## Research Paper

# Characterisation of pit latrine sludge from shackleton, a peri-urban residential area of Zimbabwe

M. C. Changara, C. Bangira, W. T. Sanyika and S. N. Misi


## ABSTRACT

The objective of this study was to characterise the physical and chemical properties of human faecal sludge from various pit latrines in relation to the differences in usage and management practices of each pit over time. Physico-chemical parameters were measured from the sludge collected from the top layers of six different pit latrines that were sampled six times at an interval of 40 days. Data were also collected on pit user habits and management practices. Multivariate statistical analyses were carried out to determine the variations in sludge physico-chemical characteristics among the pits and the associations between these and user habits and management practices. The results showed that the sludge characteristics from the six pits were significantly different from each other (global test sample statistic (R): 0.862 and $p < 0.002$). This study also indicated that user habits were important determinants of pit sludge characteristics. This study scientifically contributes to knowledge on how pit management and usage practices determine the potential value and quality of pit latrine sludge for various anaerobic digestion applications for resource recovery. The findings also contribute the knowledge required for the management and treatment of pit latrine sludge, adoption and adaptation of new treatment technologies for local use.


**Key words** | characterisation, physico-chemical parameters, pit latrine sludge, user habits

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## INTRODUCTION

Globally, the provision of adequate sanitation is a challenge and the situation is worse in developing countries (Nakagiri *et al.* 2016). Access to improved sanitation worldwide stands at 64%, with the lowest coverage of 41% in urban areas of sub-Saharan Africa (WHO & UNICEF 2014). The sanitation needs of 2.7 billion people worldwide are served by onsite technologies and that number is expected to grow to 5 billion by 2030 (Strande 2014). In urban areas of the sub-Saharan countries, 65 to 100% of households rely on onsite sanitation systems (Strauss *et al.* 2000). Despite these facts, there is typically no proper faecal sludge management system in place for most urban areas in low income countries (Strande 2014).

Pit latrines are one of the commonest basic forms of improved onsite sanitation systems worldwide. Of the 2.7 billion people using onsite sanitation worldwide (Strande 2014), an estimated 1.77 billion use some form of pit latrine as their primary means of excreta disposal (Graham & Polizzotto 2013). In Zimbabwe, it is estimated that 40.9% of the population use some type of pit latrine, with 14.3% using the ventilated improved pit latrine, 15.1% using the upgradable Blair ventilated improved pit latrine, 4.9% using pit latrines with slab, 0.1% using a composting toilet, 6.4% using pit latrines without a slab or an open pit, and 0.1% using other types of pit latrines (Zimstat 2015). There are few policies that address challenges surrounding faecal sludge management from pit latrines in developing countries, including Zimbabwe (Thye *et al.* 2011). The major challenges emerging from the use of pit technologies are: pits filling up, repeated construction at



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different sites which can be costly and, subsequently, the need for disposal of pit latrine contents once full.

One typical area that uses pit latrines in Zimbabwe is Shackleton in Chinhoyi, Mashonaland West Province, which was once a mining and smelting settlement for gold and copper. During the mining era, workers used centralised sanitation facilities which are now derelict due to lack of maintenance. The mine was closed due to operational challenges leading to loss of jobs for the majority of people. Former workers' houses were abandoned. When there was an outbreak of cholera in the Tombstone and Bere peri-urban areas of Chinhoyi in the year 2000, families were relocated to Shackleton by the government to occupy the former mine workers' houses.

Currently, Shackleton is a low income community with an average of eight adults (above 16 years) per household. Most residents do not have formal employment but depend on part-time work at nearby farms for survival. There is also another group which depends on illegal mining in areas around Shackleton. In order to improve sanitation in Shackleton, the current residents have constructed different types of pit latrines (Figure 1). Periodically, pits fill up and due to the limited sizes of the residential dwellings (<200 $m^2$) residents often find it challenging to look for an alternative space to construct new ones. There are also no provisions for a pit-emptying system in Shackleton.

Given that pit latrines will at some stage fill up and become a hazard to human health and the environment, a management system is required for the collection, transport, treatment, end use, and disposal of the faecal sludge from onsite systems (Bassan *et al.* 2013). The design, collection, transportation, treatment, end use and disposal of the faecal sludge from onsite systems requires accurate data on faecal sludge characteristics to properly size and select treatment technologies and operational parameters (Bassan *et al.* 2013). A number of previous studies have been done to characterise the physical and chemical characteristics of sludge from various pit latrines over space (Bakare *et al.* 2012; Gudda *et al.* 2017) and time (Bassan *et al.* 2013). These studies indicated that the characterisation of pit latrine sludge varies according to site and depth, characterisation over time showed that the characteristics were highly variable during both the dry or rainy seasons, and this high variability resulted in similar characteristics for faecal sludge collected during the dry and rainy seasons.

The characteristics of faecal sludge also depend on the design and construction of the sanitation technology and how the technology is used. All of these variables may result in significant differences in faecal sludge characteristics (Niwagaba *et al.* 2014). Due to this variability, it is important to consider the effect of local pit management practices, construction and user habits on the characteristics of pit latrine sludge.

Despite being the main onsite faecal management technology in rural and peri-urban settlements in Zimbabwe, there is limited detailed information on the characteristics of pit latrine sludge, which is important for making decisions on the design or adoption of a technology for local use in management of pit latrine sludge. The relationships between user habits and some physico-chemical


**Figure 1** | Typical Shackleton pit latrines (a) covered with a mixture of iron sheets and tent made of tarpaulin material, (b) covered with thatching grass and (c) covered with a 250 μm plastic tent.

properties of pit latrine sludge can also help in the management and treatment of pit latrine sludge. This research was conducted to determine the physical and chemical characteristics of sludge in selected pit latrines and to establish the relationships between those characteristics, user habits and pit latrine management over time.

## METHODS

### Study site

The study site is Shackelton (30.03° E and 17.30° S), which is located in Chinhoyi, Zimbabwe at an altitude of about 1,160 m (Figure 2). Shackleton was selected because most of the residents in this area use pit latrines as sanitation facilities. The average annual temperature and rainfall for Shackleton are 20 °C and 800 mm, respectively. The geology of the area consists of dolomitic limestone which overlies light brown clayey soils.

### Sampling procedures

Samples were collected from six pit latrines: three covered with thatching grass and the other three covered with tents in Shackleton during the period February to October 2016. Sampling was conducted six times on each pit at 40-day intervals and each sample was collected in triplicate from the topmost

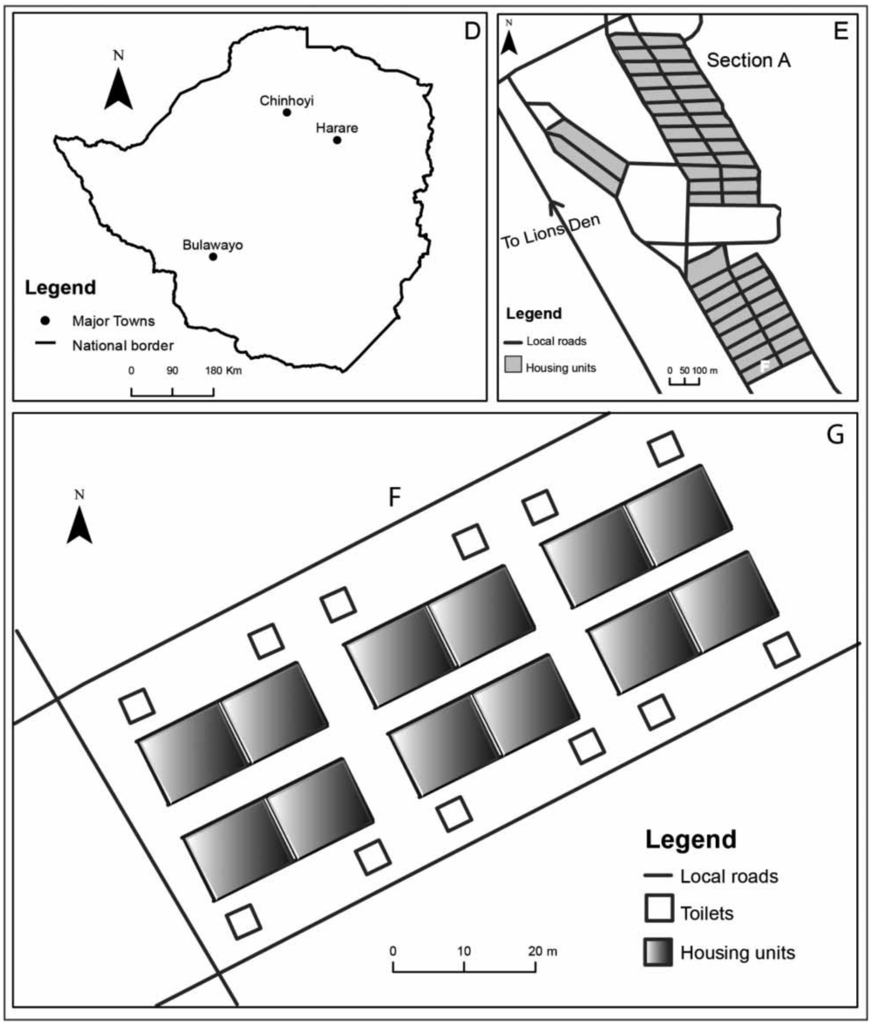


**Figure 2** | Location map of study area (insert D) and plan view of study site (E). Insert G shows the layout of semi-detached housing units in block labelled F in insert E.

contents of the pit. Purposive sampling was used in this study whereby pits that were almost full (about 40–60 cm pit to contents depth), with at least eight users and of similar age (in terms of period of start use) and depth were targeted (1.2–1.7 m). Shackleton is divided into three sections: A, B and C. Section A (Figure 2) is relatively highly populated with at least ten people per household who use pit latrines only as sanitation facilities. Sections B and C use a mixture of pit latrines and other types of toilets. Out of the 170 households in area A, 130 use pit latrines and of these 130, 60 met the selection criteria and 10% of these 60 were randomly selected and used as a sample. Sampling was conducted using a modified auger (Figure 3) which was graduated to show sampling depth. Sampling in the pit was through a squat hole (Figure 4(a)) and the sludge was collected in a plastic bucket (Figure 4(b)) before being placed in polythene bottles. Only pit latrine users who were willing to take part in the research were considered, after seeking informed consent.

Faecal sludge samples were then collected from each pit at each stage of sampling. Bulk samples (approximately 275 g) were placed in 300 mL clear polythene bottles and immediately placed on ice for transportation to the laboratory for analysis.

Data were collected on number of pit latrine users, diet, material added to pit latrines, anal cleansing material and pit management practices using a template (Table A1,


**Figure 3** | Modified auger for sampling pit latrine sludge through a squat hole. The modifications made to the conventional auger were the inclusion of a closed conical end, a lid to the cup and a rod to open and close the lid when sampling the sludge from the pit through the squat hole.


**Figure 4** | Pit latrine sludge sampling: (a) collecting sludge from a pit latrine through a squat hole and (b) pit latrine sludge withdrawn from the pit before being put in polythene bottles.

available with the online version of this paper) at each stage of sampling. In addition, information was collected on the details of pit construction. The data on diets taken by users and user habits were coded into numerical categories using presence/absence data for data analysis.

### Analytical methods

Laboratory analyses of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and pH were conducted in triplicate on the sludge samples. The properties were determined using the standard analytical methods (Reddy 2013) and American Public Health Association series of *Standard Methods for the Examination of Water and Wastewater* (APHA/AWWA/WEFW 2005).

### Statistical analysis

Primer 7 (Primer-E) version 7.0.13 software (Quest Research Limited, Auckland, New Zealand) and Multivariate Statistical Package (MVSP) version 3.1 (KOVACH Computing Services, UK) were used for statistical analysis. Hierarchical clustering and non-metric multidimensional scaling (nMDS) were based on a similarity matrix generated from standardised and normalised data. The Euclidean distance was used for the environmental data. The hierarchical clustering was conducted using the group average method. Multidimensional scaling ordinations were based on ten iterations and cluster overlays were based on cluster analysis. ANOSIM (analysis of similarity) was used to test the strength of separation and significance differences between the different clusters and pit latrine sludge samples. SIMPER (similarity/distance percentages, species/variable contributions) was used to measure the ranked correlations and dissimilarities between samples, within and between clusters of samples, based on the squared deviation of averages. For these analyses in both ANOSIM and SIMPER, variables were first standardised, transformed and then normalised. Absolute and presence/absence data of user diets and habits were both used. The presence/absence data were multiplied by number of pit latrine users on each site to get closer to the actual amount of food eaten by the whole household and the overall user habits. SIMPER was used to identify ranked correlations contributing up to a total of 70%. Principle component analysis (PCA) was preceded by a distance matrix of the dataset. MVSP was used for canonical correspondence analysis (CCA).

## RESULTS AND DISCUSSION

### Classification of pit latrine sludge samples

Each sample from the six pit latrines was considered to be a different sample at each stage of sampling. Cluster analysis of the sludge's physical and chemical characteristics at a Euclidean distance of 4 (Figure 5) and subsequent MDS

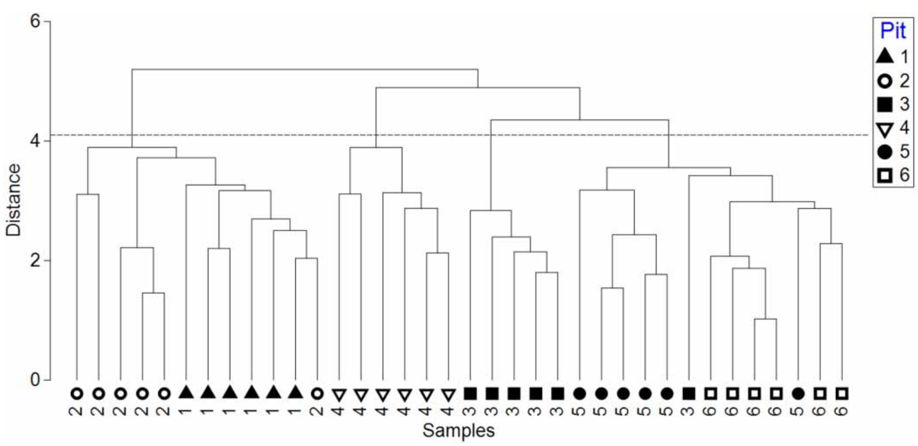


**Figure 5** | Unweighted paired group method of arithmetic average (UPGMA) clustering of sludge collected from six pit latrines (pits 1–6) over six sampling periods in eight months, based on the Euclidean distance matrix of the sludge physico-chemical characteristics.

analysis showed that the sludge samples clustered according to pit of origin (Figure 6). Pits 2 and 4 further subdivided into two distinct subgroups, respectively, at a Euclidean distance of 3.6 (Figure 6). The sludge characteristics of pits 5 and 6 were similar at that level of comparison even though they formed two distinct subgroups, indicating how the sludge characteristics clustered by pit of origin (Figure 6).

Ordination through the nMDS grouped the sludge samples into four distinct groups (Figure 6) and confirmed how the samples clustered according to pit of origin. The changes in conditions over time did not result in much variation within the pits but variation was rather observed between the different pits.

The one-way ANOSIM (global test sample statistic (R): 0.862 at the significance level of 0.1%) test confirmed the clear separation between the four clusters shown by the nMDS. There were also significant differences between each of the four clusters ($p < 0.002$, Table 1), with the strongest separation occurring between cluster 1 and cluster 3. At pit level (Euclidean distance of 3.6), there was a clear separation between all pits (R = 0.896) at the significance level of 0.1%. There was also clear separation between all pairs of pits (R) > 0.60 in all pairs excluding pits 5 and 6 which were not separated from each other.

Cluster, MDS and ANOSIM analyses showed that pit latrine sludge samples varied according to pits of origin

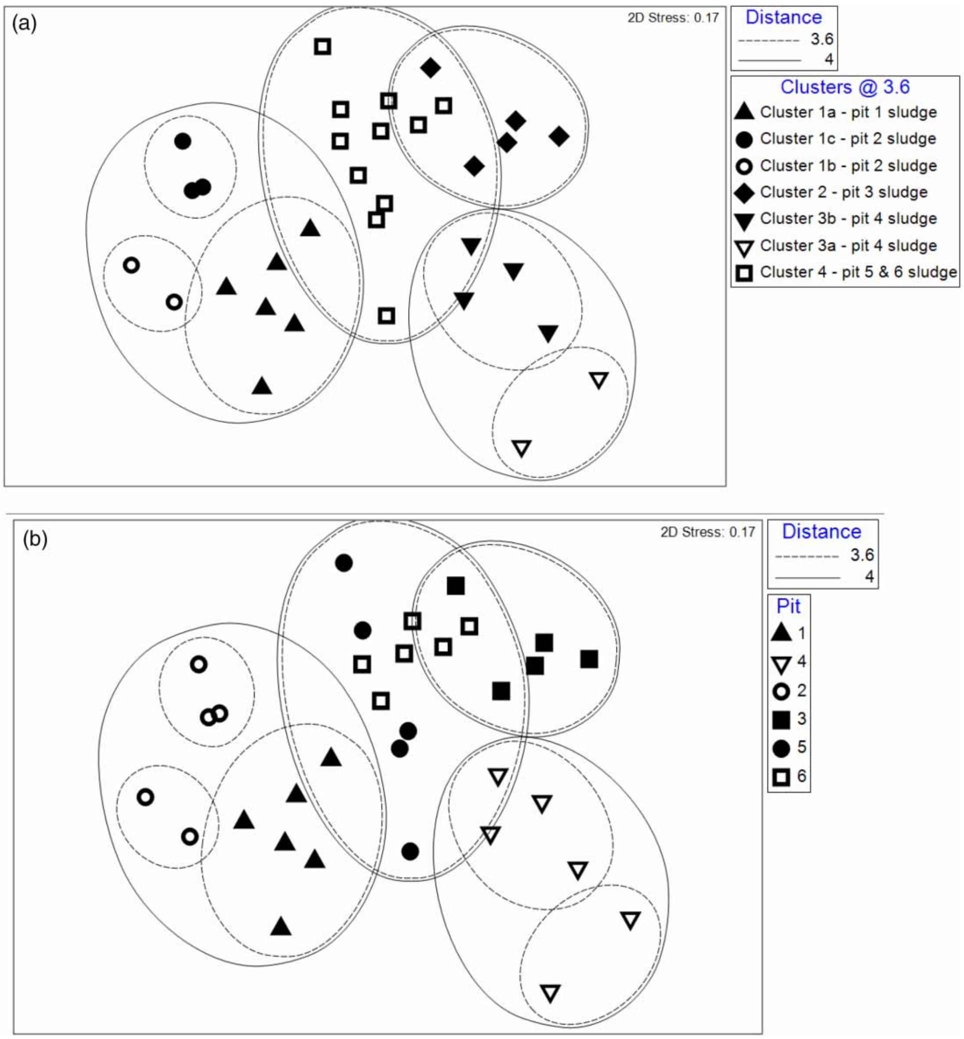


**Figure 6** | Non-metric multidimensional scaling (nMDS) ordination for sludge collected from six pit latrines (pits 1–6) over six sampling periods in eight months at (a) cluster level and (b) at pit level, based on the Euclidean distance matrix of the sludge physico-chemical characteristics. The symbols indicate the pit of origin and contours, the boundaries of the classes clustered at Euclidian distance 4.0 and subclasses at distance 3.6.

**Table 1** | Summary of ANOSIM pair-wise tests for relatively fresh pit latrine sludge samples clusters ($p < 0.002$ for all samples)

| **Test R statistic** |
| --- |
| Cluster 1-pit 1 and 2 sludge; cluster 2-pit 3 sludge. 0.932 |
| Cluster 1-pit 1 and 2 sludge; cluster 3-pit 4 sludge. 0.947 |
| Cluster 1-pit 1 and 2 sludge: cluster 4-pit 5 and 6 sludge. 0.847 |
| Cluster 2-pit 3 sludge; cluster 3-pit 4 sludge. 0.832 |
| Cluster 2-pit 3 sludge; cluster 4-pit 5 and 6 sludge. 0.84 |
| Cluster 3-pit 4 sludge; cluster 4-pit 5 and 6 sludge. 0.873 |

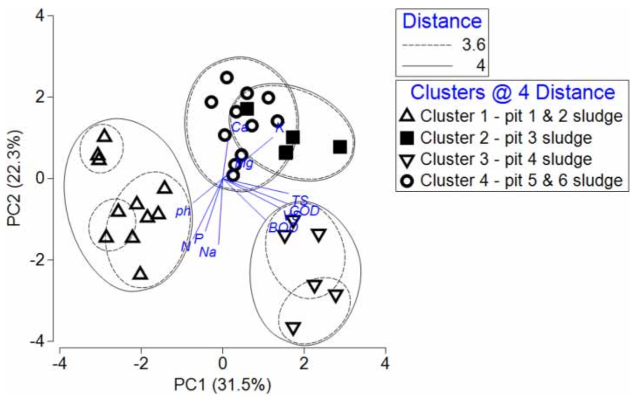


**Figure 7** | Principal component analysis (PCA) at cluster level for sludge collected from six pit latrines (pits 1–6) mapping the classes over six sampling periods in eight months, based on the sludge physico-chemical characteristics. The symbols indicate the cluster of origin and contours, the boundaries of the classes clustered at Euclidian distance 4.0 and subclasses at distance 3.6.

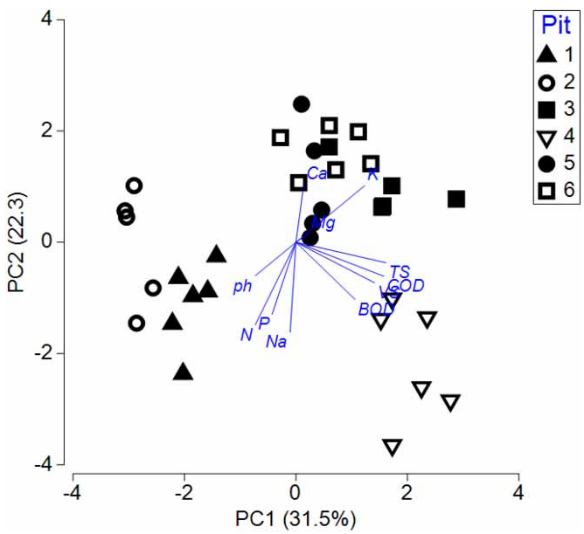


**Figure 8** | Principal component analysis (PCA) at pit level for sludge collected from six pit latrines (pits 1–6) mapping the pits over six sampling periods in eight months, based on the sludge physico-chemical characteristics. The symbols indicate the pit of origin.

when sampled over a period of time. This signifies that each pit is different from the others. In related studies, Bakare et al. (2012) reported that none of the 16 VIP latrines investigated had the same sludge characteristics and Gudda et al. (2017) found that there was significant variation in faecal sludge characteristics across pits. In our study, the clusters of pits identified also had distinct subgroups showing how the same pit sampled over time could have different characteristics even though it remains unique from other pits.

The SIMPER analysis was used to identify the variables that characterised each cluster (based on similarities) and also those variables that discriminated between each pair of clusters (based on major differences). The variables TS, VS, COD, K and Ca contributed the most to within cluster similarity in all clusters while pH, P, Mg and Na contributed the most to the within cluster variability. COD, TS, VS, N and P were the important contributors to the between group dissimilarity.

## Sources of variability in the pit latrine sludge

Using PCA analysis, the first, second and third principal components accounted for 31.5%, 22.3% (Figures 7 and 8) and 15.3% of the variation in the data set, respectively. The sludge from pit 4 (cluster 3) was characterised by high levels of TS, COD, VS and BOD and pits 1 and 2 (cluster 1) had high levels of P, Na and N. The sludge from pits 3, 5 and 6 (clusters 2 and 4) had high levels of Ca, K and Mg (Figures 7 and 8).

## Association between user habits, pit management and sludge characteristics

CCA was used to determine the relationships between the physicochemical characteristics of the pit latrine sludge and user habits. The high COD, BOD, TS and VS in pit 4 was associated with the use of newspapers and shelled maize cobs for anal cleansing. This pit also had a tent covering around the pit. The high levels of N and P in pits 1 and 2 were associated with the use of extraneous material such as kitchen waste. These pits were covered with thatching grass with some of the thatching grass falling in the pit. The high concentrations of Mg, Ca and K in pits 5 and 6 were associated with the addition of ash in the pits (Figure 9). Wood ash

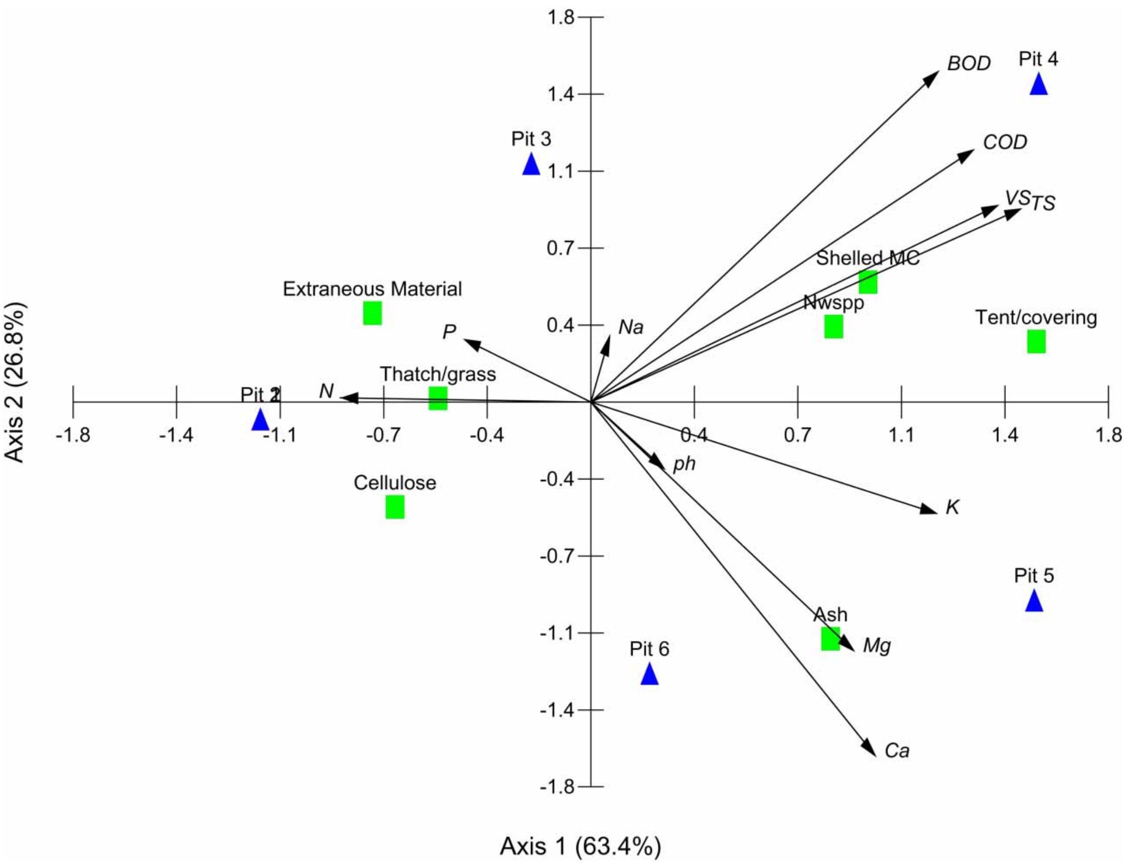


**Figure 9** | Canonical correspondance analysis depicting the relationship between pit latrine sludge environmental charactristics and user habits. Shelled MC, use of shelled maize cobs for anal cleansing; Nwspp, use of newspaper for anal cleansing.

has been reported to be a major source of alkalinity, and is composed of macronutrients Ca, K, Mg and P.

## Relationship between diet and environmental characteristics

According to Rose *et al.* (2015), human diet is also a factor that can impact the composition of faeces. In this study, we could not establish conclusive associations between diet and sludge characteristics.

Our analysis when considering descriptive data of the physico-chemical properties showed that the sludge from all the pit latrines (1–6) had high strength properties (Table A2, available with the online version of this paper) according to standard classification of sludge samples (Strauss *et al.* 1997). This property could be explained by the fact that samples were from pit latrines without connection to water sources, thus resulting in high strength sludge.

Biodegradability potential of the pit latrine sludge is relatively high in half of the pits (pits 4–6) and relatively low in pits 1 to 3 as indicated by a BOD:COD ratio closer to 3 and greater than 3, respectively (Table A2). The pit latrine sludge of pits 4 to 6 was highly biodegradable, indicating potential treatment and resource recovery from the pit latrine sludge through processes such as anaerobic digestion. The low biodegradability of pits 1 to 3 could be because of the addition of other solid waste, such as kitchen waste, which is shown to be added by the pit latrine users of pits 1 to 3 (Figure 9). Gudda *et al.* (2017) stated that household disposal of solid waste into the pit latrine vaults lowers biodegradability of faecal sludge by increasing organic load.

The BOD values of the sludge characterised from pits 1 to 6 (Table A2), were closer to the 11,835 and 24,600 mg/L reported by Appiah-Effah & Nyark (2014) and Gudda *et al.* (2017), respectively. The BOD was, however, eight times higher than the 2,126 mg/L reported by Bassan *et al.* (2013) and about two times higher than the 7,600 mg/L reported by Koné & Strauss (2004), respectively. This observed variance could be due to the differences in diet and user habits since these studies were conducted in different geographical areas associated with different diets and management practices. The samples reported by Bassan *et al.* (2013) were, however, from mixed sludge collected from trucks unlike the top layer sludge used in this study, which was sampled directly from the pit.

The COD values from all the pits (1–6) (Table A2) investigated in this study were generally in the range of those of Koné & Strauss (2004) and Appiah-Effah & Nyark (2014) of 20,000–50,000, 49,000 and 85,998 mg/L, respectively. The COD values were, however, five times higher than that of Bassan *et al.* (2013) and about two times lower than that of Gudda *et al.* (2017). The higher COD value in the pit latrine sludge samples, especially pit 4, shows the presence of high concentration organic matter in the sludge (Gudda *et al.* 2017). The presence of high concentration organic matter will necessitate higher consumption of oxygen by microorganisms to degrade the faecal sludge and leads to slow degradation. The high COD/BOD organic matter could be a result of materials from disposal of household waste like food remains and the organic loading of materials used in anal cleansing such as tissue, newspaper and corncobs as indicated by correspondence analysis (Tilley *et al.* 2008).

The total P concentration in the sludge in all pits (1–6) was very high (Table A3, available online), about 3.6 times higher than that reported by Gudda *et al.* (2017) and about six times higher than that reported by Appiah-Effah & Nyark (2014). The higher concentration of P in the sludge was attributed to the addition of extraneous materials such as kitchen waste, in addition to the diets of the pit latrine users.

The pit latrine faecal sludge in all pits (1–6) also contains high concentrations of total N compared to studies by Gudda *et al.* (2017) and Appiah-Effah & Nyark (2014). Nitrogen in the pit latrine faecal sludge is an important resource because it can be used for plant growth (Chandran 2014). There is, however, the need to assess how much of this total nitrogen is accessible to different types of plants. The high nutrient concentrations in the faecal sludge are an important justification for use as farm manure (Awuah *et al.* 2014). There have been reported beneficial uses of faecal sludge in agriculture which can be used to reduce environmental impacts of disposal into the environment (Scott *et al.* 2004). However, the high nutrient concentrations reported in this study are also of concern when it comes to the treatment, reuse and final disposal of the sludge.

The documented characteristics of the sludge are above the minimal standard disposal requirements of the Zimbabwe Environmental Management (Effluent and Solid Waste Disposal) Regulations (2007) and the World Health Organization (WHO) standards (2006) for disposal into the environment or use in crop production. As an example, COD and BOD concentrations were 100 and 170 times higher than the recommended standard of less than 60 mg/L and 100 mg/L, respectively, for safe disposal. Therefore, based on pit latrine faecal sludge characteristics documented in this research, there is a need to explore better treatment technologies prior to resource recovery for agricultural reuse and disposal into the environment to reduce potential for pollution. Appropriate treatment of pit latrine faecal sludge incorporating resource recovery would significantly contribute to achieving the Sustainable Development Goals target on sanitation provision for all, developed by the United Nations General Assembly in 2015 (Gudda *et al.* 2017).

In recent years, pit latrine faecal sludge has been gaining recognition as an important resource for bioenergy generation by poor communities and the by-product has been found to have potential use as a fertiliser and soil conditioner. The assessment carried out in this study contributes to the assessment of the sludge quality for such applications because it enables comparison and standardisation of the data on sludge from different regions. Such knowledge can be useful for informing technology development including supplementation of substrates for optimisation of sludge treatment.

## CONCLUSIONS

In this study we have shown that within a given site every pit latrine is unique in its physico-chemical properties and maintains specific characteristics that distinguish it from other pits over time due to the consistency in user habits and pit management practices. The values of the sludge physico-chemical characteristics (N, P, COD, VS and BOD) reported in this study were generally high as compared to those reported in other geographic regions. The pit latrine faecal sludge showed potential biodegradability with processes such as anaerobic digestion and contains nutrients that can potentially be useful for crop production. However, there is a need to explore appropriate onsite treatment technologies prior to resource recovery for agricultural reuse and disposal into the environment to reduce potential for pollution.

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