Research Paper

Physicochemical and bacteriological quality of sachet water used by Ghanaian university students: implications for public health

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ABSTRACT

This study analyses the quality of sachet water consumed by university students in Metropolitan Kumasi, Ghana. Thirty sachet water samples from ten different brands were tested for their physical and bacteriological quality using meters and titrimetric method and most probable number method, respectively. Overall, *one half* of the sachet water samples were highly contaminated with total and faecal coliform. While the mean total coliform/100 mL concentration of ANG, NOV, IM, PD and DKN were 9.15×10^5, 2.35×10^6, 9.15×10^5, 4.15×10^5 and 9.15×10^5 respectively, we recorded faecal coliform counts of 2.3×10^5, 4.15×10^5, 2.3×10^5, 2.3×10^5 and 2.3×10^5, respectively for ANG, NOV, IM, PD and DKN. Moreover, samples from DKN brand showed *Escherichia coli* count of 4.0×10^4. The conductivity ranged from 2.24 μS/cm to 43.60 μS/cm while the mean total alkalinity of all samples ranged from 33.33 mg/L to 120 mg/L. The coliform contamination levels of the water samples violated the guidelines and standards of WHO for drinking water quality. Ghanaian regulatory agencies should intensify the monitoring and surveillance activities to ensure compliance with strict hygienic measures by sachet water producers.

Key words | bacteriological analysis, faecal coliform, public health, sachet water, university students, water quality

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INTRODUCTION

Universal access to safe drinking water, sanitation and hygiene has become essential for human health and well-being outcomes. Although this topic has received much attention in the public health research and policy frameworks in the richer economies, service levels and research considerations are generally low in many low- and middle-income countries (LMICs) (Behnke *et al.* 2018). Paradoxically, like most sub-Saharan African countries, waterborne diseases constitute a major public health challenge and poor health among populations in LMICs (WHO 2008; Stoler *et al.* 2012). The World Health Organization (WHO 2010) noted that quality of drinking water is an essential environmental determinant of health.

Estimates show that about 80% of all disease episodes in developing countries are directly or indirectly related to lack of quality potable water (WHO 2011; Isa *et al.* 2013). Safe drinking water is, therefore, a basic need for human development (WHO 2011). However, the supply of safe drinking water is being threatened by rapid urban growth in developing countries including sub-Saharan African region (WHO 2010, 2011; Stoler *et al.* 2015). Access to safe drinking water is one of the main development agendas of the Government

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of Ghana, but the dream remains far from reach, partly due to resource constraints (Ghana Statistical Service 2014).

In effect, the ever growing urban communities in Ghana suffer lasting inadequacy in water quality and quantity largely due to poor water resource management systems (Nsiah-Gyabaah 2001). Production and distribution of drinking water, the sachet water ('pure water' as mostly referred to), to urban dwellers have, therefore, emerged to make up the clean or safe drinking water deficit (Stoler *et al.* 2012; Adewoye *et al.* 2013). Data from the 2014 Ghana Demographic and Health Survey indicate that up to 44.5% of the Ghanaian urban population rely on sachet water (Ghana Statistical Service 2015). Indeed, the influx of the commodification of sachet water is recognised as the fastest growing venture in Ghana. Most consumers perceive sachet water as a relatively safer alternative (Ghana Statistical Service 2014).

Literature is, however, replete with examples of several chemical and microbiological qualities of some packaged water that violate both national and international standards (WHO 2008; Ayodele & Ajayi 2015). Like other countries in sub-Saharan Africa, outbreak of diarrhoeal diseases, including cholera and typhoid fever which constitute major causes of admission and death in Ghana, have often been associated with the supply of contaminated water (Odeyemi 2015; Stoler *et al.* 2015). Also, the presence of toxic substances such as pesticides or heavy metals, due to uneven coverage of projects providing clean drinking water for university students has yielded serious health implications (Ghana Statistical Service 2014). For example, anecdotal evidence suggests that many students of Kwame Nkrumah University of Science and Technology have been victims and vulnerable to the eruption and diffusion of various waterborne illnesses over the past few years. Studies report that waterborne diseases such as cholera, dysentery, diarrhoea, typhoid and hepatitis remain widespread at Kwame Nkrumah University of Science and Technology and Kumasi in general, causing severe human suffering and also being responsible for many infirmities and deaths (WHO 2010; Ghana Statistical Service 2014). Despite these water quality issues and the concomitant health challenges, sachet water is highly patronised by university students in Ghana and those at Kwame Nkrumah University of Science and Technology, in particular, who perceive sachet water as relatively affordable and wholesome for drinking (Ackah *et al.* 2012; Adewoye *et al.* 2013; Ghana Statistical Service 2014; Stoler *et al.* 2015). With the clogging of university campuses with sachet water, it is indispensably important that the quality of sachet water being offered for sale is ascertained. This may be protective of the health and well-being of the unsuspecting students against potential outbreaks of and increases in waterborne diseases.

Although some Ghanaian studies have focused on the physiochemical (Ackah *et al.* 2012; Ahimah & Ofosu 2012) and bacteriological quality of water (Osei *et al.* 2013; Stoler *et al.* 2015), the complexities of standard sachet water quality among university students have received limited research attention. Understanding the linkages between the use of sachet water and the health of university students is critical because students are exposed to new eating and drinking lifestyles in their independent lives away from home. This paper presents the findings of investigation into the physicochemical and bacteriological quality of samples of various brands of sachet water commonly consumed by students at Kwame Nkrumah University of Science and Technology, Ghana. The findings will provide supporting information to guide public health surveillance agencies and policymaking discourse in water quality management in Ghanaian tertiary institutions.

MATERIALS AND METHODS

Design and procedure

This cross-sectional quantitative research was based in the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. A two-stage cluster sampling design was used to collect data to represent all sachet water producers who distribute their products on campus. At the first stage of the sampling process, a random sampling technique was applied to ten common brands of sachet water available in most stores, Junior Common Rooms (JCRs) and canteens in the halls of residence on campus during January 2016. These brand samples of sachet water were identified through pseudonyms based on their respective initials including UC, HUD, BOA, PAS, YAF, ANG, NOV, DKN, IM and PD. At the second stage, three duplicate samples of sachet water of

each brand (making 30 samples altogether) were sampled at the retail outlets. The sampled sachets of water were retained in their original sealed containers and clearly marked with letters for identification purposes.

The informal vending style popularly practised in the streets was absent on campus since it is unacceptable in the university setting. The absence of street selling allowed researchers to purchase samples from canteens, JCRs and shops, which gave the researchers the opportunity to exclude analysis from the likely effects of sunlight exposure on sachet water quality. Sachet water samples were stored in iced-coolers to avoid direct sunlight and to be kept chilled within the period of selection and analysis. Sachet water samples purchased for the study had been acquired by the vendor no more than 7 days prior to sampling. The samples were transported to the microbiology laboratory of the Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology, in a sample carrier containing ice packs and analysed for their bacteriological parameters within 2 to 4 hours of collection. Then, 50% of the samples, 500 mL of each of the ten different brands were sent to the Nuclear Chemistry and Environmental Research Center, Department of Chemistry at Ghana Atomic Energy Commission (GAEC), Kwabenya, Accra, for analysis of physical and chemical parameters with the benchmarks of the WHO standards.

Bacteriological analysis of sachet water samples

The most probable number (MPN) method was used to determine total and faecal coliforms in the samples. Serial dilutions of 10^{-1} to 10^{-4} were prepared by measuring 1 mL of the sample into 9 mL sterilised distilled water. One mL aliquots from each of the dilutions were inoculated into 5 mL of MacConkey Broth with inverted Durham tubes and inoculated at 35 °C for total coliforms and 44 °C faecal coliforms for 18–24 hours. The samples were analysed in duplicate and the average was recorded. These temperatures are known to be optimal for the growth of these bacteria. Tubes showing colour change from purple to yellow after 24 hours were identified as positive for both total and faecal coliforms. Counts per 100 mL were calculated from the MPN. In determining the *Escherichia coli* (thermotolerant coliform) from each of the positive tubes identified, a drop was transferred into a 5 mL test tube of Tryptone water and inoculated at 44 °C for 24 hours.

A drop of Kovac's reagent was then added to the tube of Tryptone water. All tubes showing a red ring colour development after gentle agitation, which denoted the presence of indole, were recorded as presumptive for thermotolerant coliforms (*E. coli*). Counts per 100 mL were calculated from the MPN table. The analysis for total coliform and faecal coliform organisms per 100 mL was reported in terms of cfu/100 mL. Glassware or materials used in this experiment were washed with distilled water and then autoclaved at 121 °C for 15 minutes to ensure sterility. The bacteriological and physical quality of the packaged water was determined by comparing it with the national (as stipulated by Ministry of Health and Foods and Drugs authority in Ghana) and WHO standards for packaged water, which requires water samples of good quality to be 0 coliforms per 100 mL of water (WHO 2008).

Physical parameter analysis

Conductivity and total dissolved solids (TDS) were determined using a conductivity meter. The conductivity cell (probe) and the beakers were rinsed thoroughly with a portion of the sample to be examined. The beaker was filled completely and the cell inserted into it and conductivity and TDS read when the indicated value (conductivity) remained stable over a period of time. Power of hydrogen (pH) was determined using the pH meter. The pH of each sample was determined after the meter was calibrated with buffer solutions of three different pH. The probe was rinsed with distilled water and immersed in the samples. Readings were taken when the indicated value was stable over a period of time. Total hardness and alkalinity were determined using titrimetric methods. Also, 20 mL of sample was mixed with two drops of phenolphthalein indicator in a conical flask. If no colour change was produced, the alkalinity to phenolphthalein was considered to be zero. If the sample turned pink or red, the alkalinity to phenolphthalein was determined by titration with 0.1 N H_2SO_4. Table 1 presents the type and model of meters used in this analysis.

Table 1 | Type and model of meters used

Instrument	Brand	Model
pH meter	HANNA	H18424
Conductivity meter	HANNA	H199301
Ion chromatograph	Metrohm	930 Compact IC flex
Flame photometer	Sherwood	410 Single channel

Chemical parameter analysis

Phosphate, nitrate, sulfate, nitrite, fluoride and chloride were determined using ion chromatography method. With this parameter determination, a stock solution of 100 ppm concentration containing the respective ions (phosphate, nitrate ion, sulfate, nitrite, fluoride, chloride) was prepared in a volumetric flask by diluting 0.1 g of potassium dihydrogen phosphate, potassium nitrate, potassium sulfate, sodium nitrite, sodium fluoride and sodium chloride in distilled water, respectively. An aliquot of 10 mL of the respective stock solution was taken and diluted in a 100 mL volumetric with distilled water. The dilution of the standard and about 10 mL of the sample were run in the ion chromatograph to determine the conductivity and the retention times. A graph of conductivity against concentration was plotted to obtain the number of ions in the sample. This determination was conducted separately for all the above parameters.

Potassium and sodium parameters of samples were determined using the flame photometer method. The Sherwood 450 flame photometer was warmed by switching it on for about 30 minutes. Blank source distilled water followed by the addition of 2 mL lithium standard and mixture was aspirated. Calibration of the standard was done by adding 5 mL of 500 mg/L of the Na and K standard which is equivalent to 10 mg/L in the flame photometer. About 2 mL of the lithium standard was mixed together and aspirated. The standard recording has a value of 99.0 mg/L. This type of flame photometer takes only a single calibration. After the calibration, sodium, potassium and magnesium concentrations of each were determined in mg/L.

In line with the Declaration of Helsinki, we sought ethical approval for this study from the Department of Chemistry, Kwame Nkrumah University of Science and Technology. Further introductory letters were obtained from the Department of Chemistry and sent to the Microbiology Laboratory of the university and to the Nuclear Chemistry and Environmental Research Center, Department of Chemistry at Ghana Atomic Energy Commission.

Further analytic strategy

To ensure quality, water samples were transported and analysed within 2–4 hours. Additionally, samples were analysed in duplicate using standard methods. Equipment was calibrated before use and a reference laboratory (GAEC) was used for validation of the findings. Raw data were analysed using the R-Software to calculate the mean and standard deviation and to establish the Pearson's correlation and the relationship between certain parameters.

RESULTS

The bacteriological analyses of the sachet water samples are depicted by Table 2. Overall, 50% of the brands sampled recorded total and faecal coliform counts. These brand samples include ANG, NOV, IM, PD and DKN which recorded total coliform counts of 9.15×10^5, 2.35×10^6, 9.15×10^5, 4.15×10^5 and 9.15×10^5 as well as faecal coliforms counts of 2.3×10^5, 4.15×10^5, 2.3×10^5, 2.3×10^5 and 2.3×10^5, respectively. Moreover, our results showed that the DKN brand was again contaminated with Escherichia coliforms of 4.0×10^4 count. The DKN brand was, therefore, contaminated with all three types of coliform

Table 2 | Bacteriological properties of sachet water

Sample brands of sachet water	Total coliform/ 100 mL	Faecal coliform/ 100 mL	*E. coli*/ 100 mL
UC	NIL	NIL	NIL
HUD	NIL	NIL	NIL
BOA	NIL	NIL	NIL
PAS	NIL	NIL	NIL
YAF	NIL	NIL	NIL
ANG	9.15×10^5	2.3×10^5	NIL
NOV	2.35×10^6	4.15×10^5	NIL
DKN	9.15×10^5	2.3×10^5	4.0×10^4
IM	4.15×10^5	2.3×10^5	NIL
PD	9.15×10^5	2.3×10^5	NIL

considered in this study. Pearson's correlation coefficient of all determined parameters revealed weak correlation with all the three forms of coliform with *r*-values less than 0.5, except for faecal coliform which had a moderate relationship with *r*-score of 0.527.

Table 3 presents the physical parameter analysis of the sachet water sampled. Our results suggest that the potential of hydrogen (pH) as a proxy of hydrogen ion concentration of the samples ranged from 5.86 to 8.03. The HUD brand had the lowest pH value of 5.86 while the DKN brand had the highest pH score of 8.03. Altogether, 40% of the sachet water samples recorded pH values outside of the recommended range of 6.5–8.5 for drinking water (Table 3). Conductivity of samples ranged from as low as 2.24 μS/cm to 43.60 μS/cm with total dissolved solids (TDS) of the samples ranging from 2.00 mg/L for ANG to 42.00 mg/L for UC. The mean total alkalinity of all samples ranged from 33.33 mg/L to as high as 120 mg/L. PAS's total alkalinity (120 mg/L) was the highest among all the samples analysed, which is exactly at the maximum permissible limit. YAF had the lowest value of 33.33 mg/L. The other physical parameters including alkalinity, conductivity and total hardness of sachet water samples analysed were within the acceptable ranges under the guidelines of the World Health Organization (WHO 2008). All tested chemical parameters of sampled sachet water were within the WHO's standards with mean calcium concentration 3.434–17.170, sodium 1.20–10.30, potassium 0.100–1.80, magnesium 0.011–0.118, fluoride 0.001–0.149, chloride 1.71–58.02, nitrate 0.008–3.95, phosphate 0.001–0.548, sulfate 0.093–4.00, ionic balance 0.190–0.683 (Table 4).

DISCUSSION

In this paper, we assessed the quality of sachet water which serves as a major drinking water source for university students in Ghana. The sachet water utilisation context depicts a substantial paradigm shift of the drinking water discourse in most parts of Ghana and among university students, in particular, who largely depend on it in their new sociocultural environment. Like the general population in many parts of sub-Saharan Africa, the use of sachet water among students has shown an increasing trend in recent times. Although contemporary documented evidence in Ghana suggests that sachet water quality is in doubt (Addo *et al.* 2016), other studies appraise the sachet water quality as a better alternative to household tap water (Stoler *et al.* 2012, 2014; Machdar *et al.* 2013). The mixed observation required a further analysis to understand the specific potential public health implications of the sachet water use among tertiary students.

Our results demonstrated that 50% of the sachet water samples were highly contaminated with total and faecal coliform counts. This invariably means that some of the sachet water samples were infused with disease-causing organisms rendering them unsafe for drinking. In addition, the samples from one of these coliform pervaded brands was again contaminated with *E. coli* counts contrary to the *zero tolerance*

Table 3 | Physical properties of sachet of water

Sample brands of sachet water	Parameters				
	pH	Conductivity/μS/m	TDS	Total hardness (mg/L)	Alkalinity (mg/L)
UC	5.94	43.60	42.00	57.120 ± 2.856	80.000 ± 0.000
HUD	5.86	22.80	22.00	67.592 ± 3.298	50.000 ± 10.000
BOA	6.35	16.42	16.00	65.688 ± 2.856	53.333 ± 15.272
PAS	6.71	14.68	14.00	21.420 ± 2.019	120.00 ± 26.457
YAF	7.72	4.89	5.00	17.136 ± 4.0389	33.333 ± 5.774
ANG	6.31	2.24	2.00	16.184 ± 4.362	36.666 ± 5.773
NOV	7.19	26.50	26.00	126.616 ± 7.187	36.667 ± 11.547
DKN	8.03	15.61	15.00	45.696 ± 4.038	35.000 ± 7.071
IM	6.59	9.08	9.00	19.992 ± 2.856	40.000 ± 0.000
PD	7.97	6.55	7.00	8.568 ± 0.000	30.000 ± 0.000

Table 4 | Chemical properties of sachet water

	Parameters (mg/L)									
Sample brands of sachet water	Ca^{2+} (calcium)	Na^{+} (sodium)	K^{+} (potassium)	Mg^{2+} (magnesium)	F^{-} (fluoride)	Cl^{-} (chloride)	NO_3^{-} (nitrate)	PO_4^{3-} (phosphate)	SO_4^{2-} (sulfate)	Ionic balance
UC	17.170 ± 0.00	1.200	0.100	0.072	<0.001	46.3905	3.5054	0.5478	1.0045	0.339
HUD	11.828 ± 2.88	4.700	0.700	0.118	<0.001	58.0214	0.521	0.0457	1.4251	0.322
BOA	9.157 ± 0.000	4.100	1.800	0.075	<0.001	15.4341	1.2051	0.0102	4.005	0.488
PAS	9.921 ± 0.660	4.400	1.500	0.040	0.1492	14.3618	0.6294	0.0401	0.0926	0.306
YAF	6.868 ± 0.000	1.900	1.000	0.018	0.0528	1.7123	0.0078	0.1250	0.117	0.190
ANG	5.723 ± 0.000	4.300	0.200	0.013	<0.001	9.1146	0.104	0.2100	0.1546	0.551
NOV	11.065 ± 0.66	10.300	0.600	0.090	<0.001	30.3136	1.6501	0.4240	0.145	0.683
DKN	9.157 ± 0.000	5.100	1.700	0.028	<0.001	17.9023	0.245	0.0010	0.1634	0.668
IM	4.960 ± 1.321	2.700	1.100	0.013	<0.001	12.477	0.06	0.1450	0.874	0.383
PD	3.434 ± 0.000	1.900	1.400	0.011	0.0108	11.8348	3.9511	0.0102	1.022	0.320

benchmark for safe drinking water (WHO 2008). *E. coli* in water samples is regarded as the most sensitive indicator of faecal pollution. Its presence in the samples of sachet water consumed by university students is a major health concern and calls for rigorous remedial attention. The presence of this pathogen in the samples was an indication of the likely presence of other enteric pathogens (Osei *et al.* 2013). Our results showed relatively higher bacterial-induced contamination than the 18% score reported in Accra, Ghana (Stoler *et al.* 2014) and also in Pakistan where 4 out of the 15 sachet water brands tested did not meet WHO and national standards of 0 cfu per 100 mL (Yousaf & Chaudhry 2013). In Ghana, Osei *et al.* (2013) also reported that 51.6% of the 60 sachet water samples analysed showed the presence of different kinds of protozoa.

The presence of total and faecal coliform in sachet water can be linked to a number of factors, such as the raw water source used, unhygienic practices observed during production, improper storage in unhygienic and high temperature conditions, and the failure of producers to use sophisticated disinfection processes against bacterial regrowth. As Addo *et al.* (2016) observed, the majority of sachet water producers draw their water from hand dug wells which are either located near latrines or contaminated by runoffs. Also, some manufacturers use uncovered and semi-treated storage tanks, thereby increasing the risk of contamination through avian and reptilian faecal material. The possibility of regrowth of micro-organisms is greatly increased considering that the surrounding temperature may be high. Micro-organisms multiply more easily in poor sanitary conditions (WHO 2008), leading to possible contamination of sachet water. Although a study in Sierra Leone observed that an increase in concentration of total coliforms may be due to the growth of micro-organisms already present within the packaged water (Fisher *et al.* 2015), our study did not take into account the water quality before packaging and, therefore, can only speculate about this proposition. Our findings suggest a needful government and other stakeholders' interventions to intensify regulatory and surveillance activities and to enforce strict hygienic measures in this rapidly expanding industry to improve the quality of water used by students as well as the general public and vulnerable groups including older people (Gyasi 2019).

The current study found that the pH values for 40% of the samples fell outside the permissible limits of 6.5–8.5, indicating unsuitability of such sachet water for consumption. Although pH value usually has no direct impact on consumers, it is one of the most important operational water quality parameters and should be taken seriously in order to ensure the suitability of sachet water consumed by students. This is because standard sachet water pH levels hold prospects for the quality of water. In our study, other tested physical parameters (alkalinity, conductivity and total hardness) of all water sampled were in line with WHO set standards. Despite the view that the correlation of pH and coliform count showed insignificant association,

there was a weak positive correlation for total coliform ($r = 0.39$), faecal coliform ($r = 0.416$) and a moderately positive correlation for *E. coli* ($r = 0.526$) for some of the sachet water consumed by students on campus. The moderately strong positive correlation shown by the coliforms is related to the fact that as the pH increases, disinfection becomes less effective.

The presence of faecal coliform is the most important indicator for water contamination (WHO 2008). Consistent with extant studies on water quality (Stoler *et al.* 2012; Halage *et al.* 2015), our investigation did not identify dreadful chemical pollutants such as biphenols and heavy metals which may have more hazardous health implications for users. In addition, other chemical parameters were in line with the WHO standards (Ghana Statistical Service 2012; Mako *et al.* 2014). With current increases in student enrolment in universities coupled with the unreliability of other drinking water sources on campus, sachet water would be the only option for students. This calls for mindful efforts to balance protection of public health and access to drinking water on university campuses. Furthermore, sachet water producers should be identified, licensed and properly regulated by the Ghanaian regulatory agencies, namely, the Ghana Standards Board and Food and Drugs Authority to ensure improvement in water quality amid the difficulty in tracking the sachet water firms, partly due to their rapid growth. Making sure that quality control and assurance practices are strictly observed in the treatment and packaging processes of sachet water may secure quality and improved health and well-being of unsuspecting university students whose survival in the university community often thrives on the sachet water sources.

While our study provides a critical contribution to addressing the existing gap in knowledge on public health concerns of sachet water utilisation among university students in Kumasi, certain limitations are noteworthy. Although our study was limited to the sachet water brands commonly distributed in and around the university campus, the samples of sachet water selected from each brand for the analysis were not many, which may have implications for veracity. Again, the cross-sectional design adopted did not allow for repeated tests for different batches of output of these selected firms. However, this study consciously prioritised important lessons that can be drawn to inform policies that seek to properly operationalise surveillance measures of the sachet water produced and strict regulations by university authorities about the quality of water that enters their campuses.

CONCLUSIONS

Utilisation of sachet water among Ghanaian university students is not an uncommon phenomenon and the practice has seen a surge in recent times. Analysis of the quality of sachet water samples used by these students revealed contamination with bacteria in the form of total, faecal coliforms and *E. coli* counts which temper or compromise standards for good quality drinking water. This may potentially lead to an outbreak of waterborne diseases among students. The pH values of most of the sachet water samples also fell outside the WHO benchmarks. The high total and faecal coliforms and the presence of *E. coli* in sachet water could present potential health risks including the outbreak of waterborne diseases and their shattering consequences, which can include increased costs of health care, burden to already edgy health care systems and death. These findings are germane for effective regulations and monitoring of sachet water production and distribution by the mandatory regulatory agencies in Ghana as well as the quality assurance bodies in the universities in order to safeguard the health and well-being of students who may depend on the available sachet water on campus.

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REFERENCES

Ackah, M., Anim, A. K., Gyamfi, E. T., Acquah, J., Nyarko, E. S., Kpattah, L. & Zakaria, N. 2012 Assessment of the quality of sachet water consumed in urban townships of Ghana using physico-chemical indicators: a preliminary study. *Advances in Applied Science Research* **3** (4), 2120–2127.

Addo, M. G., Woods, C. A., Andoh, L. A. & Obiri-Danso, K. 2016 Effect of varying storage temperatures on the microbiological quality of street sold water in the Kumasi Metropolis. *Ghana. Research Journal of Microbiology* **11** (2). doi: 10.3923/jm.2016.1816-4935.

Adewoye, A. O., Adewoye, S. O. & Opasola, O. A. 2013 Microbiological examination of sachet water experimentally exposed to sunlight. *International Journal of Pure and Applied Sciences and Technology* **18** (1), 36–42.

Ahimah, J. K. & Ofosu, S. A. 2012 Evaluation of the quality of sachet water vended in the New Juaben municipality of Ghana. *International Journal of Water Resources and Environmental Engineering* **4** (5), 134–138.

Ayodele, O. S. & Ajayi, A. S. 2015 Water quality assessment of Otun and Ayetoro Area, Ekiti State, Southwestern Nigeria. *Advancement in Science and Technology Research* **2** (1), 8–18.

Behnke, N., Cronk, R., Snel, M., Moffa, M., Tu, R., Banner, B., Folz, C., Anderson, D., Macintyre, A., Stowe, E. & Bartram, J. 2018 Improving environmental conditions for involuntarily displaced populations: water, sanitation, and hygiene in orphanages, prisons, and refugee and IDP settlements. *Journal of Water, Sanitation and Hygiene for Development* **8** (4). doi: 10.2166/washdev.2018.019.

Carlson, R. V., Boyd, K. M. & Webb, D. J. 2004 The revision of the declaration of Helsinki: past, present and future. *British Journal of Clinical Pharmacology* **57** (6), 695–713.

Fisher, M. B., Williams, A. R., Jalloh, M. F., Saquee, G., Bain, R. E. & 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 Statistical Service (GSS) 2012 *Population and Housing Census, 2010 Summary Report of Final Results*. Accra, Ghana.

Ghana Statistical Service (GSS) 2014 *2010 Population and Housing Census*. District Analytical Report, KMA.

Ghana Statistical Service (GSS), Ghana Health Service (GHS), ICF International 2015 *Ghana Demographic and Health Survey, 2014*. GSS, GHS, and ICF International, Rockville, MD, USA.

Gyasi, R. M. 2019 Social support, physical activity and psychological distress among community-dwelling older Ghanaians. *Archives of Gerontology and Geriatrics* **81**, 142–148.

Halage, A. A., Ssemugabo, C., Ssemwanga, D. K., Musoke, D., Mugambe, R. K., Guwatudde, D. & Ssempebwa, J. C. 2015 Bacteriological and physical quality of locally packaged drinking water in Kampala, Uganda. *Journal of Environmental and Public Health* **2015**, 6. http://dx.doi.org/10.1155/2015/942928.

Isa, M. A., Allamin, I. A., Ismail, H. Y. & Shettima, A. 2013 Physicochemical and bacteriological analyses of drinking water from wash boreholes in Maiduguri Metropolis, Borno State, Nigeria. *African Journal of Food Science* **7** (1), 9–13.

Machdar, E., Van Der Steen, N. P., Raschid-Sally, L. & Lens, P. N. L. 2013 Application of quantitative microbial risk assessment to analyze the public health risk from poor drinking water quality in a low-income area in Accra, Ghana. *Science of the Total Environment* **449**, 134–142.

Mako, S. L., Harrison, M. A., Sharma, V. & Kong, F. 2014 Microbiological quality of packaged ice from various sources in Georgia. *Journal of Food Protection* **77** (9), 1546–1553.

Nsiah-Gyabaah, K. 2001 The looming national dilemma of water crisis in peri-urban areas in Ghana. In: *Proceedings of the Second Workshop on Peri-Urban Natural Resource Management Project at the Watershed Level*, DFID, Kumasi, Ghana.

Odeyemi, O. A. 2015 Bacteriological safety of packaged drinking water sold in Nigeria: public health implications. *Springer Plus* **4**, 642. doi: 10.1186/s40064-015-1447-z.

Osei, A. S., Newman, M. J., Mingle, J. A. A., Ayeh-Kumi, P. F. & Kwasi, M. O. 2013 Microbiological quality of packaged water sold in Accra, Ghana. *Food Control* **31** (1), 172–175.

Stoler, J., Fink, G., Weeks, J. R., Otoo, R. A., Ampofo, J. A. & Hill, A. G. 2012 When urban taps run dry: sachet water consumption and health effects in low income neighborhoods of Accra, Ghana. *Health & Place* **18** (2), 250–262.

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. *The American Journal of Tropical Medicine and Hygiene* **90** (2), 272–278.

Stoler, J., Ahmed, H., Frimpong, L. A. & Bello, M. 2015 Presence of Pseudomonas aeruginosa in coliform-free sachet drinking water in Ghana. *Food Control* **55**, 242–247.

WHO 2008 *Guidelines for Drinking-Water Quality,* 3rd edn. *Incorporating the First and Second Addenda*, Vol. 1, Recommendations. World Health Organization, Geneva, Switzerland.

WHO 2010 *Progress on Sanitation and Drinking Water: 2010 Update*. World Health Organization, Geneva, Switzerland.

WHO 2011 *Drinking Water: Equity, Safety and Sustainability*. World Health Organization, Geneva, Switzerland.

World Medical Association 1964 Declaration of Helsinki. WMA, General Assembly, Helsinki, Finland.

Yousaf, S. & Chaudhry, M. A. 2013 Microbiological quality of bottled water available in Lahore city. *Journal of Pioneering Medical Sciences* **3** (2), 110–112.

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