourt, Nigeria. *American Journal of Tropical Medicine and Hygiene* **96**, 437–445.
- National Agency for Food and Drug Administration and Control 2015 *Registered Food Products [Online]*. National Agency for Food and Drug Administration and Control, Lagos, Nigeria. Available: <http://www.nafdac.gov.ng/index.php/product-registration/registered-food-products> (accessed 10 November 2015).
- Obiri-Danso, K., Okore-Hanson, A. & Jones, K. 2005 The microbiological quality of drinking water sold on the streets in Kumasi, Ghana. *Letters in Applied Microbiology* **37**, 334–339.
- Olaoye, O. A. & Onilude, A. A. 2009 Assessment of microbiological quality of sachet-packaged drinking water in Western Nigeria and its public health significance. *Public Health* **123**, 729–734.
- Orisakwe, O. E., Igwilo, I. O., Afonne, O. J., Maduabuchi, J.-M. U., Obi, E. & Nduka, J. C. 2006 Heavy metal hazards of sachet water in Nigeria. *Archives of Environmental & Occupational Health* **61**, 209–213.
- Rao, J. & Scott, A. 1984 On chi-squared tests for multi-way contingency tables with cell proportions estimated from survey data. *Annals of Statistics* **12**, 46–60.
- Rodwan, J. 2014 *Bottled Water 2013: Sustaining Vitality – US and International Developments and Statistics*. *Bottled Water Reporter*. International Bottled Water Association, Alexandria, VA, USA.
- Sima, L. C., Kelner-Levine, E., Eckelman, M. J., McCarty, K. M. & Elimelech, M. 2013 Water flows, energy demand, and market analysis of the informal water sector in Kisumu, Kenya. *Ecological Economics* **87**, 137–144.
- Stoler, J., Fink, G., Weeks, J. R., Otoo, R. A., Ampofo, J. A. & Hill, A. G. 2012a When urban taps run dry: sachet water consumption and health effects in low income neighborhoods of Accra, Ghana. *Health & Place* **18**, 250–262.
- Stoler, J., Weeks, J. R. & Fink, G. 2012b Sachet drinking water in Ghana's Accra-Tema metropolitan area: past, present, and future. *Journal of Water Sanitation and Hygiene for Development* **2**, 223–240.
- Stoler, J., Tutu, R. A., Ahmed, H., Frimpong, L. A. & Bello, M. 2014 Sachet water quality and brand reputation in two low-income urban communities in Greater Accra, Ghana. *American Journal of Tropical Medicine and Hygiene* **90**, 272–278.
- WHO/UNICEF 2014 *WASH Post-2015: Proposed Targets and Indicators for Drinking-Water, Sanitation and Hygiene*. Geneva, Switzerland.
- World Health Organization 2003 *Total Dissolved Solids in Drinking-Water*. Geneva, Switzerland.
- World Health Organization & UNICEF 2015 *Progress on Sanitation and Drinking-Water: 2015 Update and MDG*

Assessment. World Health Organization, Geneva, Switzerland.

- Wright, J., Gundry, S. & Conroy, R. 2004 Household drinking water in developing countries: a systematic review of microbiological contamination between source and point-of-use. *Tropical Medicine & International Health* **9**, 106–117.
- Wright, J., Dzodzomenyo, M., Fink, G., Wardrop, N. A., Aryeetey, G. C., Asanu, R. M. & Hill, A. G. 2016a Subsidized sachet water to reduce diarrheal disease in young children: a feasibility study in Accra, Ghana. *American Journal of Tropical Medicine and Hygiene* **95**, 239–246.
- Wright, J., Dzodzomenyo, M., Wardrop, N. A., Johnston, R., Hill, A., Aryeetey, G. & Adanu, R. 2016b Effects of sachet water consumption on exposure to microbe-contaminated drinking water: household survey evidence from Ghana. *International Journal of Environmental Research and Public Health* **13**, 303.
- Yang, H., Bain, R., Bartram, J., Gundry, S., Pedley, S. & Wright, J. 2013 Water safety and inequality in access to drinking-water between rich and poor households. *Environmental Science & Technology* **47**, 1222–1230.
- Zelner, J. L., Trostle, J., Goldstick, J. E., Cevallos, W., House, J. S. & Eisenberg, J. N. S. 2012 Social connectedness and disease transmission: social organization, cohesion, village context, and infection risk in rural Ecuador. *American Journal of Public Health* **102**, 2233–2239.

First received 1 March 2018; accepted in revised form 9 May 2018. Available online 30 May 2018