RESEARCH NOTE

Chemical characterization of faecal sludge in the Kumasi metropolis, Ghana [version 1; peer review: 1 approved, 1 approved with reservations]

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Abstract

**Background:** Faecal sludge (FS) represents a huge resource, which when tapped and made use properly can be of great benefit to many. However, the key to tapping this resource lies in proper characterisation, in order to make known the constituents and thereby determine the end-use.

**Methods:** Three sources of FS from 43 communities in the Kumasi metropolis of Ghana were characterised in terms of their total solids content, chemical oxygen demand (COD), pH, nitrogen, phosphorous and lipid contents. FS from pit latrines, public septage and private septage were analysed.

**Results:** On average, lipid content was found to be in the range of 8.82 – 9.66% of dry FS depending on the source of FS. Total solids were between 0.79 and 4.68%, while the COD was between 9495 and 45611 mg/L. Phosphorus content was in the range of 137 – 520 mg/L, while nitrogen was 649 – 4479 mg/L. Most FS samples were generally alkaline in nature.

**Conclusions:** These results are amongst the first long-term characterization efforts for FS in terms of conventional and non-conventional characteristics, tailored towards typical treatment and novel resource recovery options, respectively.

**Keywords**

Faecal sludge, COD, total solids, nitrogen, phosphorus, lipids

This article is included in the Water, Sanitation & Hygiene gateway.

Open Peer Review

**Reviewer Status**

1

Invited Reviewers

1

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Introduction
Access to improved sanitation facilities is still a challenge in many developing countries, including Ghana. Sadly, only 14% of the population in Ghana have access to improved sanitation facilities. A worrying 19% of the population still do not have access to any toilet facility (Ghana Statistical Service, 2014), while 18% of the entire population resort to open defecation according to the World Health Organisation. The use of modern improved sanitation facilities, like the water closet, has witnessed a marginal reduction from 15.4% in 2012 to 13.9% in 2014 (Ghana Statistical Service, 2014). Similarly, the use of public toilets, which are prevalent in both rural and urban areas, have also witnessed a marginal increase from 34.6% in 2012 to 35.7% in 2014 (Ghana Statistical Service, 2014). In terms of regional classification, the three Northern regions have the least access to toilet facilities, with ~72% of the population with no toilet facility at all (Ghana Statistical Service, 2012). Aside access to improved sanitation, one of the key challenges facing developing countries is the management of fecal sludge (FS). Unlike developed countries, most cities and towns are not centrally sewered and rely heavily on onsite holding facilities. In Ghana, Tema and Akosombo are the only fully sewered cities, while Kumasi and Accra are partly sewered, and the remaining towns, cities and villages make use of on-site sanitation systems made up of unsewered facilities and public toilets, aqua privies and septic tanks (Strauss et al., 2000). The sludges that accumulate in these on-site systems are mechanically or manually collected and dumped untreated at the shortest possible distance, on open ground, into drainage ditches, water courses or into the sea (Agyei et al., 2011; Doku, 2002; Kuffour et al., 2013). This undoubtedly has grave health implications (Koottatep et al., 2001).

Only rarely is FS subjected to treatment or resource recovery, especially in developing countries. To be able to make use of this resource, either for biofuels or fertilizer, for example, a proper characterisation of FS has to be undertaken to determine its resource or energetic potential (Arthur et al., 2011; Murray et al., 2011). Doku (2002) characterized FS in Kumasi from public, private, KVIP and non-flush aqua privies. The study did not, however, distinguish clearly between the sources of the FS but rather reported global results for the sampled FS. Kuffour et al. (2013) studying the effect of different solid loading rates of FS on the dewatering performance of unplanted filter beds characterized an unknown quantity of FS from public and private septime from Kumasi. Appiah-Effah et al. (2014) sought to establish the difference between FS from rural and peri-urban areas in Ashanti Region and concluded that location could potentially affect the physio-chemical properties of the sludge. The study focused on only public toilets leaving out private and pit septime. A comprehensive characterisation of FS taking into consideration the sources of FS to establish the variability or otherwise of the physio-chemical parameters, to the best of the authors knowledge, has not yet been carried out in Ghana. Therefore, in this study, FS from 43 communities (Dataset 1–Dataset 3) in the Kumasi metropolis and its environs were characterised, to serve as a knowledge base for any further research with end goals, such as biofuels or fertilizer.

Methods
Study area
The Kumasi metropolis was chosen because it is one of only five (Accra, Tema, Kumasi, Tamale, Takoradi) metropolises in Ghana with a well organised system for FS collection and disposal. This allowed for proper collection and identification of FS source. The sampling of FS was carried out in close collaboration with the Waste Management Department of the Kumasi Metropolitan Assembly (KMA).

Classification and sampling of FS
Although toilet facilities in Ghana are classified as water closets, Kumasi Ventilated Improved Pit latrines (KVIP), bucket/pan or public toilets (Agyei et al., 2011; Ghana Statistical Service, 2012), this work classified the FS used under three main categories based on the storage facilities from which they were taken: pit latrine (KVIP and bucket/pan), private septic (water closets) and public septic (public toilets) (Appiah-Effah et al., 2014).

A total sample size of 90, comprising 30 of each category of FS was taken based on the sample size adopted by Klingel et al. (2002). Samples for analysis were taken from vacuum trucks at the waste disposal site of the KMA’s Oti sanitary landfill site, Dompoase in the Ashanti Region, at the point of discharge for 10 continuous weeks. Sampling was carried out from the 16th of November 2011 – 18th of January 2012.

The 43 communities from whom samples were collected are detailed in Dataset 1–Dataset 3.

The method of sampling was also based on previous recommendations (Klingel et al., 2002). Three-point sampling was employed, which involved taking samples at specific times during the discharge of the FS: (a) immediately after the discharge commenced, (b) half way through the discharge, and (c) just when the tank was almost empty. 15L of sample (a full bucket) was taken from each truck, these samples were homogenized by mixing together thoroughly and a 1L sample taken from this was used as the final sample. Samples were analysed on the same day of collection, or alternately stored at -20°C and analysed within a week of collection.

Analytical methods of FS
Analyses were conducted according to standardized and well documented methods and protocols. Total chemical oxygen demand (COD), (APHA—AWWA-WEF, 1998) pH (US EPA Method 150.1), total solids/moisture content (NREL/TP-510-42621 – method), and nitrogen (US EPA Method 351.1), phosphorous (US EPA Method 365.3) and lipid content by extraction using petroleum ether and 20g of dry FS (Horwitz, 1980) were determined using analytical grade chemicals. The pH was taken on site with a KEDIDA CT 6023 digital pH probe, while the other parameters were analysed in the lab.

Statistical analysis
Means, standard deviations and T- Test were conducted for all the results, using Microsoft® Excel 2010. Results are presented as the mean ± error.
Results and discussion

Total solids (TS)

TS is a measure of the residue remaining after a waste water sample has been evaporated and dried at a specified temperature, mostly from 103 to 105°C (Metcalfe, 2003). In the present study, the TS content in all three categories of FS was found to be very low, and this invariably meant the moisture content was high in all three types of FS (Table 1). The highest TS content was obtained in the pit latrine with the lowest found in private septage. Private septage has less solids and more moisture because most of this FS type emanates from the water closet, where a substantial amount of water is used to flush the faecal matter (Agyei et al., 2011; Cofie et al., 2006; Kuffour et al., 2013). Even though traditionally, pit latrines do not use water closet facilities, during emptying of the latrines, water is pumped into the pit to allow for easy suction. This introduces large quantities of water into the FS. In most cases, FS from sources other than pit latrines are also added during collection, thus diluting the original content (Doku, 2002; Strande & Brdjanovic, 2014). The various types of FS were found to be statistically different (pit vs private, \( p = 0.00 \); pit vs public, \( p = 0.00 \); private vs public, \( p = 0.01 \)). These results are similar to those obtained by other researchers (Doku, 2002; Heins et al., 1998; Strande & Brdjanovic, 2014; Strauss et al., 2000).

pH

Generally, the pH of the FS from all three sources was found to be near-neutral to slightly alkaline and were similar (Table 2). Torondel (2010) in a review of the literature on sanitation waste characteristics identified the pH of FS to be basic, ranging from a pH of 7.1 -9. Kuffour et al. (2009) also working on FS in Kumasi observed a pH of 7.77 ± 0.13, which are both similar to those obtained in this study. In contrast, Appiah-Effah et al. (2014), working on FS in Kumasi, obtained a pH of 6.7 in peri-urban areas, but 7.3 in rural areas.

<table>
<thead>
<tr>
<th>FS source</th>
<th>Moisture content, %</th>
<th>Total solids, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit latrine</td>
<td>95.32 ± 2.57</td>
<td>4.68 ± 2.57</td>
</tr>
<tr>
<td>Public septage</td>
<td>98.10 ± 1.82</td>
<td>1.90 ± 1.82</td>
</tr>
<tr>
<td>Private septage</td>
<td>99.21 ± 1.82</td>
<td>0.98 ± 1.82</td>
</tr>
</tbody>
</table>

Chemical oxygen demand (COD)

COD is a measure of the degree of reduction (or electron content) of the organic material in wastewater (Metcalfe, 2003). In this study, the COD of the FS was found to be generally very high. Pit latrine FS was found to have the highest COD, which was almost twice as high (\( p = 0.02 \)) as the level in public septage FS, whose COD level was also almost three times higher (\( p = 0.00 \)) than that of private septage FS (Table 3). Strauss et al. (2000) found that the COD of septage in Accra, Ghana, to be about 7,800mg/L and that of public toilet FS to be about 49,000mg/L. Kuffour et al. (2009) also observed a highly variable COD in FS sampled in Kumasi (50320 ± 28780mg/L), akin to that observed in this study. The very high error margins indicate the high variability of COD in the various samples regardless of the source.

Nitrogen content

The nitrogen content in the FS collected ranged from 649.40 ± 484.52mg/L in private septage to 4479.03 ± 2323.77mg/L in pit latrine (Table 4). The various sources of FS were found to be statistically different (pit vs private, \( p = 0.00 \); pit vs public, \( p = 0.00 \); private vs public, \( p = 0.01 \)). Kuffour et al. (2009) obtained 3580mg/L of nitrogen in public toilet sludge from Kumasi. Strauss et al. (2000) working on FS in Bangkok obtained 830 mg/L of nitrogen in septage, while Strande & Brdjanovic (2014) reported that the typical nitrogen content in public septage is around 3,400mg/L, which are all similar to that obtained in this research. Nitrogen in FS is an important resource because it can be used as fertilizer for plant growth (Chandran, 2014; Strande & Brdjanovic, 2014).

Phosphorous content

Chandran (2014) suggests that global phosphorus deposits are expected to be depleted rapidly, unless replenished or recovered; thus making the recovery of phosphorous from FS an interesting prospect. For example, recovered phosphorous can typically

<table>
<thead>
<tr>
<th>FS source</th>
<th>COD, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit latrine</td>
<td>45611.67 ± 31366.37</td>
</tr>
<tr>
<td>Public septage</td>
<td>26765.85 ± 24790.87</td>
</tr>
<tr>
<td>Private septage</td>
<td>9495.36 ± 9495.36</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FS source</th>
<th>Nitrogen, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pit latrine</td>
<td>4479.03 ± 2323.77</td>
</tr>
<tr>
<td>Public septage</td>
<td>1396.63 ± 1408.04</td>
</tr>
<tr>
<td>Private septage</td>
<td>649.40 ± 484.52</td>
</tr>
</tbody>
</table>
be used as fertilizer supplements (de-Bashan & Bashan, 2007; de-Bashan & Bashan, 2004; Gaterell et al., 2000; Kuffour et al., 2013). Phosphorous content in this study ranged from 137.92 ± 139.0 in private septage, which is statistically similar (p = 0.05) to that in public septage (228.68 ± 185.26). Both are statistically lower (pit vs private, p = 0.00; pit vs public, p = 0.00) than that of pit latrine (521.07 ± 207.58) (Table 5). This might be so because according to Kuffour et al. (2013) phosphorous is equally distributed between urine and faeces, which implies that with a lot more of water used to flush faeces into soakaway pits for the private and public septage some of the phosphorous could be leached into the ground, while the pit latrine which has less water would retain more of its phosphorous.

Lipid content
Lipids are not a typical parameter characterised in FS. However, researchers looking at biodiesel production or lipids as an end use product of FS and sewage sludge have found the need to determine the lipid content (Angerbauer et al., 2008; Kargbo, 2010; Réveillé et al., 2003). Though the percentage of lipids extracted were all statistically similar (pit vs private, p = 0.51; pit vs public, p = 0.86; private vs public, p = 0.67), it must be noted that the lipids were extracted from the dried FS and the values reported are therefore normalized to a dry solids basis. Therefore, taking into account the different solids content of the different FS sources, 1000 g of FS will consequently yield 4.38 g lipids in the case of pit latrines, which is statistically higher (p = 0.02) than that of public septage (1.78 g), and further higher (p = 0.00) than private septage (0.77 g) (Table 6). Chaggu (2004) reported that there is approximately between 4–6g of lipids in fresh human faeces. However, since the method of extraction or the initial mass of FS used is not stated, it is difficult to compare the yield of lipids obtained with that obtained in this study. Typically, lipid content may degrade with the age of the faecal matter into less complex molecules (Torondel, 2010), and as the age of FS in Ghana can span between days in the case of public septage to a couple of years in the case of pit and private septage (Agyei et al., 2011; Kuffour et al., 2009) obtaining a lower lipid content was therefore not surprising.

Conclusions
Management of FS is a major problem in most sub–Sahara African countries, including Ghana. However, FS may hold the key to energy security, employment creation and sustainable use of resources, as it contains resources that can be mined for useful purposes. This study represents a systematic characterization of a significant number of samples from three principal sources of FS (pit latrines, private septage, public septage) in terms of conventional and novel parameters. Incorporation of such data into global databases, as well as process design and optimization tools is expected to result in more scientifically-informed options for overall FS management.

Data availability
Raw data are available on OSF: http://doi.org/10.17605/OSF.IO/D4HJF (Chandran, 2017)

- Dataset 1: Pit Latrine data: “chemical characterisation of FS in the Kumasi Metropolis pit latrine raw data.csv”
- Dataset 2: Private septage data: “chemical characterisation of FS in the Kumasi Metropolis private septage raw data.csv”
- Dataset 3: Public septage data: “chemical characterisation of FS in the Kumasi Metropolis public septage raw data.csv”
- Summary of analyses: “chemical characterisation of FS in the Kumasi Metropolis summary of analysis”

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

Competing interests
No competing interests were disclosed.

Grant information
Bill and Melinda Gates Foundation [OPP1019896].

| Table 5. Average phosphorous content of faecal sludge (FS) as stratified by source. |
|-------------------------------|-----------------|
| FS source                    | Phosphorous, mg/L |
| Pit latrine                  | 521.07 ± 207.58  |
| Public septage               | 228.68 ± 185.26  |
| Private septage              | 137.92 ± 139.0   |

| Table 6. Average lipid content of faecal sludge (FS) as stratified by source. |
|----------------------------|-----------------|-----------------|
| FS type                    | Lipid content, % | Grams of lipids from 1000g of FS |
| Pit septage                | 8.82 ± 3.05     | 4.38 ± 3.78     |
| Public septage             | 9.05 ± 3.99     | 1.78 ± 2.45     |
| Private septage            | 9.66 ± 3.99     | 0.77 ± 0.8      |
References


Strande L, Britjanzovic D: Faecal sludge management: systems approach for implementation and operation. IWA publishing. 2014. Reference Source


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The paper is fine and acceptable as a Research Note. Still there are a few areas where the authors could work on for improved science quality and the interested reader:

- A gap is that the data were not correlated to most of the key factors that influence FS characteristics. The variability experienced and reported could rather be more determined by other factors such as age of sludge, location of the facility, etc. and it is a bit simplistic to associate it with the type of facility only.

- A related added value from this study would have been if the study was able to advance knowledge behind prediction of FS characteristics, based on certain criteria/determinants.

- The level of detail how results are presented across different indicators, like 235634.87 imply an accuracy which common analytical instruments do not provide. In most cases, 234635 would be completely sufficient, although even this detail might exceed the detecting limit.

- In the methodology, it would be good to elaborate a bit more the sampling method for the toilets (e.g. how was it done). Please clarify further the classification of the waste storage facilities. E.g. Public toilets may use different storage systems. Why did you decide to consider them as one homogenous system? The pit latrines could also be used by both households and clients attending public toilets. How did you account for that?

- What are the implications of your findings on your specific goals? E.g. are all FS suitable for all applications? A bit more discussion in this regard would be helpful.

Is the work clearly and accurately presented and does it cite the current literature?  
Yes

Is the study design appropriate and is the work technically sound?
Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Environmental sciences, soil and water analysis, sanitation, business modeling

We confirm that we have read this submission and believe that we have an appropriate level of expertise to confirm that it is of an acceptable scientific standard, however we have significant reservations, as outlined above.

Reviewer Report 01 December 2017
https://doi.org/10.21956/gatesopenres.13817.r26094

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Astrid Michels
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The study describes a dataset of fecal sludge samples from 3 different categories and described the ranges for a number of typical sludge specific physico-chemical parameters.

It could be interesting to evaluate correlations between the different parameters and include in results.

We recommend to further reflect in the conclusions, reasons for statistically significant differences of the three types of FS categories and implications for their potential use as fertilizer/energy source. It is recommended to link more clearly the research question on which of three different FS categories can be used best for energy generation or as fertilizer.

Are there conclusions that can be drawn for FS management – which is a huge challenge in the region?

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Yes

Are all the source data underlying the results available to ensure full reproducibility?
Yes

Are the conclusions drawn adequately supported by the results?
Partly

**Competing Interests:** No competing interests were disclosed.

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