Research Paper

Characteristics of packaged water production facilities in Greater Accra, Ghana: implications for water safety and associated environmental impacts

Maxwell D. K. Semey, Winfred Dotse-Gborgbortsi, Mawuli Dzodzomenyo and Jim Wright

ABSTRACT

Packaged water (sold in bags or bottles) is widely consumed in many countries and is the main drinking-water source for most urban Ghanaian households. There are, however, few studies of packaged water production. This study aims to assess the source water, treatment, and manufacturing characteristics of sachet water (vended in 500 mL plastic bags), together with point-of-manufacture risks to hygienic production. A sample of 90 sachets was collected of brands sold in four neighbourhoods in Accra, Ghana, their packaging and physical characteristics recorded, and a risk score calculated from these. Production processes were observed at 60 associated sachet factories, producers interviewed, and surrounding neighbourhoods surveyed for contamination hazards. 80% of producers packaged groundwater from boreholes and all treated water via reverse osmosis. Almost all manufacturers (95%) reported site visits by regulators in the previous year and few risks to hygienic production were observed at factories. Sanitary risk scores were 9.2% higher at the seven factories never visited by a regulator, though this difference was not significant ($t = 1.81$; $p = 0.07$). This survey suggests most Ghanaian sachet water originates from groundwater and is comparatively safe, though a minority remains unregulated. Groundwater governance policy could support this industry in meeting Greater Accra's growing water demand through the designation of protected municipal wellfields.

Key words | groundwater, packaged water, urbanisation, water pollution, water safety

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INTRODUCTION

There has been a rapid growth in packaged water (i.e. water sold in bottles or plastic bags, the latter called 'sachets' in West Africa) consumption globally, with one or more people in five using packaged water as their main source in 15 countries in 2010–2016 (World Health Organization and UNICEF 2017). Mixed methods studies (Stoler *et al.* 2015) suggest that this growth reflects both the convenience of packaged water for consumers and its availability through periods of urban piped water supply interruptions. In Ghana, urban households reporting packaged water as their main drinking-water source rose from 16.8% in 2008 to 53.6%, equivalent to 8.3 million people, in 2017 (Ghana Statistical Service *et al.* 2018). Managing packaged water safety requires a sound understanding of manufacturing

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processes and source waters, a particular challenge given fragmented urban groundwater governance (Howard 2015). For example, public health risks relating specifically to groundwater contamination may include geogenic contaminants such as arsenic and fluoride (Amini *et al.* 2008) and in urban areas, leaking sewage pipes, leachates from land uses, such as refuse dumps, contaminants from industrial activity, and from petrol stations (Lapworth *et al.* 2017). Urbanisation is resulting in increasing water resource use at ever greater distances from Sub-Saharan cities (Showers 2002). Water may be packaged from groundwater or from piped (tap) water. In Ghana, the Ghana Water Company Limited (GWCL) is the national urban water utility and while GWCL treats piped water, running two treatment plants in Accra, water supplied to consumers is frequently microbially contaminated (Wright *et al.* 2016). If the packaged water industry predominantly relies on groundwater, then there is a need to ensure groundwater volumes abstracted to meet demand from such a large population will not result in problems such as saline intrusion into coastal aquifers, as reported in some West African urban aquifers (Nlend *et al.* 2018). If production is based on piped water, then the impact of urban sachet consumption on water resource use will be reflected in that of GWCL more generally.

Ghana's regulator, the Ghana Standards Authority (GSA), requires water to be packaged from a potable source and requires the final end product water to be free from parasites and have no detectable coliform bacteria, *Streptococci*, or *P. aeruginosa* in 250 mL (Ghana Standards Authority 2005). The GSA makes no specific prescriptions about water treatment methods but requires hygienic production conditions, such as adequate lighting and ventilation, regular cleaning and disinfection of equipment, and adequate sanitation, waste disposal, and hand-washing facilities at production premises. Packaging should protect water from contamination and odours and reusable containers should be disinfected if there is a contamination risk.

Systematic review evidence concerning faecal indicator bacteria in packaged water suggests low contamination prevalence (Williams *et al.* 2015). Most included studies tested point-of-sale or consumption samples, and there are few studies examining the safety of conditions under which sachet water is produced. In Ghana, several studies have found minimal faecal indicator bacteria at point-of-sale (Stoler *et al.* 2014; Dzodzomenyo *et al.* 2018), while a nationally representative water quality survey found significantly lower *E. coli* contamination in sachet water compared with water piped to the home (Wright *et al.* 2016). However, there have been no studies examining hygiene risks during sachet production in Ghana.

Relatively few studies have examined the production processes underpinning water manufacturing. In Ghana, one study conducted *ad hoc* interviews with several producers (Stoler *et al.* 2012), finding they packaged sachets from piped water, while a more recent study (Gronwall & Oduro-Kwarteng 2018) found several sachet manufacturers packaging groundwater from boreholes. Piped water tariffs for water packaging companies were the same as for other commercial users in 2005 (US$0.78/1,000 L) but are now 6.1 times higher ($12.84/1,000 L rather than $2.11/1,000 L) (Public Utilities Regulatory Commission 2016). This may have incentivised packaging of groundwater, rainwater, or even surface waters over piped water, but there is no published evidence of producers switching to other sources from piped water.

A *production facility* survey also provides an opportunity to evaluate *point-of-sale* packaged water surveillance methods. Some earlier studies have used sachet packaging characteristics such as printed product registration numbers as indicators of regulatory oversight of brands (Olaoye & Onilude 2009; Dzodzomenyo *et al.* 2018), but it is unclear if packaging characteristics correlate with contamination risks during production. The geography of sachet production has also been mapped via geocoding of printed addresses on packaging and distances between point-of-manufacture and point-of-sale estimated, but the precision of such mapping is unclear (Dzodzomenyo *et al.* 2017). Distances between point-of-manufacture and sale affect the industry's transport-related environmental impacts.

This study therefore aims to quantify sachet manufacturing processes in plants serving urban Accra including risks to hygienic production, contact between sachet producers and regulators, and producers' rationale for their decisions concerning manufacturing processes. It also aims to compare point-of-sale sachet packaging characteristics with observed hazards and reported regulator contact at production facilities, so as to evaluate how far packaging reflects the hygienic integrity of production.

METHODS

Overview of study site: sachet production in Greater Accra, Ghana

In Ghana, packaged water production is overseen by two government regulators, the Food and Drugs Authority (FDA) and the GSA. The GSA maintains the standards for natural mineral water and other packaged waters, while the FDA ensures its hygienic production (Stoler *et al.* 2012). Producers registered with the GSA are permitted to use its seal of conformity ('kite mark'), while producers licenced through the FDA are provided with a registration number.

Sample design

Through a two-phase cross-sectional, observational study, an initial market surveillance phase was used to record sachet brands on sale in Accra, with manufacturer details on packaging then used to recruit producers to a follow-up questionnaire survey. Four Accra neighbourhoods were chosen with contrasting socio-economic conditions. As shown in Figure 1, two neighbourhoods (Pig Farm and Abeka) were characterised by poorer quality housing and higher population density, while two (East Legon and Roman Ridge) had higher quality housing and lower population density. We chose these contrasting neighbourhoods, addressing a hypothesis that cheaper brands would target low-income neighbourhoods (Stoler *et al.* 2014). To reduce prices, such brands might avoid the costs associated with regulation, thereby compromising hygienic sachet production.

In initial market surveillance, all fixed retail outlets in each area were visited and one sachet sample collected at random from brands on sale at each outlet. The manufacturer details printed on each sampled brand's packaging were then used to request interviews with producers. The sample size was powered to estimate the proportion of sachet producers using groundwater, assumed to be 50% in the absence of any published estimate. On this basis, a

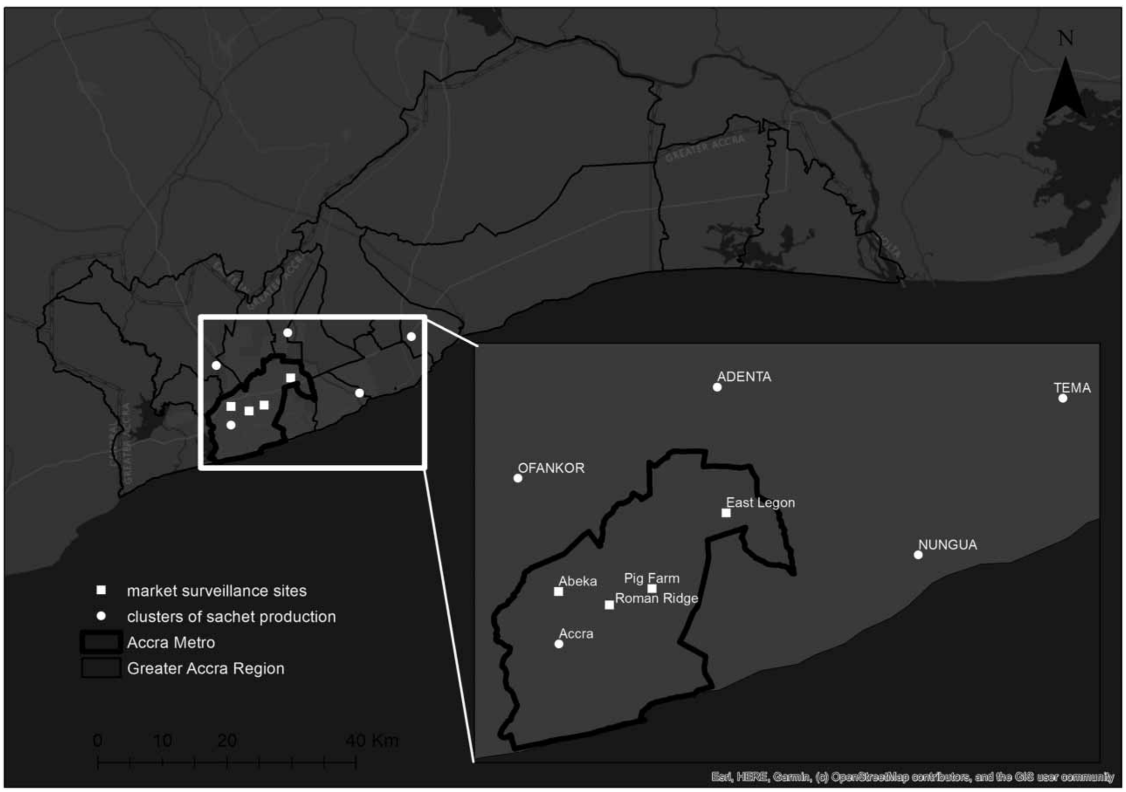

Figure 1 | Locations in Greater Accra visited during initial market surveillance and subsequent sachet producer survey.

random sample size of 60 producers was planned, powered to detect this proportion with 95% confidence limits of 12.6%, assuming binomial confidence intervals (Brown et al. 2001). To recruit this number of producers, we assumed that we would need to identify at least 72 brands through market surveillance, allowing for a 20% refusal rate among producers. We chose to interview manufacturers of brands on sale in Accra rather than interviewing GSA or FDA staff, since some brands are unregistered with the regulators (Dzodzomenyo et al. 2018) and therefore absent from their records.

Market surveillance

Following Dzodzomenyo et al. (2018), details printed on sachet packaging were recorded, alongside prices, any visible particles or water discolouration, the nature of the sachet plastic and print (e.g. blurred print, a frayed seal), and storage conditions. Supplementary Materials 1 contains the form for recording these observations; retailers were not interviewed during market surveillance. The nature of sachet plastic was assessed on its thickness and texture as low or high quality by the survey team, following a previous study (Stoler et al. 2014). Given a water density of 0.996 g/cm^3 at an ambient temperature of 30 °C, the water in a 500 mL sachet should weigh 497.8 g, with an additional 2 g for primary packaging, totalling approximately 500 g (Dzodzomenyo et al. 2018). Sachet samples were therefore subsequently weighed in the laboratory, since sample volumes deviating from 500 g could signify less robust production processes. Retail outlet locations were recorded using hand-held Global Positioning System (GPS) receivers. Market surveillance fieldwork took place between 28 April 2018 and 30 May 2018.

Follow-up manufacturer survey

Using contact details from packaging or by obtaining producers' contact details from retailers, interviews were requested with manufacturers of sampled sachets. Producers' informed consent was sought over the phone and at the start of each interview. A visit to the production premises was then arranged and a structured interview based around a questionnaire comprising mostly closed questions was then administered to each respondent (see Supplementary Materials 2 for the questionnaire used). Through the interview, producers were asked about their business history, source waters, typical production and storage capacity, treatment processes, contact with regulators and business challenges. Facility locations were surveyed with a hand-held GPS receiver and non-participant observations made concerning factory conditions, based on the GSA's protocol for inspecting production premises (Ghana Standards Authority 2005). Observations included whether workers were wearing footwear and headgear, whether floors and walls were tiled white, presence of toilet facilities, hand-washing facilities with soap and hygiene signage, adequate lighting, and presence of waste. Following the interview, the surrounding neighbourhood was surveyed to identify potential groundwater contamination hazards, including petrol stations, industrial facilities, and refuse dumps.

Ethical approval for the study was obtained from the Ghana Health Services Ethics Review Committee (10 April 2018; ref no: 067/02/18).

Analysis

Production locations printed on packaging were geocoded via Google Maps (Google 2019), and the median and maximum distance calculated between geocoded facility locations versus true locations recorded via GPS. Distances were calculated between point-of-sale and point-of-manufacture from GPS and geocoded coordinates. Sachet brand details and printed registration numbers were cross-checked against the FDA's database of registered sachet products (Ghana Food & Drugs Authority 2019). To assess possible selection bias in the follow-up sample, we tested for significant differences in sachet characteristics between brand-franchises with and without such follow-up interviews using chi-square tests, Fisher's exact test, or a *T*-test.

The percentage of indicators of an unregulated or poorly produced sachet (i.e. lack of a GSA 'kite mark', lack of a printed FDA registration number, visible particles in water, poor quality packaging, and lack of an FDA database record matching packaging details) was calculated for each brand from market surveillance data, as was the percentage of risks to hygienic production observed at each factory to form a sanitary risk score. The mean recorded sachet weight was compared to an anticipated weight of 502 g via a T-test. Pearson's correlation coefficient was calculated for the packaging risk score versus the risk score for hazards at the manufacturing facility. Risk scores for manufacturing facilities reporting contact with regulators versus those never visited were compared via least squares regression. All statistical analyses were undertaken in Stata v15.

RESULTS

Flow of sachet samples and participants

Figure 2 shows the flow of sampled point-of-sale sachets and subsequent producer interviews. 90 kiosks or stores were sampled in total, resulting in samples of 76 sachet brand-franchises (several brands were produced at multiple franchised production premises rather than a single factory and are hereafter referred to as brand-franchises). Only 40 producers could be recruited to the study by contacting the manufacturers of these 76 brand-franchises. Therefore, to meet the planned sample size of 60 producer interviews, the 40 recruited producers were asked to identify other sachet producers known to them. These other producers were then contacted, thereby enabling the recruitment of an additional 20 producers through referral sampling.

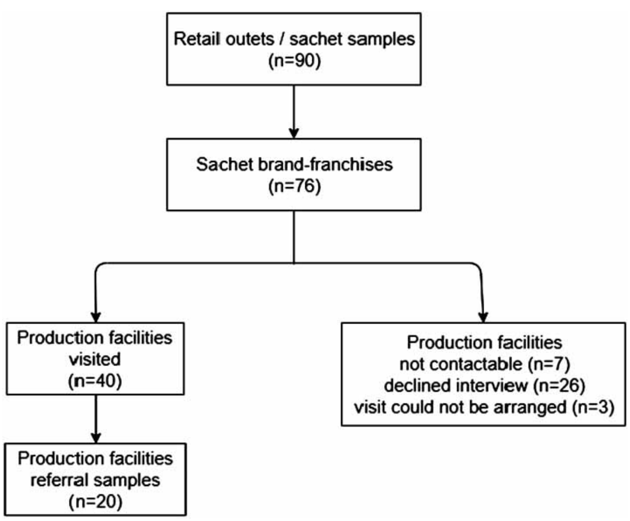

Figure 2 | Flow chart showing numbers of retail premises visited, sachet samples collected through market surveillance, and subsequent recruitment of sachet producers.

Market surveillance

Table 1 summarises the characteristics of franchise-brands identified through market surveillance, differentiating between franchise-brands with and without follow-up producer interviews, so as to quantify any significant differences between producers interviewed for our study and those who were not. Franchise-brands where producers agreed to an interview more frequently had printed GSA kite marks and FDA registration numbers, with higher quality plastic. Such brands more often had printed details that exactly matched FDA records and were slightly less often sold in the low-income areas, though neither difference was statistically significant. The franchise-brands with producer interviews were also significantly more expensive and had significantly fewer sachets with visible particles, suggesting our sample was biased towards more expensive brands. Where a specific production location was printed on packaging and geocoded, the median distance between the geocoded location and that recorded by GPS was 2.1 km ($n = 20$; maximum error 25.8 km). Where no separate production address was printed, the median distance between geocoded and actual production locations was 8.8 km ($n = 16$; maximum error 33.7 km). Clusters of sachet production were noticeable in Adenta, Tema, Nungua, and Ofankor (see Figure 1). The average weight of sampled sachets was 480.5 g (standard deviation 20.7 g), significantly lower than the 500 g expected for 500 mL of water in 2 g of packaging ($t = -7.98, p < 0.001$). More brand-franchises whose details exactly matched FDA records were found in high- versus low-income areas (47.8% versus 35.9%), but this difference was not significant (chi = 0.96; $p = 0.33$). The high standard deviation suggests that many producers find it difficult to control the water volumes packaged using the heat-sealing 'koyo' machinery commonly used. The lower than anticipated weights suggest an attempt to maximise profitability by reducing raw material costs, given that production costs were the most frequently cited business challenge among respondents.

Manufacturer survey

Table 2 shows the characteristics of sachet production facilities visited, separating the referral sample from producers traced through market surveillance. Most facilities (80%)

Table 1 | Characteristics of 76 sachet franchise-brands on sale in two high-income and two low-income neighbourhoods in Accra, Ghana, with and without follow-up visits to production premises

Characteristic	Follow-up interview conducted at production premises – % (*n*)	No follow-up interview – % (*n*)
Packaging		
Printed GSA kite mark	92.5% (37)	86.1% (31)
Printed FDA registration number	67.5% (27)	58.3% (21)
Poor quality of plastic/print	37.5% (15)	50.0% (18)
Match to FDA registered product database		
Exact: Printed registration number and brand match FDA database	45.0% (18)	33.3% (12)
Partial: No printed registration number but brand on FDA database	15.0% (6)	11.1% (4)
Partial: Brand on FDA database but printed registration number does not match database	5.0% (2)	5.6% (2)
No match: Printed registration number but brand and registration number not on FDA database	10.0% (4)	19.4% (7)
No match: no printed registration number; brand not on FDA database	25.0% (10)	30.6% (11)
Other characteristics		
Visible particles in sachet water[a]	67.5% (27)	97.2% (35)
Mean price (US$) per 500 mL sachet[a]	$0.031	$0.024
Median Distance (km) between point-of-manufacture and sale (from GPS)	10.1	N/A
Median distance (km) between point-of-manufacture and sale (from geocoded production address)	9.3	13.7
On sale in low-income neighbourhood	75.0% (30)	63.9% (23)
Total	40	36

[a]Indicates statistically significant difference between groups at alpha = 99%.
Source: primary data from sachet market surveillance survey).

were packaging groundwater from boreholes, not piped water, most frequently citing either supply continuity (47%) or cost (18%) as reasons for this. Only one longstanding producer reported switching to groundwater since beginning production. However, only six producers were in business when the higher tap-water tariff for sachet producers was introduced in 2006. Virtually all producers had storage tanks, citing either greater control over water pressure, buffering against supply interruptions, or holding water after pre-filtration as reasons for this. Only seven producers (11.7%) had sufficient tank capacity to store water for a day's sachet production, however. Sachet volumes produced varied greatly, with the largest producer manufacturing 180,020 L/day compared to 3,628 L/day for the smallest producer. Using previously published estimates of primary sachet plastic packaging (Wardrop *et al.* 2017), the largest facility's sachet production equated to 223.4 tonnes of plastic/year.

Most facilities used multiple treatment technologies, observable by the interviewer, typically combining pre-filtration, reverse osmosis, and ultra-violet treatment. Chlorination was seldom used, while all producers used reverse osmosis. While the GSA does not require any specific treatment technology according to its standards, investing in such treatment technologies would enable producers to meet the GSA's microbiological standards for packaged water. Furthermore, as noted by some respondents, reverse osmosis reduces saltiness, making water more palatable for consumers.

Nearly all producers (95%) reported contact with the FDA or GSA, with 88.3% reporting an on-site visit from a regulator. Those who did report regulatory contact were either new market entrants operating for less than a year, or respondents lacking knowledge of approvals and other key business information, such as production volumes.

Table 2 | Production facility characteristics and reported contact with regulators for 60 sachet manufacturers in Greater Accra, Ghana (*source*: primary data from manufacturer survey)

Production facility characteristic	Referral sample – % of producers (*n*)	Follow-up sample traced from market surveillance – % of producers (*n*)	Both samples – % of producers (*n*)
Borehole used as main water source	75.0% (15)	82.5% (33)	80% (48)
Mean ratio of source water used to sachets produced	5.1	3.8	4.2
Mean storage tank capacity (L)	6,500	14,738	12,358
Mean sachet volume produced (L/day)	28,053	32,349	30,673
Mean years' operating as a business	6.6	5.9	6.1
Treatment processes			
Reverse osmosis	100%	100%	100%
Pre-filtration	65.0% (13)	90.0% (36)	81.7% (49)
Ultra-violet treatment	75.0% (15)	72.5% (29)	73.3% (44)
Chlorination	10.0% (2)	2.5% (1)	5.0% (3)
Facility visit by regulator			
Within last 6 months	40.0% (8)	27.5% (11)	31.7% (19)
Within 7–12 months	50.0% (10)	47.5% (19)	48.3% (29)
Over 12 months ago	0%	12.5% (5)	8.3% (5)
Never	10.0% (2)	12.5% (5)	11.7% (7)
Contact with regulators			
Had contact with FDA only	10.0% (2)	17.5% (7)	15.0% (9)
Had contact with GSA only	10.0% (2)	5.0% (2)	6.7% (4)
Had contact with both FDA and GSA	70.0% (14)	75.0% (30)	73.3% (44)
No contact with regulators	0	2.5% (1)	1.7% (1)
Not known	10.0% (2)	0	3.3% (2)

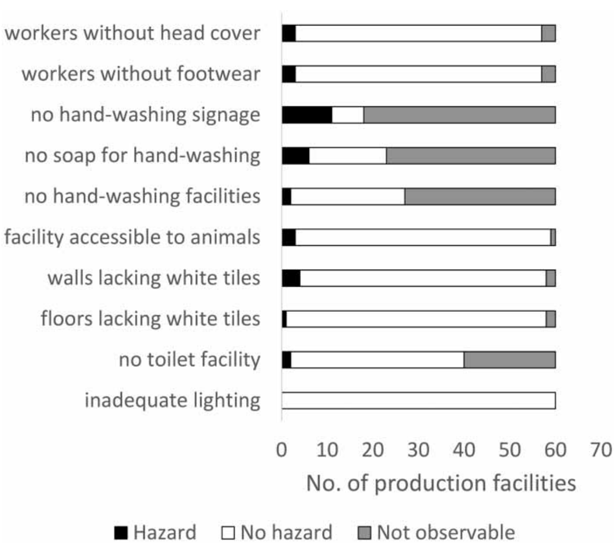

Figure 3 | Hygienic production risks observed at 60 sachet production facilities (*source*: primary data from manufacturer survey).

Figure 3 shows hygienic production risks observed at production facilities. Apart from a lack of signage concerning handwashing, other hazards, such as staff working barefoot, were observed at only a few production facilities. Most facilities had low sanitary risk scores (i.e. percentage hazards observed), with a median score of 16.7%. 5% had scores of 50% or more.

The percentage of hazards observed at production facilities was uncorrelated with the associated vended sachet risk score ($R = -0.11$, $p = 0.50$, $n = 40$). Sanitary risk scores for production facilities were 9.2% higher among the seven producers who had never been visited by a regulator, though this difference was not significant ($t = 1.81$; $p = 0.07$). This difference may reflect producers investing in more hygienic production facilities as a consequence of visits by the regulators. Point-of-sale risk scores based on sachet packaging and appearance were 19.3% higher among the five producers traced from factories never visited by a regulator, but this was not significant ($t = 1.41$; $p = 0.17$).

DISCUSSION

The producer survey presented here suggests relatively few risks to hygienic sachet production, widespread regulatory oversight, and widespread treatment of the water packaged by producers. This is consistent with low faecal indicator bacteria contamination reported for point-of-sale sachet water in Ghana (Stoler *et al.* 2014; Wright *et al.* 2016). Risks to hygienic production were directly observed at only a few production facilities and groundwater contamination hazards in the immediate vicinity of these facilities were also observed in only a few instances. All producers were using reverse osmosis to treat their water and most were using multiple forms of water treatment. Since GSA standards do not stipulate a particular form of water treatment (Ghana Standards Authority 2005), this multiple water treatment strategy appears to be a mechanism for managing contamination risks in the source water. Reverse osmosis has the additional benefit of reducing water saltiness and making it more palatable to consumers, while pre-filtration reduces 'fouling' of membranes and thereby associated operating costs. Most sachet brand registration details on packaging matched to FDA records, and most producers reported an on-site regulatory visit in the past year. These findings are consistent with evidence that point-of-consumption packaged water is less microbially contaminated than piped water, both internationally based on the systematic review (Williams *et al.* 2015) and within (Wright *et al.* 2016). Nonetheless, there remain a minority of unregulated sachet producers and risks to hygienic production were observed at a minority of facilities, suggesting some unregulated and thus potentially unsafe production occurred.

The producer survey also shows that sachet water is mostly produced from groundwater rather than piped water, abstracted via boreholes with reverse osmosis treatment. This is consistent with recent reports of *ad hoc* interviews with individual sachet producers in Accra (Gronwall & Oduro-Kwarteng 2018) but contradicts some earlier descriptions of sachet production (Stoler *et al.* 2012). As Sub-Saharan Africa's cities' utilities struggle to keep pace with urbanisation, it is well known that many slum residents have used hand-dug wells to cope with intermittent or non-existent piped supplies (Lapworth *et al.* 2017), while wealthier residents often sink boreholes. Since they draw on deep groundwaters, boreholes are typically less microbially contaminated than hand-dug wells but are costly to install and therefore preferred by the wealthy. In contrast, hand-dug wells are an affordable 'self-supply' technology, enabling poorer communities often lacking main water supplies to access more contamination-prone, shallow groundwaters, often for domestic purposes other than drinking. Our study highlights a third mechanism by which urban water demand, unserved or partially served by piped water service providers, is being met through groundwater extraction, namely the packaging and selling of groundwater from boreholes.

Risk scores for identifying potentially hazardous sachet brands at point-of-sale (e.g. those lacking a printed product registration number on packaging) were higher for production facilities that had never been visited by a regulator, as was the number of risks to hygienic production observed at the production facility. However, given the small proportion of unregistered producers, neither difference was significant. The proportion of brand-franchises whose details exactly matched FDA records was greater for retail outlets in high-income than low-income areas, though this difference was not statistically significant given the small sample size. In keeping with other studies (Wright *et al.* 2016), there is thus no evidence here to suggest that poorer households are differentially exposed to unregulated and thereby potentially unsafe sachet water.

Our study provides quantitative evidence relevant to three of the industry's environmental impacts, namely product transport, groundwater abstraction, and plastic packaging. In terms of product transport, distances between point-of-manufacture and sale were similar, whether calculated from geocoded production locations or their true GPS coordinates. However, while geocoded production locations might be suitable for regional or national mapping, delineation of a protected wellfield or other uses of such geospatial data (e.g. examining links between sachet water distribution and diarrhoeal disease outbreaks) would require more precise locational data from field-based surveys.

Almost all distances to point-of-sale (97%) were less than 25 km, confirming earlier findings (Dzodzomenyo *et al.* 2018) that sachet production occurs close to centres of consumption. Shorter transportation journeys should reduce associated environmental impacts from truck emissions, but these vehicles will still contribute to traffic on Greater Accra's congested road network. Widespread use of groundwater abstraction through boreholes highlights a need to monitor water table levels in areas such as Dodowa, where sachet manufacturing is prevalent, and to assess arrangements for outflow of brine from reverse osmosis. We also show that there is a wide variation in the volumes of sachet water manufactured. This implies that initiatives such as promoting plastic additives for biodegradation of sachet sleeves could first be targeted at the largest producers with the greatest market share.

Our study is subject to several limitations. We were unable to conduct follow-up interviews with nearly half of sachet manufacturers identified through market surveillance and resorted to referral sampling instead. Manufacturers unavailable for follow-up visits produced significantly cheaper brands and less frequently printed product registration numbers on packaging that matched to FDA records. This suggests there may have been selection bias towards better regulated and therefore more hygienic production facilities in our producer survey. In other words, unregulated producers were under-represented in the survey. Our study design relied on low- versus high-income case study neighbourhoods rather than a regionally representative survey. Brands on sale in the case study neighbourhoods may thus be unrepresentative of the wider region and we did not find a greater prevalence of unregulated brands in low-income areas as anticipated in our sample design. One study (Fisher *et al.* 2015) has tested sachet water for faecal indicator bacteria at point-of-manufacture, during transport, sale, and at point-of-consumption, finding some post-production deterioration in its safety. We have not considered such post-production risks in our study, for example, as users tear the exterior of sachet packaging. The interviews may also be subject to courtesy bias, with producers over-reporting contact with regulators. The cross-sectional, non-participant observation used to assess risks to sanitary production could have influenced the behaviour of factory staff and missed transient contamination hazards, thereby over-estimating the safety of sachet manufacturing.

While this producer survey provides evidence from the point-of-manufacture that suggests most, but not all, sachet brands are comparatively safe, evidence gaps remain, particularly concerning the industry's environmental externalities. It is unclear, for example, how far sachet delivery trucks contribute to traffic congestion and air pollution, how brine waste from reverse osmosis might affect the environment, and how many households practice waste separation and recycling of used sachet plastics (Wardrop *et al.* 2017). The presence of micro-plastics in sachet water has also not been assessed, though their presence has been quantified in bottled water (Schymanski *et al.* 2018). Internationally, there are also evidence gaps for other countries such as Togo where 9.0% of urban households used packaged water as their main source in 2014 (Ministere de la Planification du Developpement et de l'amenagement du territoire *et al.* 2015), but which lack any published studies on its safety or environmental impacts.

There are calls for policy to work with urban households currently abstracting groundwater via 'self-supply' shallow wells, for example, through provision of technical support, so as to reduce demand on municipal water utilities (Foster *et al.* 2018). In the same way, policy could work with the sachet manufacturing industry, so as to alleviate the pressures of rapid urbanisation on the national water company, Ghana Water Services Limited. One solution could be the delineation of protected municipal wellfields as previously advocated for developing cities (Foster *et al.* 2011). Such delineation of protected wellfields could draw on the existing spatial distribution of sachet manufacturing, following the methods presented in this study and previous work (Dzodzomenyo *et al.* 2017).

CONCLUSIONS

The producer survey undertaken here suggests that most sachet water is subject to some form of regulatory oversight, and risks to hygienic production at and surrounding production facilities are not widespread. However, there remain a minority of unregulated producers and some using riskier production processes. Continued market surveillance is needed to address the public health risks posed by these producers and to monitor this complex and dynamic industry. This evidence is consistent with low faecal indicator bacteria contamination in sachets at point-of-sale. Most producers interviewed manufactured sachets from groundwater, abstracting this via boreholes close to Accra and treating it with reverse osmosis. Given that water piped to the home is subject to some microbial contamination and interruptions in Greater Accra, this industry could be viewed as a private sector-led initiative to meet the water service gaps of a rapidly urbanising region. Groundwater governance policy could support the industry in supplementing urban piped water through the delineation of protected municipal wellfields, where land use is controlled to reduce aquifer degradation.

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AUTHOR CONTRIBUTIONS

M.D. and J.A.W. conceived and designed the analysis; M.S. undertook data collection; M.S., W.D., and J.A.W. processed and analysed the data; J.A.W. and M.D. drafted the paper.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this paper is available online at https://dx.doi.org/10.2166/washdev.2020.110.

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