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A critical analysis of physiochemical properties influencing pit latrine emptying and feacal sludge disposal in Kampala Slums, Uganda

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Inadequate information on physiochemical properties of faecal sludge leads to inappropriate design of pit emptying devices and poor faecal sludge disposal contributing to environmental pollution. This study undertook a critical analysis of physiochemical properties of feacal sludge that influence design and performance of pit emptying devices and faecal sludge disposal for improved faecal sludge management in urban slums. The physiochemical properties determined were; Moisture content (MC), ash content (AC), total solids (TS), volatile solids (VS), nitrogen (N), phosphorous (P), potassium (K) and pH. Samples were collected from 55 unlined pits at depths of 0, 0.5, 1 and 1.5 m from pit surface. The unlined pits in this study were purposively selected from slums in Kampala. A sample of 300 g was sucked from each depth using a manual sampling tool and emptied into a plastic container. The container was then wrapped in a black plastic bag and transported in cooler boxes to the lab for analysis. The properties were subjected to Principal Component Analysis to isolate the critical parameters that affect pit emptying and faecal sludge disposal. The mean results were: MC of 86 ± 8.37%; TS of 0.14 ± 0.08 g/g wet sample; VS of 0.73 ± 0.32 g/g dry sample; pH of 8.0 ± 1.5; AC of 0.35± 0.18 g/g dry sample; TN of 3.5 ± 0.08%; K of 2.2± 0.13% and P of 1.4± 0.05%. It was concluded that physiochemical properties in Ugandan pits are comparable to those of global pits except for the acidic conditions at top surface in some pits, and higher moisture content in pits due to the high water table. PCA results showed that moisture content and total solids affected pit emptying techniques while fractional content of N, P and pH affect most choice of faecal sludge disposal technique.

Key words: Pit latrine, faecal sludge management, developing countries, physiochemical properties, pit emptying.

INTRODUCTION

Over a billion people worldwide are served by onsite sanitation technologies (Strande et al., 2014). In many Sub-Saharan Africa cities onsite technologies have much wider coverage than sewer systems and this is mainly attributed to rapid population growth and urbanization associated with the proliferation of informal settlements in those cities (Tsinda et al., 2013). Despite the fact that sanitation needs are met through onsite technologies for a vast number of people in urban areas of low- and middle-income countries (Strande et al., 2014), there is typically no proper faecal sludge management system in place.

Poor faecal sludge management and inadequate access to proper toilets has far reaching adverse impacts on sanitation and hygiene conditions in most slum areas (Nakagiri et al., 2015). No wonder the United Nations has reported that at least 1.8 billion people globally use a source of drinking water that is contaminated with faeces and as in response, the United Nations General Assembly has recognised sanitation as a separate human right in a bid to curb a major source of deadly infections. In the same vein, over 90% of the population living within Kampala slums use onsite sanitation facilities (Semiyaga et al., 2015; Günther et al., 2011), particularly pit latrines because they are relatively affordable and ease to construct. When filled, the pits are either abandoned so that a new facility is constructed or can be restored by emptying (Tilley et al., 2014). However, it is always a challenge to empty unlined pit latrines in informal settlements because often pit latrine sites are not accessible due to the narrow roads which lead to the latrines resulting from high population density and the ensuing congestion of homesteads. In addition, the pits are generally not lined with bricks and can collapse after a period of use (Hohne, 2011). Thus unlined pits are increasingly becoming unsustainable due to high fill-up rates caused by ingression of water which is exacerbated by the high water table in most slum areas. In addition, non-faecal material is deposited into the pit by the users partly due to limited space in the slums and the poor pit latrine user habits accelerates pit latrine filling rates (Zziwa et al., 2016). However, there are several challenges preventing communities from use of existing pit latrines including stigmatization (Eales, 2006). It is reported that almost 35% of the pit latrines within the Kampala slums are full and not emptied (Zziwa et al., 2014). This is mainly due to the high costs incurred in emptying the full pits (Dodane et al., 2012) and the risk associated with disposing of the sludge properly without polluting the environment. As a result, in some places, faecal matter accumulates around homes and in garbage dumps (Katukiza et al., 2010). During rainy seasons, people empty their full pit latrines into nearby drainage channels contributing to water pollution and poor sanitation in the city (Kulabako et al., 2007).

Knowledge of chemical and physical characteristics of faecal sludge (FS) is a prerequisite consideration to proper FS management for design of emptying and treatment systems which form part of the sludge management chain (Heinss and Strauss, 1999). The problems of data reduction, interpretation and change in FS quality parameters can be approached through the use of the Principal Component Analysis (PCA). Feoli (1997) noted that PCA could provide unique and objective representations on the essence of certain parameters within a given data set. In recent years, the PCA technique has been applied to various environmental applications, including assessment of environmental quality indicators (Ouyang, 2005; Mayanja, 2014; Seema and Muhammad, 2013) but fewer studies on FS characterization have utilised the technique. This study applied PCA to the data set in order to establish critical properties of FS which affect pit latrine emptying and FS disposal so that emptiers and designers of pit emptying devices can easily understand the nature of faecal sludge.

MATERIALS AND METHODS

Ethical clearance and research approval

Due to the fact the study looked at human feces, ethical clearance was obtained from Uganda National Council for Science and Technology (UNCST) prior to conducting the study. In addition, permission was also obtained from Kampala Capital City Authority (KCCA) and the local leaders in each of these divisions before faecal sludge sampling.

Study area

This study was carried out in slums located in the five divisions of Kampala city, Uganda. The slums selected were those located between 1140 and 1200 m above sea level and were faced with sanitation challenges such as FS management (Günther et al., 2011; Kulabako et al., 2005). These included Kamwokya (in Central division), Luzira (in Nakawa division), Bwaise (in Kawempe division), Nankulabye (in Rubaga division), Kibuye (in Makindye division) and Kalerwe (in Kawempe division); two slums were selected from Kawempe division because it consists of the majorly studied slums in Kampala (Figure 1). In addition, these slums are unplanned with lack of basic services, poor road access and poor housing (Kulabako et al., 2005). In order to ensure that the selected areas were lying in the same elevation, a GPS machine was used.

Sludge sampling

Samples were collected from fifty five (55) unlined pit latrines using a manual sampler (Figure 2) which was locally designed and fabricated for this purpose. Purposive sampling was used in this study where local council leaders and pit latrine emptiers in the area were used for identifying unlined pit latrines for sampling since they had knowledge of their designs. Four grab samples were collected from each pit latrine at four sludge depths (0.0, 0.5, 1.0 and 1.5 m) as specified by Buckley et al. (2008). Hence a total of

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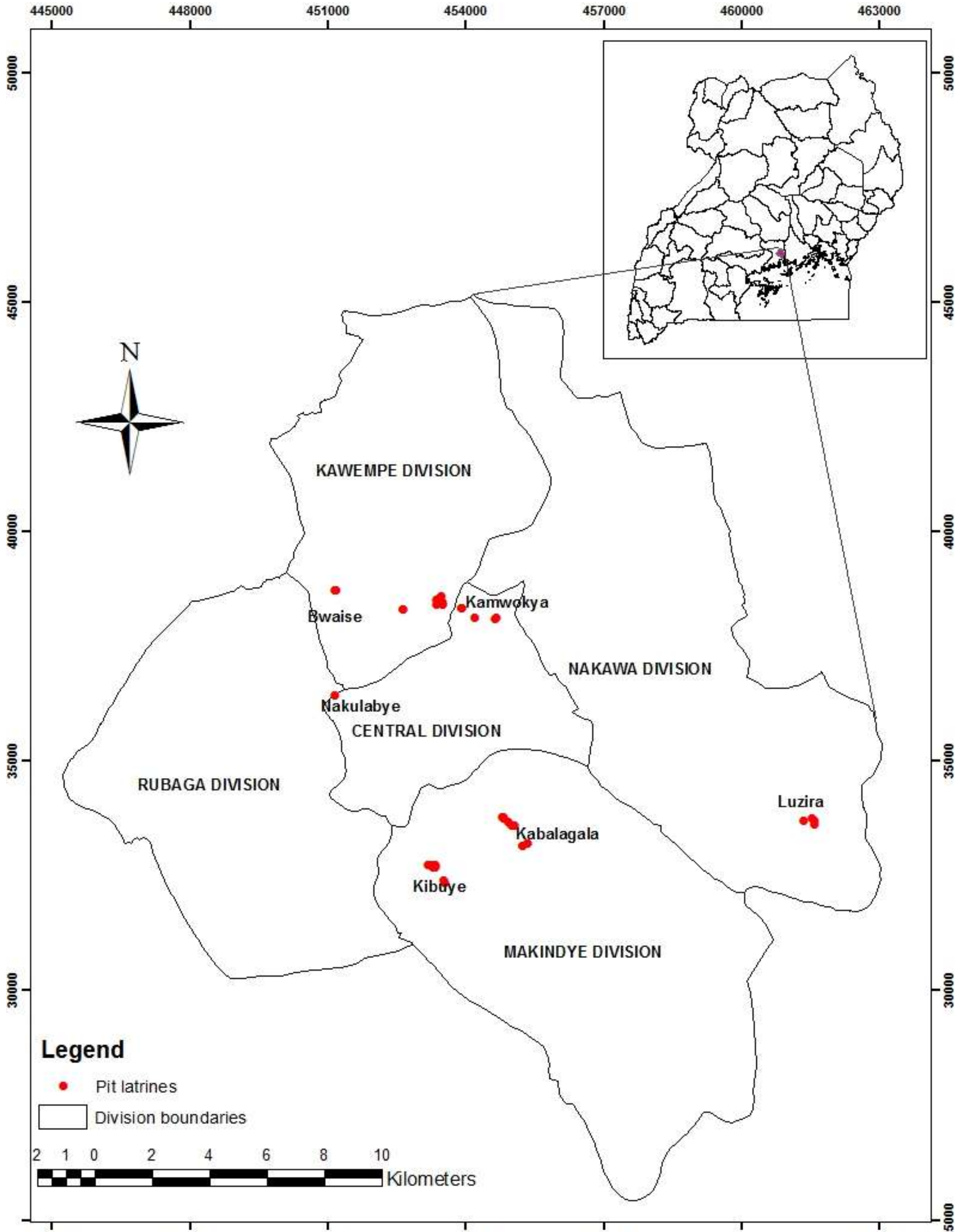

Figure 1. Map of Kampala city showing selected pit latrines.

220 samples were collected for analysis. A sample of ±300 g was obtained from each depth and emptied into a plastic container. The container was then wrapped in a black plastic bag and transported in cooler boxes to the College of Veterinary Medicine, Animal Resources and Bio-security (COVAB) laboratory at Makerere University for analysis.

Health and safety standards for field work

According to Niwagaba (2009) and Reddy (2013) faecal material can host a number of pathogens and as such is classified as a biologically hazardous material. Accordingly, prior to field work, all researchers and field assistants were immunized against

Figure 2. Sludge sampling using a manual sampling tool.

Figure 3. On-site measurement of FS pH.

opportunistic diseases such as tetanus and Hepatis B. The researchers and field assistants used recommended field gear including safety gum boots, nose masks, safety goggles, overalls and disposal gloves during sampling. In addition, the field team cleaned hands and sampling tools after each day of field sampling using antiseptic liquid soap. Careful disposal of used gloves was also done after each day of field sampling. During sampling maximum care was done to avoid spillage and contact of faecal sludge with skin. Furthermore, all waste samples onsite were disposed of according to the standards for faeces sample disposal and where possible pits were dug for purposes of burying the wastes.

Laboratory analysis

Prior to analysis, removal of trash by screening using 5 mm sieve was done. FS is highly variable; therefore, samples were homogenized by use of an electric blender prior to analysis. The physiochemical characteristics that were analyzed included total solids (TS), volatile solids (VS), moisture content (MC), ash content, pH, total phosphorus (TP), total nitrogen (TN) and potassium. These properties were selected because they are the ones that affect design of pit latrine emptying equipment, treatment and disposal of FS (Niwagaba et al., 2014). The FS total solids and moisture content were determined according to techniques specified by APHA (1998). FS samples were oven-dried at 105˚C for 12 h. The difference in mass before and after drying was used to determine moisture content of the samples on gravimetric (*g* water/*g* sludge) basis. Volatile solids and ash content were determined by weight loss on ignition heating for 4 h in a muffle furnace at 550˚C, with the measured weight representing the latter.

The pH of samples from the three sampling depths of 0, 0.5, 1 and 1.5 m from pit surface was measured on site using a digital HI 98127 meter (Hanna instruments, UK) with a pH electrode which was immersed into the sample immediately after collection from the pit latrine to avoid degradation (Figure 3).

Nitrogen, phosphorus and potassium analyses were done using the method described by Okalebo et al. (2002).

Nitrogen

About 0.3 g oven dried sample was weighed into dry clean digestion tubes and 4.4 mL digestion mixture was added to each test tube. The digestion mixture was prepared by adding 0.42 g selenium powder as a catalyst, 14 g of lithium sulphate to raise the boiling point and 350 mL, 30% volume of hydrogen peroxide as an additional oxidising agent and mixed well. Then 420 mL of concentrated sulphuric acid was slowly added and the mixture stored at 2°C to avoid further reaction. Digestion was done at 360°C for two hours until the solution turned clear and was allowed to cool. Approximately 0.2 mL of digested sample and the blanks were taken into labelled test tubes and 5 mL of reagent N1 (34 g sodium salicylate, 25 g sodium citrate, 25 g sodium tartrate and 0.12 g sodium nitroprusside in 750 mL water) was added to the sample and blanks, 5 mL of reagent N2 (30 g sodium hydroxide and 10 mL sodium hypochlorite in 750 mL distilled water) was added to samples and blanks. Samples were allowed to stand for 2 h and the absorbance of the samples and the blanks were measured using a spectrophotometer (Model: Jenway 6405 UV/Vis., Bibby Scientific Ltd., UK) at 650 nm. A calibration curve was plotted and the concentration of nitrogen was read off. The nitrogen content in the sample was calculated using Equation 1.

$$N(\%) = \frac{(a-b)\times v}{10000\times w\times al} \quad (1)$$

Where a is the concentration of N in the solution, b is the concentration of N in the blank, v is the total volume at the end of analysis procedure, w is the weight of the dried sample and al is the aliquot of the solution taken.

Potassium

Analysis of potassium was done using standard methods as described in Okalebo et al. (2002); about 0.3 g of oven dried sample (70°C) was weighed into a labelled dry clean digestion tube and 4.4 mL digestion mixture was added to each tube and also to two reagent blanks for each batch of samples. The samples were digested at 360°C for 2 h in the digestion block (Plate 4). After digestion, 25 mL distilled water was added and mixed well until no more solutes dissolved. The contents were allowed to cool. Distilled water was added to make up to 50 mL and mixed well. The sample was allowed to settle so that a clear solution could be taken from the top of the tube for analysis. About 2 mL of digested sample solution was pipetted into a 50 mL volumetric flask. The obtained solutions, starting with the standards, the sample and blank were sprayed directly into the flame of the photometer, Model: Jenway PFP 7, Bibby Scientific Ltd. in UK. A graph of the emissions of the standards against their concentrations was plotted to get the slope. The content of potassium in the sample was calculated according to Equation 2.

$$K(\%) = \frac{1}{S}\times\frac{E\times V_f}{10{,}000\times W_d}\times D_F \quad (2)$$

Where K is the percentage potassium content, S is the slope, E is the emission, V_f is the final volume of dilution, W_d is the weight of dry sample and D_F is the dilution factor.

Phosphorus

About 10 mL of digested sample solution was pipetted into a 50 mL volumetric flask and 0.2 mL of 0.5% p-nitro- phenol indicator solution added. The solution was made alkaline (yellow colour) with 6 M NH_3 solution by drop-wise addition with gentle shaking, after which 1 M HNO_3 was added drop-wise with shaking until the solution just turned colourless. About 5 mL ammonium molybdate/ammonium vanadate mixed reagent, 50 mL of distilled water were added to the contents and mixed well. The contents of the flask were kept for 30 min and the absorbance of the solution was measured using a spectrophotometer (Model: Jenway 6405 UV/Vis., Bibby Scientific Ltd., UK) at 400 nm wavelength setting. The amount of phosphorus present in the solution was read off from a calibration curve developed from standard concentrations. The phosphorus concentration in the sample was calculated using Equation 3.

$$P(\%) = \frac{c\times v\times f\times 1000000}{w} \quad (3)$$

Where c is the corrected concentration of P in the sample, v is the volume of the digest, f is the dilution factor and w is the weight of the sample.

Data analysis

One-way ANOVA was used to analyze data on physical and chemical properties of FS. Separation of means based on the least significant difference (LSD) allowed determination of significant differences in physiochemical properties between sampling layers. These analyses were all done using Genstat software Edition 4. To obtain critical parameters that affect pit latrine emptying, PCA was performed using R-studio, the Statistical Analysis Software Version 0.99.484 developed by R-Studio team in Boston, USA (Jolliffe, 2002). Standard procedures followed in PCA included: (1) Extraction of all principal components constituting a small number of uncorrelated variables; (2) Selection of meaningful components with use of scree plot criterion; (3) Obtaining Varimax rotation solution to infer the principal parameters; and (4) Interpreting the solution. In PCA, eigenvalues were used to determine the number of principal components (PCs) that could be retained for further analysis (Bengraine and Marhaba, 2003). PCA was preferred to other techniques because it explores and visualizes data by emphasizing variation and identifying strong patterns in a dataset. Based on the significant loadings obtained after a varimax rotation, each component was assigned whether or not it influences pit emptying or sludge disposal. A scree plot was used to visualize the relative importance of the principal components, a sharp drop in the plot indicated that subsequent components were ignorable. A varimax rotation which is a form of orthogonal solution was applied to the PCs to minimize the contribution of variables that had minimal significance (that is, low loadings) and maximize the contribution of variables with high loadings (Ouyang et al., 2006; Nyenje, 2014). A varimax rotation was done so as to have the highest loading on the very few selected variables for easy interpretation.

RESULTS AND DISCUSSION

Physiochemical properties of faecal sludge

Table 1 shows physiochemical characteristics of FS from 55 pit latrines. It should be noted that there is a high coefficient of variation (CV) in total solids, volatile solids,

Table 1. Physiochemical characteristics of pit latrine FS (n= 220).

Parameter	Units	Mean	Min	Max	Std Dev	CV (%)
Total solids	g/g wet	0.14	0.01	0.68	0.08	58.7
Moisture content	%/ g wet	86	64	99	8.37	9.4
Volatile solids	g/g dry	0.73	0.01	2.31	0.32	43.9
Ash	g/g dry	0.35	0.02	0.99	0.18	49.4
TKN	%	3.45	1.68	5.66	0.08	29.9
Potassium	%	1.82	0.23	9.7	0.13	71.9
Phosphorus	%	1.37	0.18	3.47	0.05	47.7

n = total number of samples analyzed, Min = minimum value measured, Max = maximum value measured, Std. Dev = standard deviation, CV = coefficient of variation, indicating the extent of variability between samples.

ash content, potassium and phosphorus content indicating a large variability among the parameters for the studied pit latrines. The high coefficient of variation for total solids, volatile solids and ash content could have resulted from collecting samples from pit latrines used by different people living in different households (Günther et al., 2011). The baseline survey revealed that the households had different diets and lifestyles; this could have been the cause of the variation in the physiochemical properties of FS (Zziwa et al., 2014). Similar observations have been reported in literature by Still and Foxon (2012). The variability of FS has also been confirmed by other researchers like Niwagaba et al. (2014); Bakare et al. (2012); Nwaneri (2009); and Buckley et al. (2008). The average moisture content for sampled pits was 86%; this falls within the ranges reported by Tamakloe (2014) and Chaggu (2004). The high moisture content was expected because the studied pit latrines are unlined hence ingress of water from underground sources into the pit latrine is inevitable. The majority of slum areas in Kampala are located in low lying areas (altitudes between 650 and 850 m above sea level) with high water tables (Lugali et al., 2016). In addition, most of the pit latrines in the slum areas are found in high water table areas and so most are shallow. In addition, given that the sampled pit latrines were located in high water table areas, it is probable that there is water movement from the surrounding surface into the pit latrines and could have been by osmosis due to the high concentration of salts in urine. On-site sanitation allows leaching of high loads of human excreta directly into the subsurface within the built-up area such as congested slums (Sorensen et al., 2016). It is also possible that there could be leaching of excreta from subsurface storage which could adversely impact underlying groundwater resources upon which slum populations are dependent for domestic water supply.

User behaviours could also have contributed the observed moisture content because most users particularly in the slums disposed domestic wastewater and grey water in the pit latrines. In addition, use of some pit latrines as anal cleansing (ablution) facilities and the routine use of water for cleaning of pit latrines as reported by Zziwa et al. (2014) could have contributed to the observed moisture content levels. It should be noted that the disposal of FS on agricultural land would be influenced by the amount of N and P found in the sludge at a given layer and also whether the sludge would make the soil acidic or alkaline if disposed on agricultural land. It was observed that the phosphorous content of faecal sludge was much higher than that obtained for municipal solid waste (MSW) of 0.27% as reported by Komakech et al. (2014), but the content was in ranges reported by Kimuli et al. (2015). This is agreement with Diener et al. (2014) who noted that the most common form of endues and resource recovery from sludge is land application on the basis of its desired soil nutrient content. However, for effective use of composted MSW as a soil conditioner or fertilizer, it may be necessary to add some FS to increase its phosphorous content where possible. Pathogen reduction should be one of the critical steps of the resource recovery process prior to use of FS as a soil conditioner.

The analysis of variance of physiochemical properties showed that there was a significant difference between different layers in moisture content, total solids and ash content (p = 0.001), and in volatile solids (p = 0.032). It had earlier on been established that there was no significant difference between different pits.

The average pH generally increased with sampling depths from the surface layer to the second and then it remained constant in the last two depths (Figure 4).

Total solids decreased with sampling depth. However, a slight increase was registered at the 1.5 m layer (Figure 5). The analysis of variance indicated a significant difference (p = 0.001) in total solids between the sampling layers.

The moisture content increased from the first sampling layer to the third and decreased in the bottom layer of the pit latrines with average moisture content of 86% (Figure

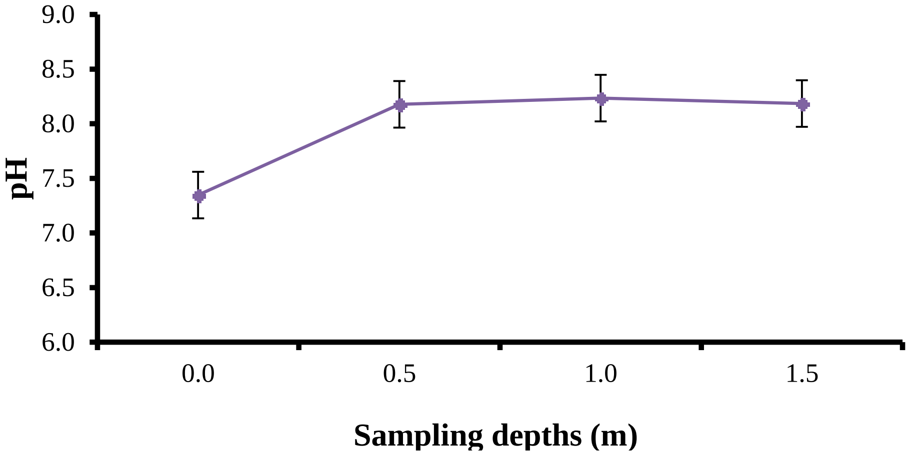

Figure 4. Mean pH of faecal sludge sampled from different layers.

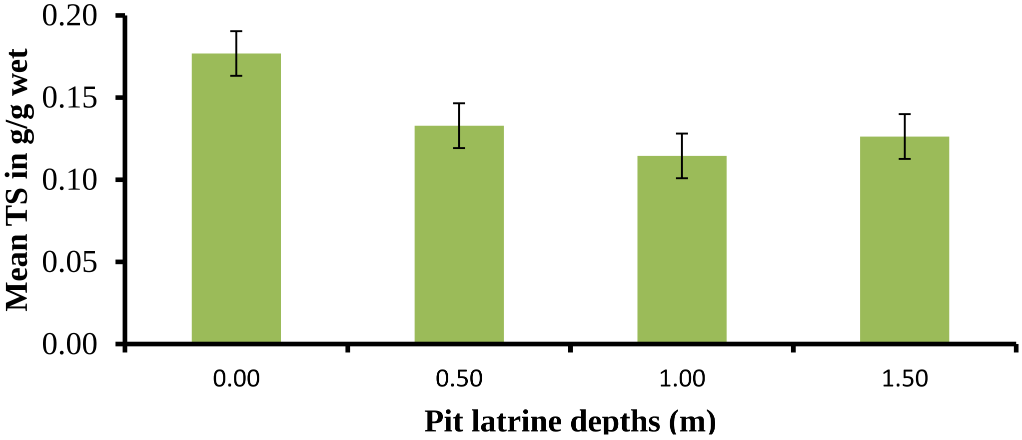

Figure 5. Mean total solids of faecal sludge.

6). Analysis of variance indicated that moisture content differed significantly (p = 0.001) between the different layers across the pits.

The multiple comparisons of means using LSD test revealed a significant difference in moisture content and total solids between the 0.0 m layer and the other three layers. For volatile solids, the 0.0 m layer was significantly different from the bottom layers (Table 2). This suggests that the degree of degradation of FS in the pit latrine increases down the pit with increasing depth (Nwaneri, 2009) and as expected this implies that the age of FS influences its quality. The characterisations also indicate that the surface layer is significantly different from the bottom layer for all characteristics; this means that there are processes such as anaerobic and aerobic bio-degradation and stabilisation that take place in the pit latrine causing the differences (Nwaneri, 2009). The nature of these processes would determine the emptying techniques for sludge at different layers, whether pumping, vacuum evacuation or manual emptying. It also influences processing of emptied FS whether by anaerobic digestion, composting, drying or incineration and the disposal of FS whether buried underground or used for agricultural purposes.

Variations of faecal sludge quality properties

PCA was the most innovative and novel aspect of the study because it helped to identify the most critical physiochemical properties of feacal sludge that influence design and performance of pit emptying devices and faecal sludge disposal for improved faecal sludge management, something which has been missing in the feacal sludge management chain in Uganda. In PCA, eigen values were used to determine the number of

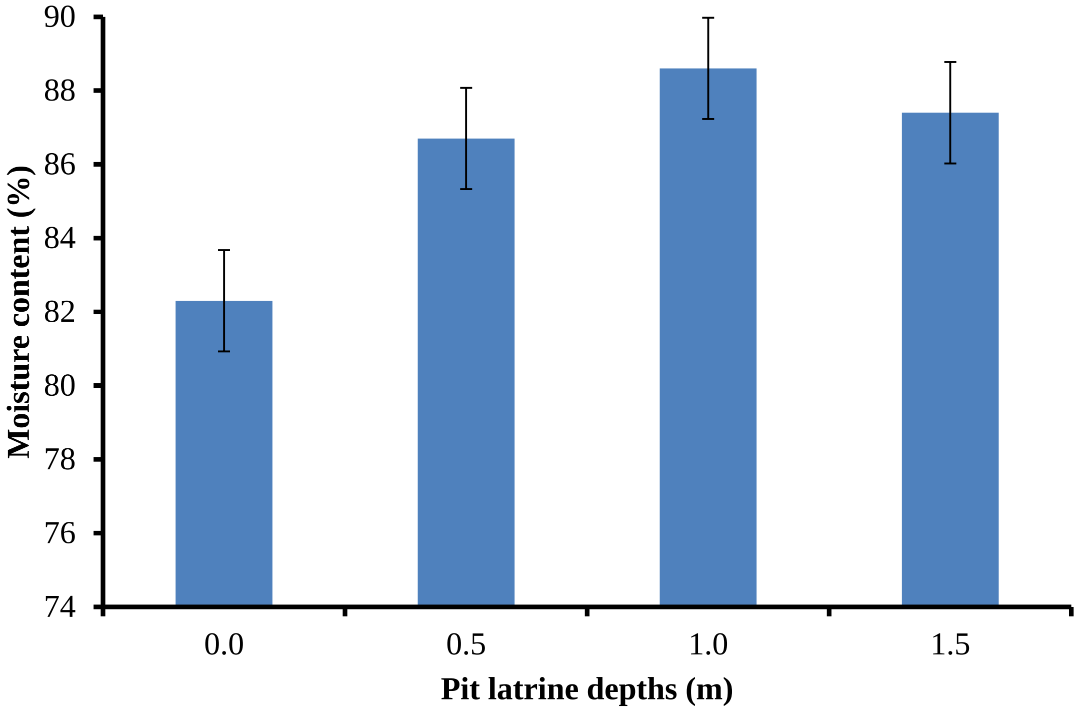

Figure 6. Mean moisture content of faecal sludge.

principal components that can be retained for further analysis. A scree plot was specifically used to visualize the relative importance of the factors. Four principal components were retained for further interpretation because they were located in the curve before the first point that starts the flat line trend on the scree plot. This is in agreement with Abdi and Williams (2010) and Ouyang et al. (2006). In addition, the four principal components were retained because their eigenvalues were greater than one (Figure 7). Similar findings have been reported by Mohapatra et al. (2011), Han et al. (2012), and Mayanja (2014). These four principal components have eigenvalues greater than or close to unity and explain 29.6, 18.4, 15.6 and 14% of the total variance contained in the dataset (Table 3).

Table 3 shows component loadings indicating correlation coefficients between principal component and variables. The component loadings were used to determine the relative importance of a variable as compared to other variables in a PC in the set of variables that were tested in accordance to Ouyang et al. (2006). Retaining variables with coefficients greater than or equal to magnitude of 0.3 was considered because they represent less than 10% of the variance (Kellow, 2006). Four principal components were identified to be responsible for pit latrine emptying and sludge disposal, because they revealed significant loadings of properties that were considered in the analysis. Properties namely volatile solids, moisture content, total solids, ash content, pH, Phosphorus, total nitrogen and Potassium accounted for 77.6% of the overall total variance (Table 3). The 77.6% variance indicated that there was a variation within the parameters mainly because all the 55 pit latrines analyzed were used by different households living in different slums with various user habits. In addition, since their economic status is different, their diets are also different thus contributing to variation in FS properties (Rose et al., 2015; Zziwa et al., 2014; Nwaneri, 2009). The first principal component (PC1) accounted for 29.62% of the total variance and was positive and largely contributed to by moisture content (MC) and total solids (TS) and least due to Ash content (AC). This component shows the importance of water input into the pit latrine during emptying implying that in a given pit latrine wherever water is added, the emptier should expect the sludge to mix with water and this might complicate manual emptying. The high moisture content loading is as a result of added grey water used for cleaning, water used for anal cleansing and urine excreted directly or poured in the pit. Other sources of moisture in form of water can be surface run off from the steep slopes into the pit latrines on low lying land, and intrusion of ground water due to rainfall which raises the ground water table since the pit latrines are unlined (Nyenje, 2014; Kulabako et al., 2007). The results further indicate that there is an interaction between the pit contents and the pit

Table 2. Multiple comparison of physiochemical properties between the pit depths (n=55).

Sampled depth (m) below top of sludge	Moisture content (%)	Volatile solids (g/g dry)	Ash (g/g dry)	pH
0.0	83	0.81	0.28	7.3
0.5	87	0.75	0.33	8.2
1.0	87	0.71	0.37	8.2
1.5	89	0.63	0.42	8.2
$LSD_{0.05}$	3	0.12	0.06	0.6

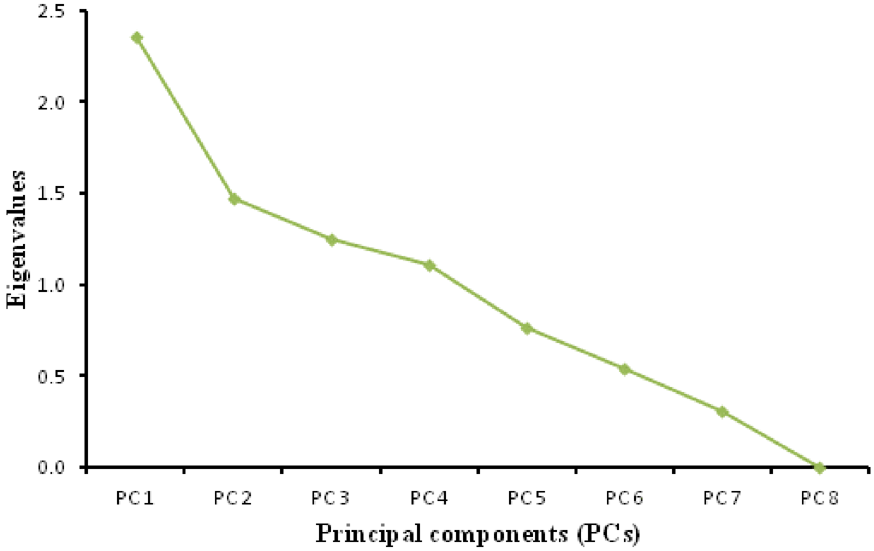

Figure 7. Scree plot showing eigenvalues obtained in PCA.

environment such as soil types, ground water levels, topography and rainfall distribution.

As expected that an increase in moisture content causes a decrease in total solids and ash content because the water dissolves soluble faecal solid materials hence making it easily flow as semi-fluid during pit emptying. This means that FS located at any depth with high moisture content has low total solids content and is hence easily pumpable. Similar observations of the FS nature have been reported in literature (Rogers et al., 2014). Such conditions are expected to occur on the top layer decreasing down to bottom of the pit due to user practices, role of ingress water and the pit depth (Nwaneri, 2009; Buckley et al., 2008). However, this was not the case found in pits considered in this study because of the presence of micro and macro organisms which moved throughout the entire FS in the pit latrine (Tamakloe, 2014; Belen, 2010). Results showed that FS had less Phosphorus (P), Nitrogen (N) and Potassium (P) represented by the low correlations (Table 3). This was as a result of the degradation process where volatile solids are lost and some potassium, phosphorus and nitrogen are converted into total solids, of which some are lost in the shallow ground water through the movement of soluble substances out of the pit latrine (Kulabako et al., 2007). The increase in total solids could also be as a result of addition of non-biodegradable material into the pit such as household waste, plastics, solid anal cleansing materials such as hard papers (Buckley et al., 2008) and sediments transported through erosion or run-off.

Principal component 2 (PC2) explained 18.39% of the total variance and was positively and largely contributed to by Nitrogen, Phosphorus and Total Solids and was negatively and least contributed to by moisture content and pH (Table 3). This component shows the importance of organic related parameters which are as a result of nutrient rich inputs such as stone elements thrown in the pit after being used for anal cleansing and addition of waste water containing detergents in a bid to suppress smell (Bakare, 2008). This could also be caused by people's diets in which sources of Nitrogen and Phosphorous are originally taken up in the human body through food consumption. The nitrification process

Table 3. Correlations of principal components with observable variables.

Variable	Principal components			
	PC1	**PC2**	**PC3**	**PC4**
VS	0.267	0.282	**0.374***	**0.560**
MC	0.581*	-0.325*		-0.145
TS	-0.581*	0.325*		0.145
AC	-0.354*	-0.281	-0.483*	
Ph	-0.130	-0.329*	-0.157	0.647*
P		0.490*	-0.142	-0.373*
N	0.217	0.523*	-0.353*	0.197
K	0.249		-0.675*	0.206
Eigen value	2.36	1.47	1.25	1.11
Explained variance (%)	29.62	18.39	15.61	13.99
Cumulative variance (%)	29.62	48.01	63.62	77.61

*figures are correlation coefficients greater than or equal to 0.3.

taking place in the pit latrine is due to the presence of aerobic microorganisms also increases the concentration of nitrogen in the FS. The observed parameters with low correlations on PC2 are moisture content and pH. The low correlation coefficients were caused by the anaerobic degradation process where the moisture was used to break down the FS material by micro and macro organisms in the pit latrine. This leads to digestion and stabilization of FS which increases with pit depth. According to Buckley et al. (2008), the reason for a positive correlation with N, P and TS is that organic solids are decomposed into nutrients such as N and P, where TS is the dependent factor. N and P are end products which may later be oxidized and hydrolyzed with low MC changing pH thus showing a negative correlation between pH and MC. Principal component 2 revealed that emptying a pit latrine where people feed on nutrient-rich foods would be easy because the solid content would have decomposed hence becoming soft and pumpable. In addition, some FS materials that are soluble would dissolve and leach out of the pit environment hence reducing the amount of sludge to be removed from the pit.

Principal component 3 (PC3) explained 15.61% of the total variance and was positively and strongly contributed to by volatile solids and was negatively and highly contributed to by potassium, ash content and Nitrogen (Table 3). PC3 explains the importance of organic formation processes such as leaching and denitrification occurring in the pit latrine. The two processes are controlled by the presence of microorganisms in the pit latrines which reduce the nitrogen content by converting it into nitrogen gas (N_2) which is lost through the pit hole or vent (Nyenje, 2014). The negative correlation of N and P is due to the volatization at high temperatures and neutral pH forming ammonia which is lost as gas. PC3 also explains that at the surface layer of FS within the pit latrine where the volatile solids are high, the FS is not safe for disposal or reuse especially as a soil conditioner due to the less content of nitrogen and potassium, implying that this sludge has not yet stabilized.

PC4 explained 13.99% of the total variance and was positively and highly contributed to by pH and volatile solids and was negatively and highly loaded on phosphorus (Table 3). In addition, disposal of urine in the pit latrines could also explain the observed high pH values. The addition of detergents and additives which may be chemical, microbiological and enzymatic in nature, which are used for sludge stabilization and odor reduction, as found out during the baseline survey, could have contributed to increased phosphorous content. The oxidation and hydrolysis of phosphorous produces phosphates which combine with available water producing a weak phosphoric acid hence changing the pH (Rose et al., 2015). In addition, decomposition processes occurring in the pit latrine convert the phosphorus into orthophosphates which leach out of the pit to the groundwater (Nyenje, 2014). Dissolved phosphorus is directly available and can therefore affect eutrophication hence FS should be treated first before disposal to the environment (Nyenje et al, 2010). These findings point to the need for careful disposal of feacal sludge after pit emptying.

Identification of important FS quality properties in pit emptying

The component loadings obtained after a varimax rotation are given in Table 4. The component loadings included both positive and negative loadings. Loadings close to ±1 indicate a strong correlation between the

Table 4. Correlation between FS properties and the principal components.

Variable	Principal components			
	PC1	PC2	PC3	PC4
VS				
MC	0.707			
TS	-0.707			
AC				
PH				1.000
P				
N		1.000		
K			1.000	

variable and the component. Loadings between ±0.5 and ±0.74 are considered moderately correlated and loadings approaching 0 indicate weak correlations (Ouyang et al., 2006; Liu et al., 2003).

An interpretation of the rotated four components was made by examining the component loadings noting the relationship to the original variables. PC1 gives a variation in MC and TS; in this component, loadings indicate that soluble feacal matter and water which could be attributed to user practices, geological location of the pit latrines and composition of people's diets greatly affected the sludge to be emptied from the pit latrines (Eawag and Sandec, 2008; Yoke et al., 2011). Based on principal component one, selection of emptying technique whether by the vacuum tanker, manually designed equipments or by use of forks and spades could be done by emptiers based on a prior inspection of the pit latrine content composition (Zuma et al., 2015). PC2 and PC3 explained property patterns influencing the disposal of faecal sludge which consisted of Nitrogen and Potassium respectively. The two principal components show the pollution of pit latrines from domestic, industrial and agricultural solid waste damped into the pit and anal cleansing materials used. Therefore, the property pattern obtained from PC2 and PC3 revealed that carefully selection of sludge disposal method is very important after emptying.

PC4 explained 14% of the total variance and was positively and strongly contributed to by pH; the high pH was mainly due to intrusion of basic surface run off from rains, run off from dumping sites and fertilized farm lands. Similarly PC4 guides on the disposal and treatment of FS either by anaerobic digestion or by composting. The need for high moisture content in the pit during emptying is to make soluble material (Total Solids) dissolve and form a solution whose viscosity is low because the particle to particle interactions will be destroyed by the water added. The high moisture content also makes biodegradable material to decompose thus reducing the total solids content, this reduces the amount of FS to be emptied from the pit latrine. This makes FS easily flow during emptying and it reduces the amount of sludge that is to be pumped. It is reported that the added water during emptying is pumped out with FS hence increasing the volume of sludge to be removed from the pit latrine (Runyoro, 1981). To increase the volume of FS pumped out, sludge needs to be mixed during emptying and hence improvement in the design of pit emptying devices is required. The composition of Nitrogen and Phosphorus of feacal sludge is very important at the time of disposing the FS; because these nutrients can cause eutrophication of water bodies if disposal is not regulated (Beyene et al., 2015). FS contains plant nutrients; however, this study revealed that if sludge is to be used as a soil conditioner, supplements of Phosphorus nutrients should be added to the soil.

CONCLUSION AND RECOMMENDATIONS

The pit latrines studied revealed that in terms of physiochemical characterization, FS in unlined pit latrines has average moisture content of 86%, total solids of 0.14 g/g wet mass, volatile solids of 0.73 g/g dry mass and ash content of 0.35 g/g dry mass. Volatile solids decrease with pit depth implying that sludge at the bottom of the pit is more stable hence pit emptying frequency may be designed considering the required stability of sludge when the pit is to be emptied. Moisture content, ash content and total solids in pit latrines vary considerably between layers; it is therefore important to design pit emptying tools that can handle this variation. FS is alkaline with a pH value of 8 and it contains relatively 3.5% total nitrogen, 1.8% potassium and 1.4% phosphorus. Basing on this nutrient content, FS has the potential for use as a soil conditioner for agricultural purposes. The faecal sludge in the surface layer of the pit is less stable and easier to empty than that in the bottom layer of the pit; this conclusion is based on the average volatile solids in these layers. It was concluded that the physiochemical properties in Ugandan pits are comparable to those of global pit latrines except for the acidic conditions at top surface layer which was attributed to disposal of alcoholic remains in pits, and the higher moisture content in most pits which was attributed to the high water table of study sites. The study has also shown that moisture content increases with increasing depth below the top surface while total solids decrease with depth, hence pit emptying devices should be designed to cater for the differences in moisture content and total solids at the different sludge depths. It was also concluded that moisture content and total solids critically affect pit latrine emptying techniques while Nitrogen, Potassium and pH greatly influence the disposal of FS hence planning for treatment of sludge before it is disposed to the environment would be a good sanitation practice by emptiers. The paper provides important information to policy makers, practitioners and researchers and provides a basis for improvement of pit emptying devices for improved FS management in slum areas. However, further research should be done to understand the processes that lead to the transformations of FS at the different layers and how these ultimately affect the properties of FS. There is also need to formulate sustainable technologies for the treatment of FS in order to enable utilisation of FS nutrients and reduce on effects indiscriminate sludge disposal in slums.

Conflict of Interests

The authors have not declared any conflict of interests.

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