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Research Article

A Comprehensive Study on the Physicochemical Characteristics of Faecal Sludge in Greater Accra Region and Analysis of Its Potential Use as Feedstock for Green Energy

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Design of treatment plants for faecal sludge management systems relies on a comprehensive accurate knowledge of FS (faecal sludge) characteristics, but this information is lacking. Developing countries like Ghana, where large proportion of the urban population (Accra) rely on onsite sanitation systems, face a lot of FSM (faecal sludge management) design challenges as a result of lack of a comprehensive study data on physicochemical characteristics of raw faecal sludge after primary dewatering. Achieving a fully operational FSM chain would imply a well understanding of the characteristics of the FS and its dynamics after primary dewatering. A study was carried out to determine the characteristics of faecal sludge brought to the Lavender Hill treatment plant, Accra Metropolis, and environs to ensure the treatability and uses of the products after treatment. The treatment plant receives an average of 150 trucks (1350m^3) a day with 58% coming from private homes and 42% from public toilets. Composite samples were made from both public and private toilets facilities. Samples were taken from a reservoir holding faecal sludge from both public and private facilities, examined on daily basis and characterized. The values obtained showed high concentrations of BOD and COD values. The COD: BOD ratios showed that the faecal sludge is not stabilized yet and can be further degraded. The calorific value for the dry sludge was found to be 15.16-15.82 MJ/kg and 16.39–18.31 MJ/kg for the wet sludge. The calorific value of the sludge is adequate enough to be used as potential feedstock for green energy generation. The high concentrations of COD and organic matter of the faecal sludge make it suitable enough for biogas generation. A good correlation (r = 0.909, R^2 = 82.6%) between the calorific value and the TVS was found to be CV = 0.122TVS + 7.44. Heavy metal concentrations were low and satisfied the EPA Ghana guidelines for sludge. Thus products from the treatment can be used for agricultural purposes.

1. Introduction

Faecal sludge management (FSM) has not been given the needed attention for the past decades in Africa [1, 2] making FSM difficult and cumbersome for states to manage [3–5] and Greater Accra Region of Ghana is not in exception. Accra and other urban areas in Ghana are often faced with poor sanitation situation [3, 6] leading to faecal sludge management crises [3]. Lack of standardized methodologies for the quantification or characterization of FS has partly contributed to the crises [7]. It is estimated that one-third of the world's population, approximately 2.4 billion urban dwellers, rely on onsite sanitation system (OSS) installations such as public latrines, aqua privies, and septic tanks [8]. More than half of the entire population of Ghana (58%) rely on cesspit and Kumasi ventilated improved pit (KVIP) latrines [8]. Faecal sludge (FS) generated in Ghana and many developing countries is mainly made up of public toilet sludge (PTS) and septage [8] which are disposed of untreated and indiscriminately into lanes, drainage ditches, and open urban spaces [3, 4, 6, 9–12]. There are very few faecal sludge treatment facilities available to treat the many tons of sludge generated [9, 10, 13] specifically in Accra, thus making treatment of FS very abysmal. The process involved in FSM in Ghana within the context of FSM chain is fourfold: collection, transportation, disposal, and treatment.

Collection and transportation are the areas where Ghana had seen consistency and improvement over the years [14–16]. Disposal and most importantly treatment are the areas where Ghana had seen a short fall. This is evidenced by the work of Doku [17] which indicates that high volumes of faecal sludge collected by vacuum tankers from cities and towns in Ghana were disposed on land and water bodies. The utilization of waste stabilization ponds, maturation ponds, facultative ponds, and anaerobic ponds had been the most used treatment technologies in Ghana over the years [10, 18]. Most of these facilities had been reported to be in a deplorable state or not working effectively [14, 19, 20] and be used as dumping sites for nonfaecal matter [10, 21, 22]. The large volumes of FM being disposed into the sea has caused stench in some of the areas around James Town, Korle Gonno, and the environs in the Greater Accra Region of Ghana. The alternative solution employed by Sewerage Systems Ghana Limited uses an integrated system of faecal sludge management techniques using the Upflow Anaerobic Sludge Blanket for generating biogas.

The characterization of faecal sludge based on public and private toilets differs widely by locality, from household to household, city to city, and district to district, but their characterization based on history only gives qualitative information [1, 8, 23]. The characteristics of collected faecal sludge vary greatly and depend on a number of factors [1, 10, 14, 23, 24]. What are these factors? Design of faecal sludge treatment plants requires a reliable and accurate data on faecal sludge characteristics and quantities to properly size and select treatment technologies and operational parameters [1, 24, 25]. Research presented so far has reported on varying data characteristics of faecal sludge, making it very difficult for design usage purposes [1, 3, 6–10, 14, 23, 24, 26, 27]. This may have resulted in the collapse of most of the treatment facilities in the cities of Ghana [10, 21, 28] as engineers do not have access to comprehensive study of the physicochemical characteristics of the FS and its dynamics after application of some primary treatment such as dewatering. This information is not available in any of the current literature works [1, 3, 6–14, 24, 26–31].

The breakdown of these treatment facilities had been attributed by some researchers to financial constraints and poor management practices [10, 26] but the question is, if there are financial capabilities, how can one converts an input into an output having scanty or no comprehensive details of the input? Developing country like Ghana which is gradually giving its FSM a facelift needs to have a study detailing the comprehensive characterization of its FS which is a critical input into its treatments. This would serve as a baseline and reference point for design purposes and choice of technologies for the application of the FSM in Ghana and even the subregions. Again the solid sludge generated after dehydration of the raw sewage has gained more attention in recent days in Ghana in terms of its utility into organic manure [11, 12, 32–34] and/or conversion into electricity using applicable technology [34–36]. Recent works even indicate that the solid sludge (biosolids) generated from raw faecal sludge has been used as a source of raw material for fish feed [27, 29]. This interest also raised the need for the comprehensive study of the solid sludge (biosolids) obtained after the dehydration process.

Comprehensive information detailing the FS physicochemical characterization and its constituent properties in the Greater Accra Region of Ghana is required not only for academic purposes but for the establishment of a reliable database for national policy makers, researchers, practitioners, and public institutions, to develop national policy and action plans aiming at a holistic approach for FSM. Furthermore, a wide-ranging understanding of the FS characteristics influencing the solid/liquid separation is important for outlining dewatering as a potential treatment option and potential for beneficial use of treatment end products especially in green energy generation. Research has indicated that stabilized sewage sludge and fresh faecal sludge can be made viable feedstock for green energy [37, 38].

The new Lavender Hill faecal treatment plant which is being managed by Sewerage Systems Ghana Ltd. in the Greater Accra Region of Ghana employs an integrated system of FST [10, 13, 30, 31] and even though few works have been done on characterizing the faecal sludge in Greater Accra Region, being only limited to few parameters and not entirely all that is needed for design purposes and choice of technology in its treatment. This work seeks to determine the characteristics of faecal sludge brought to the Lavender Hill treatment plant, Accra Metropolis, and environs to ensure the treatability and its potential uses, to comprehensively study the characteristics of the biosolids after screening and dewatering, to explore the possibility of using the solid sludge after filtration or dewatering of the raw sludge for energy generation.

We present first extensive investigation into the characterization of FS from the Greater Accra Region of Ghana.

2. Materials and Methods

2.1. Study Area. Accra is the capital of Ghana with a population of about 4,010,054 [39]. Almost 97% of all public owned and public managed sewage/faecal treatment plants are nonfunctional [40]. Out of about 35 institutional treatment plants in the country, only 4 are operational [40]. About 23% of the households in the region practice open defecation. In terms of basic sanitation, it is reported that about more than 50% of the total households use shared facilities which is considered unhygienic and about 13% only have access to unimproved toilets [40].

The quantity of FS collected daily is estimated to be between 150 and 250 cesspit trucks [10–13, 30, 31]. There are three FS treatment plants in Accra (the new Lavender Hill faecal treatment plant, Kotoku Waste Water treatment plant, and Mudor Waste Water treatment plant) managed by Sewerage Systems Ghana Ltd., so all the cesspit emptiers dislodge FS at the Lavender Hill and Kotoku plants while Mudor receives FS from the networked sewer lines [10, 13, 30, 31], cesspit trucks from Greater Accra and some parts of Eastern and Central Regions. For this study, the Lavender Hill faecal treatment plants of the three sites where almost all the cesspit trucks from the regions dislodged were selected, located in James Town. These sites or plants were selected because they are receiving faecal sludge from cesspit emptiers across the various sections of the region in consideration (Figure 5).

2.2. Sampling of Untreated Faecal Sludge. FS samples were taken at the discharge site directly from the trucks for the public and private raw faecal sludge daily. The trucks have variable capacities ranging from about $6m^3$ to $15m^3$ per truck. For each day, samples were taken from about 50 trucks from both the public and the private toilet facilities. For each truck, about 1L of sample volume was taken and composited for the 50 trucks for both the private and public faecal sludge. The composite of the faecal sludge from the public toilet facilities that was made from 50 different trucks each day was repeated for a period of six months. Another composite from the private toilet facilities that was also made from 50 different trucks each day was also repeated for the same period of six months. All the trucks received per day which are about 150 trucks on average go through mechanical screening to remove both thrash and grit and are then stored in a reservoir. The third composite sample of the faecal sludge was taken from the reservoir which is a representation of the mixture of faecal sludge from both private and public facilities daily and was also done for a period of six months. Analyses were selected to understand FS characteristics influencing the solid/liquid separation, dewatering potential of treatment options, and possibility of utilizing the end product, i.e., the solid sludge, in green energy generation. Some of the analyses conducted on the liquid faecal sludge were based on the procedures reported in the Standard Methods for the Examination of Water and Wastewater (Eaton et al., 2005) [41]. Some of the parameters measured were total suspended solids (mg/L), total volatile solids (TVS) (mg/L), and biochemical oxygen demand (mg/L) at various days (as BOD_5, BOD_{10}, BOD_{15}, and BOD_{20}). Other parameters were also measured using the convectional HACH method and they include total nitrogen (mg/L), ammonia nitrogen (mg/L), total phosphorus (mg/L), dissolved oxygen (mg/L), electrical conductivity (μS/cm), turbidity (NTU), salinity (PSU), sulphate (mg/L), and chlorides (mg/L). The calorific value (CV) and the heavy metals were quantified using a bomb calorimeter and Atomic Absorption Spectrometry. Heavy metals measured were Cu, Zn, Cd, Mo, Fe, Vn, Ni, As, Se, and Ti in mg/kg. Both wet and dry solid sludge were sampled and subsequently analyzed. The wet sludge was obtained as a composite sample from dewatering of the raw FS. The performance of the dewatering would be published in the next paper. The dry sludge was taken after the wet sludge had been allowed to stay on a sand drying bed for about four months to dry at ambient conditions. The electronic supporting data (ES1) provide details of the equipment used, it makes and models.

2.3. Quality Control Summary: Sampling and Storage. Samples were manually collected by first selecting a location that is well mixed. The actual sample container which will be used to transport the sample to the laboratory was used for the sampling so as to eliminate the possibility of contaminating the sample with intermediate collection containers. Before sampling began on each day, the entire sample collection system was rinsed with deionized water followed by subsequent drying. For the compositing of samples, the individual sample portions were thoroughly mixed before pouring the individual aliquots into the appropriately labelled composite container. During the compositing period the individual sample aliquots were preserved at the time of sample collection and this was accomplished in the field by using ice in a well cleaned ice chest. The samples collected at the end of each day were immediately sent to the laboratory for analysis.

3. Results and Discussion

3.1. FS Characterization. The characteristics of the raw faecal sludge from both public and private sources are tabulated in Table 1. The analysis indicated that the FS is of "low strength" for the domestic source samples; this is consistent with the works of Bassan, Heinss, and Koottatep [1, 42, 43]. The "low strength" is attributed to high level of degradation that might have taken place before desludging as longer period is taken for a domestic/private toilet to be dislodged. From the results (Table 1), the public FS is of "high strength" which is also consistent with earlier works conducted [1, 8, 42–44]. The high strength of the public toilet is attributed to the slight or partial degradation to almost no degradation of the faecal sludge. The public toilets usually take about a week to three weeks to be dislodged and as a result have high contents of most of the parametric indicators like COD (Table 1). The ratio of TVS to TSS for the domestic source (Table 1) is a clear indication that there is a partial stabilization which takes place before they are desludged. However, there is still a significant amount of degradable organic matter in the faecal sludge. The public toilet has high sludge volume index (SVI), an indication of the faecal public sludge to settle overtime, and is evidence by the high settling ability. The settleability potential is an important information on the sludge property with regard to the ability of significant reduction to be achieved with settling tanks. One of the critical and most important parametric indicators in faecal sludge characterization is the COD to BOD ratio as it forms the basis of whether it could be biologically treatable or not. Even though, wide range of variability was noted for the COD to BOD ratio for the domestic, public, and composite samples, the average ratios were significantly greater than three for the composite (4.83) and public (5.89) and less than three for the domestic samples. This shows that the FS has slightly low biodegradability potential. This is also consistent with the work of Bassen [42]. The work of Heinns [42] indicates that low biodegradability characterized by COD:BOD ratio as high as 26 can be attributed to FS that is stored for long periods of time or due to the presence of inorganic pollutants.

One parameter that has eluded many researchers in their FS studies is the electrical conductivity and its dynamics. The EC, being the parameter used as surrogate measure of total dissolved solids concentration, was realized to be very high in domestic, public, and composite samples. This is an interesting observation which needs to be seriously taken

Table 1: Summary Analysis of Faecal Sludge Characteristics (Number of samples = 6,000 trucks).

parameter	unit	Public				Private				Composite			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
COD	mg/L	25407	8637	8394	48000	8361	5944	800	24000	13906	9728	800	32000
BOD_5	mg/L	4313	210.1	4100	4520	3993	90.18	3900	4080	2878.33	1946	500	5280
BOD_{10}	mg/L	5256.8	202.8	4978	6750	4085.7	98.5	3915	4236	3125	986.9	687	5350
BOD_{15}	mg/L	5485.1	137.5	5096	6936	4123.3	76.9	3985	4536	3215	895.7	721	6020
BOD_{20}	mg/L	5497.6	120.8	5128	7012	4185.6	66.5	4082	4623	3295	798.5	785	6095
TSS	mg/L	20367	12333	8400	55800	7850	7742	800	25200	16445	16424	500	54800
TVS	mg/L	84.92	2.65	81.50	87.99	73.46	11.61	54.5	83.85	81.78	5.799	70	89
pH		7.58	0.20	7.33	7.91	7.66	0.16	7.47	7.96	7.43	0.25	6.72	7.98
EC	μs/cm	10977	2917	7590	14530	5340	1143	3487	6884	7062.77	2497.64	253	13050
TDS	mg/L	5552	1312	3795	7268	2587	799.8	1090	3448	3580	993.80	246	5039
Turbidity	NTU	13523.60	4663.20	782	19890	4369.12	2508.91	1897	12867	14921	14117	735	56000
DO	mg/L	0.80	0.9	0	2.29	0.76	1.28	0.00	3.27	0.85	1.22	0	5.47
Salinity		6.62	2.39	4.19	11.06	2.86	0.63	1.83	3.37	3.99	0.90	2	5.66
Temp	$^{\circ}$C	25.30	3.45	18.90	29.11	26.55	2.68	22	30.07	24.53	2.93	18	28.75
DOM	mg/L	5000	59.8	3000	7600	2900	59.8	1950	4200	2500	352	3400	5600
TOC	%	8520	298	4150	8530	3500	195.6	2200	4530	3500	216	3150	6840
$COD:BOD_5$		5.89	41.11	2.05	0.88	2.09	65.91	0.21	5.88	4.83	5.00	1.6	6.06
TVS: TSS (E^{-3})		4.2	0.21	9.70	1.58	9.36	3.35	14.10	3.33	4.97	0.35	140	1.62
Settleable	ml/L	221.1	84.18	100	300	81.88	15.59	60	100	184.2	77.66	80	250

Table 2: Summary results for the nutrient composition of the faecal sludge.

Parameter	Unit	Public				Private				Composite				P-value
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	
TP	mg/L	110.8	2.8	95.8	125.7	89.5	6.54	50.8	98.7	96.3	5.26	75.8	105.8	0.825
TN	mg/L	1550	12.85	1050	2105	1280	10.65	890	1650	1300	15.6	950	1850	0.818
NH_3-N	mg/L	1950		1120	2410	1320	11.63	895	1650	1805	10.5	990	2010	0.732
Phosphate	mg/L	236	18.4	195	3010	199	3.2	176	201	215	2.8	187	296	0.743

into consideration during operational activities to meet EPA Ghana effluent requirement. Ionic distribution of the FS leading to the high EC is of great concern to designers, and for that reason this work had further measured the ionic contents (cationic and anionic) of the FS to see the main contributions towards the high EC (Table 3). It was realized that nitrate was contributing about 0.004% (Table 3) which is the least among the anions, while chloride is about 39.895%. For the cationic contributions it was realized that magnesium was the least with recorded percentage of about 0.495% while the highest cationic contributor was seen to be potassium with about 31.738%. The anions contribute about 40% and the remaining 60% was as a result of the cationic contribution. However, the main ion contributor leading to the high EC in the faecal sludge is the chloride ion which was found to be 39.895%. This characteristic of the FS raises questions regarding the method of choice for disinfection in the treatment process. But clearly chlorination would be the least option compared to UV system as chlorinating the final effluent water may increase the ionic distribution which would increase the EC. However, if the technological design of the treatment process could reduce the EC to less than 1000μS$\cdot$cm^{-1}, then it is possible that the chlorine effect may not take the EC above the regulatory requirement of 1,500 μS$\cdot$cm^{-1} in Ghana. It was also seen that, as the TDS increases, the salinity and the EC also increase.

The nutrient aspect of the FS characterized showed interesting trends. It was realized that the total nitrogen for both the public and domestic samples was not significantly statistically different (Table 2) unlike the other parameters like COD, TDS, and BOD (Table 1) that differed greatly. Again, ammonia nitrogen and total phosphorus showed similar trend. Ammonia nitrogen is one of the most difficult parameters to control in waste water or FS treatment and the gathered information is necessary for both treatment options and effective design requisite to bring it down to the acceptable regulatory limit of 1.0mg/L. The level of the ammonia in the influent (Table 2) is more than hundredfold of the EPA effluent requirement and the aerobic process to be chosen for the denitrification process during the FS treatment should be highly efficient. For those treatment technologies, employing fertilizers to feed bacteria in the system should resort to carbon based (like molasses or glucose) rather than the typical ammonium or phosphate based fertilizers.

Table 3: Summary results for ionic composition of the faecal sludge.

Parameter	Unit	Public				Private				Composite				
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	% cont
SO_4^-	mg/L	1.62	0.45	<1	1.75	1.10	0.61	<1	1.25	1.45	0.51	<1	1.58	0.065
Cl^-	mg/L	950	12.5	783	1030	668	11.4	540	754	895	10.89	658	994	39.895
NO_3^-	mg/L	0.12	0.52	0.07	0.14	0.09	0.54	<0.06	0.08	0.08	0.61	<0.06	0.11	0.004
NO_2^-	mg/L	0.88	0.49	0.68	0.95	0.48	0.55	0.45	0.54	0.75	0.42	0.60	0.86	0.033
K+	mg/L	750	18.9	712	890	615	21.5	589	635	712	52.4	698	830	31.738
Na+	mg/L	578	50.8	501	601	498	71.5	445	550	531	68.9	495	589	23.670
Mg2+	mg/L	12.35	3.2	10.1	13.1	10.44	5.2	9.4	11.05	11.1	4.6	9.8	12.7	0.495
Ca2+	mg/L	98	10.08	85	112	78	10.14	64	85	92	9.89	72	102	4.101

Table 4: Summary results for heavy metals composition of the faecal sludge.

Parameter	Unit	Public				Private				Composite			
		Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Cu	mg/kg	0.028	0.002	0.024	0.030	0.021	0.0005	0.018	0.020	0.024	0.004	0.018	0.026
Zn	mg/kg	0.085	0.010	0.074	0.094	0.042	0.012	0.058	0.068	0.070	0.011	0.068	0.082
Co	mg/kg	0.014	0.008	0.010	0.018	0.009	0.001	0.008	0.010	0.011	0.012	0.009	0.015
Cr	mg/kg	<0.01	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01	<0.01	0.00	<0.01	<0.01
Mo	mg/kg	0.0084	0.002	0.0069	0.009	0.0028	0.0012	0.0035	0.0049	0.007	0.0021	0.0059	0.0086
Ni	mg/kg	0.006	0.001	0.004	0.007	0.003	0.0005	0.001	0.004	0.004	0.0012	0.003	0.006
As	mg/kg	0.008	0.001	0.003	0.010	0.002	0.0007	0.001	0.003	0.005	0.0018	0.002	0.007
Pb	mg/kg	0.007	0.001	0.005	0.010	0.004	0.0010	0.002	0.007	0.006	0.0021	0.004	0.008

Heavy metals are usually found in commercial and industrial wastewater and may have to be source-controlled if the wastewater is to be reused [37]. The quantification of heavy metals in influent waste water or faecal sludge had not been given the attention it requires and it is not even outlined in all the categories (except for only few ones like the mining sector) of the EPA guidelines for effluent waste water discharge requirement in Ghana. However, the guideline is stringent on some of the heavy metals like cadmium, chromium, and lead in the solid sludge. For the purposes of effluent water reuse and possible use of solid sludge for compost and feedstock for green energy generation, this work analyzed some heavy metals in the composite sample of the FS (Table 4). The highest recorded concentration of the measured heavy metals was 0.070mg/L representing that of zinc while the lowest was nickel with 0.04mg/L. The order of decreasing concentrations of the measured heavy metals is Zn>Cu>Co>Mo>Pb>As>Ni. The concentrations of the heavy metals in the FS are less than those that had been reported for other African countries [35].

3.2. Dewatered Solid Sludge (Biosolids). Results of the solid sludge compositions for both wet and dry samples are presented in Table 5. Several metal compositions, chloride, moisture content, total volatile solids, and the calorific value were analyzed for both sludge samples. From the results obtained, it was seen that most of the chemical compositions of the wet sludge (CV, Cu, Zn, Cd, Zn, Mo, Al, B, Fe, Vn, Calcium, Mg, and P) were relatively higher than in the dry sludge samples (Figure 1). Cr, Na, and K followed a different trend with the concentrations being rather high in dry sludge than wet one (Figure 2). However, the contents of the Cl, nickel, sulphur, arsenic, selenium, manganese, and titanium did not follow any of these trends (Figure 3).

Most of the metals like magnesium, sodium, potassium, phosphorus molybdenum, copper, and aluminum required by plant for growth and high yields recorded interestingly high values (Table 5). Even with unfavorable or uncontrolled treatment technology of sludge to compost, there is no possibility that the sludge would lose all these vital metals and this is a clear indication of possible use as compost in agriculture. The possible use for agricultural purposes is consistent with earlier works [32, 33].

Cadmium, being one of the heavy metals expected to be about 0.1mg/L according to the Ghana EPA regulatory requirement for dry sludge, recorded values close to 0.1mg/L, thus about 0.55mg/L for dry sludge and about 0.89mg/L for the wet sludge. That is to say, treating the sludge for possible compost would have the cadmium component having high probability of falling within the requirement. There are other heavy metals like lead and chromium which are also about 0.1mg/L but the recorded values were averagely far above the requirement. Lead recorded an average of 6.76mg/Kg and 18.94mg/Kg for the dry and wet sludge, respectively. Chromium yielded an average of 42.56mg/Kg for the dry sludge and about 34.75mg/Kg for the wet sludge. These two heavy metals are going to be among the potential challenges in the conversion of the dry sludge for compost referencing the requirement, if the sludge is only obtained

Table 5: Summary physicochemical parameters for both wet and dried dewatered solid sludge.

Determinant	Units	Dry dewatered faecal sludge				Wet dewatered faecal sludge			
		Mean	SD	Min	Max	Mean	SD	Min	Max
Chloride	mg·kg^{-1} cl	22.04	24.15	2.40	49	30.11	10.06	20.74	40.74
Moisture	%	15.78	3.97	13.16	20.35	84.79	3.13	81.19	86.88
CV	MJ/kg^{-1}	15.58	0.36	15.16	15.82	17.12	1.04	16.39	18.31
TVS	% dry basis	67.10	6.39	60.00	72.4	78.73	4.86	73.7	83.4
Copper	mg·kg^{-1}	125.93	14.37	115.40	142.3	185.30	3.24	181.8	188.2
Chromium	mg·kg^{-1}	42.53	6.23	37.42	49.47	26.33	11.94	12.65	34.63
Zinc	mg·kg^{-1}	694.00	72.56	647.40	777.6	923.77	86.65	824.6	984.9
Nickel	mg·kg^{-1}	25.12	4.05	21.79	29.63	22.04	1.82	19.94	23.16
Cadmium	mg·kg^{-1}	0.60	0.11	0.52	0.72	0.86	0.04	0.83	0.91
Lead	mg·kg^{-1}	6.69	1.10	5.45	7.54	18.77	1.45	17.21	20.08
Arsenic	mg·kg^{-1}	10.82	0.46	10.48	11.34	10.02	3.26	7.44	13.69
Barium	mg·kg^{-1}	119.60	13.52	110.20	135.1	176.10	32.43	142.9	207.7
Molybdenum	mg·kg^{-1}	12.05	1.41	10.90	13.62	14.42	0.64	13.76	15.03
Selenium	mg·kg^{-1}	6.27	2.65	3.72	9.01	9.73	7.13	4.42	17.83
Aluminium	mg·kg^{-1}	3,701.33	380.53	3,318.00	4079	7,168.00	642.24	6704	7901
Boron	mg·kg^{-1}	41.31	6.11	37.19	48.33	75.37	8.33	65.82	81.15
Iron	mg·kg^{-1}	5,517.67	669.33	5,069.00	6287	9,159.33	1,013.46	8456	10321
Manganese	mg·kg^{-1}	241.83	41.96	203.40	286.6	269.90	94.46	168.8	355.9
Titanium	mg·kg^{-1}	53.36	5.31	50.19	59.49	58.57	15.76	48.15	76.7
Vanadium	mg·kg^{-1}	12.46	1.83	11.03	14.52	22.12	2.17	20.7	24.62
Calcium	mg·kg^{-1}	28,746.00	5,450.53	24,653.00	34933	44,305.67	6,742.42	37658	51139
Magnesium	mg·kg^{-1}	6,538.67	979.80	5,684.00	7608	9,446.00	532.79	8837	9826
Sodium	mg·kg^{-1}	2,246.33	478.67	1,783.00	2739	860.90	241.38	676.1	1134
Potassium	mg·kg^{-1}	2,660.00	265.88	2,417.00	2944	1,977.00	595.04	1386	2576
Phosphorous	mg·kg^{-1}	16,305.00	3,127.61	13,541.00	19700	24,668.50	3,043.79	21684	27653
Sulfur	mg·kg^{-1}	9,332.00	1,778.69	7,780.00	11273	12,367.00	2,952.14	10977	13757

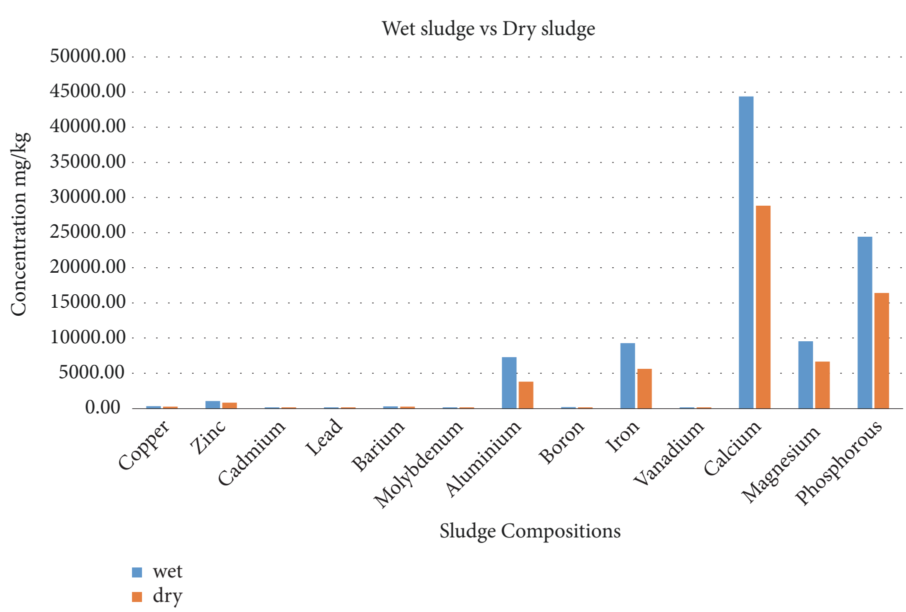

Figure 1: A graph of sludge composition having higher concentrations in wet sludge than dry sludge.

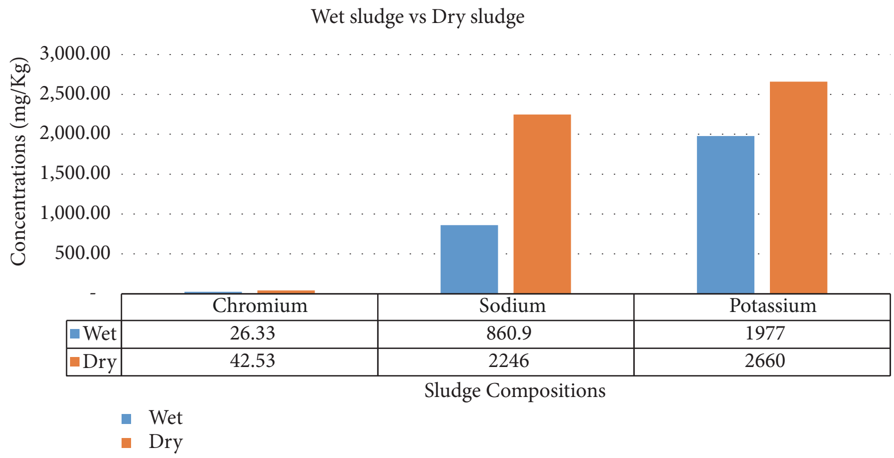

Figure 2: A graph of sludge composition having higher concentrations in dry sludge than wet sludge.

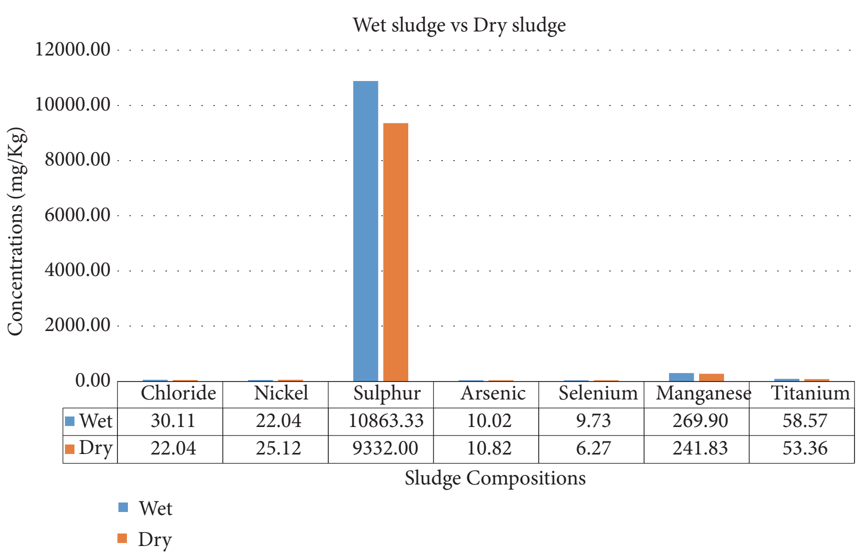

Figure 3: A graph of sludge composition with the state (wet or dry) having no particular effect.

from dewatering the raw sludge without having gone through any biological treatment.

The total volatile solids obtained for both the wet and dry dewatered sludge were at least 60% dry basis (Table 5) and this is a good indication of the dewatered sludge containing high amount of organics. Again, the calorific value, being the key indicator in the conversion of the faecal sludge or any organic containing compound to electricity, is highly encouraging. It was noted that the calorific value (CV) for the dry dewatered sludge was 15.16-15.82 MJ/kg and 16.39–18.31 MJ/kg for the wet dewatered sludge. Research has also indicated that the calorific value of biomass is determined by its moisture content [45], and up to 60% moisture content, the calorific value of wood may be between 6 and 18MJ/kg while air-dried wood with 15–20% moisture has a calorific value between 14 and 15.2MJ/kg. From Table 5, it is proved that this work is consistent with literature [45] as the moisture content of the wet dewatered sludge is 81.19%–86.88% and 13.16–20.35% for the dry dewatered sludge. The sludge calorific value obtained has been speculated to be more than that in the UK and other European countries. However, the works of Murray [36] reported an average CV of about 19MJ/Kg of FS (raw and untreated) obtained from Kumasi in Ghana. This also agrees with the CV of this work. Considering the extent of the CV in the sludge, technologies like patented advanced gasification technology of Egnedol and other incineration methods are capable of generating an electricity of about 1.5–2.02 MW per hour utilizing feedstock of about 14 tons/day of sludge containing such amount of CVs. There is no doubt that the Ghanaian faecal sludge after dewatering is capable of generating substantial amount of electricity for the utility of the plant with possible extension of the excess to the grid.

Due to the current limited capacity available for the analysis of CV of samples in Ghana, this work expanded the horizon of findings to develop a quick, relatively less expensive, and yet reliable way to estimate the CV of sludge samples. The TVS is a known parameter for estimation of

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Regression Analysis: CV versus TVS, ASH

* ASH is highly correlated with other X variables
* ASH has been removed from the equation.

The regression equation is
CV = 7.44 + 0.122 TVS

Predictor      Coef  SE Coef     T      P
Constant      7.442    2.054  3.62  0.022
TVS         0.12214  0.02803  4.36  0.012

S = 0.510723   R-Sq = 82.6%   R-Sq(adj) = 78.3%

Analysis of Variance

Source          DF      SS      MS      F      P
Regression       1  4.9529  4.9529  18.99  0.012
Residual Error   4  1.0434  0.2608
Total            5  5.9963

Correlations: CV, TVS

Pearson correlation of CV and TVS = 0.909
P-Value = 0.012
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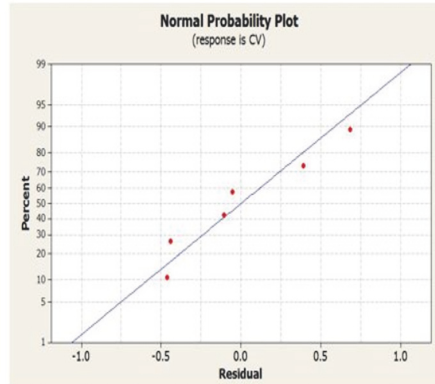

Figure 4: Correlation between the CV, TVS, and ASH content of the solid FS.

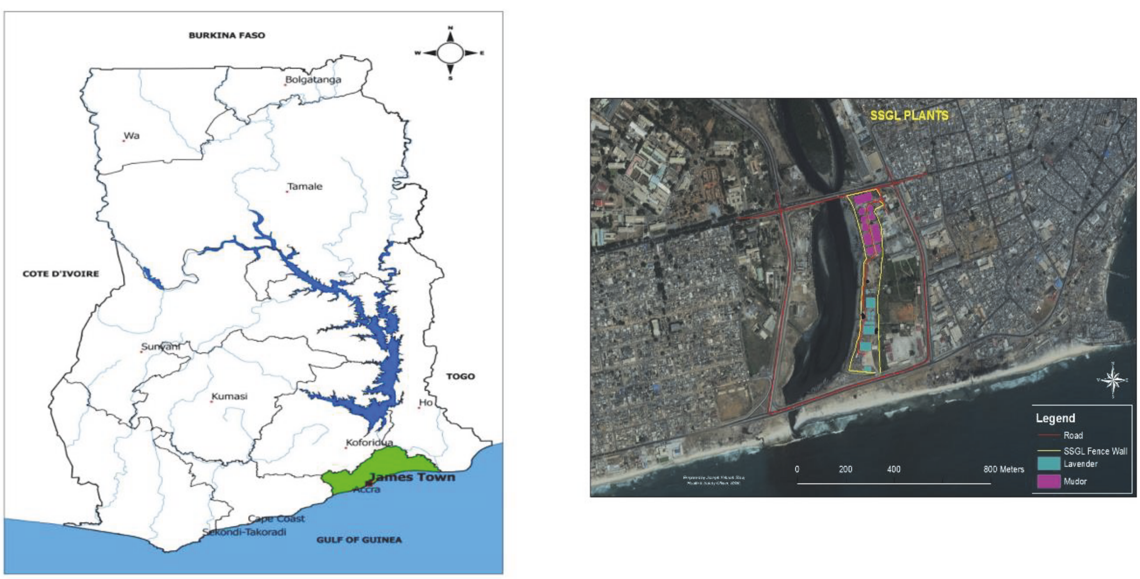

Figure 5

organics in samples as the CV is also known to be highly dependent on the organics of a sample. The organic matter is responsible for the energy content of the fuel, while it is the mineral matter that presents significant challenges in the design and operation of a power plant [45]. The TVS of the sludge samples was then chosen as a primary indicator among all other parameters analyzed to find the correlation between it and the CV (Figure 4). The motivation to use the TVS to estimate the CV had come from the basis and/or the principle from which the zeroth law of thermodynamics had existed; also research has indicated that higher heating values (calorific values) can also be determined by correlations between the heating value and analysis values from statistical studies [45]. The values calculated this way, however, are only approximate. The results (Figure 4) indicate that there is a strong positive correlation between the TVS and CV as the Pearson correlation value is near unity (0.909) and the R^2 value close to 90% (82.6) having a p value less than 0.05. The obtained relation for the estimation of the calorific value was found to be CV = 0.122TVS + 7.442. This is a quick and inexpensive way to estimate the calorific value of the faecal sludge using the TVS value on dry basis as the primary indicator. Inasmuch as the calorific value of the dewatered sludge is high potential feedstock for green energy, it is worth noting that from Table 1, with the high strength faecal sludge (high COD) obtained and the levels of organic matter realized, the faecal sludge has a good indicative base for biogas generation.

Table 6: Quality control summary on some selected parameters.

KEY PARAMETER	Unit	RL	MB	DUP %RPD	LCS %Recovery
COD	mg/L	5	<5	13	NA
BOD	mg/L	5	<5	3	96
PH		0.1	<0.1		3
EC	mg/L	10	<10	0	NA
TP	mg/L	0.03	<0.03	0	NA
NH_3-N	mg/L	0.02	<0.02	183	98
Phosphate	mg/L	0.02	<0.02		90
SO_4^-	mg/L	1	<1	3	86
NO_3^-	mg/L	0.1	<0.1	94	113

3.3. Study Limitations. This study has potential limitations. The calorific value estimates are based on total volatile solids of the sludge on the basis that they are all dependent on the organics. The method of estimating the calorific value from the derived correlative equation is a quick and inexpensive way to estimate the calorific value of the faecal sludge using the TVS value on dry basis as the primary indicator. It is therefore subject to bias as the values calculated this way, however, are only approximate.

The research period spanned for about six months; during this period of study both dry and rainy season were experienced. Research has also indicated that quality of faecal sludge is affected by seasons (dry and rainy season in tropical areas). This makes some aspect of the sampling subject to bias.

3.3.1. Quality Control Summary: Analysis. The blank results were compared to the Limit of Reporting. The LCS and MS spike recoveries were measured as the percentage of analyte recovered from the sample compared to the volume of analyte spiked into the sample. DUP and MSD relative percentage differences were as well measured against their original counterpart samples according to the formula: the absolute variance of the results pair divided by the average of the two results as a percentage, where the DUP RPD is "NA"; the results are less than the LOR and thus the RPD is not applicable (Table 6).

4. Conclusion

This study presents for the first time comprehensive insight into the understanding of the raw faecal sludge and its potential utility in composting and feedstock for green energy. The reasons behind the high electrical conductivity of the faecal sludge in the region as well as the treatment option with regard to dewatering and disinfection have been outlined. Important conclusions include the following:

The presented results give an about and the need to understand the comprehensive characteristics of the FS before choosing any treatment technology and/or the design of the plant.

Huge amounts of settleable solids were noted in the faecal sludge especially for public samples and there is a need to explore for the type of solids (sand, grit, etc.) with their respective ratios for design purposes.

Due to the high content of ammonia and electrical conductivity in the raw faecal sludge, treatment technologies should reduce or possibly avoid the use of ammonia containing compounds and the use of chlorination as disinfection option if the effluent water is to be discharged into the environment bearing in mind the EPA guidelines.

This research had considered both the raw FS and the solid sludge after dehydration for the first time and would serve as route to innovative end uses as the work has increased on this field to include correlation between the TVS and calorific value. Examples include the use of FS treatment end products as a potential energy source and quick estimation of calorific value of FS using the TVS.

Transforming solid faecal sludge to a renewable biofuel (green energy) may be utilized as a means of tackling sanitation challenges in Ghana. With its calorific value seen to be equitably consistent across regions, as the results of this study suggest, faecal sludge-to-solid-biofuel could be a widely transferable solution for FS management. This is consistent with the work of Moritz [35]

Dewatering (thus flocculating the raw liquid faecal sludge with polymer and mechanical pressing) the raw faecal sludge has shown a potential to be a key step through FS treatment interventions, which have potential to remove the solid sludge within a short period for the utilization of the solid sludge for either compost or feedstock for energy.

Considering the amount of FS generated in Greater Accra Region and other regions in Ghana, large-scale energy production utilizing the FS could provide increased revenue, compensating treatment costs, as well as acting as an incentive to sustain FS treatment. FS resource recovery has the additional benefit of reducing pathogen transmission pathways and land requirements for treatment plants.

The concentrations of the heavy metals in the solid sludge (Table 5) are significantly lower and are clear indication of a potential for energy recovery from sludge collected from liquid/solid separation of raw faecal sludge because of its lower concentrations of heavy metals and ash.

The quick, less expensive, and yet reliable way to estimate the calorific value of Faecal sludge using the knowledge of its volatile solids is given by the relation CV = 0.122TVS + 7.44.

The high COD and organic matter concentrations of the raw faecal sludge make it a good indicative base for biogas generation.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request. The corresponding author is responsible for data distribution and can be reached via the email eagleskertoozer@yahoo.co.uk. However, substantial data information on the research is provided in the electronic supporting information.

Conflicts of Interest

The authors would like to declare that they have no significant financial, professional, or personal conflicts of interest that might have influenced the performance or presentation of the work described in this paper.

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Supplementary Materials

The supplementary material file contains a description of the instrument used in the research work detailing the instrument make and model. Also, the content highlights some graphical representation of parametric trends in both wet and dry dewatered sludge. The correlational knowledge between the total volatile solids and the calorific value is also highlighted in this material. *(Supplementary Materials)*

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