Journal of Environmental Management 206 (2018) 498–506

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman

Research article

Greywater characterization and generation rates in a peri urban municipality of a developing country

M. Oteng-Peprah [a], [b], [*], N.K. de Vries [b], M.A. Acheampong [c]

[a] *Water and Sanitation Unit, Department of Chemistry, University of Cape Coast, Ghana*
[b] *Department of Health Promotion, Peter Debyeplein 1, University of Maastricht, The Netherlands*
[c] *Faculty of Engineering and Technology, Kumasi Technical University, Kumasi, Ghana*

ARTICLE INFO

Article history:
Received 7 June 2017
Received in revised form
26 October 2017
Accepted 29 October 2017

Keywords:
Peri-urban
Greywater
In-house
Outside source
Ghana

ABSTRACT

The quantity and quality of combined greywater from houses with in-house water supply and houses that rely on external sources of a peri-urban area in a developing country were determined. Data for quantity of greywater was collected from 36 households while 180 samples of greywater were collected from 60 households between December 2016 and February 2017. The results indicate that, average water consumption from households with in-house access was 82.51 ± 12.21 $Lc^{-1}d^{-1}$ while households which rely on external sources was 36.64 ± 4.31 $Lc^{-1}d^{-1}$ with return factors of 74.16% and 88.57% respectively. Quality analysis also showed significant differences between greywater from the two sources with most of the quality parameters exceeding the regulatory limit. The ratio between biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD) ranged between 0.22 and 0.59 for greywater from in-house sources and 0.23–0.62 for external sources indicating low biodegradability of the greywater. The nutrients recorded exceeded the trigger levels for eutrophication while significant levels of microorganisms such as *E. Coli* and *Salmonella* spp. were also detected in both streams. Direct reuse of greywater for irrigation was found to be unsuitable based on the salinity and sodium hazard analysis. Principal component analysis of the data indicated that the characteristics of the combined greywater in the study area is influenced by cooking and cleaning practices, personal hygiene, biodegradability, frequency of water use before disposal and sanitary practices in the bathroom. The greywater discharged is detrimental to the environment and poses a health risk to humans and livestock. There is therefore the need for authorities involved to prioritize greywater management and treatment in peri-urban areas of developing countries.

1. Introduction

The united nations define a peri-urban area as an area between consolidated urban and rural region (UNICEF, 2012). In developing countries, it is where poverty and social displacement are more common, a frontline between the problems of the city and the rural areas. The growth of these peri-urban areas in developing countries are associated with sanitation challenges such as solid waste, excreta collection and management, and wastewater management for the relevant institutions. Due to the disparities in economic and social status associated with peri-urban areas in developing countries, certain basic amenities like water supply within a house is not automatic for every house. Houses without piped water in their dwelling will have to resort to other sources of water such as from water vendors, springs, streams among others. Many of these peri-urban areas in developing countries are saddled with wastewater management largely due to the non-existence of sewer network. The primary focus on peri-urban areas by authorities has remained solid waste and excreta management which is aimed at improving the sanitary conditions and improving public health. However, this is in sharp contrast to greywater management which accounts for the high volumetric flux of wastewater generated in non-sewered areas. There is a clear lack of planning in addressing greywater management in peri-urban areas in developing countries mostly arising from lack of commitment or by the overwhelming rapid growth associated with these areas. Lack of proper management of greywater in peri-urban areas of developing

---

[*] Corresponding author. Water and Sanitation Unit, Department of Chemistry, University of Cape Coast, Ghana.
E-mail address: m.oteng-peprah@maastrichtuniversity.nl (M. Oteng-Peprah).

https://doi.org/10.1016/j.jenvman.2017.10.068

countries has led to indiscriminate discharge of greywater, which has contributed to public health issues arising out of uncontrolled and unmonitored discharges. These discharges result in both short term and long-term effects on both environment and human (Gross et al., 2005; Scott and Jones, 2000). It also affects water resources and soils due to the presence of surfactants (Mohamed et al., 2013), and heavy metals (Aonghusa and Gray, 2002; Eriksson et al., 2010) in high concentrations. Nutrient buildup in water bodies as a result of greywater discharge may lead to eutrophication which is detrimental to aquatic environment. Kohler (2006) identified sodium polyphosphate which is a major ingredient in soaps to be a major contributor of nutrients in eutrophication. Studies conducted by (Escher and Fenner, 2011; Taghipour and Mosaferi, 2013) identified a distortion in the ecological balance due to toxicity of food chain caused by accumulation of heavy metals and micro-pollutants in the environment which negatively affects both plants and animals alike after long exposure times. Long periods of exposure to pathogens and microorganisms in greywater has been reported to cause diseases that results in either mortality or morbidity (Birks and Hills, 2007; Ottoson and Stenstrom, 2003). Many studies have all analyzed greywater without cognizance to the source of water and the lifestyle patterns. Research on greywater characterization and quantity generations has largely focused on sources such as kitchen, bathroom, hand wash basin (Abedin and Rakib, 2013; Katukiza et al., 2014), water use fixtures such as washing machines, dishwashers (Abedin and Rakib, 2013; O'Toole et al., 2012) and location or type of settlement such as peri-urban and slums, (Antonopoulou et al., 2013; do Couto et al., 2013; Katukiza et al., 2014; Ramona et al., 2004).

However, the differences in quality and quantity between greywater from houses fitted with household taps and those that rely on other external sources of water in a peri-urban area in a developing country remains uninvestigated. According to the UNDP (2017), about 663 million people lack access to improved water and a majority of this fraction are in developing countries. This is an indication that greywater discharges from peri-urban areas in developing countries should not be treated as all coming from one source as has always been the case in many studies that have characterized greywater quality and quantities.

The objective of this study therefore is to characterize greywater and quantify its pollutant loads for these two categories in a typical peri-urban area of a developing country within sub-Saharan Africa and provide the relevant data necessary to policy makers to inform decision and influence policy.

2. Materials and methods

2.1. Study area

This study was conducted in the Komenda Edina Eguafo Abirem (KEEA) municipality of the Central region of Ghana during the periods of December 2016–February 2017. KEEA is located in the central region of Ghana between longitude 1° 20′ West and 1° 40′ West and latitude 5° 05′ North and 15° North and covers an area of 452.5 km^2 with a population of 144,705 (GSS, 2014). It is located within the coastal belt of the country along the Atlantic Ocean and it is drained by the Benya lagoon. Potable water supply to the area is exclusively by Ghana Water Company Limited (GWCL) which has a network coverage of less than 40% within the municipality while other areas which are not connected to the GWCL lines resort to alternative water supply systems such as groundwater, streams and springs, rainwater and water vendors. Greywater is discharged through open gutters and undeveloped plots. Other methods of disposal also include direct irrigation of certain plant species such as *Musa Balbisiana*, *Carica Papaya* among others and open discharge onto compounds in areas where there are no gutter or undeveloped plots. Majority of residents use on-site sanitation systems such as septic tanks and household latrines while others rely on public sanitation facilities. These practices are mostly common in peri-urban areas in developing countries within the sub-Sahara Africa, Latin America, and Asia. There is no wastewater management system in place and wastewater is discharged without any regulation. This survey was done in different towns/villages within the study area in order to have a cross-sectional variation in water use and greywater generation rates and also mimic similar conditions in other developing countries.

2.2. Selection of households: characterization

Greywater samples were collected from all six zonal councils within the study area. A total of one hundred and eighty (180) samples were collected from the study area. Sixty households were selected to participate in the study within the six zonal councils after consultation with local leaders within the community. The criteria for selecting these households were willingness to participate in the study, households with in-house access, households that rely on outside sources, households with children under age 3, households that have greywater from kitchen, hand wash basin and bathrooms going through one discharge point. Volunteers were asked to discharge water used for laundry into this drain during the periods of data collection.

2.3. Selection of households: volume estimation

Volume estimation was done by recruiting two sets of volunteers – those with in-house access and those who rely on an outside source. Criteria for selection of volunteers with in-house access was willingness to participate in the study. With respect to those who rely on outside sources, the criteria for selecting such volunteers were willingness to participate, willingness to use special 20L buckets provided for the study to collect both potable and greywater after use.

2.4. Collection of greywater samples: quality estimation

Greywater samples ($n = 180$) were collected and stored in sterilized 0.5L sample bottles and 0.2L sterilized glass bottle for oil and grease analysis. The sampling points indicated with round dots are shown in Fig. 1. These samples were stored in laboratory ice chest with ice packs and transported to the laboratory for analyses within 24 h.

2.5. Collection of greywater samples: volume estimation

A total of 18 households with in-house access were provided with a special digital flow meter – white-line smart flowmeter. The discharge spouts of their wastewater discharge lines were retrofitted in order to install this flowmeter. This flowmeter is not disturbed by solids and has a very low sensitivity (0.5 $Lmin^{-1}$). However, the drawback of this flowmeter is its inability to read more than 1000L. Volunteers were alerted of this and were given a tally card to record the number of times it resets itself after recording 1000L. The volume recorded on the water meter supplied by GWCL is taken before the study was initiated in order to estimate the volume of water that will be used by the household. Sampling points represented by triangle are presented in Fig. 1. Participants were also asked to note any day when there was no water supply.

A total of 18 households that relied on outside sources were selected in this study. These households were given special 20L buckets for use during the study period to help estimate the

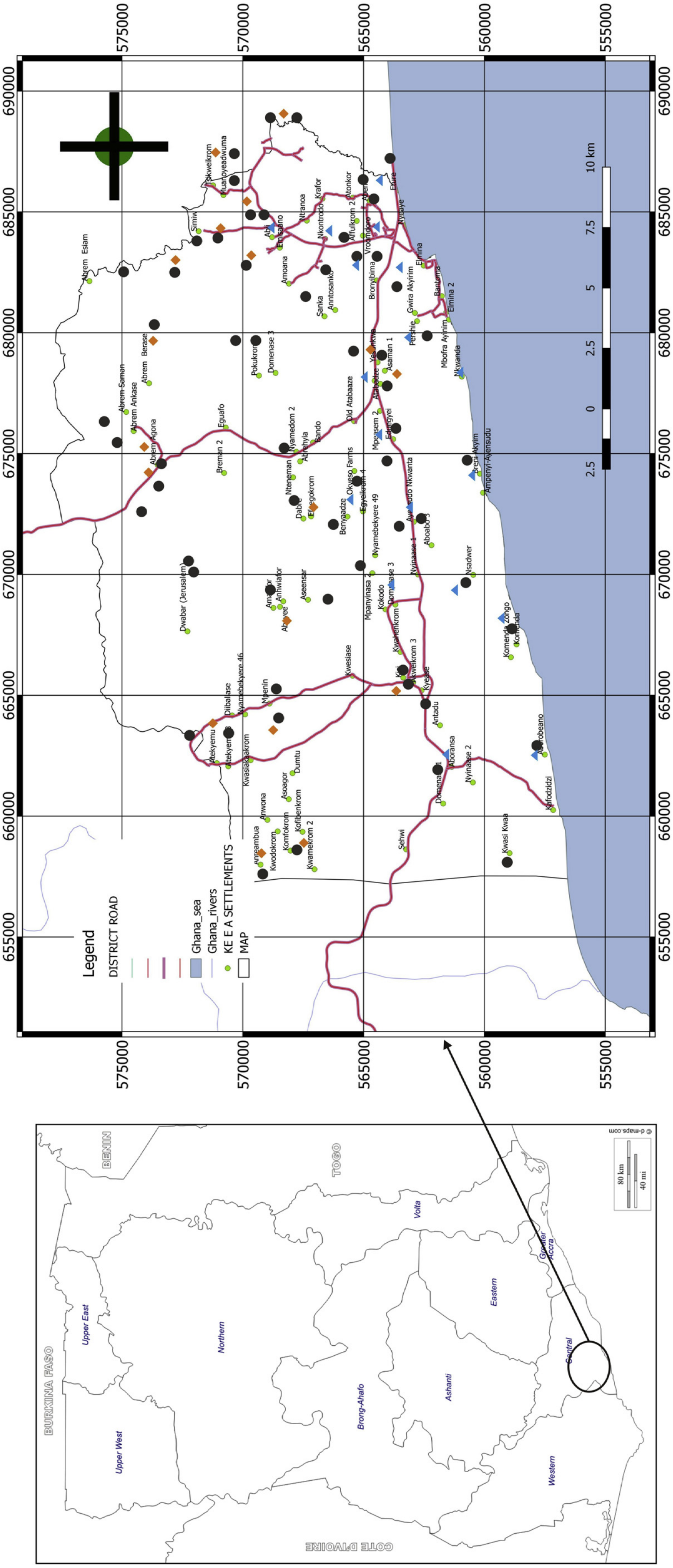

Fig. 1. Map of study area with sampling points.

quantity of water used. To help estimate the volume of greywater discharged, they were asked to pour greywater generated into these 20L buckets before final disposal. A tally card indicating the number of times the bucket got full and was emptied and the number of times they fetched water with the bucket was given to each household. Sampling points represented by diamond is presented on Fig. 1.

3. Laboratory analysis

The following parameters: pH, Dissolved Oxygen (DO), Electrical Conductivity (EC) and Total Dissolved solids (TDS) were measured on site using a Horiba U-50 multi parameter water quality meter. The concentrations of Nitrate-nitrogen (NO_3-N), Ammonium-nitrogen (NH_4-N), Total Suspended Solids (TSS), Chloride (Cl^-) and Potassium (K) were measured using a HACH DR6000 spectrophotometer according to HACH methods 8171, 8006, 8113 and 8049, respectively. The five-day Biochemical Oxygen Demand (BOD_5) concentration was determined using the Lovibond BD 606 BOD system. The concentration of Chemical Oxygen Demand (COD) was determined using the closed reflux colorimetric method as stated in (APHA) 5220C. The concentration of Sodium (Na^+) was determined with flame photometer while total phosphorous (T-P) was determined using the persulfate method as stated in (APHA) 4500-P. Oil and grease concentrations were determined using the partition gravimetric method as stated in the (APHA) 5520-B. Concentrations of Magnesium (Mg^{2+}) and Calcium (Ca^{2+}) were determined with atomic absorption spectrometric method using a Varian AA 50 spectrometer. The bacteriological parameters (Total coliforms, *E. coli* and *Salmonella* spp.) were determined with *chromocult* coliform agar media using spread plate method as outlined in the (APHA) 9215C.

4. Statistical analysis

Independent t-tests were used to determine the statistical significance in the parameters measured between greywater from Inhouse and outside sources. Principal component analysis (PCA) was used to reduce the dimensionality of the data from 17 to 5 using Oblique rotation (direct oblimin). Field (2014) recommends oblique rotation if there are good reasons to suppose that the underlying factors could be related in theoretical terms. This method of rotation was adopted because there is theoretical evidence that suggests some of the factors may be related. PCA is used to reduce a data set to a more manageable size while retaining as much of the original information as possible. All statistical analyses were carried out using IBM SPSS statistics 21 and Microsoft Excel.

5. Results and discussion

5.1. Water consumption and greywater volume generation

Independent sample t-tests were conducted to compare water consumption, greywater generation and return factors between in-house access and outside access. Summary results are presented in Table 1.

The average water consumption of and 36.64 $Lc^{-1}d^{-1}$ for outside access and 82.51 $Lc^{-1}d^{-1}$ for in-house source were above the minimum recommended value of 30 $Lc^{-1}d^{-1}$ (UNICEF, 2016) but below the national average of 100 $Lc^{-1}d^{-1}$ (GWCL). These differences can be attributed largely to lifestyle and sanitation facilities and practices adopted by these two groups. The water consumption recorded for in-house access falls within the range of a similar study in South Africa by (CSIR, 2001; Schalkwyk, 1996), which recorded water consumption within 30–100 $Lc^{-1}d^{-1}$ for in-house access. The return factors of 88.57% and 74.16% recorded for this study were within the range reported by other studies (Alderlieste and Langeveld, 2005; Busser et al., 2006; Faraqui and Al-Jayyousi, 2002; Shresta, 1999). These results suggest that access to in-house connection is likely to lead to increase in water consumption and its associated greywater generation. The high return factor recorded for greywater from outside access can be attributed to sanitation and hygiene practices. Most people under this category use dry sanitation systems such as pits or patronize public sanitation facilities. It could also be attributed to other factors such as distance, reliability of source and many other latent factors. SANDEC (2006) reported that households with dry latrines can record as high as 100% return factors. Studies of greywater generation rates from different sources is presented in Table 2.

5.2. Greywater characteristics

Summary results of independent t-tests on greywater quality parameters comparing in-house and outside source is presented in Table 3. Most of the physical parameters measured exceeded the permissible limits set by the regulating agency which is the Environmental Protection Agency of Ghana (EPA). The pH recorded was within a range of 5–8 but the average pH of 7 was within the acceptable range of 6–9. The extreme pH of 5 recorded in some of the samples could be attributed to organic acids produced by edible organic compounds while the high pH of 8 could be partly attributed to the use of sodium hydroxide-based soaps. However, there is no significant difference between the pH recorded in both groups ($p = 0.62$). This indicates that having in-house source or relying on outside source has no influence on the pH of the greywater generated. The average values of (DO) recorded within the study area were within the acceptable limits. However, the range recorded showed some samples which were below the acceptable limits set by the EPA. Although no significant differences were observed between these two groups the low DO recorded could be attributed to water storage practices which is very common within the study area. Low dissolved oxygen impairs aquatic organisms and also creates septic conditions for water. The average electrical conductivity (EC) of 2044 μScm^{-1} for outside sources and 1617 μScm^{-1} for in-house sources recorded were above the regulatory limit of 750 μScm^{-1} for both groups. There is a significant difference ($p = 0.00$) between the two groups, which implies EC of greywater from outside sources is higher than in-house sources. This could be

Table 1
T-test Results of water consumption and greywater generation rates.

	Outside Source *N = 18*	In-house Access *N = 18*	*t*-test for equality of means		
			p	t	df
Water Consumption ($Lc^{-1}d^{-1}$)	36.64 (±4.3)$_a$	82.51 (±12.21)$_b$	0.00	15.02	34
Greywater generation ($Lc^{-1}d^{-1}$)	32.44 (±3.83)$_a$	73.41 (±11.01)$_b$	0.00	14.91	34
Return factor %	88.57 (±3.4)$_a$	74.16 (±2.56)$_b$	0.00	14.32	34

Values in the same row not sharing the same subscript are significantly different at $p < 0.05$ in the two-sided test of equality for in-house and outside source greywater.

Table 2
Rates of greywater generation from in-house and outside water sources reported in similar studies.

Location	Generation ($Lc^{-1}d^{-1}$)	Water source	Reference
South-Africa	20	Outside source	(Adendorff and Stimie, 2005)
Mali	30	Outside source	(Alderlieste and Langeveld, 2005)
Nepal	72	In-house source	(Shresta, 1999)
Vietnam	80–110	In-house source	(Busser et al., 2006)
Jordan	50	In-house source	(Faraqui and Al-Jayyousi, 2002)
Ghana	32	Outside source	This study
Ghana	73	In-house source	This study

Table 3
Summary of physicochemical, microbiological and recommended discharge standards of greywater quality parameters for in-house and outside waters sources N = 180.

Parameter	Outside Source			In-house Source			Discharge Standard	*t*-test for equality of means		
	Mean	Max	Min	Mean	Max.	Min		p	t	df
pH	7.0 (±0.9)$_a$	8	5	6.89 (±0.9)a	8	5	6.0–9.0*	0.62	0.498	178
DO (mgL^{-1})	6.1 (±1.7)$_a$	9.0	2.2	6.0 (±1.7)a	9.0	2.3	5.0*	0.76	0.30	178
EC (μS/cm)	2044.2 (±314.4)$_a$	2530	1208	1617.4 (±320.2)b	2434	1204	750*	0.00	9.02	178
TDS (mgL^{-1})	1288.7 (±210.6)$_a$	1584	720	1010.3 (±221.9)b	1584	700	50*	0.00	8.63	178
TSS (mgL^{-1})	537.5 (±120.07)$_a$	744	333	296.8 (±65.12)b	414	192	1000*	0.00	16.72	178
Oil and Grease (mgL^{-1})	67.2 (±56.19)$_a$	170	0	65.8 (±54.36)a	170	0	30**	0.86	0.175	178
BOD_5 (mgL^{-1})	252.6 (±81)$_a$	394	114	204.1 (±61.5)b	301	87	50.0*	0.00	4.53	178
COD (mgL^{-1})	757.7 (±325.4)$_a$	1595	270	643.8 (±249.9)b	1299	207	250.0*	0.00	2.63	178
Cl^- (mgL^{-1})	36.3 (±7.6)$_a$	50	18	31.9 (±7.3)b	49	18	140*	0.00	3.91	178
Ca^{2+}(mgL^{-1})	27.2 (±7.9)$_a$	43	10	23.2 (±8.2)b	43	9	NS	0.00	3.32	178
Mg^{2+} (mgL^{-1})	9.8 (±2.5)$_a$	14	3	8.4 (±2.7)b	15	3	NS	0.00	3.60	178
Na^+ (mgL^{-1})	140.0 (±30.79)$_a$	203.84	72.94	118.6 (±29.65)b	190	52	100**	0.00	4.75	178
K^+ (mgL^{-1})	10.9 (±5.0)$_a$	22	2	9.0 (±4.6)b	18	0	NS	0.01	2.71	178
Tot-P (mgL^{-1})	2.3 (±0.7)$_a$	3	1	2.3 (±0.6)a	3	1	20.0**	0.72	0.35	178
$NO^-{}_3$ (mgL^{-1})	2.5 (±1.3)$_a$	5	0	2.5 (±1.3)a	5	0	11.5*	0.87	0.168	178
NH_4^-N (mgL^{-1})	14.8 (±4.1)$_a$	22.0	7.0	14.2 (±4.3)a	22.0	7.0	1.5*	0.35	0.94	178
Total Coliforms (CFU/100 mL)x10^6	3.8 (±0.8)$_a$	4.9	2.5	3.7 (±0.8)a	4.9	2.5	400*	0.34	0.95	178
E.coli (CFU/100 mL) x10^4	2.4 (±2.5)$_a$	6.7	0.0	1.8 (±2.4)a	6.9	0.0	10*	0.10	1.67	178
Salmonella spp. (CFU/100 mL) x10^3	3.1 (±3.0)$_a$	7.9	0.0	2.4 (±2.9)a	7.9	0.0	10*	0.09	1.70	178

Values in the same row not sharing the same subscript are significantly different at $p < 0.05$ in the two-sided test of equality for in-house sources and external sources means.
*standards as stated by (Ghana, 2000) ** Standards as stated by (WHO, 2006) NS = No Standard.

due to extensive use of water in the form of internal recycling practices such as reusing laundry water for scrubbing or rinsing cooking pots and pans in the same bowl of water, which are mostly practiced by houses that rely on outside source. This internal recycling leads to massive buildup of dissolved ions in the water, which increases the electrical conductivity. It could also be from the sources of water, which might largely be groundwater sources. Since the study area is close to the sea, groundwater supplies could have very high EC. This phenomenon is also confirmed in the results from the Total Dissolved Solids. The average TDS of 1288 mgL^{-1} recorded for greywater from outside sources is higher than concentration of 1010 mgL^{-1} recorded for greywater from in-house sources, which is statistically significant at $p = 0.00$. The TDS concentrations for both groups also exceed the regulatory guideline limits of 50 mgL^{-1}. TDS is largely due to the presence of salts and other dissolved fractions in greywater. A linear trend with positive slope shows a significant correlation between these two parameters, which is also supported by reports from Tchobanoglous et al. (2003) that TDS is a factor of EC.

The concentration of Total Suspended Solids (TSS) for both groups were below the regulatory limits. The TSS measured also indicate that greywater from in-house sources had lower TSS concentration of 269 mgL^{-1} than that of 538 mgL^{-1} from outside sources, the difference of which is statistically significant ($p = 0.00$). These differences in concentrations can be attributed to the quantity of water used. High total suspended solids in greywater can lead to cloudiness in the receiving water body, impair visibility and cause reduction in dissolved oxygen in the receiving water body. It can also lead to buildup of sediments in the receiving water body or drain and create suitable conditions for flooding. The high concentration recorded for greywater from outside sources could be due to the repeated use of water for different activities before it is finally disposed.

The average concentration of BOD_5 for in-house access was 204 mgL^{-1} and outside access was 253 mgL^{-1} while the COD concentrations were 644 mgL^{-1} for in-house and 744 mgL^{-1} for outside access. This difference is statistically significant at $p = 0.05$ and $p = 0.00$ for BOD_5 and COD respectively. Comparing the concentration range of greywater from outside sources to greywater from in-house sources, which is BOD_5 of 61.5 mgL^{-1} – 301 mgL^{-1} and COD of 207 mgL^{-1} – 1299 mgL^{-1}, it can be seen that all the concentrations are above the permissible limits set by the regulatory agency. This indicates that greywater from outside sources had higher BOD_5 and COD than those from in-house source. This could be due to some form of internal recycling within the house before the greywater is finally discharged, hence, accounting for the higher concentration of biodegradable and non-biodegradable materials within the greywater. It could also be attributed to excessive disposal of biodegradable and non-biodegradable materials into greywater. Nevertheless, BOD_5 and COD values recorded for both areas were within the range for greywater (Tchobanoglous et al., 2003). The relatively low values recorded for in-house source may, however, be attributed to dilution. Therefore, discharging greywater with high BOD_5 and COD concentrations into drains and surface water can result in oxygen depletion and impair aquatic life. Hernandez Leal et al. (2007) in a similar study have reported BOD_5

ranges of 102–215 mgL^{-1} and COD of 425–1583 mgL^{-1} for greywater.

The concentration of Sodium (Na^+) in greywater samples from outside sources, which is 140 mgL^{-1} was significantly higher than that of in-house source of 119 mgL^{-1} at $p = 0.00$. The concentration of both groups exceeded the regulatory limit. The differences observed can be attributed to the type of soaps used by both groups. The source of Na^+ could be from cooking salt and detergents. Dilution or the source of water can also play a role in the marked differences recorded between these two groups. The presence of Na^+ in greywater can lead to Na^+ buildup within the environment, which is detrimental to plant growth (Tavakkoli et al., 2011). It also increases the electrical conductivity of water as well as its Total Dissolved Solids. The results obtained in this study is within the range reported in a similar study by Leal et al. (2011), which reported Na^+ concentrations of 123–144 mgL^{-1}. The average concentrations of chloride (Cl^-), potassium (K), calcium (Ca^{2+}) and magnesium (Mg^{2+}) from outside source were slightly higher than in-house sources. The observed differences are statistically significant at $p = 0.00$ for Ca^{2+}, $p = 0.00$ for Magnesium and $p = 0.00$ for Cl^- and $p = 0.01$ for potassium. The presence of Cl^- can be attributed to the use of table salt for cooking. Cl^- has also been reported as being a component of urine (Tchobanoglous et al., 2003) suggesting the practice of urination during showering also contributes chlorine into greywater. The difference in the Cl^- concentrations between these groups can be due to dilution and cooking practices. The presence of excessive concentration of Cl^- in the environment may impact freshwater organisms and plants by increasing species mortality and changing reproduction rates (WHO, 1996). Cl^- ions can also percolate down into the water table and affect groundwater quality. There were significant differences between concentration of K for outside source and in-house source. Greywater from outside sources recorded an average concentration of 10.9 mgL^{-1} while in-house sources recorded an average of 9.0 mgL^{-1}. The presence of K could also be from use of certain potassium based soaps. K may contribute nutrients to a receiving water body or environment and promote eutrophication in ponds and streams. The results obtained for K in this study falls within a similar study by (Christova-Boal et al., 1996; Hernandez Leal et al., 2007) which reported concentrations of K within 8.13–15.2 mgL^{-1}.

5.3. Oil and grease

Although the concentrations of oils and grease from greywater from outside sources of 67 $mgL^{-1}$was slightly higher than that from in-house source of 66 mgL^{-1}, this difference is not significant ($p = 0.86$). From the 180 samples taken, 81% recorded positive results for oil and grease. This is to be expected since mixed greywater samples include greywater from the kitchen, where oil and grease are mostly used. Christova-Boal et al. (1996) also recorded oils and grease in greywater within a concentration range of 37–78 mgL^{-1}. Oil and grease in greywater is a major concern because of the translucent film it forms on the surface of water blocking the water-oxygen interface, which is detrimental to aquatic life. In an area where there are limited major drains, current practices of open disposal of greywater may impair soil porosity and ultimately affect infiltration, which can lead to flooding in the extreme circumstances.

5.4. Nutrients

The average concentration of NH_4-N for greywater from outside and in-house sources were both 14.8 and 14.4 mgL^{-1} respectively. However, this observed difference was not statistically significant ($p = 0.35$). The average values recorded for NH_4-N in both groups seems to deviate from what has been widely reported in literature. However, Katukiza et al. (2014) has also reported NH_4-N values for greywater within the range of 22–33 mgL^{-1}. This indicates that the levels of NH_4-N recorded in this study and other studies are all above the regulatory limit. The average concentration of NO_3-N for greywater samples from outside sources and in-house source had the same average values of 2.5 mgL^{-1}. These results were, however, not statistically significant ($p = 0.87$). Katukiza et al. (2014) also recorded NO_3-N in greywater samples within the range of 1.9–3.1 mgL^{-1}. Since NH_4-N is not used in production of soap, the most probable source of NH_4-N and NO_3-N in greywater might be from urine, which can be explained by the habit of some users probably urinating during showers and also from mineralization of organic materials from kitchen.

The Total Phosphorous (TP) concentrations for greywater from outside sources and in-house were both 2.3 mgL^{-1}, but these average concentrations were not statistically significant ($p = 0.72$) (Elmitwalli and Otterpohl, 2007). in a study on greywater also recorded NO_3-N concentrations within the range of 5.2–6.3 mgL^{-1}, which were slightly higher than what is recorded in this study. The main sources of phosphorous are soaps and cleaning materials. The concentration of these nutrients recorded in this study exceed the trigger values of 0.1 mgL^{-1} for TP, 0.1 mgL^{-1} for NO_3-N and 0.01 mgL^{-1} for fresh water which is stated by ANZECC (2000). This implies their continued buildup within the environment can lead to excessive eutrophication in streams and water bodies. The presence of nutrients suggests that the nutrients content can also be exploited for beneficial use.

5.5. Salinity hazard

One of the most important characteristics of determining the suitability of water for direct irrigation is the relative proportion of sodium to other principal cations which is termed the salinity hazard. A better measure of sodium hazard for irrigation is known as sodium adsorption ratio SAR which is used to express reactions with the soil. This parameter is computed using equation (1). All the samples are found to be less than 10 for both groups and are classified as excellent for irrigation. Fig. 2 presents a graphical representation of SAR. This is generated by plotting the specific conductance and SAR values on the US salinity diagram (USSL). When the specific conductance and SAR are known, the classification of irrigation water can be graphically determined by plotting these values on the US salinity diagram. From the results obtained, only 3 samples from In-house sources and 26 samples from outside source were found to be unsuitable for irrigation. However, the remaining samples were all within the doubtful class. Low sodium water can be used for irrigation on most soils with little danger of developing harmful levels of exchangeable sodium while medium sodium is not suitable for fine textured soils but can be safely applied to coarse soils. High and very high sodium water are not suitable for irrigation since they may produce harmful levels of exchangeable sodium and this will lead to soil sodicity which is highly undesirable in irrigation. From the chart, it can be observed that all the samples fall within the sodium hazard class C3S1, C4S1 and C4S2 which is an indication of high to very high salinity. This therefore suggests that greywater within the study area cannot be safely used for irrigation based on the salinity hazard. The (SAR) values obtained in this study (4–11.7) are within than what is reported in a similar study by Katukiza et al. (2014) in Uganda which recorded (4–15). The high SAR values could probably be due to the use of more sodium based detergents.

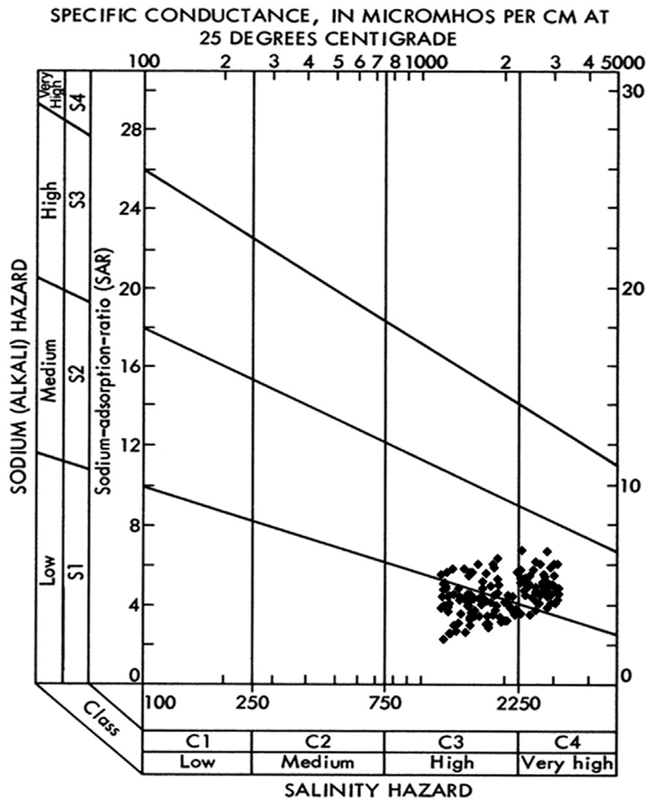

Fig. 2. USSL classification of greywater for Irrigation within the study area.

$$SAR = \frac{[Na^{+}]}{\sqrt{\frac{([Ca^{2+}]+[Mg^{2+}])}{2}}} \tag{1}$$

where $[Na^{+}]$, $[Ca^{2+}]$ and $[Mg^{2+}]$ are in $mmolL^{-1}$

5.6. Biodegradability potential of greywater

The potential of biodegradability of greywater is largely based on the BOD_5/COD ratio. According to Tchobanoglous et al. (2003), a BOD_5 to COD ratio close to or above 0.5 is an indication of good biodegradability of the greywater and as such any treatment schemes can rely on microbiological processes. In this study, a BOD_5 to COD ratio for greywater from outside sources ranged between 0.23 and 0.62 while greywater from in-house sources ranged between 0.22 and 0.59. This shows a very wide variability within which to justify the biodegradability of the greywater. About 78% of the BOD_5 to COD ratios recorded for greywater from outside sources fell below the recommended ratio of 0.5 while about 83% recorded from in-house sources also fell below the 0.5 ratio. This is an indication that, the greywater analyzed from both sources have low potential for biodegradability. It also supports the assertion that mixed greywater is not easily biodegradable. The results obtained in this study however fall within the range of typical BOD_5 to COD ratios reported by Tchobanoglous et al. (2003) of 0.3–0.8.

5.7. Microbiology

There were significant number of microorganisms in the samples taken from the sampling sites. Total Coliforms, *E. coli* and *Salmonella* spp. were detected in 100%, 52% and 48% respectively out of 180 samples tested. The presence of *E. coli* is a strong indication of fecal contamination, which is registered in both groups. This could be due to washing of babies nappies or from ablution. The presence of *Salmonella* spp. is also a strong indication of fecal contamination. It can also be attributed to washing of meats and other household items which already carry the bacteria. There were no significant differences between microorganism loads recorded between outside and in-house sources. This could be an indication of probably equal sanitation lifestyles practiced by both groups. These high concentrations of *E. coli* and *Salmonella* spp. in greywater from households pose a health risk to residents. Similar studies conducted by (Alsulaili and Hamoda, 2015; Birks and Hills, 2007; Dalahmeh et al., 2016; Sievers et al., 2016) also identified these microorganisms in greywater samples. A study by Westrell et al. (2004) states about 8% of *E. coli* and *Salmonella* spp. are pathogenic hence the occurrence of fecal coliform and *Salmonella* spp. in greywater indicates a risk of human illness or infection through contact with water. Therefore 10^2-10^6 cfu $(100\ mL^{-1})$ is a clear indication that the greywater is not fit for direct reuse or human contact.

5.8. Constituent loading

In estimating constituent loading, the parameter of interest are the parameters analyzed and the volume of greywater discharged into the environment. It was calculated using equation (2).

$$P_{av.c} = C_n Q_{av.c} \tag{2}$$

P_{avc} = the specific pollutant load generated per capita per day
C_n = is the average concentration of parameter n in greywater
Q_{av} = is the average greywater generated per capita per day.

The specific pollutant loads calculated for all the parameters indicates that houses with in-house source generate higher loads than outside source. This can be due to the volume of water consumption, which is about twice that of outside source. Some of these values obtained in this study compared with other studies is presented in Table 4. However, some studies also showed completely wide variations from this study as also reported in the table below. It was impossible to calculate the overall pollutant load per day due to unavailability of data on numbers who have in-house connection and those without. A relative pollution contribution of in-house and outside sources is shown in Fig. 3.

5.9. Evaluation of factors influencing greywater quality (principal component analysis)

A principal component analysis was conducted on 17 out of 19 parameters because two (2) parameters pH, and oil and grease failed the Kaiser-Meyer-Olkin (KMO) test. An oblique rotation (direct oblimin) was used and the KMO measure verified the sampling adequacy for the analysis, KMO = 0.757 which is adequate based on the classification of adequacy of KMO by Hutcheson and Sofroniou (1999). All the KMO values for the individual items were greater than 0.5 which is above the acceptable limit as described by Field (2014). An initial analysis was run to obtain eigenvalues for each factor in the data. Five (5) factors had eigenvalues over the Kaiser's criterion of 1 and in combination explained 61.45% of the variance. The scree plot was unambiguous and showed inflexion that would justify retaining 5 factors. Table 5 presents the principal components after rotation.

Principal component 1 explained 26.93% of the total variance and the variables which most positively contributed to it were EC,

Table 4
Pollutant loading from different studies.

Parameters	Outside Source	In-house source	(Friedler, 2004)	(SANDEC, 2006)	(Busser et al., 2006)	(Sievers et al., 2016)
TSS ($gc^{-1}d^{-1}$)	17.2	22.0	29	10–30	–	–
Oil and Grease ($gc^{-1}d^{-1}$)	2.15	4.9	19	–	–	–
BOD_5 ($gc^{-1}d^{-1}$)	8.06	15.1	23	20–50	–	–
COD ($gc^{-1}d^{-1}$)	24.24	47.6	46	–	18–37	45
NH_4 ($gc^{-1}d^{-1}$)	14.8	1.1	0.15	–	–	–
TP ($gc^{-1}d^{-1}$)	0.1	0.2	–	0.2–6	0.4–0.6	0.4
Salmonella spp. ($CFUc^{-1}d^{-1}$) $\times 10^5$	9.9	17.8	–	–	–	–
E.coli ($CFUc^{-1}d^{-1}$) $\times 10^6$	7.7	13.3	–	–	–	–
Total Coliforms ($CFUc^{-1}d^{-1}$) $\times 10^9$	1.2	2.7	–	–	–	–

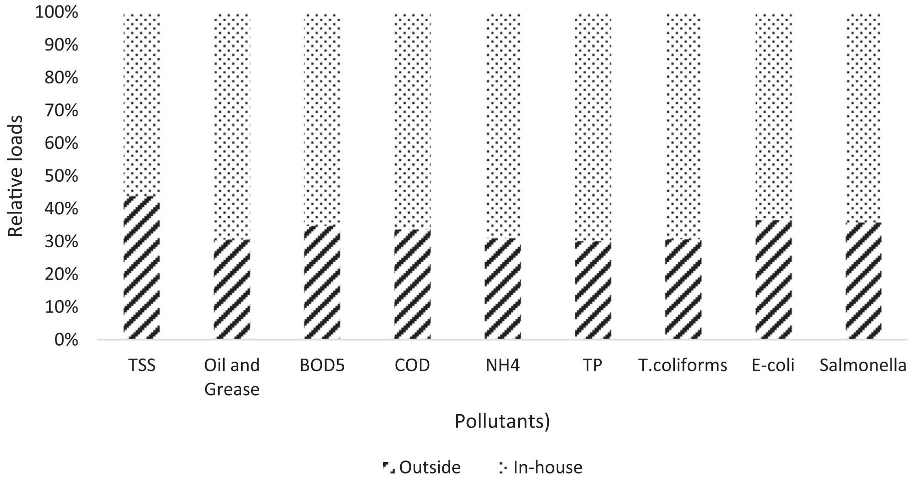

Fig. 3. Relative distribution of load between in-house and outside sources.

Table 5
Coefficients for each variable in the first five principal components.

Variables	PC1	PC2	PC3	PC4	PC5
DO (mgL^{-1})	0.127	−0.028	−0.039	−0.004	−0.243
EC (μScm^{-1})	**0.769**	0.127	−0.015	0.394	0.025
TSS (mgL^{-1})	0.309	0.083	0.273	**0.438**	−0.029
TDS (mgL^{-1})	**0.770**	0.122	−0.022	0.381	0.038
BOD_5 (mgL^{-1})	−0.013	0.075	**0.905**	0.078	−0.044
COD (mgL^{-1})	0.016	−0.022	**0.899**	−0.074	−0.024
Cl^- (mgL^{-1})	**0.851**	−0.056	0.069	−0.161	0.021
Ca^{2+}(mgL^{-1})	**0.725**	−0.213	−0.028	−0.221	−0.032
Mg^{2+} (mgL^{-1})	**0.773**	0.023	0.090	−0.163	0.063
Na^+ (mgL^{-1})	**0.833**	0.016	0.015	−0.050	0.086
K^+ (mgL^{-1})	**0.529**	0.057	0.024	0.090	−0.238
TP (mgL^{-1})	−0.035	0.117	0.085	0.127	−**0.575**
NO_3-N (mgL^{-1})	−0.179	−0.178	−0.057	**0.735**	0.007
NH_4-N (mgL^{-1})	0.125	0.157	−0.157	0.194	**0.666**
Total Coliforms	0.081	−0.131	0.337	−0.049	**0.505**
E.coli	−0.064	**0.929**	0.095	−0.092	0.013
Salmonella spp.	0.015	**0.928**	−0.060	−0.129	−0.009
Eigen Values	4.58	1.90	1.67	1.16	1.14
% Variance explained	26.93	11.20	9.82	6.80	6.70
% cumulative	26.93	38.13	47.95	54.75	61.45

The bold values represent variables that accounted for the variance in the principal components.

Cl^-, Ca^{2+}, Mg^{2+}, K, and TDS. This component shows the importance of certain migratory ions in solution and their impact on greywater quality. The main sources of these variables are cleaning materials and salt. It is possible to state that PC1 represents cooking and cleaning activities. Principal component 2 explained 11.20% of the total variance and presents a strong contribution by the variables *E. coli* and *Salmonella* spp. The main sources of these variables are associated with fecal contamination therefore it is possible that Principal component 2 represents personal hygiene. Principal component 3 explained 9.82% of the total variance and the variables which most positively contributed to it were BOD_5 and COD. The main sources of these variables can be associated with biodegradable and non-biodegradable materials in the greywater. It is therefore justified to state that PC3 represents biodegradability of the greywater. Principal component 4 explained 6.80% of the total variance and the variables associated with it are Total Suspended Solids and NO_3-N. These could be associated with the frequency of water use before final disposal. It is therefore possible to state that PC4 represent internal recycling activities. Principal component 5 explained 6.70% of the total variance and the variables associated with this are NH_4-N, TP and Total Coliforms. NH_4-N is a component of urine and TP is a component of detergents. It is possible that this component is associated with sanitary practices in the bathroom. do Couto et al. (2013) also performed PCA on greywater samples and observed three components that explained 72.63% of the total variability in the samples. These components were source of water, biodegradability and faecal contamination which have also been confirmed as being contributing factors in this study.

Long term disposal of untreated greywater can result in increases in soil chemical parameters and may further result in negative soil and human health impacts (Siggins et al., 2016).

6. Conclusions

- The study concludes that there are significant differences in quantity and quality of greywater between in-house sources and outside sources and this is largely influenced by lifestyle and water use. This is an indication that there is the need for a critical look at the impact of greywater management in peri-urban areas in developing countries. Due to the level of contamination coupled with the practice of irrigation with water from open drains as practiced in most developing countries, public health could be at a great risk. The contaminated greywater can also serve as drinking water for some livestock which stray out of their pens to graze in the open fields and the implications of these cannot be over emphasized. This situation should therefore inform the policy makers in formulating appropriate policies that aim at addressing the impact of untreated greywater discharge into the environment without recourse to treatment. It should also bring to bear the need to start thinking about domestic greywater treatment systems in such areas before the greywater is finally discharged into the environment.

Acknowledgement

This work was supported by the Netherlands Government under the NUFFIC project NICHE 194-01 [grant number CF9419] and the University of Maastricht Netherlands.

References

Abedin, S.B., Rakib, Z.B., 2013. Generation and quality analysis of greywater at Dhaka city. Environ. Res. Eng. Manag. 64, 29–41.

Adendorff, J., Stimie, C., 2005. Food from Used Water - Making the Previously Impossible Happen. South African Research Commission (WRC), pp. 23–29. http://journals.co.za/docserver/fulltext/waterb/4/1/waterb_v4_n1_a4.pdf?expires=1493811214&id=id&accname=guest&checksum=510AA057CDF6FD48ADB3BCB40047FFDC.

Alderlieste, M.C., Langeveld, J.G., 2005. Wastewater planning in Djenne, Mali. A pilot project for the local infiltration of domestic wastewater. Water Sci. Technol. 51, 55–64.

Alsulaili, A.D., Hamoda, M.F., 2015. Quantification and characterization of greywater from schools. Water Sci. Technol. 72, 1973–1980.

Antonopoulou, G., Kirkou, A., Stasinakis, A.S., 2013. Quantitative and qualitative greywater characterization in Greek households and investigation of their treatment using physicochemical methods. Sci. Total Environ. 454–455, 426–432.

ANZECC, 2000. National Water Quality Management Strategy. Australian and New Zealand guidelines for fresh and marine water quality volume 2. Australian Water Association, Aukland.

Aonghusa, C.N., Gray, N.F., 2002. Laundry detergents as a source of heavy metals in Irish domestic wastewater. J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng. 37, 1–6.

APHA, 2005. Standard Methods for the Examination of Water and Wastewater, twenty-first ed. American Public Health Association, American Water Works Association, Water Environmental Federation, Washington.

Birks, R., Hills, S., 2007. Characterisation of indicator organisms and pathogens in domestic greywater for recycling. Environ. Monit. Assess. 129, 61–69.

Busser, S., Pham, T.N., Morel, A., Nguyen, V.A., 2006. Characteristics and Quantities of Domestic Wastewater in Urban and Peri-Urban Households in Hanoi. http://ir.library.osaka-u.ac.jp/dspace/bitstream/11094/13204/1/arfyjsps2006_395.pdf.

Christova-Boal, D., Eden, R.E., McFarlane, S., 1996. An investigation into greywater reuse for urban residential properties. Desalination 106, 391–397.

CSIR, S.A., 2001. Building and Construction Technology Guidelines for Human Settlement Planning and Design. Pretoria SA.

Dalahmeh, S.S., Lalander, C., Pell, M., Vinneras, B., Jonsson, H., 2016. Quality of greywater treated in biochar filter and risk assessment of gastroenteritis due to household exposure during maintenance and irrigation. J. Appl. Microbiol. 121, 1427–1443.

do Couto, E.d.A., Calijuri, M.L., Assemany, P.P., Santiago, A.d.F., Carvalho, I.d.C., 2013. Greywater production in airports: qualitative and quantitative assessment. Resour. Conserv. Recycl. 77, 44–51.

Elmitwalli, T.A., Otterpohl, R., 2007. Anaerobic biodegradability and treatment of greywater in upflow anaerobic sludge blanket (UASB) reactor. Water Res. 41, 1379–1387.

Eriksson, E., Srigirisetty, S., Eilersen, A.M., 2010. Organic matter and heavy metals in grey-water sludge. Water Sa 36, 139–142.

Escher, B.I., Fenner, K., 2011. Recent advances in environmental risk assessment of transformation products. Environ. Sci. Technol. 45, 3835–3847.

Faraqui, N., Al-Jayyousi, O., 2002. Greywater reuse in urban agriculture for poverty alleviation. A case study in Jordan. Water Int. 27, 387–394.

Field, A., 2014. Discovering Statistics Using IBM SPSS Statistics. Sage, London.

Friedler, E., 2004. Quality of individual domestic greywater streams and its implication for on-site treatment and reuse possibilities. Environ. Technol. 25, 997–1008.

Ghana, E., 2000. General Environmental Quality Standards. EPA, Ghana.

Gross, A., Azulai, N., Oron, G., Ronen, Z., Arnold, M., Nejidat, A., 2005. Environmental impact and health risks associated with greywater irrigation: a case study. Water Sci. Technol. 52, 161–169.

GSS, 2014. 2010 Population and Housing Census: District Analytical Report. Komenda-Edina-Eguafo-Abirim Municipal. Ghana Statistical Service, Accra.

Hernandez Leal, L., Zeeman, G., Temmink, H., Buisman, C., 2007. Characterisation and biological treatment of greywater. Water Sci. Technol. 56, 193–200.

Hutcheson, G., Sofroniou, N., 1999. The Multivariate Social Scientist. Sage, London.

Katukiza, A.Y., Ronteltap, M., Niwagaba, C.B., Kansiime, F., Lens, P.N.L., 2014. Grey water characterisation and pollutant loads in an urban slum. Int. J. Environ. Sci. Technol. 12, 423–436.

Kohler, J., 2006. Detergent phosphates: an EU policy assessment. J. Bus. Chem. 3, 15–30.

Leal, H.L., Zeeman, H., Buisman, C., 2011. Characterization and anaerobic biodegradability of greywater. Desalination 270, 111–115.

Mohamed, R.M., Kassim, A.H., Anda, M., Dallas, S., 2013. A monitoring of environmental effects from household greywater reuse for garden irrigation. Environ. Monit. Assess. 185, 8473–8488.

O'Toole, J., Sinclair, M., Malawaraarachchi, M., Hamilton, A., Barker, S.F., Leder, K., 2012. Microbial quality assessment of household greywater. Water Res. 46, 4301–4313.

Ottoson, J., Stenstrom, T.A., 2003. Faecal contamination of greywater and associated microbial risks. Water Res. 37, 645–655.

Ramona, G., Green, M., Semiat, R., Dosoretz, C., 2004. Low strength graywater characterization and treatment by direct membrane filtration. Desalination 170, 241–250.

SANDEC, 2006. Greywater management in low and middle income countries. In: Morel, A., Stefan, D. (Eds.), Eawag Aquatic Research. SANDEC, Switzerland, pp. 18–26.

Schalkwyk, V.A., 1996. Guidelines for the Estimation of Domestic Water Demand of Developing Countries in the Northern Trasnvaal.

Scott, M.J., Jones, M.N., 2000. The biodegradation of surfactants in the environment. Biochim. Biophys. Acta 1508, 235–251.

Shresta, R.R., 1999. Application of Constructed Wetlands for Wastewater Treatment in Nepal. University of Agricultural Sciences, Vienna, Vienna, p. 300.

Sievers, J.C., Watzel, T., Londong, J., Kraft, E., 2016. Case study: characterization of source-separated blackwater and greywater in the ecological housing estate Lubeck “Flintenbreite” (Germany). Environ. Earth Sci. 75.

Siggins, A., Burton, V., Ross, C., Lowe, H., Horswell, J., 2016. Effects of long-term greywater disposal on soil: a case study. Sci. Total Environ. 557–558, 627–635.

Taghipour, H., Mosaferi, M., 2013. Heavy metals in the vegetables collected from production sites. Health Promot. Perspect. 3, 185–193.

Tavakkoli, E., Fatehi, F., Coventry, S., Rengasamy, P., McDonald, G.K., 2011. Additive effects of Na+ and Cl- ions on barley growth under salinity stress. J. Exp. Bot. 62, 2189–2203.

Tchobanoglous, G., Burton, F., Stensel, D., 2003. Wastewater Engineering Treament and Reuse, fourth ed. McGraw Hill Education, New York.

UNDP, 2017. Sustainable Development Goals. Goal 6 Targets Facts and Figures. http://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-6-clean-water-and-sanitation/targets/.

UNICEF, 2012. Definitions. https://www.unicef.org/sowc2012/pdfs/SOWC-2012-DEFINITIONS.pdf.

UNICEF, W, 2016. Progress on sanitation and drinking water-2015 update and MDG assessment. In: UNICEF (Ed.), Joint Monitoring Programme. UNICEF, USA.

USSL, 1954. Diagnosis and Improvement of Saline and Alkali Soils: US Department of Agriculture Handbook. US Salinity Laboratory Staff.

Westrell, T., Schonning, C., Stenstrom, T.A., Ashbolt, N.J., 2004. Quantitative microbial risk assessment (QMRA) and Hazard analysis and critical control points (HACCP) for management of pathogens in wastewater and sewage sludge treatment and reuse. Water Sci. Technol. 50, 23–30.

WHO, 1996. Guidelines for Drinking-Water Quality, second ed., vol. 2. World Health Organization, Genever.

WHO, 2006. Guidelines for the Safe Use of Wastewater, Excreta and Greywater, vol. 2. WHO, France.