

Greywater in the drains of a sewerred community in Ghana

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Abstract

With less than 5% sewerage coverage and abysmal greywater management, Ghana's environment could be highly polluted, especially water resources. The few sewerred communities may be guilty of pollution from greywater discharge into stormwater drains. In this study, Asafo, Ghana, was used as a case study to assess greywater characteristics in the major drains in a sewerred community. The approach involved desk study reviews and laboratory analysis of greywater samples. The findings showed some inhabitants discharge greywater into neighbourhood drains instead of sewers. Most greywater sources from reviews and sampled drains failed the discharge limits for major contaminants including turbidity (39.4–2,880 NTU), BOD₅ (64–700 mg/L), COD (207–2,308 mg/L), TSS (70–4,720 mg/L), TDS (420–2,860 mg/L), nutrients – TKN, NH₃-N, NO₃-N, NO₂-N (0–218.5 mg/L), total P and PO₄³⁻ (1.24–26.18 mg/L), elemental species – Na, K, Mg, etc (0–1.6 mg/L), and microbiological – total and faecal coliforms, and *E. coli* (2.95–10.4 log CFU/100 ml). High strength greywater accounted for odour emissions where flows stagnated. Greywater characteristics are highly variable but have potential for biological treatment as the BOD₅:COD ratios ≥ 0.5 . Ghanaian greywater, including flows from a sewerred community, is untreated and polluted, and our environment is unsafe.

Key words: biodegradability, characteristics, drains, ghana, greywater, strength, wastewater

INTRODUCTION

Poor greywater management is associated with nuisance as well as threat to public and environmental health. Ghana is among many developing countries where greywater management is largely ignored (Dwumfour-Asare *et al.* 2017). Evidence indicates that domestic greywater disposal in Ghana is haphazard, with little or no treatment (GSS 2013). The situation is worst in cities and larger towns, which witness large volumes of greywater generation and various inappropriate disposal practices. Appropriate greywater disposal practices in Ghana are low with only 6% coverage, mainly through the use of sewerage and soakaways (Dwumfour-Asare *et al.* 2018b). Meanwhile, there is very limited use of sewerage systems nationwide, with less than 5% coverage (Amoah *et al.* 2007; Agyei *et al.* 2011; GSS 2013; Appiah-Effah *et al.* 2014). Lack of adequate wastewater management infrastructure is attributed to perceived prohibitive costs of investment without reference to the benefits derived from improved sanitation management (Agodzo *et al.* 2003; Dwumfour-Asare *et al.* 2017). Although wastewater management in Ghana is generally poor, the worst probably relates to greywater, because

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that is usually perceived as ‘not readily offensive but tolerable’ in the environment compared to black-water (faecal matter), which is given some attention. In the developed world, grey- and black-water streams are well managed, and receive almost equal attention (Karabelnik *et al.* 2012). This is not observed in developing countries.

Unfortunately, urbanisation and overpopulation in towns are associated with large volumes of relatively polluted greywater, especially with emerging contaminants (Amoah *et al.* 2007; Nair 2008; Germer & Sinar 2010). Ignoring greywater management in Ghana has consequences for public and environmental health, especially in urban areas where vegetable farmers and household gardeners rely on informal water sources, including wastewater from drains, for watering plants (Keraita *et al.* 2003; Azanu *et al.* 2016; Dwumfour-Asare *et al.* 2018a; Dwumfour-Asare *et al.* 2018b). There could also be public health risk associated with water resource pollution as at least one-third of Ghanaians depend on groundwater (Hyde & Maradza 2013), which could easily be polluted by inappropriate disposal of untreated wastewater (Cronin *et al.* 2007). Most groundwater sources, especially in cities and large towns, could receive recharge from natural and artificial drains, including rivers, streams, ponds, etc, that have become conduits and recipients of wastewater discharges (Cronin *et al.* 2007; Barnes *et al.* 2008; Schaidler *et al.* 2013; Awuah *et al.* 2014). There is evidence of groundwater pollution by anthropogenic activities associated with waste disposal, including sanitation systems and wastewater (Lewis & Claasen 2018; Lutterodt *et al.* 2018; Yu *et al.* 2018). Unfortunately, there is little information on the characteristics of domestic greywater generated in Ghana, whether direct from homes and/or on the streets, including drains. Adequate understanding of greywater characteristics is the first step, however, in finding appropriate technologies and principles for safe management (Mohamed *et al.* 2019).

Asafo is one of the few communities with sewerage systems for domestic wastewater (black-water and greywater), in Kumasi Metropolis, Ghana (Keraita *et al.* 2002; Keraita *et al.* 2003). It could therefore manage greywater through the sewerage system, thereby protecting the River Subin in the area. A recent evaluation of Asafo sewerage does not reveal that all domestic greywater is discharged to sewers, but hinted that sullage (greywater) from kitchens is (Salifu 2013). Although no data exist on greywater characteristics in Asafo, unlike sewage data published in an earlier study (Awuah *et al.* 2014), it is accepted that some greywater may be discharged into drains and onto the streets. In Ghana, wastewater found in urban drains and channels is mostly considered domestic greywater (Ansah *et al.* 2011) as it is the principal discharge to these drains. High strength (i.e. with high pollutant loads) (Barişçi *et al.* 2016), or dark greywater, depending on the nutrient and chemical load (Cook 2016), could produce the smells commonly experienced in urban environments.

This study was designed to contribute baseline data to the scanty information available on greywater characteristics in urban Ghana. It is imperative to build adequate databases to describe the Ghanaian greywater characteristics spectrum.

RESEARCH METHODOLOGY

Study area

Only about 8% of the population of Kumasi, the second largest city in Ghana, are connected to simplified sewerage systems. Some 38% use unsewered public toilets, 30% of household toilets are connected to septic tanks, 8% have ventilated improved pit (VIP) latrines, and about 24% have unimproved systems (Muspratt *et al.* 2014). Asafo (Figure 1) is one of the few seweraged suburbs in Kumasi. Unlike a similarly seweraged community at Kwame Nkrumah University of Science and Technology (KNUST), there is little or no documentation on Asafo’s greywater. The suburb has several stormwater drains that are not supposed to carry domestic wastewater, especially black-water, and the worst quality influent discharges

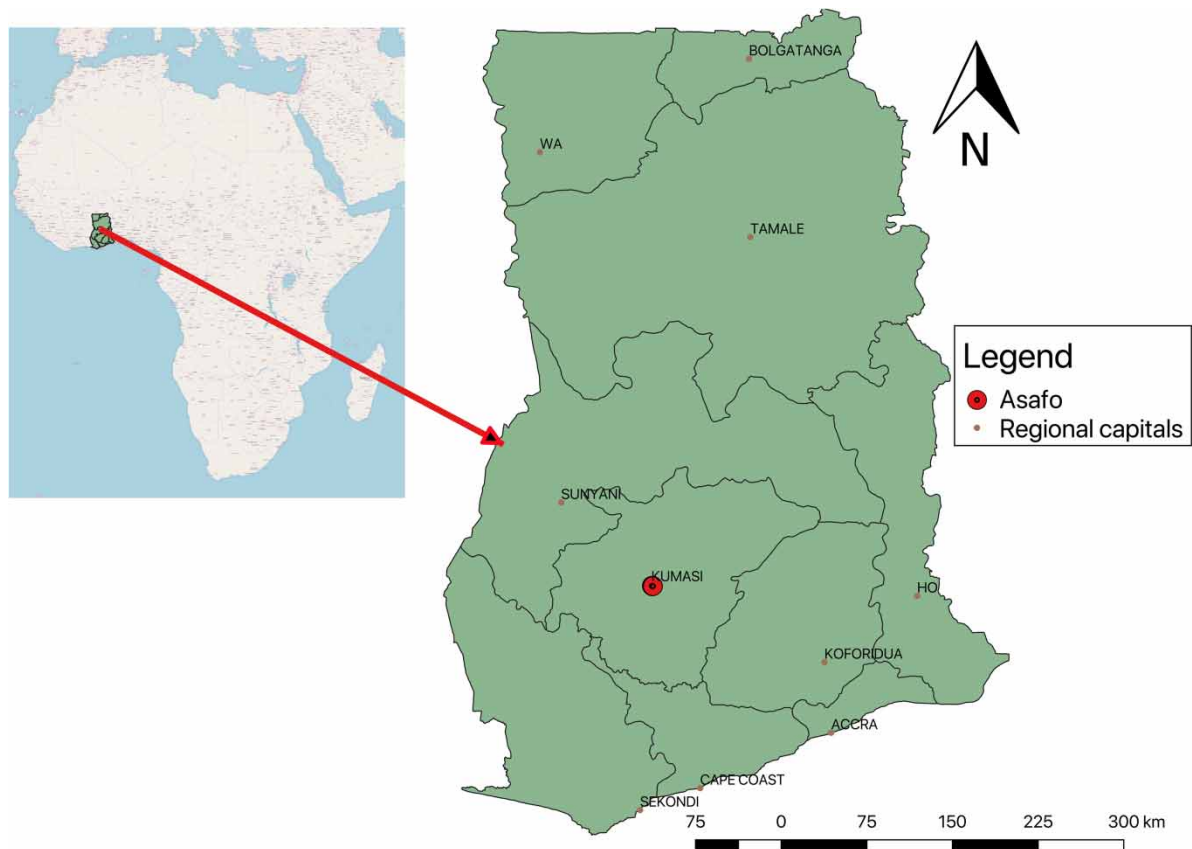


Figure 1 | Map of Ghana showing the regions and their capitals, including Kumasi (and Asafo).

should be flows of light residential greywater from showers and baths. The sewerage system was modified to allow discharge of both grey- and black-water into sewers to minimize blockages, especially during periods of unreliable water supply (Awuah *et al.* 2014). Sampling points in Asafo were chosen following discussion with the Subin sub-metro Environmental Health Officer (EHO).

Data collection and analyses

The sampling sites were chosen following discussion with the EHO, who indicated the main odour complaint locations. A transect walk enabled identification of six sampling sites in the study area. Greywater grab samples were taken at the sampling points within a two-hour period on 17 May 2017. Some physicochemical parameters were determined in the field – e.g., temperature, pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) – using Milwaukee Portable pH/EC/TDS (MW-802) and HACH (HQ30d flexi) meters, and an Intellical™ LBOD101 optical DO probe. Samples were stored in an icebox and taken to the laboratory within 30 minutes of taking the last sample. The parameters determined in the laboratory included elemental species (cadmium, calcium, copper, iron, lead, magnesium, manganese, mercury, and zinc), nutrients (nitrogen and phosphorus), biochemical oxygen demand (BOD₅), chemical oxygen demand (COD), and microbial identification and enumeration. All laboratory analyses followed the standard methods of wastewater analysis according to the manual of American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF) (Clesceri *et al.* 1999).

The contaminant levels found in this study are compared with the characteristics of greywater reported by others, and the wastewater discharge guidelines published by Ghana's Environmental Protection Agency (GEPA). The GEPA is the main government agency that regulates all discharges

(including domestic wastewater) into the environment, including watercourses. GEPA's discharge guidelines are relevant because the sampled stormwater (public) drains immediately discharge into the environment, including the urban river found in the community. They also enabled greywater samples to be identified as potential sources of nuisance and/or hazard to public health. Any material including wastewater (i.e., 'water tainted with impurities') with potential to cause nuisance and/or public health hazard should not be discharged into public drains (gutters) according to the local authority (KMA) by-laws and the national building regulation (Fosu 1996; Ghana Local Government 1998). This study is based on greywater samples taken from major drains in the study area, as indicated, and review of available literature. All data were processed and analysed using Microsoft Excel.

RESULTS AND DISCUSSION

Asafo and its sanitation systems

Asafo is part of Kumasi's main business district, within the Subin sub-metro (Subin) under the Kumasi Metropolitan Assembly (KMA). Subin is one of nine sub-metros within the KMA as at the time of study. Kumasi is the second largest city in Ghana and has a population of 2 to 2.7 million people. With an area of about 250 km², its population density is about 5,400/km² (Mensah 2006). The extent of the city's sewerage is thought to be similar to that in other Ghanaian cities, including Accra – i.e., well below 10%. Typically on-site household facilities (water closets, aqua privies, VIPs and other pit latrines, etc.) serve about 47% of the population, while public/communal toilets serve about 38%. Open defecation is thought to be practiced by around 3 to 5% of the population (Mensah 2006; Furlong & Mensah 2015). Kumasi's sewerage coverage extends to six communities including Asafo (Maoulidi 2010; Furlong & Mensah 2015).

Key characteristics of Asafo include: 1) it is a community of tenements and business entities, distinguished by two- to three-storey buildings interspersed with single storey buildings; 2) its population density is up to 600 persons/hectare; 3) most houses have 20 to 30 rooms and are shared by up to 20 families (40 to 100 people); 4) the main water source is the Ghana Water Company Limited (GWCL), but there is growing demand for groundwater (mainly for self supply) due to unreliable service; and 5) private flush toilets are common in houses, but there are also public toilets (mostly water closets) (Apau 2017).

Asafo's simplified sewerage system

Asafo's simplified sewerage system (ASSS) was a pilot scheme launched in the mid-1990s and is one of six functional systems in Kumasi (Maoulidi 2010; Furlong & Mensah 2015). It is over 20 years old (Salifu 2013) and owned by KMA, but operated and maintained by a private franchisee. ASSS was initially designed for 20,000 users (Salifu 2013) but now serves about 50,000 from households, four schools, public toilets, a tertiary institution (Kumasi Technical University), and the Golden Tulip Hotel (Furlong & Mensah 2015).

Initially, ASSS was reported to be operating below its intended capacity by serving 60% of the target population due to issues such as unreliable water supply for toilet flushing, user inability to pay connection fees, and access difficulties due to heavily built-up surroundings (Keraiya *et al.* 2003). This probably contributed to the low initial subscription of 255 houses instead of the 320 target (Awuah *et al.* 2014). The subscription trend was:

- 1997 initial wave of house connections (30% in the first three years);
- 2004/2005 end of slow build up to achieve 50%; and,
- 2008/2009 final achievement of 100% connection (Salifu 2013).

The unreliable and inadequate water supply for toilet flushing became an initial operational issue, causing frequent sewer and manhole blockages, largely because the system was only designed to handle black-water (faecal waste) flushed from toilets. It was later corrected by adding domestic grey-water flows to the sewers (Awuah *et al.* 2014).

There is no current indication of potential expansion of the 900 m³/day waste stabilization pond treatment facility in Asafo (Salifu 2013). While the capacity has remained the same, the user population has doubled, and the sewerage system could be overstretched and stressed. Asafo's demography has changed since the sewerage system was designed, because of rapid population growth and urbanisation. The population was 20,000 in 1997, with 63 people, on average, in 320 houses – roughly 4.6 per household – with moderate water consumption of 68 l/c/d (Salifu 2013). The 2010 Census reports a population of 28,100 comprising 8,162 households inhabiting 1,913 houses (GSS 2014). Clearly, some houses might not be connected – other studies indicate that between 60 and 90% of houses are connected to the sewerage system (Awuah *et al.* 2014; Greenland *et al.* 2016). The number of houses has increased six-fold over almost two decades with no evidence of commensurate system expansions. A recent report on wastewater flows in Kumasi asserted that ASSS serves 50,000 people, not 20,000 (Furlong & Mensah 2015). It is probable that houses not connected to the sewer dispose of greywater into lanes, drains, ditches, open urban spaces, streets, etc. although faecal matter may be contained onsite, a common practice in urban Ghana (Vodounhessi & Münch 2006; Kuffour 2010; Gretschi *et al.* 2016; Nkansah *et al.* 2016; Dwumfour-Asare *et al.* 2017; Oteng-Pepurah *et al.* 2018).

Greywater studies in Ghana

Few greywater studies have been done in Ghana, although greywater research appears to be increasing and more data may become available soon. Greywater includes wastewater from showers/baths, wash basins, laundries, kitchen sinks and dishwashers, but has no feeds or joint flows from toilets, or black-water (Shi *et al.* 2018).

A brief review of greywater (quality) studies in Ghana is presented in Table 1. Eight studies from five different Ghanaian locations are reported. The common parameters are pH, EC, TSS, turbidity, BOD₅, and COD. The least reported parameters are TDS, TKN and phosphorus, followed by trace elements and heavy metals (except lead), and then microbiological factors – *E. coli* and total coliforms. The studies covered communities, schools (residential halls/hostels), and hotels, and samples were taken from households (with categories composite/mixed, laundry, kitchen, and bathroom), drains, a lagoon, and a salon.

Almost all studies reveal greywater diversity, probably because greywater characteristics depend on a variety of factors including water supply quality and type, household activities (lifestyle, custom, personal care product use, etc), greywater origin (kitchen sink, bathroom, etc), geographic location and demographic characteristics (De Gisi *et al.* 2016).

The pH of greywaters was generally within the range 6.3 to 10 – slightly acidic to alkaline (El-Fadl 2007; Mohamed *et al.* 2019). The pH values were also within the GEPA pH discharge limits – 6 to 9 (GEPA n.d). On EC, some studies showed failed discharge limits – 1,500 µS/cm (GEPA n.d) – but other greywaters passed. Two studies reported DO levels well below 4 mg-O/L, which could impact biota negatively, especially in water environments, according to National Academies of Sciences, Engineering, and Medicine (NASEM 2015). The TSS and turbidity levels varied widely across the studies (Table 1). One study passed the GEPA discharge limit for turbidity (75 NTU), but the rest failed in addition to the GEPA's TSS discharge limit of 50 mg/L (GEPA n.d). High levels of greywater TSS and turbidity, perhaps due to the presence of solids, fabric softeners, and detergent residues (Mohamed *et al.* 2019), caused failures against GEPA discharge limits. TDS was

Table 1 | Greywater characteristics (quality) from some studies in Ghana

Water quality parameters	KNUST, University campus	Kpeshie, Accra	Eastern region	Accra Metropolis	Three suburbs, Kumasi
pH	7.5 ± 0.2 ^{a,b} , 6.85 ^c , 7.74 ^d	7.84 ± 0.09	7.84 ± 0.09	6.3 ± 0.47	6.4–9.7
EC (uS/cm)	656.42 ^c , 965.2 ^d	17,100 ± ~3,400	628.43 ± 57.46	2,985 ± 755.6	351–3,530
Temperature (°C)	29.2 ± 0.7 ^{a,b} , 29.6 ^d	29.11 ± 0.34	29.11 ± 0.34	–	–
DO (mg/L)	2.7 ± 0.9 ^{a,b}	–	1.6 ± 0.30	–	–
TDS (mg/L)	–	–	488.85 ± 23.01	–	–
TSS (mg/L)	212 ± 20.8 ^{a,b} , 222.83 ^c , 347 ^d	92.39 ± 26.48	92.39 ± 26.49	11,866 ± 1,603 ^e	372–4,720
Turbidity (NTU)	279.89 ^c	72.14 ± 20.47	90.14 ± 3.47	–	204–729
BOD ₅ (mg/L)	198.3 ± 33.3 ^{a,b} , 420.22 ^c , 538.5 ^d	63.79 ± 26.49	89.79 ± 26.49	309 ± 82	132.5–269
COD (mg/L)	399 ± 108.4 ^{a,b} , 707.28 ^c , 874 ^d	236.99 ± 66.35	612.99 ± 66.35	555 ± 119	400–2,210
Total coliforms log CFU/100 ml	6.4 ± 5.8 ^{a,b} , 5.7 ^c	–	–	–	2.6–8.3
Faecal coliform log CFU/100 ml	4.93 ^d	5.21	2.95	–	–
<i>E. coli</i> log CFU/100 ml	6.2 ± 5.3 ^a	–	–	–	1.0–7.0
Nitrate (mg-N/L)	0.7 ± 0.06 ^b , 12.91 ^c , 15.25 ^d	2.04 ± 0.49	–	5.2 ± 1.4 ^f	–
Nitrite (mg-N/L)	0.0 ^b , 0.19 ^c , 57.5 ^d	0.1 ± 0.03	–	–	–
Ammonia (mg-N/L)	8.4 ± 1.8 ^b	–	2.88 ± 0.48	101.3 ± 23.3 ^f	–
TKN (mg-N/L)	–	–	–	–	7.7–29.5
Total phosphate – PO ₄ ³⁻ (mg/L)	12.43 ^c , 26.18 ^d	1.24 ± 0.26	–	–	11.3–23.2
Phosphorus (mg-P/L)	11.8 ± 4.0 ^{a,b}	–	–	–	–
Calcium (mg-Ca/L)	2.81 ± 0.01 ^b	–	–	–	–
Magnesium (mg-Mg/L)	6.1 ± 0.4 ^b	–	–	–	0.33–5.67
Cadmium (mg-Cd/L)	0.01 ± 0.001 ^b , 0.015 ^c	0.003 ± 0.002	–	–	–
Copper (mg-Cu/L)	<0.01 ^b , 0.135 ^c	–	0.001 ± 0.0	–	–
Iron (mg-Fe/L)	0.37 ± 0.08 ^b	–	–	–	0.129–0.469
Lead (mg-Pb/L)	<0.01 ^b , 0.316 ^c	0.01 ± 0.0005	0.003 ± 0.0	–	–
Manganese (mg-Mn/L)	0.04 ± 0.01 ^b , 0.098 ^c	0.61 ± 0.13	–	–	–
Mercury (mg-Hg/L)	0.4 ± 0.08 ^b	–	–	–	–
Zinc (mg-Zn/L)	0.03 ± 0.001 ^b , 0.151 ^c	–	–	–	–
Settings & sampling sources	School halls/hostels & drains	Community, drains and lagoon	Hotel & hostels	Households (composite, kitchen, bathing & washing)	Households (composite, laundry, kitchen, bathroom & salon)

References

Note: ± standard deviation; ^aMonney *et al.* (2013), ^bAnsah *et al.* (2011), ^cAnim *et al.* (2014), ^dMohammed *et al.* (2015), ^eDwumfour-Asare *et al.* (2017); ^fAwuah *et al.* (2014); ^gMuzola (2007); ^hNiyonzima (2007); ⁱTotal solids; ^jUnit is mg/kg.

recorded in only one of the greywater studies, and the level complied with the GEPA discharge limit of 1,000 mg/L.

The BOD₅ and COD contents exhibited the high variability commonly associated with greywater (Sievers & Londong 2018). The lowest values reported in the studies were around 60 mg-BOD₅/L and 230 mg-COD/L, and the highest around 540 mg-BOD₅/L and 2,200 mg-COD/L (Table 1). The BOD₅ and COD values of the greywaters were high and exceeded the GEPA discharge limits (50 mg-BOD₅/L and 250 mg-COD/L). The biodegradability ratios (BOD₅:COD) also showed a wide range, from 0.12 to 0.62. Based on the biodegradability ratio reference level of 0.5 (Kulabako *et al.* 2011), only greywater from the two Ghanaian locations – KNUST Campus (Kumasi), and Accra Metropolis – can be described as potentially biodegradable, the others having ratios below 0.5. Greywaters with low BOD₅:COD ratios are generally rich in chemical contaminants

like non-biodegradable surfactants, detergents, etc, and generated by people with low water consumption behaviour (El-Fadl 2007; Boyjoo *et al.* 2013; Mohamed *et al.* 2019). It is noted in this context that GEPA's BOD₅ and COD discharge thresholds do not favour potential environmental biodegradability. The ratio for GEPA limits is around only 0.20, far below the minimum 0.5 biodegradability reference point.

The microbial contaminants found in the greywater sources studied included total coliforms, faecal coliforms and *E. coli*. The microbial loads were high at around 1 to 8 log CFU/100 ml (Table 1), similar to the pathogenic loads reported in the literature (De Gisi *et al.* 2016; Shi *et al.* 2018). However, some greywater sources exceeded the GEPA limits for *E. coli* (1 log CFU/100 ml) and total coliforms (2.6 log CFU/100 ml), while others did not. Greywater may contain faecal coliforms from bathrooms, laundries, kitchen sinks and dishwashers – e.g., washed off clothing, hands, diapers, childcare items, etc (Ottoson & Stenstrom 2003; Gilboa & Friedler 2008). The findings indicate that greywater flows in Ghana contain similar infectious agents to those in other studies, the diversity and concentrations depending on the greywater sources, health status and number (diversity) of waste generators, and the geographic location and its seasonality (Mohamed *et al.* 2019).

The greywaters also contained nutrients (nitrogen and phosphorus), with appreciable levels of nitrate, nitrite, ammonia, and phosphate (Table 1). Of the other studies reviewed, those that reported on nitrate showed levels far below GEPA's 75 mg-N/L limit, but failed in ammoniacal nitrogen (limit 1 mg/L) and phosphorus (2 mg/L) by between three and eight times. High levels of ammoniacal nitrogen are mostly associated with fresh greywaters, suggesting that little or no nitrification has occurred (Mohamed *et al.* 2019). The phosphorus and phosphate in greywater are connected to the use of household detergents, etc, while the nitrogenous components come mainly from cationic surfactants – e.g., fabric softeners and laundry disinfectants (El-Fadl 2007; Li *et al.* 2008; Widiastuti *et al.* 2008; Mohamed *et al.* 2019).

Greywater also contains some cationic species – e.g., calcium and magnesium – and heavy metals (copper, cadmium, iron, lead, mercury, manganese and zinc) at varying concentrations (Table 1). However, for those macro elements with GEPA-specified discharge limits, the levels were generally below the GEPA thresholds – e.g., 2.5 mg-Cu/L, <0.1 mg-Cd/L, 0.1 mg-Pb/L, and 5 mg-Zn/L. Only one study showed a failure to meet the GEPA discharge limits for lead and mercury – with lead, around 0.30 mg/L, exceeding by about three times and mercury 80-fold. Similar macro-element concentrations are found in greywaters world-wide (Mohamed *et al.* 2019). Metal sources are likely to include household plumbing materials, as well as jewellery, cutlery, coins, etc, which can be absorbed onto the skin and washed off, as well as general wear and tear of metal containing household products (Eriksson & Donner 2009).

Observations and characterization of Asafo greywater

Physical observations from sampling sites

The physical observations centred on qualitative information, especially the hygienic conditions around the sites. Figure 2 shows two sampling points in the study area, while Table 2 provides information from observations made during visits.

All the drains where samples were taken are along tarred roads in the community and are engineered (in concrete). The greywater sampled came from residential buildings and other local activities (Table 2). The 'other activities' include those of vendors, petty traders and squatters, and are similar to household chores – e.g., cooking, washing and cleaning.

At two of the six sampling sites there were no petty traders, food vendors and/or squatters, just mainly residential buildings. There were no visible signs of black-water or faecal matter discharges



Figure 2 | Sampling site 1 (a), and site 3 (b).

at any sampling sites, including the two occupied by squatters. This is in contrast to what is reported from some urban slum neighbourhoods (Owusu & Afutu-Kotey 2010; Monney *et al.* 2013).

People discharged domestic greywater from kitchens, laundries, bathrooms, etc, at almost all sites and only one of the six was not associated with greywater malodour. Typically, the smell included strong fresh urine-like odours, and ranged upward from mild. It is thought that the source could be the ammonia in urine and/or septic conditions arising from the decomposition of organic contaminants, probably aided by the greywater's slow flow and stagnation. There were also instances of solid waste and silt contributing to drain blockage and stagnant greywater flow, conditions that are not uncommon in urban Ghana (Labite *et al.* 2010; Gretsche *et al.* 2016).

Characteristics of greywater samples

The characteristics of the greywater samples collected in Asafo are presented in Table 3. The greywater pHs, which showed slightly acidic to alkaline quality, all fell within the GEPA range acceptable for discharge. The ECs of the greywater at only two sites (5 and 6) were below the 1,500 $\mu\text{S}/\text{cm}$ GEPA limit, the lowest being recorded at site 6. High EC levels indicate high loads of dissolved salts and inorganic materials (Prieto *et al.* 2001). No site's greywater met GEPA's TSS discharge limit (50 mg/L), and only that from site 6 met the turbidity limit (75 NTU). The greywater at site 6 was stagnant and had settled (Table 2). The DO concentrations reported were low at between 0.3 and 1.6 mg/L (Table 3), which probably explains the malodourous environment at some sampling sites, especially sites 3 and 4.

The BOD₅ and COD concentrations at five sites exceeded GEPA's discharge limits (BOD₅ – 50 mg/L, COD – 250 mg/L) significantly. Site 6, however, reported a COD concentration of 207 mg/L (Table 3). Generally, the BOD₅ and COD levels are similar to those established in literature – see above.

Nitrogen and phosphorus were analysed for this study as TKN, total phosphate and phosphorus. Phosphorus concentrations were in the range 5 to 23.3 mg/L, even the lowest exceeding the GEPA discharge limit (2 mg-P/L) by a factor of more than two (Table 3). Similarly, nitrogen levels were high, with TKN measured in the range 28 to 218.5 mg-N/L. The high nutrient levels found in Asafo's greywater reflect the findings reported by others, confirming that Ghanaian greywaters pose a potential eutrophication threat to urban water bodies.

Table 2 | Summary of key physical observations made at sampling sites during field visits

Observations	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
<i>Sampling point</i>	Minor and major drain confluence	About 100 to 120 m from, and below, Site 1	About 20 to 35 m from and above site 2	Highest elevation of all sites. Confluence of drains serving residential buildings.	About 200 to 250 m downstream of Site 4	About 100 to 120 m downstream of Site 5
<i>Key features/ landmarks</i>	Asafo market, bus terminal	Main drain in Asafo market	Stormwater drain inspection chambers with cover ripped off	Business enclave in old Asafo township.	Residential area with private kindergarten and pre-school agency.	Residential area opposite a basic school (primary and JSS)
<i>Greywater sources</i>	Residential buildings upstream	Residential buildings and drains uphill, squatters' greywater	Nearby houses and main drains upstream	Residential buildings within the drain catchments	Residential buildings and other drains upstream	Residential buildings and neighbourhood drains
<i>Vendors/ squatters</i>	Vendors/squatters living in area	Vendors/squatters living in area	Store owners, petty traders, and food vendors nearby	No squatters or evidence of them, but some food vendors	No food vendors or squatters, or evidence of them	No food vendors, petty traders or squatters
<i>Faecal matter and/or solid waste</i>	No faecal matter. Some solid waste – e.g., plastics, food peel, leaves, old clothes, etc – Figure 2(a)	No faecal matter, but some solid waste identified – e.g. food and kitchen debris.	No faecal matter either inside or around the spot/chamber. Possibility of solid waste below the silt deposits	Only kitchen wastewater from food vendors disposed casually into drains	None. No significant silt, either	No faecal matter, but drain choked with silt and solid waste. Two people seen pouring soapy water into the drain
<i>Stench/ odour/ malodour</i>	Minimal	Strong, urine-like odour	Presence of malodour	Strong stench. Very turbid and dark greywater flowing through	No odour, even from the sample(s)	Some odour, and there was a complaint of the same in addition to mosquito nuisance.
<i>Greywater stagnation</i>	Minimal. (The concrete drain ends in a runoff created earthen drain)	Slow flow, almost stagnant. Informants confirmed that stagnation always occurs during peak flows	Chamber silted with stagnant greywater (Figure 2(b)) and wastewater up to 14 cm deep	Greywater relatively free flowing without significant stagnation	No stagnation, freest flow of all drains visited. Flowing greywater depth was just 5 cm	Silted/choked drain caused greywater stagnation. Flow minimal
<i>Other remarks</i>	Solid waste appeared to have been transported and gathered at the concrete drain end	New stores have been built on the drain. People seen urinating and pouring kitchen wastewater into drain	Traces of recurrent kitchen wastewater discharge seen (kitchen oil, food, etc) by the chamber openings	Comparatively small drains – less than 35 cm deep.	Greywater free-flowing and relatively clear	Least turbid greywater of all sampled, because of stagnation and settling. Water was 25 cm deep because drain was choked

Apart from discharge limits, knowledge of greywater contaminant and nutrient levels is critical for decisions on treatment options. The desirable COD:N:P ratio for biological treatment is 100:20:1 (Bojoo *et al.* 2013). Those for the sampled greywaters were between 7:1:1 and 55:5:1, however (Table 3). They are too low and none of the greywaters is considered biologically treatable, as there is no biochemical balance between the biodegradable organics and nutrient levels. However, almost all samples (83% or 5 out of 6) were biodegradable according to the BOD₅:COD ratio. Greywater with a BOD₅:COD ≥ 0.5 is potentially biodegradable (Kulabako *et al.* 2011), and five sampled sites gave ratios between 0.58 and 0.65 (Table 3). The ratio at Site 2 is substantially below 0.5. The findings are similar to those found in Accra – BOD₅:COD ratios of 0.29 to 0.86 (Mohammed *et al.*

Table 3 | Asafo greywater characteristics

Parameters	^a GEPA guidelines	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Mean	Std. Dev.
pH	6–9	8	6.7	6.6	7.7	7.6	8.2	7.5	0.7
EC ($\mu\text{S}/\text{cm}$)	1,500	1,830	2,950	1,840	4,210	1,280	620	2,121.7	1,278.7
DO mg/L	na	1.5	1.6	0.3	0.5	1.5	1.4	1.1	0.6
TDS (mg/L)	1,000	1,220	2,020	1,250	2,860	870	420	1,440.0	872.1
TSS mg/L	50	248	1,490	447	2,550	272.5	70	846.3	976.3
Turbidity (NTU)	75	360	484	442	2,880	301	39.4	751.1	1,054.6
BOD ₅ (mg-O/L)	50	610	600	580	700	480	121	515.2	205.5
COD (mg-O/L)	250	952	2,308	967	1,167	744	207	1,057.5	695.2
BOD ₅ /COD ratio	na	0.64	0.26	0.60	0.60	0.65	0.58	0.56	0.15
TKN (mg-N/L)	na	117.7	198.9	117.7	218.5	67.2	28	124.7	73.6
Total phosphate (mg-P/L)	na	27.4	41.8	29.6	71.5	15.4	30.4	36.0	19.3
Phosphorus (mg-P/L)	2	9	13.8	9.6	23.3	5	9.8	11.7	6.3
COD:N:P ratio	na	35:4:1	55:5:1	33:4:1	16:3:1	48:4:1	7:1:1	29:3:1	–
Calcium (mg-Ca/L)	na	15.7	7.2	50.3	21.7	12.4	15.9	20.5	15.3
Magnesium (mg-Mg/L)	na	1.2	0.5	3.0	3.1	3.3	0.1	1.9	1.4
Sodium (mg-Na/L)	na	7.3	0.5	2.3	3.4	2.9	8.7	4.2	3.1
Iron (mg-Fe/L)	na	0.1	0	0.3	0	0.1	0	0.1	0.1
Arsenic ($\mu\text{g-As}/\text{L}$)	500	125.8	102	191.8	159.1	149	49	129.4	49.8
Mercury ($\mu\text{g-Hg}/\text{L}$)	5	540	221	264.0	1,673.5	874	1,366	823.1	595.9
Total coliforms Log CFU/100 ml	2.6 ^b	9	9.6	9.4	10.4	8.3	9.2	9.3	0.7
Faecal coliform Log CFU/100 ml	na	7.6	8	7.3	9	7.2	7.9	7.8	0.6

^a(GEPA n.d).^bLogMPN/100 ml.

na – not available.

Note: 1 CFU is equivalent to 1 MPN (Noble *et al.* 2004; Chen *et al.* 2017; AWQC 2018).

2015). The BOD₅:COD ratio of 0.26 from Site 2 indicates low potential for biodegradability, similar to some other greywaters studied in Kumasi (Dwumfour-Asare *et al.* 2017). The characteristics of greywater vary widely but those with low potential biodegradability could probably be improved by combination with waters from other sources.

The elemental species determined in the greywater samples were calcium (7.2–50.3 mg/L), magnesium (0.1–3.3 mg/L), sodium (0.5–8.7 mg/L), iron (0–0.3 mg/L), arsenic (49–191.5 $\mu\text{g}/\text{L}$) and mercury (221–1,673.5 $\mu\text{g}/\text{L}$) – see Table 3. According to the GEPA discharge limits no sample failed on arsenic (500 $\mu\text{g}/\text{L}$) but all failed on mercury (5 $\mu\text{g}/\text{L}$). This is not positive for the environment or public health since greywater contaminated with heavy metals is currently discharged untreated.

All samples reported the presence of high total and faecal coliform loads, at around 7.2 to 10.4 log CFU/100 ml (Table 3). There is no discharge limit for faecal contaminants, but the levels (7.2 to 9 log CFU/100 ml) match the total coliforms loads, which exceed the limit between three- and four-fold. The presence of faecal coliforms indicates that the greywater sources were contaminated with faecal matter (from humans and/or animals). Also solid waste was seen at some sites as well as kitchen greywater discharges (Table 2).

Assessment of Table 3 shows that four sampling sites (1 to 4) failed all discharge limits for which the relevant species were determined. Two were within the discharge limits for some parameters, however – thus Site 5 was acceptable in relation to TDS and EC, and Site 6 to TDS, EC, turbidity and BOD₅. The threat to the environment, especially water resources but also public health, from urban greywater in Ghana, including this sewered community, is real because of widespread failure in pollutant discharge limits.

Strength of sampled greywater

Greywater can be of high (dark) or low (light) strength depending on its pollutant load. In some studies categorisation is by qualitative (source) descriptions – e.g., using ‘dark greywater’ for kitchen, laundry and dishwasher sources, and light for bathroom, shower, bath and washbasin sources (Karabelnik *et al.* 2012; Barışçı *et al.* 2016; Cook 2016). The greywater sources in this study are categorised quantitatively using key chemical and nutrient contaminant concentrations. The framework adopted (Table 4) is based on a comprehensive global review of greywater characteristics (Boyjoo *et al.* 2013). The classification in this study is simplified for logical and practical application purpose, cognisant of greywaters’ inherent high variability regardless of its strength. The simplification means that any failure in concentration of a single parameter at the low strength limit pushes the greywater to a higher strength class.

Table 4 | Classification framework for Asafo greywaters

Parameters (unit)	High pollutant-load/strength	Low pollutant-load/strength
BOD ₅ (mg/L)	>300	≤300
COD (mg/L)	>630	≤630
Nutrient – phosphorus (mg/L)	>2	≤1.8
Nutrient – nitrogen (mg-N/L)	>17	≤16.4

Source: Adapted from (Boyjoo *et al.* 2013).

The greywater classification assigned to each site using the framework in Table 4 is presented in Table 5. All six sites have high (dark) greywater (Table 5), suggesting that the greywaters came predominantly from kitchens and/or laundries (Karabelnik *et al.* 2012; Boyjoo *et al.* 2013; Barışçı *et al.* 2016; Cook 2016). This would explain why samples consistently failed to meet most GEPA discharge limits, as well as the strong smell associated with sampling sites (Boyjoo *et al.* 2013).

Table 5 | Asafo greywater classifications

Parameter (units)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
TKN (mg-N/L)	117.7	198.9	117.7	218.5	67.2	28
Total phosphate (mg-PO ₄ ³⁻ /L)	27.4	41.8	29.6	71.5	15.4	30.4
Phosphorus (mg-P/L)	9	13.8	9.6	23.3	5	9.8
BOD ₅ (mg/L)	610	600	580	700	480	121
COD (mg/L)	952	2,308	967	1,167	744	207
Classification	High	High	High	High	High	High

Note: Nutrient nitrogen was measured as Total Kjeldahl Nitrogen (TKN) instead of total nitrogen.

CONCLUSIONS

Connections to Asafo’s sewerage system have exceeded its design capacity about twofold. Not all inhabitants’ greywater discharge points are connected to the sewerage system partially or even at all.

Greywater characteristics are highly variable across the study area. High variability was also inherent in the greywater’s potential biological treatability, with some BOD₅:COD ratios below the 0.5 threshold. There was also a biochemical imbalance between the organic and nutrient contents, with COD:N:P ratios outside the desirable 100:20:1 level.

Greywater in sewered community’s drains is similar to that sampled from point sources (houses, hostels, hotels, kitchens, etc), neighbourhoods, and receiving water bodies reported in literature.

Most of Asafo's greywater sources failed the GEPA wastewater discharge limits. The greywaters were of high strength, and offer a potential threat to the urban environment, especially water bodies. The untreated greywater discharged to the sewer community's drains is no different and could pose similar risks (nuisance and public health hazards) to those associated with disposal practices from non-sewered households and communities.

The study contributed data to the limited general information on greywater in Ghana. While such data are limited, they do indicate that current greywater disposal practices threaten public health. There is urgent need to find a lasting solution to the greywater disposal threat to the environment and public health in Ghana. Meanwhile, the extent of data and information on greywater characteristics in Ghana must be increased.

CONFLICT OF INTEREST

Authors declare no conflict of interest.

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REFERENCES

- Agodzo, S. K., Huibers, F. P., Chenini, F., van Lier, J. B. & Duran, A. 2003 Use of wastewater in irrigated agriculture. Country studies from Bolivia, Ghana and Tunisia. In: *W4F-Wastewater*. Wageningen University and Research, Wageningen, The Netherlands, p7.
- Agvei, P. A., Awuah, E. & Oduro-Kwarteng, S. 2011 Faecal sludge management in Madina, Ghana. *Journal of Applied Technology and Environmental Sanitation* 1(3), 239–249.
- Amoah, P., Drechsel, P., Henseler, M. & Abaidoo, R. C. 2007 Irrigated urban vegetable production in Ghana: microbiological contamination in farms and markets and associated consumer risk groups. *Journal of Water & Health* 5(3), 455–466.
- Anim, S. O., Agyemang, E. O. & Wiafe, S. 2014 The use of a model sand filtration system for greywater treatment: a case study of hotels and hostels in Eastern Region, Ghana. *Health, Safety and Environment* 2(8), 159–166.
- Ansah, M., Awuah, E., Oduro-Kwarteng, S. & Ackerson, N. O. B. 2011 The use of natural system for the treatment of greywater: a case study of Kpeshie Lagoon, Accra, Ghana. *International Journal of Water Resources and Environmental Engineering* 3(11), 238–250.
- Apau, K. B. 2017 *Developing A Conceptual Solution for Domestic Wastewater Management in Developing Countries: Kumasi (Ghana) as a Case Study*. PhD Thesis, Brandenburg University of Technology Cottbus – Senftenberg, Cottbus. https://opus4.kobv.de/opus4-btu/files/4154/Kwaku_Boakye_Apau.pdf (accessed June 27, 2018).
- Appiah-Effah, E., Nyarko, K. B., Gyasi, S. F. & Awuah, E. 2014 Faecal sludge management in low income areas: a case study of three districts in the Ashanti region of Ghana. *Journal of Water, Sanitation and Hygiene for Development* 4(2), 189–199.
- AWQC, Australian Water Quality Centre 2018 *AWQC Demystifying Microbial Detection Methods*. <https://www.awqc.com.au/news/awqc-demystifying-microbial-detection-methods> (accessed April 25, 2018).
- Awuah, E., Amankwaah-Kuffour, R., Gyasi, S. F., Lubberding, H. J. & Gijzen, H. J. 2014 Characterization and management of domestic wastewater in two suburbs of Kumasi, Ghana. *Research Journal of Environmental Sciences* 8(6), 318–330.

- Azanu, D., Mortey, C., Darko, G., Weisser, J. J., Styrihave, B. & Abaidoo, R. C. 2016 Uptake of antibiotics from irrigation water by plants. *Chemosphere* **157**, 107–114.
- Barişçi, S., Turkay, O. & Dimoglo, A. 2016 Review on Greywater Treatment and Dye Removal from Aqueous Solution by Ferrate (VI). In: *Ferrites and Ferrates: Chemistry and Applications in Sustainable Energy and Environmental Remediation*. Sharma, V. K., Doong, R-a, Kim, H., Varma, R. S. & Dionysiou, D. D. (eds). American Chemical Society, Washington, DC, pp. 349–409.
- Barnes, K. K., Kolpin, D. W., Furlong, E. T., Zaugg, S. D., Meyer, M. T. & Barber, L. B. 2008 A national reconnaissance of pharmaceuticals and other organic wastewater contaminants in the United States–I groundwater. *Science of The Total Environment* **402**(2–3), 192–200.
- Boyjoo, Y., Pareek, V. K. & Ang, M. 2013 A review of greywater characteristics and treatment processes. *Water Science & Technology* **67**(7), 1403–1424.
- Chen, Y., Pouillot, R. g., Burall, L. S., Strain, E. A., Van Doren, J. M., de Jesus, A. J., Laasri, A., Wang, H., Ali, L., Tatarvarthy, A., Zhang, G., Hu, L., Day, J., Sheth, I., Kang, J., Sahu, S., Srinivasan, D., Brown, E. W., Parish, M., Zink, D. L., Datta, A. R., Hammack, T. S. & Macarasin, D. 2017 Comparative evaluation of direct plating and most probable number for enumeration of low levels of *Listeria monocytogenes* in naturally contaminated ice cream products. *International Journal of Food Microbiology* **241**, 15–22.
- Clesceri, L. S., Greenberg, A. E. & Eaton, A. D. 1999 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), USA.
- Cook, C. 2016 Regulating the risks of domestic greywater reuse: a comparison of England and California. *Built Environment* **42**(2), 230–242.
- Cronin, A. A., Pedley, S., Hoadley, A. W., Kouonto Komou, F., Haldin, L., Gibson, J. & Breslin, N. 2007 Urbanisation effects on groundwater chemical quality: findings focusing on the nitrate problem from 2 African cities reliant on on-site sanitation. *Journal of Water & Health* **5**(3), 441–454.
- De Gisi, S., Casella, P., Notarnicola, M. & Farina, R. 2016 Grey water in buildings: a mini-review of guidelines, technologies and case studies. *Civil Engineering and Environmental Systems* **33**(1), 35–47.
- Dwumfour-Asare, B., Adantey, P., Nyarko, K. B. & Appiah-Effah, E. 2017 Greywater characterization and handling practices among urban households in Ghana: the case of three communities in Kumasi Metropolis. *Water Science & Technology* **76**(4), 813–822.
- Dwumfour-Asare, B., Nyarko, K. B. & Adams, A. 2018a Land tenure and water sources for urban vegetable farmers in Asante-Mampong, Ghana. *Indian Journal of Science and Technology* **11**(17), 1–9.
- Dwumfour-Asare, B., Nyarko, K. B., Awuah, E., Essandoh, H. M. K., Gyan, B. A. & Ofori-Addo, H. 2018b Indigenous plants for informal greywater treatment and reuse by some households in Ghana. *Journal of Water Reuse and Desalination* **8**(4), 553–565.
- El-Fadl, K. 2007 Technical Bulletin on Greywater Treatment and Reuse in the MENA Region. In: *IDRC/CRDI Technical Bulletin*. Regional Water Demand Initiative (WaDImena), Canada, pp. 1–6.
- Eriksson, E. & Donner, E. 2009 Metals in greywater: sources, presence and removal efficiencies. *Desalination* **248**, 271–278.
- Fosu, E. K. 1996 Part 9.6 – Building services: Water supply, drainage and sanitation (including solid waste management). In: *National Building Regulations, 1996*. Government Printer, Assembly Press, Accra, Ghana, pp. 46–59.
- Furlong, C. & Mensah, A. 2015 *SFD Report – Kumasi, Ghana*. SFD Promotion Initiative Water, Engineering and Development Centre (WEDC), Loughborough, United Kingdom.
- GEPA, Ghana Environmental Protection Agency n.d *General Environmental Quality Standards (Ghana)*. Ghana Environmental Protection Agency (GEPA), Kumasi, Ghana.
- Germer, J. & Sinar, E. 2010 Pharmaceutical consumption and residuals potentially relevant to nutrient cycling in Greater Accra, Ghana. *Journal of Agriculture and Rural Development in the Tropics and Subtropics* **111**(1), 41–53.
- Ghana Local Government 1998 Bye-laws of Kumasi Metropolitan Assembly. *Local Government Bulletin* No. 20(31st December), 224–65.
- Gilboa, Y. & Friedler, E. 2008 UV disinfection of RBC-treated light greywater effluent: kinetics, survival and regrowth of selected microorganisms. *Water Research* **42**(4–5), 1043–1050.
- Greenland, K., de-Witt Huberts, J., Wright, R., Hawkes, L., Ekor, C. & Biran, A. 2016 A cross-sectional survey to assess household sanitation practices associated with uptake of ‘Clean Team’ serviced home toilets in Kumasi, Ghana. *Environment and Urbanization* **28**(2), 583–598.
- Gretsch, S. R., Ampofo, J. A., Baker, K. K., Clennon, J., Null, C. A., Peprah, D., Reese, H., Robb, K., Teunis, P., Wellington, N., Yakubu, H. & Moe, C. L. 2016 Quantification of exposure to fecal contamination in open drains in four neighborhoods in Accra, Ghana. *Journal of Water & Health* **14**(2), 255–266.
- GSS, Ghana Statistical Service 2013 *Ghana 2010 Population & Housing Census: Demographic, Social, Economic, Housing, Characteristics*. Ghana Statistical Service, Accra, Ghana.
- GSS, Ghana Statistical Service 2014 *2010 Population and Housing Census: District Analytical Report – Kumasi Metropolitan*. Ghana Statistical Service, Accra, Ghana.
- Hyde, K. & Maradza, E. 2013 An evaluation of the theoretical potential and practical opportunity for using recycled greywater for domestic purposes in Ghana. *Journal of Cleaner Production* **60**, 195–200.

- Karabelnik, K., Köiv, M., Kasak, K., Jenssen, P. D. & Mander, Ü. 2012 High-strength greywater treatment in compact hybrid filter systems with alternative substrates. *Ecological Engineering* **49**, 84–92.
- Keraita, B., Drechsel, P., Huibers, F. & Raschid-Sally, L. 2002 Wastewater Use in Informal Irrigation in Urban and Periurban Areas of Kumasi, Ghana. *UA-Magazine* December, 11-5.
- Keraita, B., Drechsel, P. & Amoah, P. 2003 Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. *Environment & Urbanization* **15**(2), 171–178.
- Kuffour, R. A. 2010 *Criteria for Improving the Operation and Maintenance of Unplanted Filter Beds for Dewatering of Faecal Sludge*. PhD, Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. [https://ocw.unihe.org/pluginfile.php/4126/mod_resource/content/1/Kuffour_ImprovementUnplanted Drying Beds.pdf](https://ocw.unihe.org/pluginfile.php/4126/mod_resource/content/1/Kuffour_ImprovementUnplanted_Drying_Beds.pdf) (accessed June 27, 2018).
- Kulabako, N., Ssonko, N. & Kinobe, J. 2011 Greywater characteristics and reuse in tower gardens in peri-urban areas—experiences of Kawaala, Kampala, Uganda. *Open Environmental Engineering Journal* **4**, 147–154.
- Labite, H., Lunani, I., van der Steen, P., Vairavamorthy, K., Drechsel, P. & Lens, P. 2010 Quantitative Microbial Risk Analysis to evaluate health effects of interventions in the urban water system of Accra, Ghana. *Journal of Water & Health* **8**(3), 417–430.
- Lewis, E. & Claasen, T. 2018 Monitoring groundwater quality in a Namibian rural settlement. *Water Practice & Technology* **15**(2), 312–320.
- Li, F., Behrendt, J., Wichmann, K. & Otterpohl, R. 2008 Resources and nutrients oriented greywater treatment for non-potable reuses. *Water Science & Technology* **57**(12), 1901–1907.
- Lutterodt, G., van de Vossenbergh, J., Hoiting, Y., Kamara, A., Oduro-Kwarteng, S. & Foppen, J. 2018 Microbial groundwater quality status of hand-dug wells and boreholes in the Dodowa area of Ghana. *International Journal of Environmental Research and Public Health* **15**, e730.
- Maoulidi, M. 2010 A water and sanitation needs assessment for Kumasi, Ghana. In *MCI Social Sector Working Paper Series*. MCI Social Sector Research, New York, USA, pp. 1–32.
- Mensah, A. 2006 Faecal sludge management in Kumasi – Perspective as seen by the Municipality. *First International Symposium/Workshop on Faecal Sludge Management (FSM) Policy*, 09–12 May, 2006, Hotel Novotel, Dakar, Senegal.
- Mohamed, R. M. S. R., Al-Gheethi, A. A. S. & Kassim, A. H. M. 2019 *Management of Greywater in Developing Countries: Alternative Practices, Treatment and Potential for Reuse and Recycling*. Springer International Publishing AG, Switzerland.
- Mohammed, M., Donkor, A. & Dubey, B. 2015 *Biogas Production Potential of Greywater From Households in Accra Metropolis, Ghana*. <http://www.iseesonline.org/wp-content/uploads/2015/01/Poster-BIOGAS.pdf> (accessed June 13, 2016).
- Monney, I., Odai, S., Buamah, R., Awuah, E. & Nyenje, P. 2013 Environmental impacts of wastewater from urban slums: case study—Old Fadama, Accra. *International Journal of Development and Sustainability* **2**(2), 711–728.
- Muspratt, A. M., Nakato, T., Niwagaba, C., Dione, H., Kang, J., Stupin, L., Regulinski, J., Mbéguéré, M. & Strande, L. 2014 Fuel potential of faecal sludge: calorific value results from Uganda, Ghana and Senegal. *Journal of Water, Sanitation and Hygiene for Development* **4**(2), 223.
- Muzola, A. 2007 *Grey Water Treatment Using Natural Wetlands*. Master of Science Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. http://www.switchurbanwater.eu/outputs/pdfs/W5-3_GEN_PHD_D5.3.12_MSc_Muzola_Greywater_treatment_with_natural_wetland.pdf (accessed June 18, 2017).
- Nair, J. 2008 Wastewater garden – a system to treat wastewater with environmental benefits to community. *Water Science & Technology – WST* **58**(2), 413–418.
- NASEM, The National Academies of Sciences, Engineering, and Medicine. 2015 *Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits*. The National Academies Press, Washington, DC.
- Niyonzima, P. 2007 *Grey Water Treatment Using Constructed Wetland at KNUST in Kumasi*. Master of Science (MSc) Thesis, Civil Engineering Department, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. http://www.switchurbanwater.eu/outputs/pdfs/W5-3_GEN_PHD_D5.3.12_MSc_Niyonzima_Greywater_treatment_with_constructed_wetland.pdf (accessed June 17, 2017).
- Nkansah, M. A., Opoku, F., Ephraim, J. H., Wemegah, D. D. & Tetteh, L. P. M. 2016 Characterization of beauty salon wastewater from Kwame Nkrumah University of science and technology, Kumasi, Ghana, and its surrounding communities. *Environmental Health Insights* **10**, 147–154.
- Noble, R. T., Leecaster, M. K., McGee, C. D., Weisberg, S. B. & Ritter, K. 2004 Comparison of bacterial indicator analysis methods in stormwater-affected coastal waters. *Water Research* **38**, 1183–1188.
- Oteng-Peprah, M., de Vries, N. K. & Acheampong, M. A. 2018 Greywater characterization and generation rates in a peri urban municipality of a developing country. *Journal of Environmental Management* **206**, 498–506.
- Ottoson, J. & Stenstrom, T. A. 2003 Faecal contamination of greywater and associated microbial risks. *Water Research* **37**, 645–655.
- Owusu, G. & Afutu-Kotey, R. L. 2010 Poor urban communities and municipal interface in Ghana: a case study of Accra and Sekondi-Takoradi metropolis. *African Studies Quarterly* **12**(1), 1–16.
- Prieto, F., Barrado, E., Vega, M. & Deban, L. 2001 Measurement of electrical conductivity of wastewater for fast determination of metal ion concentration. *Russian Journal of Applied Chemistry* **74**(8), 1321–1324.
- Salifu, L. Y. 2013 *A Rapid Field Evaluation of the Pilot Asafo Simplified Sewerage Scheme in Kumasi, Ghana*. pS-Eau, France.

- Schaider, L., Rodgers, K. & Rudel, R. 2013 *Contaminants of Emerging Concern and Septic Systems: A Synthesis of Scientific Literature and Application to Groundwater Quality on Cape Cod*. Silent Spring Institute, Newton, MA.
- Shi, K. W., Wang, C. W. & Jiang, S. C. 2018 [Quantitative microbial risk assessment of greywater on-site reuse](#). *Science of the Total Environment* **635**, 1507–1519.
- Sievers, J. C. & Londong, J. 2018 [Characterization of domestic graywater and graywater solids](#). *Water Science & Technology* **77**(5–6), 1196–1203.
- Vodounhessi, A. & Münch, E. v. 2006 Financial challenges to making faecal sludge management an integrated part of the ecosan approach: case study of Kumasi. *Ghana. Water Practice and Technology* **1**(2), 1–8.
- Widiastuti, N., Wu, H., Ang, M. & Dong-ke, Z. 2008 [The potential application of natural zeolite for greywater treatment](#). *Desalination* **218**, 271–280.
- Yu, L., Ding, Y., Chen, F., Hou, J., Liu, G., Tang, S., Ling, M., Liu, Y., Yan, Y. & An, N. 2018 [Groundwater resources protection and management in China](#). *Water Policy* **20**(3), 447–460.