Original Research Article

Characterization of faecal sludge from pit latrines to guide management solutions in Cape Coast, Ghana

.

ABSTRACT

Aims: This study characterised faecal sludge from public ventilated improved pit (VIP) latrines in Cape Coast to assess their potential impact on the environment and to guide the selection of appropriate management solutions. The paper also estimates the amount of beneficial resources wasted due to the lack of a faecal sludge (FS) treatment facility

Study design: The study employed a quantitative design involving laboratory analysis of FS sampled from 13 VIP latrines.

Place and Duration of Study: Sampling activities were carried out in Cape Coast, Ghana in January and February (dry season) and September and October (wet season) of 2015.

Methodology: Samples of unhardened pit latrine sludge were collected from all 13 pit latrines for quality assessment. Physico-chemical parameters (moisture content, COD, BOD_5, total solids and total volatile solids) of homogenous samples from the surface, middle and bottom of pit contents were analysed following standard procedures.

Results: Apart from total solids, all other parameters decreased with depth of sampling and the differences were statistically significant ($p<.01$). Seasonal variation in faecal sludge characteristics was not significant except for BOD_5. A high COD:BOD_5 (3.8-4.5:1) shows faecal sludge that is characterised by slowly degradable organic matter.

Conclusion: Even though the FS at the bottom of the pits was found to be the most stabilized, its characteristic parameters indicate that discharging it into the environment without any further treatment would pose a significant threat to public health. The characteristics suggest that co-composting would be the most appropriate option for treating the FS and also underscore the fact that the VIP latrine technology is not suitable for use as a public toilet.

Keywords: Cape Coast, faecal sludge, Ghana, public toilets, ventilated improved pit latrines.

1. INTRODUCTION

Pit latrines have been used in Ghana for several centuries largely as traditional pit latrines in rural communities. Majority of these latrines were unimproved and therefore did not ensure hygienic separation of human excreta from human contact. In recent times, ventilated improved pit (VIP) latrines and septic tank systems have become more common and the predominant form of sanitation in urban and peri-urban areas due to the limited coverage of conventional sewerage systems.

The World Health Organisation (WHO) and UNICEF's Joint Monitoring Programme (JMP), which is responsible for monitoring progress towards the Sustainable Development Goal on water, sanitation and hygiene (WASH), considers otherwise improved facilities shared by two or more households as a ‘limited service’ [1]. However, factors such as costs, space constraints, high population density in urban areas and absence of functional wastewater treatment plants have compelled householders in urban and peri-urban areas of Ghana to depend heavily on public toilets. This is particularly the case in Cape Coast where 40% of residents are reported to depend on public toilets [2]. The Ghana National Environmental Sanitation Strategy and Action Plan (NESSAP) 2010 – 2015 also reported that 37.6% of residents of the Central Region of Ghana (where Cape Coast is the Regional Capital) use public latrines, the third highest in the country after the Ashanti (46.3%) and Brong Ahafo (39.7%) Regions. These public toilets are either water closets connected to septic tanks, or ventilated improved pit (VIP) latrines.

The SDGs 6.2 and 6.3 emphasize the need for safe management of excreta and wastewater, with the UN progress reports on SDG 6 shows that the number of people using safely managed sanitation services is increasing [3]. However, it is recognized that unsafe management of faecal waste and wastewater is a major public health and environmental problem [4]. It is therefore not enough to have hygienic toilets but there should be facilities for the safe collection, treatment and disposal or reuse of excreta desludged from the toilet facilities. Indiscriminate disposal of FS without treatment poses a grave public health risks to communities and the aquatic environment. It defeats the purpose of sanitation as a barrier to disease transmission.

The most fundamental step involved in the management of any type of waste is the identification of its constituents [5]. There is complex heterogeneity in the characteristics of FS depending on factors such as type of onsite sanitation system, season, emptying frequency, extent of water intrusion into the facility and user habits [6, 7]. Knowledge of the characteristics of FS is required for the selection of appropriate technology for treatment, sizing of treatment units and assessment of the prospects of resource recovery from the sludge [8].

Currently, there is no conventional wastewater or faecal sludge treatment system serving the Cape Coast Metropolitan Area (CCMA). Faecal sludge (FS) desludged from on-site sanitation facilities (both private and public) are discharged on a bare ground near the City’s solid waste dump site without further treatment. To the best of our knowledge, there is limited information on the characteristics of FS produced in Cape Coast, the extent of stabilization that the FS attains prior to disposal and, for that matter, its anticipated impact on the environment. The absence of such data could hamper the adoption of well-informed excreta management practices. This study was conducted to characterise FS from ventilated improved pit latrines used as public toilets in Cape Coast, Ghana. The objective was to assess their potential impact on the environment and to guide the selection of appropriate management solutions. The paper also estimates the amount of beneficial resources wasted due to the lack of FS treatment facility.

2. MATERIAL AND METHODS

2.1 The study setting

The study was conducted within the Cape Coast Metropolitan Area (CCMA). The Cape Coast Metropolitan Area is the administrative capital of the Central Region of Ghana and lies in the coastal part of the country. It is located on longitude $1^{o}11'$ - $1^{o}41'$W and latitude $5^{o}07'$ - $5^{o}20'$N [9] and covers a land area of approximately 122 km^2. According to Ghana’s 2010 population and housing census, the population of the CCMA was 169,894 with a density of 1,392/km^2 [2] making it the 7th most populated city in Ghana. Currently, the estimated population is 186,159 with a density of 1,520km^2 [10]. The average minimum and maximum temperatures are 24 and 32^{o}C respectively with relative humidity ranging from 70% to 90% [11]. Located in a tropical country, CCMA has two main seasons: wet and dry seasons. The bimodal wet seasons occur in March to July and September to November [12]. The total annual rainfall for the metropolis ranges between 750mm and 1,000mm (CCMA 2014). Most communities in the CCMA have low water table making the lands suitable for pit latrines. In 2014, more than 100 public toilets (both dry and wet systems) operated in the metropolis [9], with approximately one public toilet for 1.22 square kilometres. Public toilets are operated and managed by community members who collect user fees per person per visit and pay daily or monthly franchise fees to the Metropolitan Assembly. The metropolis currently has no FS treatment facility. FS desludged from private and public toilets are discharged in an open area at the City's solid waste dump site. The liquid waste generation rate in Cape Coast for 2014 was estimated to be 16,000 tonnes and expected to increase to 20,000 tonnes in 2020 [9]. These figures translate into a daily generation rate of 44 tonnes and 55 tonnes for 2014 and 2020 respectively which are disposed on a bare ground without any treatment.

2.2 Latrine selection

Thirteen (13) public VIP latrines located in various urban and peri-urban areas of the CCMA were selected. The latrines were selected to ensure that all the various zones in the metropolis is covered. These thirteen latrines have been reported to serve over 4,100 people each day [13].

2.3 Samples and sampling procedure

Samples of unhardened pit latrine sludge of approximately one (1) litre were collected from three (3) layers (surface, middle and bottom) of each of the thirteen pit latrines. A rod was driven through the sludge to determine the penetrable depth of each pit and hence the depth of the middle layer. The surface samples were collected early in the morning when majority of the users were expected to use the facility. To sampling from the middle and bottom layers, a sampler was constructed from a 150 mm diameter PVC pipe. An opening with moveable cover was constructed at the bottom and middle of the PVC pipe based on the depth of the pit. The bottom of each opening was sealed at a height of 60mm below the opening to provide enough space for sampling. The openings were closed before inserting the sampler into the pit to prevent sampling from an unintended depth. Sampling activities were carried out in January and February (dry season) and September and October (wet season) of 2015. The choice of wet and dry seasons for sampling was to ascertain whether FS characteristics will vary with season. Two (2) samples were taken each month. Samples were randomly taken from five (5) different locations in each pit and thoroughly mixed to obtain a composite sample.

2.4 Sample preservation techniques

To mimic the dark environment of the pit and to ensure that the bioactivity of the samples is not altered, storage containers were wrapped in black polythene bags before transporting them to the laboratory. All samples were stored in a cold environment at 4°C to inhibit microbial activities and allowed to reach room temperature before laboratory analysis. Tests were conducted within 24 hours of sampling. Storage of faecal samples at 4^{o}C for 24hrs have been reported to have no significant effect on microbiota composition [14, 15].

2.5 Sample preparation and analysis

Preparation of samples and testing protocols for COD (total, soluble and particulate), BOD_5, solids (total and volatile) and moisture content were carried out based on standard methods. The test method used for each of the parameters are as shown in Table 4. The COD fractionation test followed the protocol used by Nwaneri [16]. The fractionated COD, BOD_5, Solids and moisture content of all samples were measured according to Standard Methods for the Analysis of Water and Wastewater [17]. All analysis was performed in triplicates and the average results taken.

2.6 Parameters for characterization of faecal sludge and potential impact on the environment

Samples of pit latrine sludge were characterised using parameters adopted by [16, 18]. The physico-chemical parameters analysed were moisture content, total solids, total volatile solids, total COD, BOD_5, soluble COD and particulate COD. The soluble and particulate COD were measured only for the samples taken from the surface layers. These parameters were selected to determine the biodegradable content of the FS and, hence, the potential of reducing sludge volume by latrine additives. As noted by Bakare [19], the amount of biodegradable or non-biodegradable material present in a pit latrine determines the efficacy of latrine additives added to it. The physico-chemical characteristics and the test method used are listed in Table 1.

Table 1. Parameters used to measure physico-chemical properties of fresh faeces and faecal sludge

Parameter	Reason	Test Method	Reference
Moisture content	To quantify the moisture content of the samples	Thermogravimetric	AWWA [17]
Total COD (tCOD)	To measure oxidizable organic matter in the different samples	Open reflux colorimetric	AWWA [17]
BOD_5	To quantify the biodegradable material present in the samples	Titrimetric	AWWA [17]
Soluble COD (sCOD)	To quantify dissolvable oxidizable organic matter	Open reflux colorimetric	AWWA [17]
Particulate COD (pCOD)	To quantify particulate oxidizable organic matter	Open reflux colorimetric	AWWA [17]
Total solids	To determine total solids in the samples.	Thermogravimetric	AWWA [17]
Total volatile solids (TVS)	To quantify the organic material present in the samples	Thermogravimetric	AWWA [17]

For these parameters, review of existing literature could not identify any authoritative set of guideline limits for the disposal of FS into the environment. The closest guidelines are those related to the use of excreta in agriculture, which mainly focus on heavy metals, pathogens and some organics [20, 21]. Nevertheless, to appreciate the environmental risks associated with the disposal of FS into the environment, the discussion of the results of this study makes reference to the general characteristics of untreated septage, a material removed from septic tanks, usually with the aid of a cesspit emptier. Environmental Regulations in most countries require that septage is treated prior to reuse or disposal into the environment [22, 23]. The results are also compared with Ghana EPA effluent quality discharge standards.

2.7 Data analysis

Data analysis was performed using Microsoft Excel and SPSS statistical software. The descriptive statistics was used to present the mean and standard deviations of the results from the 13 pit latrines at different depths, with the exception of total COD for which the median and interquartile range (IQR) were presented because the data was found to be non-normally distributed. A one-way ANOVA test (α = 0.05) was used to test whether there are statistically significant differences in the characteristics among the three sampling depths but for total COD a nonparametric test (Kruskal-Wallis) was used. Multiple comparisons of parameters at the three sampling levels were done using Bonferroni (ANOVA) and Dunn-Bonferroni (Kruskal-Wallis) post hoc analysis. A two-sample t-test for means at 95% significance level was further used to compare FS characteristics for dry and wet seasons.

3. RESULTS AND DISCUSSION

3.1 Characteristics of FS

The results of the physico-chemical characteristics of FS and their seasonal variations are presented in Table 2. The table also shows the average characteristics of untreated septage and Ghana Environmental Protection Agency (EPA) effluent quality discharge standards which were adopted for assessing the environmental risks associated with the disposal of untreated faecal sludge into the environment.

Table 2: Characteristics of FS in Cape Coast (N = 13)

Parameter	**Unit**	**Mean (SD)**			***Seasonal difference[a] (p-value)***	**Septage [22]**	**Ghana EPA Discharge Standard**
		All samples	***Dry season***	***Wet season***			
Moisture Content	% wet sample	63.9 (2.2)	63.1 (2.3)	64.6 (3.0)	*1.5 (.11)*	-	-
Total COD[b]	mg/L	58,740 (1,556)	57,866 (3,807)	59,349 (2,239)	*1480 (.58)*	31,900	250
BOD_5	mg/L	14,356 (1,443)	13,197 (1,532)	15,515 (1,730)	*2318 (.00)****	6,480	50
Soluble COD	mg/L	16,205 (1,729)	15,822 (1,629)	16,588 (2,990)	*766 (.43)*	-	-
Particulate COD	mg/L	45,806 (648)	45,387 (744)	46,224 (1,091)	*837 (.045)*****	-	-
Total Solids	% wet sample	36.4 (2.5)	36.9 (2.3)	35.4 (3.0)	*-1.5 (.11)*	34,106[c]	-
Total Volatile Solids	% TS	65.8 (1.2)	65.5 (2.7)	66.1 (2.3)	*.6 (.61)*	68	-
$COD:BOD_5$		4.1	4.5	3.8		-	-
pCOD:sCOD		2.9	2.9	2.8		-	-

SD – Standard deviation; a – Wet season-Dry season; b – Median (IQR); c – In mg/L
*** Significant at 1% level *** Significant at 4.5% level*

Generally, the results do not show significant differences between the dry and wet seasons with the exception of BOD which increased significantly in the wet season. Usually, changes in FS characteristics between the dry and wet seasons are attributed to intrusion of water into the pits during the dry season [24]. However, the results of this study suggests that the VIP latrines studied in Cape Coast were, probably, constructed in a manner that controls water intrusion into the pits. Results of the overall characteristics of the FS are discussed in the following sections:

3.1.1 Moisture content

Water constitutes about 64% (SD=2.2) of the FS. For the purpose of environmental protection, no threshold value for moisture content has been set by the Ghana EPA. Various studies report moisture content of faeces as ranging from 50% to 90% [25, 26] depending on the source. Generally, faeces from dry sanitation systems such as the pit latrines involved in this study tend to have a lower moisture content while samples from wet sanitation systems like the water closet have higher moisture contents.

The significance of the moisture content of FS lies in its influence on the biological degradation of the organic matter in the faeces as well as the possibility of desludging with a vacuum truck. To enhance microbial activity, a moisture content ranging from 50% to 60% is considered adequate [27]. It could be inferred that the moisture content recorded in this study is ideal for microbial activities. With adequate retention time and organic matter, the microorganisms can further stabilize the FS.

On the other hand, the lower moisture content recorded in this study would make it difficult to desludge the contents of the pits with a vacuum truck since that technical option for pit emptying requires much higher moisture content to ensure adequate fluidity of the faeces. For instance, the moisture content of samples taken from vacuum trucks at the FS disposal site in Kumasi, Ghana, was reported by Fanyin-Martin [28] to be as high as 98%. Conventionally, desludging by a vacuum truck is only done for wet sanitation systems. However, there is a practice in Ghana where water is pumped into pit latrines to loosen the contents and subsquently desludge with a vacuum truck. Fanyin-Martin [28] analysed such FS desludged from pit latrines in Kumasi and found the moisture content to be 95%.

3.1.2 Chemical and biochemical oxygen demand

The average total COD of FS measured in this study was 58,928 mg/L (SD=8,305mg/L), with the average BOD_5 being 24% of the average total COD. The COD results in this study fall within the range reported in Ghana (49,000-85,998mg/L) [28, 29] but higher (4.7 times) than those reported in Ouagadougou (12,437mg/L) [8]. On the contrary, the results are lower than those reported in Kenya (112,800mg/L) [30] and Malawi (45,447mg/L) [31]. The results from Cape Coast are far higher than that of septage [22] and the Ghana EPA effluent discharge standard. The significant increase in BOD during the wet season suggests that microbial activity in breaking down the biodegradable component of the FS is sensitive to the marginal increase in moisture content.

The implication of these results is that it is not appropriate to discharge the FS into the environment without further treatment. This is because the high COD and BOD_5 indicate that the faecal matter is characterized by high oxygen demand (from its high organic content) and would therefore utilize high amount of oxygen during aerobic degradation. The impact of discharging this untreated FS (in terms of oxygen depletion) on the receiving environment, particularly surface waters, is very grave.

The total COD comprises of particulate COD (pCOD) and soluble COD (sCOD). The amount of particulate COD was higher than the soluble and constitute 78% of the total COD. The high ratio of particulate COD to soluble COD (2.9:1) suggests that most of the degradable COD present in the faeces are slowly degradable [32] and this is confirmed by the high COD:BOD_5. Results from this study is within the amount of slowly biodegradable organic fraction (up to 80%) reported in literature [33]. The presence of high amounts of slowly biodegradable organic matter implies that the microorganisms will require much longer time to degrade the organic matter in the sludge. The disposal of FS in this state into the environment will have a dire environmental and public health consequence [7] particularly when it finds its way into surface water bodies.

3.1.3 Solids

The mean total solids content measured in this study was 36% (SD=2.5) of wet sample. This value is over 5 folds higher than those measured in pit latrines (4.68%) and public toilet septage (1.90%) in Kumasi [28]. Of the total solids content recorded in this study, between 64% and 68% are organic matter that are biodegradable. The ratio of organic solids to the total solids indicates the relative amount of organic matter present and the biochemical stability of the faecal sludge [24]. It therefore has implications for the choice of treatment technology to be applied. The percentage of organic solids recorded in this study are consistent with those generally reported in literature [6, 29]. As noted under the results on COD and BOD, a high percentage of the organic matter is slowly biodegradable and could account for the relatively high desludging rate observed among public pit latrines in Cape Coast [34]. This is because the retention time that informed the sizing of the pits may not be adequate for the biological degradation of all the organic matter in the faeces, which would quickly fill up the pit and call for desludging.

3.2 Variation of FS characteristics with depth

The variation in the FS characteristics among the three sampling layers are shown in Table 3.

Table 3. **Variation of FS characteristics with depth in Cape Coast (N = 13)**

Parameter	Unit	Mean (SD)			F (p-value)
		Surface layer	Middle layer	Bottom layer	
Moisture Content	% wet sample	76.7 (1.7)	63.8 (4.7)	51.0 (3.0)	187.34 *(.00)***
Total COD	mg/L	61,817 (2,527)[a]	57,938 (830)[a]	55,921 (2,192)[a]	16.53[b] *(.00)***
BOD_5	mg/L	20,248 (3,054)	13,695 (2,500)	9,125 (726)	75.69 *(.00)***
Total Solids	% wet sample	23.7 (2.7)	36.2 (4.7)	49.3 (2.8)	167.36 *(.00)***
Total Volatile Solids	% TS	75.7 (2.0)	67.5 (2.0)	54.3 (2.2)	364.12 *(.00)***

*SD – Standard deviation;   a – Median (IQR); ** Significant at 1% level; b – H for Kruskal-Wallis test*

All the parameters measured in this study generally decreased significantly among the three sampling layers from the surface layer to the bottom layer (*p=.00* for all parameters) except for total solids which rather increased significantly from the surface to the bottom layer (*p=.00*). Furthermore, a comparison of the inter-layer characteristics of FS shown in Table 4 reveal that the variation in the parameters are also significant between all pairs of layers as shown in Table 4.

Table 4. **Results of inter-layer comparisons of FS characteristics (N = 13)**

Parameter	Unit	Inter-layer difference in mean (p-value)

		Surface-Middle	Surface-Bottom	Middle-Bottom
Moisture Content	% ws	12.9 *(.00)***	25.7 *(.00)***	12.8 *(.00)***
Total COD[a]	mg/L	3,879 *(.02)**	5,895 *(.02)**	2,017 *(.02)**
BOD_5	mg/L	6,553 *(.00)***	11,123 *(.00)***	4,570 *(.00)***
Total Solids	% ws	-12.5 *(.00)***	-25.6 *(.00)***	-13.1 *(.00)***
Total Volatile Solids	% TS	8.2 *(.00)***	21.4 *(.00)***	13.2 *(.00)***

*[a] – Difference in median (p-value); * Significant at 5% level; ** Significant at 1% level*

The change in trend of the total solids is expected as a decrease in moisture content corresponds to an increase in total solids. In describing the processes that occur in pit latrines, Nwaneri, Foxon [18] and Buckley, Foxon [25] noted that the addition of new faeces to the heap results in the mechanical compaction of the bottom layers and the squeezing of moisture out of the bottom content. This process may have accounted for the decreasing trend of moisture content from the surface to the bottom. The decrease in FS characteristics from the surface to the bottom layer have also been observed and reported in other studies [16, 18, 30]. The percentage decrease in the moisture content, total COD, BOD_5 and TVS were in the range of 4% to 32% (surface - middle), 11% to 55% (surface - bottom) and 7% to 33% (middle - bottom).

The results show that FS sampled from the bottom layer were more stabilized than those at the surface and middle layers. Notwithstanding, the mean total COD (55,245mg/L) and BOD_5 (9,125 mg/L) at the bottom were much higher than the Ghana EPA effluent discharge standards (COD=220-fold; BOD_5=180-fold) and characteristics of raw septage (COD=1.7-fold; BOD_5=1.4-fold). This indicates that, it is not appropriate to dispose the faecal sludge into the environment without further treatment. The current disposal practice in Cape Coast is greatly polluting the environment and poses public health risks.

3.3 Implications of findings for management solutions

<u>3.3.1 Technology selection for public use</u>

The findings of this study highlight the inappropriateness of the choice of the VIP latrine technology for public use. The need to desludge unstabilized FS from the latrines is an indication of the failure of the choice of technology. By its conventional design, it is expected that when the pit is full it would be sealed to allow the sludge to decompose, usually within two years [35] before the stable compost is removed and used as manure or safely disposed of with no or minimal environmental risks. This raises the question of how to provide an alternative facility for this fallow period. The immediate solution is the use of the alternating or double-pit design option which allows pit rotation within the same latrine facility. Pit rotation is a perfect option for VIP latrines used at the household level where the low faecal loading rate affords the contents the first pit adequate time to stabilize while the second one is in use. However, when the technology is applied in a public toilet, the high usage rate leads to a rapid filling up of the alternative pit before the content of the first pit becomes fully stabilized [36, 37].

The latrines studied in Cape Coast were not designed with double pits to allow pit rotation. Nevertheless, the potentially high content of slowly degrading organic components suggested by the high COD:BOD ratio recorded in this study implies that a long retention period would be required to stabilize the contents of the first pit to be filled. This, in turn, implies that the sizes of the alternating pits required to support such long retention period would be unreasonably large. Unfortunately, the moisture content of FS in such dry sanitation systems is usually too low to allow pit emptying by a vacuum truck as encountered by Obeng, Keraita [38] in Prampram, Ghana. It is, therefore, recommended that the authorities in Cape Coast consider replacing the VIP technology with a water-depended, easy-to-desludge technology such as the aqua privy, the pour-flush or the water closet with septic tank technology, subject to other technical and economic considerations

3.3.2 Selection of a treatment option

As noted earlier, there is the need for treatment of FS in Cape Coast to forestall the public health hazards associated with the current FS disposal practice. A wide variety of technologies exists for the treatment of FS and septage including waste stabilization ponds, co-composting, anaerobic digestion, vermicomposting, etc. However, with the relatively large amount of total solids in the FS, the choice of co-composting as a treatment option would be highly viable and beneficial to local farmers. From Table 5, between seven and thirteen tonnes (depending on the treatment technology selected) of soil conditioner could be available for agricultural use daily. The Cape Coast Metropolis is surrounded by farming communities who could benefit from relatively cheaper soil conditioners (manure). To the best of our knowledge, there are currently no reports of the direct application of faecal sludge in agriculture in and around Cape Coast, but the practice of dumping faecal sludge into the environment means large volumes of beneficial organic matter is wasted. Nevertheless, constant monitoring would be required to ensure that the manure is free from heavy metals and pathogens.

3.3.3 Potential resource recovery

Aside the recovery of manure from the FS, other beneficial resources such as biogas, biofuel and protein source for poultry could be obtained from the FS treatment in line with Ghana's Environmental Sanitation Policy principle of treating sanitation as an economic good [39]. Untapped beneficial resources from faecal sludge produced in Cape Coast is shown in Table 5. These are based on calculations used by Diener [40].

Table 5. Estimated beneficial resources from FS produced in Cape Coast.

Beneficial resource	Unit	Value	Basis for Calculation
Average quantity of FS production in Cape Coast	tonnes/day	49.0	2014 and 2020 estimates [9]
Average solids content in FS	tonnes/day	17.8	Average results of 36.4% from this study
Biogas potential	m^3/day	1,548.6	87mL of gas/g FS at a temperature of 30^{o}C [41]. 6 days a week for 52 weeks a year
Biofuel potential	GJ/day	302.6	Calorific value of 17GJ/tonne [42]
Black soldier fly (BSF) larva as poultry feed	kg/day	356	20kg BSF larva for 1 tonne of FS [43]
Protein potential from BSF larva	kg/day	124.6	35% protein/kg of BSF larva [44]
Soil Conditioner from BSF larva production	tonnes/day	7.1	60% solids reduction by larva [40]
Soil conditioner from biogas plant	tonnes/day	12.5	30% reduction of volatile solids [41]

Studies have shown that FS is a potential biofuel with calorific value comparable to other fuels [45]. An estimated 302.6 GJ of biofuel could be obtained from FS produced in Cape Coast (refer to Table 5). This amount of biofuel could provide an important energy source for small and medium scale industries in Cape Coast and its environs. Furthermore, biogas technology is becoming increasingly prominent in Ghana. As an important energy source, biogas can reduce the dependence on firewood for household, institutional and industrial uses. With the current FS production rate in Cape Coast, about 1,549 m^3 of biogas is wasted each day. Using 2,500 litres/day of cooking energy requirement for a household size of five [46], the biogas potential of Cape Coast could provide energy for more than 600 households. This could go a long way to reduce the amount of greenhouse gases in the local atmosphere.

The use of black soldier fly (BSF) (*Hermetia illucens*) larva in the treatment of solid waste and excreta has attracted a lot of attention and research. More information on the application of BSF larva for biowaste treatment can be found in Gold [47]. The BSF larvae has been identified as an important protein source for chicken [48] and fish [49]. Nguyen [43] reported that one tonne of FS with 40% dry solids could produce 20kg of BSF larva providing about 35% of protein source for poultry [44]. Based on these figures, the FS produced in Cape Coast can generate about 356 kg of BSF larva meal and 125 kg of protein each day (see Table 5). This could significantly boost poultry and fish farming. Whiles this is a potentially beneficial resource, public education to ensure product acceptance is very necessary.

3.3.4 Improving degradation using additives

Pit latrine additives that boost nutrients, enzymes, bacteria [50] can potentially be used to improve the degradation rate of organic matter. Without prejudice to the earlier concerns raised about the appropriateness of VIP latrines used as public toilets, pit latrine additives that enhance the activities of microorganism would be very useful in Cape Coast due to the presence of adequate moisture for microbial activity and the high organic matter recorded in this study. A successful application of additives to improve the degradation rate of faecal sludge in public toilets will increase the period between desludging, consequently minimising the risk of environmental pollution.

4. CONCLUSION AND RECOMMENDATIONS

Generally, the characteristic parameters (COD, BOD_5, moisture content, and organic solids) decreased from the surface to the bottom of the pits except total solids which increased from the surface to the bottom. The mean moisture content ranged from 60.1-68% while the mean total solids ranged from 32% to 40.2%. The proportion of total solids that are volatile ranged from 63.7% to 67.8%. Mean total COD ranged from 36,355 mg/l to 73,250 mg/l with particulate COD accounting for 78% of total COD. The mean BOD_5 ranged from 11,654 mg/l to 16,655 mg/l with a high COD:BOD_5 of 4.1. With the exception of BOD, the FS characteristics did not show any significant variation between the dry and wet seasons. Even though the FS at the bottom of the pits was found to be the most stabilized, its characteristic parameters indicate that discharging it into the environment without any further treatment would pose a significant threat to public health. Additional treatment is therefore required prior to final disposal or reuse of the sludge to protect public health. The large particulate COD and COD:BOD_5 show that the FS is characterised by high content of slowly degradable organic matter which would be suitable for co-composting as a treatment option. The findings of this study underscore the inappropriateness of the use of the VIP latrine as a public toilet and the need for managers of sanitation systems to recognise faecal sludge as valuable economic resource.

REFERENCES

1. UNICEF/WHO. Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities. New York: UNCEF/WHO; 2019.
2. GSS (Ghana Statistical Service). 2010 Population and housing census: Summary reports of final results. Accra, Ghana: Ghana Statistical Service; 2012.
3. UN. Special Edition - Progress towards the SDGs: Report of the Secretary-General. New York: UN Economic and Social Council; 2019.
4. UN. Special Edition - Progress towards the SDGs: Report of the Secretary-General. New York: UN Economic and Social Council; 2016.
5. Koné D, Cofie O, Nelson K. Low-Cost Options for Pathogen Reduction and Nutrient Recovery from Faecal Sludge. In: Drechsel P, Scott C, Raschid-Sally L, et al., editors. Wastewater Irrigation and Health: Assessing and Mitigating Risk in Low-income Countries. London: Earthscan; 2010. p. 1-18.
6. Koné D, Strauss M, editors. Low-cost options for treating faecal sludges (FS) in developing countries–Challenges and performance. 9th International IWA Specialist Group Conference on Wetlands Systems for Water Pollution Control and 6th International IWA Specialist Group Conference on Waste Stabilisation Ponds; 2004; Avignon, France: IWA.
7. Strauss M, Larmie S, U H. Treatment of sludges from on-site sanitation—low-cost options. Water Science and Technology. 1997;35(6):129-136. doi: 10.1016/S0273-1223(97)00103-0.
8. Bassan M, Tchonda T, Yiougo L, Zoellig H, Mahamane I, Mbeguere M, et al., editors. Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. 36th WEDC International Conference; 2013; Nakuru, Kenya: WEDC, Loughborough University; (Delivering Water, Sanitation and Hygiene Services in an Uncertain Environment.
9. CCMA (Cape Coast Metropolitan Assembly). Cape Coast Metropolitan Assembly WASH Master Plan. Cape Coast, Ghana: Cape Coast Metropolitan Assembly; 2014.
10. City Population. Cape Coast Metropolis. 2019 [cited 2019 30 September]. Available from: https://www.citypopulation.de/php/ghana-admin.php?adm2id=0202
11. Asamoah G. Soils of the proposed farm site of the University of Cape Coast. Soil Research Institute Technical Report. Cape Coast, Ghana: University of Cape Coast; 1973.
12. Ampofo E. Soil moisture dynamics in coastal savanna soils in the tropics under different soil management practices. Hydrological sciences journal. 2006;51(6):1194-1202. doi: 10.1623/hysj.51.6.1194.
13. Awere E, Edu-Buandoh KM. Assessing The Usage Rate And Management Practices Of Public Latrines In Urban Ghana: The Case Of Cape Coast. International Journal of Scientific & Technology Research. 2016;5(6):184-189.
14. Choo J, Leong L, Rogers G. Sample storage conditions significantly influence faecal microbiome profiles. Scientific Reports. 2015;5:16350. doi: 10.1038/srep16350.
15. Lauber C, Zhou N, Gordon J, Knight R, Fierer N. Effect of storage conditions on the assessment of bacterial community structure in soil and human-associated samples. FEMS Microbiology Letters. 2010;307(1):80-86. doi: 10.1111/j.1574-6968.2010.01965.x.
16. Nwaneri CF. Physico-chemical characteristics and biodegradability of contents of ventilated improved pit latrines (VIPs) in eThekwini Municipality. Durban: University of KwaZulu-Natal; 2009.

17. AWWA, APHA, WEF. Standard methods for the examination of water and wastewater. Washington, DC: American Public Health Association; 1998.
18. Nwaneri C, Foxon K, Bakare B, Buckley C. Biological degradation processes within a pit latrine. WISA 2008 Conference, 2008 19-21 May 2008; Sun City.
19. Bakare B, Nwaneri C, Foxon K, Brouckaert C, Still D, Buckley C. Pit latrine additives: laboratory and field trials. Proceedings WISA Biennial Conference & Exhibition; 2010 18-22 April; Durban, South Africa.
20. WHO. WHO Guidelines for the safe use of wastewater, excreta and greywater. Vol. 4. 2006. (Excreta and greywater use in agriculture.).
21. WHO. WHO Guidelines for the safe use of wastewater, excreta and greywater. Vol. 3. 2006. (Wastewater and Excreta use in aquaculture).
22. USEPA. Guide to septage treatment and disposal. Washington, DC: Office of Research and Development, US Environmental Protection Agency; 1994.
23. Koottatep T, Surinkul N, Polprasert C, Kamal ASM, Kone D, Montangeo A, et al. Treatment of septage in constructed wetlands in tropical climate: lessons learnt from seven years of operation. Water Science and Technology. 2005;51(9):119-126. doi: 10.2166/wst.2005.0301. PubMed Central PMCID: PMCPMC16042250.
24. Niwagaba CB, Mbéguéré M, Strande L. Faecal sludge quantification, characterisation and treatment objectives. In: Strande L, Ronteltap M, Brdjanovic D, editors. Faecal Sludge Management: Systems Approach for Implementation and Operation. New York: IWA Publishing; 2014. p. 19-44.
25. Buckley C, Foxon K, Brouckaert C, Rodda N, Nwaneri C, Balboni E, et al. Scientific support for the design and operation of ventilated improved pit latrines (VIPs) and the efficacy of pit latrine additives. . Pretoria, South Africa: Water Research Commission; 2008.
26. Strauss M. Health aspect of nightsoil and sludge use in agriculture and aquaculture: Part II: Survival of excreted pathogens in excreta and faecal sludges. IRCWD News. 1985;23(4-9).
27. Peavy H, Rowe D, Tchobanoglous G. Environmental Engineering. New York: McGraw-Hill; 1985.
28. Fanyin-Martin A, Tamakloe W, Antwi E, Ami J, Awarikabey E, Apatti J, et al. Chemical characterization of faecal sludge in the Kumasi metropolis, Ghana. Gates Open Research. 2017;1(12):1-9. doi: 10.12688/gatesopenres.12757.1.
29. Appiah-Effah E, Nyarko KB, Awuah E. Characterization of public toilet sludge from peri-urban and rural areas of ashanti region of Ghana. Journal of Applied Sciences in Environmental Sanitation. 2014;9(3):175-184.
30. Gudda F, Moturi W, Omondi S, Muchiri EW. Analysis of physiochemical characteristics influencing disposal of pit latrine sludge in Nakuru Municipality, Kenya. African Journal of Environmental Science and Technology. 2017;11(3):139-145. doi: 10.5897/AJEST2016.2226.
31. Chiposa R, Holm RH, Munthali C, Chidya RCG, de los Reyes FL. Characterization of pit latrines to support the design and selection of emptying tools in peri-urban Mzuzu, Malawi. Journal of Water, Sanitation & Hygiene for Development. 2017;7(1):151-155. doi: 10.2166/washdev.2017.096.
32. Orhon D, Çokgör E. COD fractionation in wastewater characterization—the state of the art. Journal of Chemical Technology and Biotechnology: International Research in Process, Environmental and Clean Technology. 1997;68(3):283-293. doi: 10.1002/(SICI)1097-4660(199703)68:3<283::AID-JCTB633>3.0.CO;2-X.
33. Zavala M, Funamizu N, Takakuwa T. Characterization of feces for describing the aerobic biodegradation of feces. Journal of Environmental Systems Engineering. 2002;25(720):99-105. doi: 10.2208/jscej.2002.720_99.

34. Awere E, Edu-Buandoh KM. Reducing sludge volume in pit latrines: Can latrine additives in ghana help? International Journal of Advanced Research. 2016;4(8):325-334. doi: 10.21474/IJAR01/1221.
35. Mara D. The design of ventilated improved pit latrines. Technology Advisory Group Technical Note No. 13. Washington, DC: International Bank for Reconstruction and Development/The World Bank; 1984.
36. Saywell D, Hunt C. Sanitation programmes revisited. WELL Study. London: Water and Environmental Health at London and Loughborough (WELL); 1999.
37. Vodounhessi A, von Münch E. Financial challenges to making faecal sludge management an integrated part of the ecosan approach: Case study of Kumasi, Ghana. Water Practice and Technology. 2006;1(2):1-8. doi: 10.2166/wpt.2006.045.
38. Obeng P, Keraita B, Oduro-Kwarteng S, Bregnhoj H, Abaidoo RC, Awuah E, et al. Usage and barriers to use of latrines in a Ghanaian peri-urban community. Environmental Processes. 2015;2(1):261-274. doi: 10.1007/s40710-015-0060-z.
39. MLGRD (Ministry of Local Government and Rural Development). Revised Environmental Sanitation Policy for Ghana. In: MLGRD, editor. Accra, Ghana2010.
40. Diener S, Semiyaga S, Niwagaba CB, Muspratt AM, Gning JB, Mbeguere M, et al. A value proposition: Resource recovery from faecal sludge—Can it be the driver for improved sanitation? Resources, Conservation and Recycling. 2014;88:32-38. doi: 10.1016/j.resconrec.2014.04.005.
41. Song ZL, Qin JJ, Yang GH, Feng YZ, Ren GX. Effect of human excreta mixture on biogas production. Advanced Materials Research. 2012;347-353:2570-2575. doi: 10.4028/www.scientific.net/AMR.347-353.2570.
42. Muspratt AM, Nakato T, Niwagaba C, Dione H, Kang J, Stupin L, et al. Fuel potential of faecal sludge: calorific value results from Uganda, Ghana and Senegal. Journal of Water, Sanitation & Hygiene for Development. 2013;4(2):223-230. doi: 10.2166/washdev.2013.055.
43. Nguyen H. Decomposition of organic wastes and fecal sludge by black soldier fly larvae: Asian Institute of Technology, Thailand; 2010.
44. Diener S, Zurbrügg C, Tockner K. Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. Waste Management & Research. 2009;27(6):603-610. doi: 10.1177/0734242X09103838.
45. Gold M, Murray A, Niwagaba C, Niang S, Strande L. Faecal Sludge – From Waste to Solid Biofuel? Excreta and Wastewater Management: Sandec News; 2013.
46. Msibi SS, Kornelius G. Potential for domestic biogas as household energy supply in South Africa. Journal of Energy in Southern Africa. 2017;28(2):1-13. doi: 10.17159/2413-3051/2017/v28i2a1754.
47. Gold M, Tomberlin JK, Diener S, Zurbrugg C, Mathys A. Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Management. 2018;82:302-318. doi: 10.1016/j.wasman.2018.10.022.
48. Schiavone A, Dabbou S, Petracci M, Zampiga M, Sirri F, Biasato I, et al. Black soldier fly defatted meal as a dietary protein source for broiler chickens: Effects on carcass traits, breast meat quality and safety. Animal. 2019;13(10):2397-2405. doi: 10.1017/S1751731119000685.
49. Belghit I, Liland NS, Gjesdal P, Biancarosa I, Menchetti E, Li Y, et al. Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (Salmo salar). Aquaculture. 2019;503:609-619. doi: 10.1016/j.aquaculture.2018.12.032.
50. Harvey P, editor. Excreta disposal in emergencies: a field manual. Loughborough, UK: Water, Engineering and Development Centre (WEDC), Loughborough University; 2007.