EFFECT OF SCUM ON THE DEWATERABILITY OF FAECAL SLUDGE FROM SEPTIC TANKS.

BY

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DECLARATION

I, Wonaira Sheila, hereby declare that this submission is my original work and that, to the best of my knowledge and belief, has never been presented for a degree in any other university or other institutes of higher learning, except where due acknowledgement has been made in the text and reference list.

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Signature   Date

CERTICIFICATION

The undersigned certify that we have read and hereby recommend for acceptance by Kyambogo University a dissertation entitled: Effect of scum on the dewaterability of faecal sludge from septic tanks. This work was done under our supervision.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
Ca	Calcium
COD	Chemical Oxygen Demand
CST	Capillary Suction Time
EXT	Dewaterability Extent
EPS	Extracellular Polymeric Substances
FS	Faecal Sludge
FSM	Faecal Sludge Management
FSS	Faecal Sludge Scum
HCl	Hydrochloric Acid
Mg	Magnesium
N	Nitrogen
OP	Orthophosphates
ORP	Oxygen Reduction Potential
OSS	On-Site Sanitation Systems
SDG	Sustainable Development Goal
SEM	Scanning Electron Microscope
TP	Total Phosphates
TS	Total Solids
TSS	Total Suspended Solids
TVS	Total Volatile Solids
%FSS	Percentage of Faecal Sludge Scum in Faecal Sludge

ABSTRACT

Understanding the properties of Faecal sludge (FS) is critical for over all faecal sludge management. This study investigated the impact of faecal sludge scum (FSS) on the dewaterability of faecal sludge (FS) from septic tanks. Samples of FS and FSS were collected from 35 septic tanks across Kampala. In-situ measurements and data on demographic, environmental, and technological variables were also recorded. Dewaterability rate (CST) was assessed using the capillary suction time method, while the extent of dewaterability (EXT) was determined through centrifugation.

FSS depth ranged from none to 50 cm, with a median of 0.05 mm. Most scum was black (61%) and solid (77.4%), while 22.3% was foamy and watery. FSS showed high variability in characteristics with statistically significant differences between FSS and FS observed for Chemical Oxygen Demand ($p=0.046$), Total Solids ($p<0.001$), density ($p=0.032$), Oxygen Reduction Potential ($p=0.008$), Magnesium ($p=0.010$), Electrical Conductivity ($p=0.025$), Moisture Content ($p<0.001$), and Nitrogen ($p=0.003$).

FSS had higher capillary suction time (CST) values with a mean of 163.5s compared to FS with a mean of 59.5 s, indicating lower dewaterability. Mean cake solids were 12.8% for FSS and 11.4% for FS. In FS samples, TS and OP positively correlated with CST, while MC showed a significant negative correlation ($r = –0.532$, $p = 0.002$). Findings showed that the percentage of FSS was positively associated with CST, while total FS volume had a significant negative correlation with CST ($r = –0.3245$, $p = 0.0337$). FSS percentage had a weak positive association with cake solids, whereas FS quantity was negatively correlated ($r = –0.2142$).).

Scum dewaterability was found to be strongly influenced by FS characteristics. COD, ORP, fat, total solids (TS), and orthophosphates (OP) were positively associated with CST with increase in these parameters generally leading to longer dewatering times. In conclusion, the amount of FSS in FS has a greater impact on the time it takes for water to be drawn out from the sample i.e. dewaterability rate. Therefore, more scum in the sludge slows down the dewatering process but does not significantly affect the dryness of the resulting cake.

Key words: Capillary Suction Time (CST), Characteristics, Dewaterability Extent (EXT), Faecal Sludge (FS), Faecal Sludge Scum (FSS)

CHAPTER ONE : INTRODUCTION

1.1 Background to the study

Due to its affordable capital and maintenance requirements, on-site sanitation systems (OSS) are used to meet the sanitation demands of the majority of people in poor nations (Strande, 2014). As such, pit latrines and septic systems, both types of onsite facilities for sanitation, continue to serve a sizable fraction of the global population (Samal et al., 2022). Faecal sludge (FS) accumulates as a result of the use of these systems, which calls for careful management to safeguard both the environment and public health (Junglen et al., 2020; Akumuntu et al., 2017) but in many poor countries, Faecal sludge management is insufficient largely due to limited financial resources, poor technologies and difficulties in accessing the containment units (Parkinson et al., 2014; Diener et al., 2014).

Because of poor Faecal sludge management, an estimated 0.7 billion persons globally have insufficient access to sanitary services that are safely managed (Samal et al., 2022). Safe Faecal sludge management is necessary for sustained sanitation access and public health and environmental gains that it brings (Harper et al., 2021). This is of particular interest in low-income communities, which frequently feature unplanned settlements with large human densities, sanitary conditions are of particular importance (Delaire et al., 2021). Target 6.2 of the Sustainable Development Goals (SDGs) emphasizes universal access to safe sanitation by 2030. Most people living in poor nations continue to face significant difficulties in achieving fair access to sanitation, encompassing faecal sludge collection, collecting, and transportation services (Berendes et al., 2017; Schoebitz et al., 2017). Improving public access to properly managed sanitation services is a major concern of many nations to meet the sanitation targets of the SDGs (Simiyu et al., 2021).

Faecal sludge has long been viewed as dangerous in Africa (Lugali et al., 2022). Many waste management professionals perceive waste as a problem rather than a resource (Otoo et al., 2015). This is dangerous to both the population and the environment (Hafford et al., 2018). Despite the associated threats, numerous advantages can result from better containment and treatment of faecal sludge, including decreased disease transmission, environmental protection, and utilization of materials in excreta for uses like crop fertilizers (Butte et al., 2021) and Faecal sludge briquettes especially when sourced from 40% Faecal sludge (Lugali et al., 2022). Furthermore, organic materials and minerals found in Faecal sludge are important for agricultural productivity (Nikiema et al., 2014; Otoo et al., 2015). On-site treatment facility faecal sludge is an important soil supplement due to its low chemical and metal contamination (Otoo et al., 2015). Enhancing desludging faecal sludge generated by on-site sanitation infrastructure in a safe manner is essential for achieving this goal in many low-income nations such as Uganda (Seleman et al., 2021).

Uganda, like many other low-income countries, is working to ensure that its people have access to sanitation because significant investments in this area are required to meet SDG 6 (McConville et al., 2019). While toilet coverage may still be low in most metropolitan areas of SSA, the sanitation value chain's weakest link is unquestionably the safe extraction and handling of feces from current systems (Muspratt et al., 2014). Limited extraction and disinfection of Faecal sludge from on-site facilities characterizes rapidly expanding cities, like Kampala in Uganda (Fuhrimann et al., 2014). In Kampala, sludge from non-household sources makes up a sizeable portion of sludge in the city (Strande et al., 2018). Due to inadequate management of Faecal sludge, there have been reported cases of Schistosoma mansoni and helminths transmitted through the soil especially in slum areas of Kampala (Fuhrimann et al., 2016). Relatedly, with a prevalence of 53.2%, 44.7%, 41.9%, and 35.8% among members of the exposed community, non-exposed community members, wastewater treatment facility staff, and Faecal sludge collectors, in that order; poor waste and Faecal sludge management in Kampala has been associated to intestinal parasite diseases (Fuhrimann et al., 2014). Faecal sludge management in urban areas such as Kampala remains a challenge (Semiyaga et al., 2017a).

Currently a lot of research is being undertaken on dewatering of faecal sludge (Basamykina et al., 2020; Ge et al., 2019; Gold et al., 2018; Semiyaga et al., 2015, 2017b, 2017a; Ward et al., 2023; Zhou et al., 2011). For instance, dewatering is the first step in the localized processing of faecal sludge (FS) generated by pit latrines, a most common sanitation method in urban slums (Semiyaga et al., 2017a). Relatedly, Basamykina et al., 2020 contend that dewatering of Faecal sludge is the most effective way of preprocessing for biologically active molecules Faecal matter to minimize faecal sludge volume (Basamykina et al., 2020). However, the broader aspect of understanding the properties of FS remains limited. This study seeks to characterize Faecal sludge scum and determine its influence on the dewaterability of onsite sanitation systems.

1.2 Problem statement

Inadequate sanitation and inefficient faecal sludge management (FSM) remain critical public health and environmental challenges, especially in low-income urban areas. Globally, an estimated 3.6 billion people lack safely managed sanitation services, with 494 million still practicing open defecation (WHO/UNICEF, 2023). In Uganda, only 19% of urban households are connected to centralized sewer systems, while the majority rely on onsite sanitation technologies like septic tanks (UBOS, 2021). In Kampala, where centralized sewer access is limited, septic tanks are the primary form of onsite sanitation (Semiyaga et al., 2017a; Delaire et al., 2021). However, the accumulation of FSS within these tanks may significantly alter sludge properties and reduce dewaterability hence worsening FSM challenges.

While prior studies in Uganda have examined pit latrine sludge dewaterability, resource recovery, and sludge characteristics (Diener et al., 2014; Semiyaga et al., 2017b; Gold et al., 2018), little is known about the formation, composition, and influence of FSS in septic tanks. The few existing studies do not adequately address how demographic, environmental, and technological factors affect FSS formation and its role in solid-liquid separation. This knowledge gap limits the development of effective, context-specific strategies for sludge treatment and septic system sustainability. This study therefore seeks to characterize FSS in Kampala's septic tanks and assess its impact on dewaterability, with the goal of informing improved design, operation, and maintenance of FSM systems.

1.3 Objectives

The study purpose was to investigate the influence of Faecal sludge scum (FSS) on the properties and dewaterability of Faecal sludge (FS) from septic tanks.

Specifically, the study sought:

i. To quantify FSS from different septic tanks.
ii. To characterize the physical and chemical properties of FSS and FS extracted from septic tanks.
iii. To investigate the solid- liquid separation performance of FS
iv. To investigate the influence of FSS on the solid- liquid separation of FS

1.4 Research Questions

The study was guided by the following research questions:

i. What are the characteristics of FSS from different septic tanks?
ii. What are the physical and chemical characteristics of FSS and FS from septic tanks?
iii. What is the solid-liquid separation performance of FS?
iv. To what extent does FSS influence the solid-liquid separation of FS?

1.5 Scope of the study

Geographically, the study was limited to septic tanks within Kampala, Uganda. Conceptually, the study explored the faecal sludge scum, its physical and chemical characteristics, and its influence on the solid-liquid separation of faecal sludge. It also looked at the possible demographic, environmental and technological variables that could account for its existence in septic tanks.

Samples were collected between March to August 2022. The whole research was done during my masters' research period.

1.6 Significance of the Study

The study findings are a basis for further research into resource recovery from faecal sludge. In addition, due to limited literature on faecal sludge scum, the study contributes to literature on Faecal sludge management. This will not only be useful for other researchers but will also help inform decision making in the treatment, use and disposal of Faecal scum for various purposes including energy generation, fertilizers among others. SDGs 6 (Clean water and sanitation), 7 (Clean energy), 11 (Sustainable Cities and Communities), and 12 (Responsible consumption and production) will all benefit from this research.

This study directly contributes to Sustainable Development Goal (SDG) 6.2, which aims to ensure access to adequate and equitable sanitation for all. By examining how FSS affects sludge properties and treatment efficiency, this study addresses operational inefficiencies in urban FSM systems. The findings support the development of safer and more sustainable sanitation services in underserved areas where septic tanks are the primary sanitation option. Additionally, the insights generated inform the design, maintenance, and treatment processes of septic systems, ultimately contributing to more effective FSM. By improving service reliability in informal settlements and low-income communities, the research promotes greater equity in access to sanitation, aligning with the core objectives of SDG 6.2.

1.7 Justification

Dewatering of FS is the most effective technique of preprocessing biodegradable human waste for reducing volume of faecal sludge. It reduces the moisture content from 98% to 75% while increasing the solids content from 2% to 25%. This can significantly reduce FS transportation and handling costs (Basamykina et al., 2020).

This study therefore provides data and analyses which can be based on to improve the efficiency of dewatering systems, and to provide a guide to handling FS and FSS at treatment plants for further reduction of FS volumes. Results of this study will also inform the effective design and operation of the dewatering processes of faecal sludge management in include drying beds, solar drying, and mechanical dewatering. This will help in achieving SDGs 6, 11, and 12, which respectively target to improve access to clean water and sanitation, create sustainable cities and communities, and ensure responsible consumption and production.

The role of scum in faecal sludge (FS) treatment processes, particularly in relation to dewatering efficiency, warrants focused investigation due to its critical yet often underestimated influence. Scum, which primarily consists of fats, oils, grease, and floating solids, can significantly alter the physical and chemical behavior of sludge during treatment. Despite its prevalence in FS, scum has received relatively little attention in existing literature compared to other sludge components, resulting in a notable gap in current research. Addressing this gap is essential for advancing knowledge in faecal sludge management. Furthermore, a deeper understanding of how scum affects sludge dewaterability can inform the development of more effective pre-treatment and conditioning strategies, thereby enhancing the overall efficiency and sustainability of sludge treatment technologies.

1.8 Conceptual framework

The study's conceptual framework is presented in Figure 1.1 below.

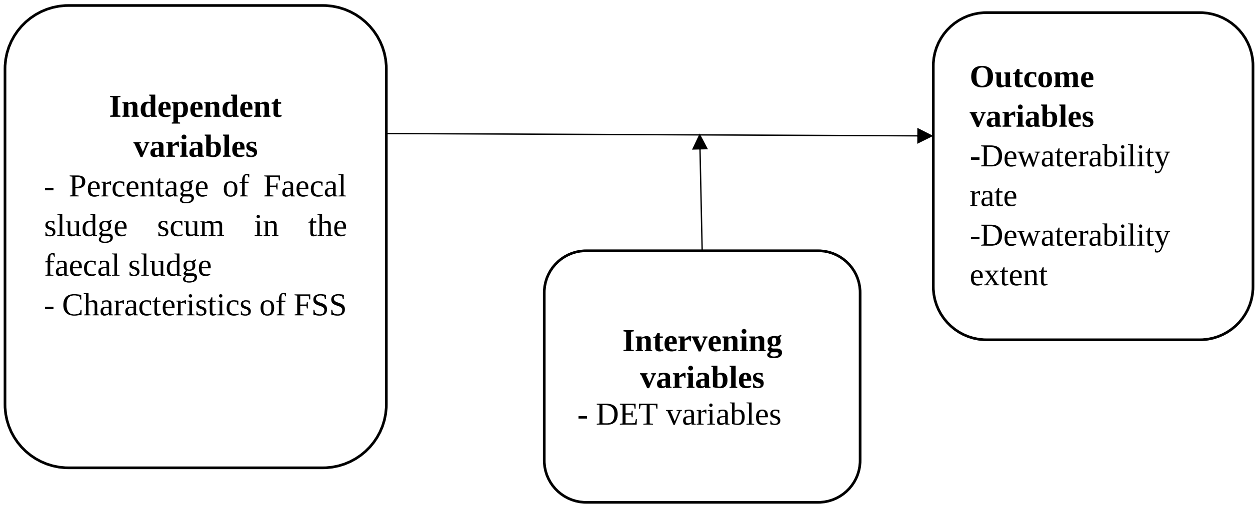

Figure 1.1: Study conceptual framework

1.9 Outline of the dissertation

This dissertation is divided into five chapters. The first chapter contains the study's background, problem statement, objectives, research questions, scope of the study, significance, justification, and conceptual framework. The second chapter is a review of the literature on faecal sludge management, origins of faecal sludge, septic tanks, faecal sludge and faecal sludge scum, quantification of faecal sludge and scum, physical-chemical properties of FS and FSS, dewaterability of FS, solid-liquid separation of FS, influence of FSS on the solid-liquid separation of FS and summary of literature. The study area, research design, sampling of FS and FSS, sample, preparation, sample analysis, data analysis, and ethical considerations are presented in chapter three. Chapter four presents; Quantification of FSS scum from septic tanks, characteristics of FSS and FS; Solid-liquid separation performance of FS and FSS and Influence of FSS on the solid-liquid separation of FS while chapter five presents the summary of findings, conclusions, recommendations and areas for further research.

CHAPTER TWO : LITERATURE REVIEW

2.1 Introduction

The literature on faecal sludge dewaterability is examined in this chapter. The literature is reviewed along the following themes namely, Faecal sludge and Faecal sludge scum, its management, functions of septic tanks, composition of faecal sludge, its composition, and properties in comparison with that from wastewater treatment plants, quantification of Faecal sludge, physio-chemical characteristics of faecal sludge scum and faecal sludge, faecal sludge solid-liquid separation performance and the effect of faecal sludge scum on faecal sludge solid-liquid separation. In addition, it also highlights the impacts of FSS properties on dewatering and the key dominating parameters to FSS. The sources of literature for the study are scholarly articles, journals, and other online publications.

2.2 Faecal Sludge Management

Faecal sludge management (FSM) entails collecting, moving, treating, and using or discarding the contents of feces which are partially digested (Strande & Brdjanovic, 2014). Improper FSM endangers human health and causes environmental pollution because human excreta contains many diseases and contaminants (organic materials and minerals) (Semiyaga et al., 2017a). Based on the OSS which consist of either septic tanks or pit latrines, the collection of FS may involve the use of fully mechanized vehicles like vacuum trucks or semi-mechanized portable equipment like the Gulper, Manual Pit Emptying Technology and Vacutugs. In urban slums without access for vacuum trucks, manual emptying of pits and vaults is a common practice (Semiyaga et al., 2017a), and it is a simple method in which the pit is emptied by a person or people using basic hand tools such as spades, buckets, or cans.

The majority of countries in Sub-Saharan Africa (SSA) discharge untreated FS from on-site sanitation technologies into neighboring watercourses or fields, or use it untreated for farming or aquaculture (Klingel et al., 2002). This discharge could make the water more polluted and pose health risks (Semiyaga et al., 2017a). Using FS in agriculture is one of the alternative ways to get rid of it, but there are still problems with how it gets collected, transported, and treated before being used on land (Semiyaga et al., 2017a).

The initial step of establishing autonomous FSM systems in urban slums is dewatering, which is a method of separating solid and liquid streams by means of evaporation, sedimentation, and filtration (Semiyaga et al., 2017a). This approach is backed by evidence demonstrating that water accounts for over 90 percent of the FS recovered from septic tanks and pit latrines (Muspratt et al., 2014), certain amounts of which can be retrieved, treated, and safely disposed of, or used to reduce pollution in slum areas (Semiyaga et al., 2017a). In addition to reducing management costs, dewatering reduces the water content of the sludge, making it easier to handle, store, transport, dispose of, or convert into useful products (Houghton et al., 2000; Novak & O'Brien, 1975; Schoebitz et al., 2017). Dewatering of FS also makes additional treatment procedures easier (Sam et al., 2022). Dewatering technologies are chosen based on a variety of factors, including capital costs, space accessibility, and the nature and features of FS (Metcalf & Eddy, 2003). In countries with low and middle incomes, sewage and FS are already dewatered at the treatment facilities using sand beds. Here, water evaporates from the surface exposed to the atmosphere after filtering through layers of sand. Lack of space, however, restricts the use of sand beds in urban slums (Semiyaga et al., 2017a). Other common methods of dewatering sewage sludge including belt presses, filter presses, and centrifuges (Pan et al., 2003) have not received extensive research in the treatment of FS, and it is unknown whether they would be effective in urban slums (Semiyaga et al., 2017a).

2.3 Origins of faecal sludge

Onsite sanitation technologies, like pit latrines and septic tanks, provide for the 2.7 billion people's needs for sanitation worldwide. Technologies for on-site sanitation can provide sufficient and affordable sanitation with the right FSM (Ziebell et al., 2016). In a septic tank, the three layers of feces—scum, sludge, and effluent—combine to form the sludge (Septic Max, 2021). Sludge is a solid substance made up of non-liquid substances like soil, bones, food particles, etc. that collects at the bottom of septic tanks to form a thick layer. The anaerobic bacteria that live in the tank's bottom feed on the sludge layer, and as they perish, they too are assimilated into the sludge layer.

Scum is the collective term for the group of materials in a septic tank that are lighter than water and typically include oil, fats, and grease. The aerobic bacteria work to digest most the floating solid waste materials when these substances float to the top, above the water. Most of the liquid in a septic tank is effluent, which is the clarified wastewater that is left over after the scum and sludge have risen to the top and fallen to the bottom, respectively.

The accumulation of fats, oils, grease, and long-chain fatty acids in the scum layer is harmful to the stable functioning of bioreactors used to treat non-oily wastewaters such as domestic sewage. Sludge flotation is most likely caused by an excess of fats, oils, grease, and long-chain fatty acids (Wang et al., 2018).

2.4 Septic Tanks

Septic tanks are an essential part of onsite sanitation technologies (Figure 2-1), which are described as a system installed near toilets (as opposed to centralized treatment systems, in which water carries excreta and urine in the form of wastewater), to collect excreta, urine, and other waste (such as vegetable peals, cooked food, and so on) and allow it to partially degrade. OSTs can be broadly divided into two categories: (i) wet OSTs, like septic tanks, which need water to be flushed, and (ii) dry OSTs, like pit latrines, which don't need any water at all (Chandana & Rao, 2022). Septic tanks' primary purpose is to separate the scum layer, sludge, and effluent from the domestic water. Most often, they are employed in on-site applications for the pre-treatment of home wastewater (Adhikari & Lohani, 2019).

In addition to having their own ecosystem and intricate biochemical processes powered by facultative and anaerobic organisms, septic tanks are inactive low-rate anaerobic digesters. Because the tank functions as a plug flow reactor, there is typically no mixing or heating, and instead, particles ascend or descend and stratification forms. In the absence of this stratification, effluent quality suffers. Sites within the sludge and scum layers may be completely free of oxygen, or anaerobic, whereas the clear zone of the tank tends to be anoxic, or oxygen deficient. The inflowing wastewater which the inlet fixture guides into the clear zone (just below the scum layer) usually contains high levels of dissolved oxygen and a healthy microbial population. However, as the flow dissipates in the tank towards the outlet, the dissolved oxygen levels rapidly decrease (Bounds, 1997).

Septic tanks are available in a variety of shapes and sizes, with an inlet and outlet, access points for regular removal of digested solids, and one or more compartments. By directing the flow into the middle of the liquid level, the inlet improves the retention and accumulation of floating materials through making sure that the scum layer is not mixed or disturbed by the in-rushing flow. The performance of the tank depends on how well its dimensions and general shape are configured; for example, square tanks or tanks with close distances between inlets and outlets have a tendency to short circuit, which lowers the effluent quality. The distance between the inlet and outlet fittings must be greater than their width or depth. Precast length to liquid depth ratios that are used (L: D) are typically between 1:1 and 3:1. The standard height to width ratio (H: W) is one to one. It is possible for the reserve storage/vent volume between the tank's liquid surface and soffit to be between 10 and 20 percent of the tank's overall volume (Bounds, 1997).

Septic tanks must meet the requirements of IS 2740, which state that they must be 750 mm wide, 1 m or more below water, and have a minimum liquid capacity of 1000 L. The minimum diameter and depth of a circular septic tank should not be less than 1.35 and 1.0 m, respectively, while the length of rectangular septic tanks shouldn't be more than twice as wide (Standards, 1985).

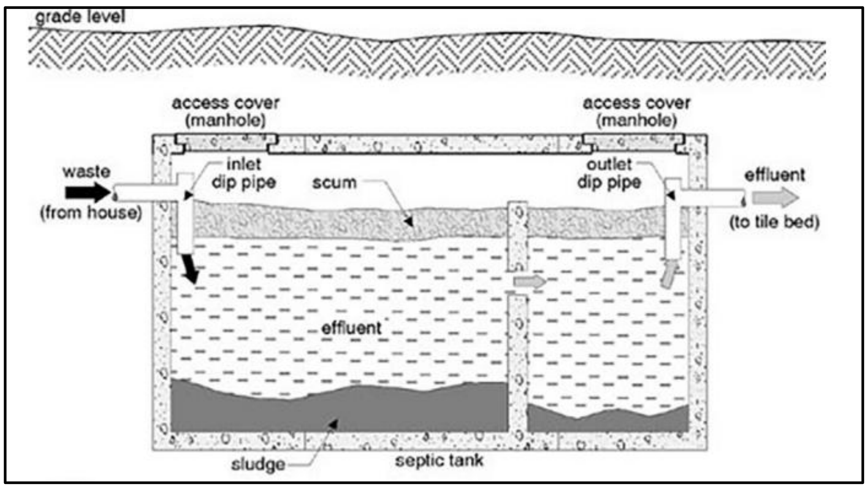

Figure 2.1: A schematic of a convectional septic tank (Soil Resolution Technologies, 2019)

2.5 Faecal sludge and Faecal sludge scum

Sludge is the concentrated substance left over after a separation procedure, which usually refers to water or wastewater treatment (Dentel & Qi, 2014). Faecal sludge is a semisolid combination of partially digested human excreta that is often collected from on-site sanitation facilities and deposited into open sewers and aquatic bodies (Samal et al., 2022). Faecal sludge must be safely contained on site before being safely emptied, conveyed to a treatment facility, treated, and either reused or disposed of in a safe manner (Harada et al., 2016).

Faecal sludge scum (FSS) is the layer of floating solids and substances that accumulate on the surface of faecal sludge during storage or treatment. It typically consists of fats, oils, grease (FOG), lighter organic materials, and other buoyant particles that separate from the bulk sludge due to differences in density and hydrophobicity. It is produced by thickening and dewatering faecal sludge in settlers, foul condensate tanks, sedimentation tanks, and sewer systems (Rohilla et al., 2019). Sludge from human waste naturally separates into three layers as it fills a septic tank: scum, bulk liquid, and sludge. Floating fats, oils, and greases make up the FSS, which is a layer at the top of the water (Novozymes, 2021). FSS is mostly made up of fats, oils, and grease as well as other light organic particles. These particles have hydrophobic properties, liquefy when heated, release methane when anaerobically digested, and generate a significant amount of energy when thermally oxidized (Cockrell, 2011). Purified water is the end result of separation procedures used water and wastewater treatment (Dentel & Qi, 2014). The separation processes work by removing impurities from the aqueous stream. The separated materials are concentrated versions of the original problem (Dentel & Qi, 2014).

2.6 Quantification of Faecal Sludge

Faecal sludge (FS) refers to waste removed from the on-site facilities (Nikiema et al., 2014). FS is produced by onsite sanitation methods and is not a product of sewer transportation (Penn et al., 2018). Faecal sludge is a slightly diluted mixture of human excreta that includes toilet wastewater, tissue paper, and various waste materials such as sponges, wood, bones, fabrics, sand, seeds, plastics, and stones (Nikiema et al., 2014). The amount of FS is influenced by the amount of excrement and the quantity of water utilized for cleaning and draining, onsite containment systems, and other factors (Samal et al., 2022). Because there are so many different onsite sanitation technologies being used, including latrines, septic systems, and toilets, it is difficult to ascertain typical amounts and characteristics of Faecal sludge (Penn et al., 2018). However, the properties of faecal sludge as well as those of faeces are comparable (Penn et al., 2018). COD (chemical oxygen demand), biochemical oxygen demand (BOD), minerals, microorganisms, micronutrients, ions, faecal coliforms, parasitic eggs, and so on must all be described for FS. When compared to household wastewater sludge, FS organic products, sediments, parasitic eggs, and ammonia concentrations are often 10 to 100 times greater (Samal et al., 2022).

The amount of sludge is measured in dry tons of solids, but because sludges vary in solid content from 1% to 25% at various stages of processing before drying by heating or disposal, depending on the procedure or scenario, the concentration of "wet" sludge output may very well be 4-100 times greater than the dry mass (Dentel & Qi, 2014). Various groups of environmental contaminants, such as including trace metals, pharmaceuticals, products for personal care food products, detergents, chemicals, microorganisms, and synthetic compounds, are frequently found in urban wastewater and sewage sludge (Sarkar et al., 2019).

There are reported variations in total solids (TS) by source of faecal sludge. The fuel potential of faecal sludge was examined in studies conducted in Uganda, Ghana, and Senegal. According to the findings, the TS of FS from unprotected pit latrines was more than that of adequately covered sanitation facilities and septic systems, which estimated 2.7 and 1% of moisture content, respectively (Muspratt et al., 2014).

A study conducted in Kampala, Uganda reported that sludge from non-household sources, which make up a sizeable portion of sludge in the city differs from that from households in several ways (Strande et al., 2018). Faecal sludge may be classified into two depending on the concentration and source. A study that assessed essential analytical variables for characterizing faecal sludge revealed that the source of the faecal sludge greatly affects the composition of the sludge (Krueger et al., 2021). Faecal sludge can be diluted/low-strength sludge or concentrated/high-strength sludge. Low-strength (diluted) Faecal sludge originates from the septic tanks in residential buildings (Nikiema et al., 2014). Due to its age (often one to three years), it is frequently stabilized (digested), making it appear dark brown or black. FS contains total solids in concentrations that range from fewer than 10,000 mg per liter (l) to 30,000 mg per liter (mg/l). Chemical oxygen demand (COD) levels in such liquid waste are typically under 15,000 mg per liter (Nikiema et al., 2014). The low strength faecal sludge depends on the source which may be influenced by temperature, rain, and intrusion of ground water while its density depends on the type of sanitation facility. A study conducted in Ghana found that for the samples from domestic sources, the examination revealed that the FS is "low strength"(Ahmed et al., 2019). The high strength or concentrated Faecal sludge is found from public restrooms, other sanitary facilities that are not flush or flush by pouring water (Nikiema et al., 2014). This type of sludge has a COD level above 20,000 mg per liter and includes more than 30,000 mg of TS per liter. It is younger than a year old and has a yellowish-brown tint (typically as low as one week) (Nikiema et al., 2014). Faecal sludge may also be classified as dry if it originates from dry toilets or pit latrines (Nikiema et al., 2014). The composition of Faecal sludge is also associated by other factors in addition to the source. For instance, according to findings of a study conducted in Kampala city of Uganda, Sludge quality is predicted by level of income, water link, black water alone, solid waste, user count, containment size, frequency of emptying, and truck size (Strande et al., 2018).

2.7 Physical-chemical characteristics of Faecal Sludge Scum and Faecal Sludge

Successful FS management and planning requires a thorough understanding of factors like degradability, mineral composition, dewaterability, waste recycling capacity, microorganisms, and potentially inhibiting chemicals (Velkushanova, Strande, & Ronteltap, 2021). FS is a mixture of water, both organic and inorganic materials, and human excrement (Samal et al., 2022). A study conducted in Uganda discovered that variables like sand concentration, dissolved solids and total suspended solids have an impact on the dewaterability of pit latrine sludge (Semiyaga et al., 2017a). The design of pit latrines, particularly whether they are lined, has an impact on the properties of FS evacuated and the resulting dewaterability extent (Semiyaga et al., 2017a). At 0.5 m intervals, the physiochemical composition of latrine faecal sludge changes noticeably (Mrimi et al., 2020). A study conducted in Ghana discovered significant levels of BOD and COD values in Faecal sludge (Ahmed et al., 2019). The study found that the FS was still degradable and hadn't yet reached a stable state based on the COD to BOD ratios (Ahmed et al., 2019).

Figures 2 depict the evolution of some of the physio-chemical characteristics of a septic tank, including TS, COD, and methane (CH4). In the first year, solid matter (TS) and volatile solids (VS) rise rapidly; after that, the rise slows, and the TS-VS ratio widens. The VS increases from 19 to 29 g/L between 0.5 and 3.5 years, while the TS rises from 27 to 42 g/L (Philip et al., 1993). In addition, there is an increase in the soluble Chemical Oxygen Demand (COD) during the first two years, which is followed by a sharp decline. This is due to the concentration of organic matter that is dissolved in the sludge's interstitial liquids because of the exoenzymatic degradation of the solid particles. The rise in methane production from hydrolyzed products and volatile fatty acid (VFA) consumption is connected to the COD decline after the second year. A more diverse bacterial community gradually establishes itself and promotes a more thorough biodegradation over time. Up until the second year, methane production is actually very minimal (10 ml/liter of FS/day), and it only becomes significantly significant after this time (Philip et al., 1993).

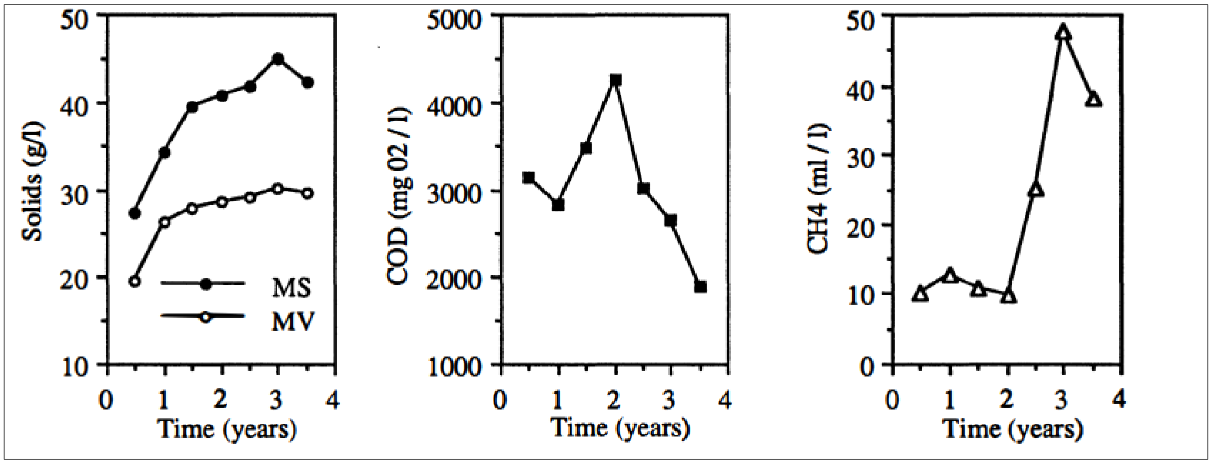

Figure 2-2: The evolution in the solids (TS and VS), COD and methane production of FS from Septic Tank over a period of 4years (Philip et al., 1993).

Furthermore, Andrade et al. (2017) report that the concentrations of TS, VTS, COD, BOD, TKN, N-NH4+, Total Coliforms, and Escherichia Coli in the FS septic tank have mean and standard deviation values of 2349±10358 mg/l, 1133±9440 mg/l, 2937±7284 mg/l, 1074±4355mg/l, 88±103 mg/l, 82±52mg/l, $9.8x10^{10}$ and $3.6x\ 10^{9}$ respectively (Andrade et al., 2017). Furthermore, Bassan et al., (2013) reported different parameters of FS values from septic tanks as shown in **Table 2-1.**

Table 2.1: Septic Tank FS Characteristics (Bassan et al., 2013)

Parameter	Mean	Standard deviation
SVI (ml/g TSS)	24	11
TS (mg/l)	8984	8926
TVS (% TS)	57	-
TSS (mg/l)	7077	7478
VSS (mg/l)	74	-
COD (mg/l)	7607	6718
BOD_5 (mg/l)	1453	1237
COD: BOD_5 ratio	6.7	6.5
NH_4^+	-	-

2.7.1 Total solids (TS)

Total solids (TS) are the residues that remain after a waste water sample has been evaporated and dried out at a specific temperature, usually between 103 and 105°C (Fanyin-Martin et al., 2017). A study conducted in Ghana very low TS content in FS (Fanyin-Martin et al., 2017). All of the different types of FS were discovered to be statistically distinct. A study conducted on faecal sludge drying beds for fuel resource recovery on SSA revealed a low concentration of TS (mean concentration of 5.5 g/l) in faecal sludge (Seck et al., 2015). The study attributed this low concentration to the predominant use of septic tanks. According to a study on the design of a faecal sludge treatment plant (FSTP) and the availability of its treatment technologies, total solids in septic tanks are estimated to be 22,000 mg/l (Samal et al., 2022). The average amount of total solids in faecal sludge from septic tanks has been reported to be 1.92 g/l (Wanda et al., 2021).

2.7.2 Total suspended solids

The average total suspended solids concentration in faecal sludge was reported to be 7077 mg/l, with a standard deviation of 7478 mg/l (Bassan et al., 2013). Similar findings were reported in a study conducted in Phnom Penh, Cambodia, on the factors influencing the physicochemical properties of faecal sludge (Eliyan et al., 2022).

2.7.3 Total volatile solids

Research has indicated that total volatile solids in faecal sludge from septic tanks ranges from 50 to 73% of total solids (Samal et al., 2022). Another study indicates that the total volatile solids in faecal sludge range from 7,000 to 52,000 mg per litre (Velkushanova, Strande, & Ronteltap, 2021).

2.7.4 Moisture content

The moisture content in FS is crucial for assessing the effectiveness of dewatering and drying technologies like drying beds and settling-thickening tanks (Velkushanova & Strande, 2021). Faecal sludge's moisture content varies greatly (Velkushanova & Strande, 2021).

2.7.5 Density

In a study that reviewed synthetic human faeces and faecal sludge for sanitation and wastewater research, Penn et al., (2018) reported that the density of faecal sludge ranges from 1.0 to 2.2 (Penn et al., 2018).

2.7.6 Orthophosphates

Due to its solubility, ability to interact with other positive elements or compounds, and bioavailability, orthophosphate is also referred to as reactive or available phosphorus (Velkushanova, Strande, & Ronteltap, 2021). Presence of high amounts of orthophosphates and nitrates causes eutrophication (Joceline et al., 2016).

2.7.7 Fibre content

The nature and concentration of the fibre may increase the amount of faeces produced and its capacity to hold water (Velkushanova & Strande, 2021). According to available literature the fibre content in FS ranges from 0.5 to 24.8 g (Penn et al., 2018).

2.7.8 Magnesium and Calcium

The Magnesium and calcium content has been reported in one study to be 12 and 30 g/kg of dry solid respectively (Septien et al., 2020).

2.7.9 Fats and oils

Various sources, such as lard, meats, seeds and nuts, kerosene, and lubricating oils, contribute to the fats, oils, and grease found in FS (Samal et al., 2022). These cause maintenance issues by thickening the scum layer in settling tanks and, if discharged, create films in surface waters (Samal et al., 2022). Available evidence estimates that the fat content of FS is in the range 19 to 6.4 grams (Penn et al., 2018).

2.7.10 Protein

The protein content of FS has been reported to range from 2 to 25 percent weight of solids (Penn et al., 2018).

2.7.11 pH

A study on the chemical characterization of faecal sludge (FS) carried out in Kumasi, Ghana, found that the pH of the FS from all sources was nearly neutral to slightly alkaline, and that the results were highly comparable (Fanyin-Martin et al., 2017). A study conducted in Uganda reported the pH range of faecal sludge to 6.84-9.1 with a mean 7.75 and 0.6047 standard deviations (Atwijukye et al., 2016). Similarly, according to a review of synthetic human faeces and faecal sludge for wastewater and sanitation research, the pH of faecal sludge ranged from 6.7 to 8.5 (Penn et al., 2018).

2.7.12 Chemical oxygen demand (COD)

The COD of the FS was discovered to be very high in general (Fanyin-Martin et al., 2017). According to a study of the design of low cost autonomous faecal sludge treatment systems, the mean COD was 23657.82 (mg/l) with a standard deviation of 10746.08 (Atwijukye et al., 2016). According to a study that assessed resource recovery of fuel from faecal sludge in SSA, the average

COD in faecal sludge drying beds was 9.3 (Seck et al., 2015). The chemical oxygen demand (COD) of synthetic human feces and faecal sludge for wastewater treatment and sanitation research was found to be between 46 and 96 g/cap.day (Penn et al., 2018).

2.7.13 Electrical conductivity

According to a review of synthetic human faeces and faecal sludge for wastewater and sanitation research, faecal sludge's electrical conductivity varies from 2.2 to 14.6 (Penn et al., 2018). Another study found that in septic tanks, the electrical conductivity value was 1.18 mS/cm (Wanda et al., 2021).

2.7.14 Nitrogen content

A study carried out in Kumasi, Ghana, revealed that the nitrogen content in the FS collected varied from 649.40 ± 484.52 mg/L in private septage to 4479.03 ± 2323.77 mg/L in pit latrine (Fanyin-Martin et al., 2017). It was discovered that the different sources of FS differed statistically.

2.7.16 Phosphorous content

An investigation conducted in Kumasi, Ghana, found that the phosphorus content of private septage ranged from 137.92 ± 139.0, which is statistically similar ($p = 0.05$) to that of public septage (228.68 ± 185.26) (Fanyin-Martin et al., 2017). In comparison to pit latrine (521.07 ± 207.58), both pit vs private and pit vs public were statistically lower ($p = 0.00$) (Fanyin-Martin et al., 2017). FS from septic tanks may have much lower P concentrations since P is not retained in septic tank sludge (Changara et al., 2018).

2.7.17 Ash content

It is estimated that the ash content in FS is in the range of 47-59% of TS (Velkushanova, Strande, & Ronteltap, 2021). A study found that the dried material had an average ash content of 41.7 weight percent. The ash content of dried FS was 6 weight percent higher than FS prior to being applied to drying beds after five iterations of the drying experiments (Seck et al., 2015).

2.8 Dewaterability of FS

Dewaterability refers to the ease or efficiency with which water is removed from sludge through mechanical, physical, or chemical methods (Bolto & Gregory, 2007). It is a key factor in sludge treatment, impacting the reduction of sludge volume and thus affecting handling, transport, and disposal costs (Smith et al., 2019). Dewaterability is commonly evaluated using parameters such as capillary suction time (CST), percent cake solids, and filtration rate, which indicate the resistance of sludge to water removal (Dempsey et al., 2018). Efficient dewatering reduces the volume of sludge for transport and treatment, significantly lowering operational costs and environmental impact (Strande et al., 2014).

Recent studies on FS dewaterability have found statistical correlations between physical and chemical properties like pH, conductivity, total solids, extracellular polymeric substances (EPS), particle size distribution, and microbiology and FS dewaterability (Gold et al., 2018; Ward et al., 2019). It is widely acknowledged that the stabilization of FS in containment gradually influences sludge dewaterability (Sam et al., 2022).

In a study by Semiyaga et al. (2017a), it was found that the capillary suction times (CST) of FS from lined and unlined pits were 1122 and 1485, respectively, showing low dewaterability rates (Semiyaga et al., 2017a). On the other hand, the degree of FS dewaterability from lined pit latrines reduced as TVS increased. Furthermore, the degree of dewaterability may increase if FS from lined pit latrines has more sand than FS from unlined pit latrines. Semiyaga et al. (2017a) found a significant relationship between the differences in dewaterability extent between FS from lined and unlined pit latrines and TS, TVS, and sand content. There was a correlation between a lower proportion of TVS and an increase in sand content and a decreased dewaterability extent of FS from lined pit latrines.

The dewaterability of FS is highly variable and depends on several factors, including its origin, retention time, solid content, and the presence of scum or other surface layers. Commonly used indicators of dewaterability include CST, which measures the rate of water release, and centrifuge-based methods, which quantify the extent of water removal from sludge solids (Bassan et al., 2013). Studies have consistently shown that TS and COD positively correlate with improved dewaterability, as higher TS increases the solid matrix's capacity to release water (Radford & Fenner, 2013). Conversely, MC often exhibits a negative relationship with dewaterability; sludge with high MC is more difficult to dewater and results in longer CST values (Gold et al., 2018).

The organic composition of sludge, particularly oil, grease, and fats, significantly impairs dewaterability by increasing the hydrophobicity of the sludge matrix (Kengne et al., 2011). High concentrations of OP and TVS can also alter sludge structure, reducing permeability and slowing water release during treatment (Strande et al., 2014). Moreover, ORP and EC have been observed to influence floc formation and filterability, although their effects are less consistent across different contexts (Diener et al., 2014).

Sludge age and emptying frequency are also crucial. Older sludge typically has higher TS and thicker scum layers, which can slow dewatering due to compaction and layering (Semiyaga et al., 2015). Scum, though often overlooked, has been found to significantly increase CST without a proportionate increase in cake solids, indicating its strong influence on dewatering rate but minimal effect on final dryness (Gold et al., 2018).

In summary, the dewaterability of FS is a multifaceted issue governed by both intrinsic sludge characteristics and external containment conditions. Understanding and managing these factors is essential to improving FSM efficiency and sustainability.

2.9 Solid-liquid separation performance of Faecal sludge

Dewaterability is used to separate sludge into two flows; one which is mainly liquid and the other which contains highly concentrated particle materials (Dentel & Qi, 2014). Although there may be a large amount of water in the particle solids, the product is dry enough to be transported as a solid (Dentel & Qi, 2014). The best method for dewatering faecal sludge is mechanical dewatering. It is associated with quick operation, high dewatering effectiveness, the potential for process automation, low environmental impact but requires a substantial technological infrastructure, reagents, and expensive capital and operating expenditures (Basamykina et al., 2020). A study conducted in Ghana reported that drying beds were successful in separating Faecal sludge's solids from its liquids while retaining, on average, 96 percent of suspended solids (Cofie et al., 2006).

2.10 Influence of Faecal Sludge Scum on the solid- liquid separation of Faecal Sludge

The composition of Faecal sludge varies greatly across communities and is influenced by on-site confinement options, latrine building techniques, different house utilization dynamics, regularity of dumping, hydrology, and group extraction processes (Mrimi et al., 2020). Animal fat, meat, seeds and nuts, gasoline, and fuel oil are just a few of the many fats, oil, and grease sources in FS. The content of oil and grease is critical to consider in FSS analysis since it may; limit microbial decomposition due to poorer dissolution rate, elevate the sedimentation tanks' scum layer, and present servicing concerns (Samal et al., 2022). According to findings of a study conducted in Ghana, domestic sources of Faecal sludge were of low strength because home or private toilets may have undergone significant degradation prior to desludging (Ahmed et al., 2019).

A cross-country examination of the dewatering of FS showed that while dewaterability varied greatly within the same technology, the dewatering rate of FS from various methods also varied significantly (Gold et al., 2018). Relative to wastewater sludge, FS showed a much lower rate of dewatering but had higher dewaterability (Gold et al., 2018). The results of a study conducted in Uganda showed that the rate of dewaterability of FS from covered as well as uncovered sanitation facilities was not markedly different, despite being very low relative to sewage sludge (Semiyaga et al., 2017a). Furthermore, the findings indicated that the solids of FS from covered and uncovered pit latrines were nearly twice as high as their initial values after dewatering (Semiyaga et al., 2017a). A research review revealed that the dewaterability rate of faecal sludge was 115 of TS in dewatered cake (Penn et al., 2018).

2.11 Summary of literature on FS dewaterability

The reviewed literature indicates that various studies have assessed and examined wastewater sludge and its dewaterability, the potential resource recovery from the wastes including recovery and reuse of products from Faecal sludge. Some studies have also explored Faecal sludge and its management while others have related relevant FS characteristics to dewaterability rate as measured by capillary suction time (CST) and dewaterability extent. There is however inadequate information on how scum influences the dewaterability of Faecal sludge. Information on the composition, characteristics, and dewaterability of FSS from septic tanks is inadequate or insufficient. This highlights a knowledge gap, which calls for more research. The information on scum that is currently available relates to scum from settling and thickening tanks and wastewater. This study aims to fill the knowledge gap in the literature regarding the dewaterability of FS from septic tanks as well as investigating the impact of scum on dewaterability. The table below summarizes some of the citations that have been used in this report.

Citation	**Nature of technology**	**Focus of study**	**Findings**
Semiyaga et al., 2017a	Lined and unlined pit latrines	The dewaterability of sewage sludge and its consequences FSM in urban slums	The average dewaterability extent of FS from unlined pit latrines was significantly higher than in lined latrines, but the dewaterability rate of FS from both lined and unlined pits was very low.

Strande et al., 2018	Septic tanks and pit latrines	Techniques for estimating the amounts and characteristics of faeces for the purpose of designing treatment technologies and management strategies	Public toilets did not appear to be a determining factor in the dilution of septic tank sludge compared to pit latrine dirt. Predictors of sludge quality included truck size, containment volume, frequency of emptying, income level, water connection, black water only, solid waste, and number of users
Gold et al., 2018;)	Septic tanks, lined pit latrines, unlined pit latrines.	Cross-national examination of dewatering faecal sludge	Dewatering rates differed significantly between FS from different technologies and differed significantly within the same technology. FS dewatered at a much slower rate than wastewater sludge.
Dentel & Qi, 2014	Wastewater treatment plant	Biosolids, Sludges, and Residuals Management	Dewatering reduces cake volume, which lowers the cost of final use options that necessitate cake transportation. Dewatering technologies' effectiveness differs depending on the type of solids and upstream processing
Cofie et al., 2006	Drying beds	Implications for nutrient recycling in urban agriculture from Ghana's solid-liquid separation of faecal sludge using drying beds	The percentage reduction in solids and organic constituent concentrations during FS dewatering was greater than 80%. This demonstrates that drying beds are effective in achieving FS solids-liquid separation.
Mrimi et al., 2020	Pit latrines	Evidence from an inventive treatment system in rural Tanzania about safe	To treat Faecal sludge and increase its value through resource recovery, new treatment technologies are required. In rural Tanzania, a novel low-cost treatment system demonstrated that pit

		resource recovery from faecal sludge	latrine sludge could be effectively treated. Local farmers can safely use dried biosolids and heat-sterilized leachate.
Fanyin-Martin et al., 2017	Pit latrines, Septic tanks and Wastewater treatment plants	Chemical analysis of faecal sludge in Ghana's capital city of Kumasi	The lipid content of dry FS was found to be in the range of 8.82 - 9.66% on average, depending on the source of FS. Total solids ranged between 0.79 and 4.68%, and COD ranged between 9495 and 45611mg/L. Phosphorus content ranged from 137 to 520mg/L, while nitrogen content ranged from 649 to 4479mg/L.
Krueger et al., 2021	Pit latrines, Urine diverting toilets and Septic tanks	Important analytical factors for characterizing faecal sludge that guide the use of heat treatment techniques	According to the findings, more than 90% of samples can meet these requirements using commonly used dewatering technologies. A comparison of technologies revealed strong evidence that the source of faecal sludge has a significant influence on sludge composition

CHAPTER THREE : MATERIALS AND METHODS

3.1 Introduction

This chapter covers the research methods that were used. The chapter describes the study area, design of the study, Faecal scum sampling, quantification of Faecal scum, sample preparation, characterization of Faecal sludge sum, Particle size analysis, Dewaterability rate and extent, and Statistical Analysis.

3.2 Study Area

Samples of faecal sludge and faecal sludge scum were collected from septic tanks located within Kampala city, which is Uganda's capital city. It is located at 0°19′N 32°35′E, at 3,900 ft (1,189 m) above sea level. Kampala metropolitan area has an estimated population of 3.2 million people. It has 5 Sub Counties which include Kampala Central, Kawempe, Makindye, Rubaga and Nakawa divisions. The existing sewage system only serves 10% of Kampala metropolitan area's population. On-site sanitation facilities service the remaining population (McConville et al., 2019). A total of 34 samples were collected from public and private properties which included schools, markets, hotels, hostels, malls, healthcare centers and households. Figure 3.1 shows the type of sanitation system used in Kampala.

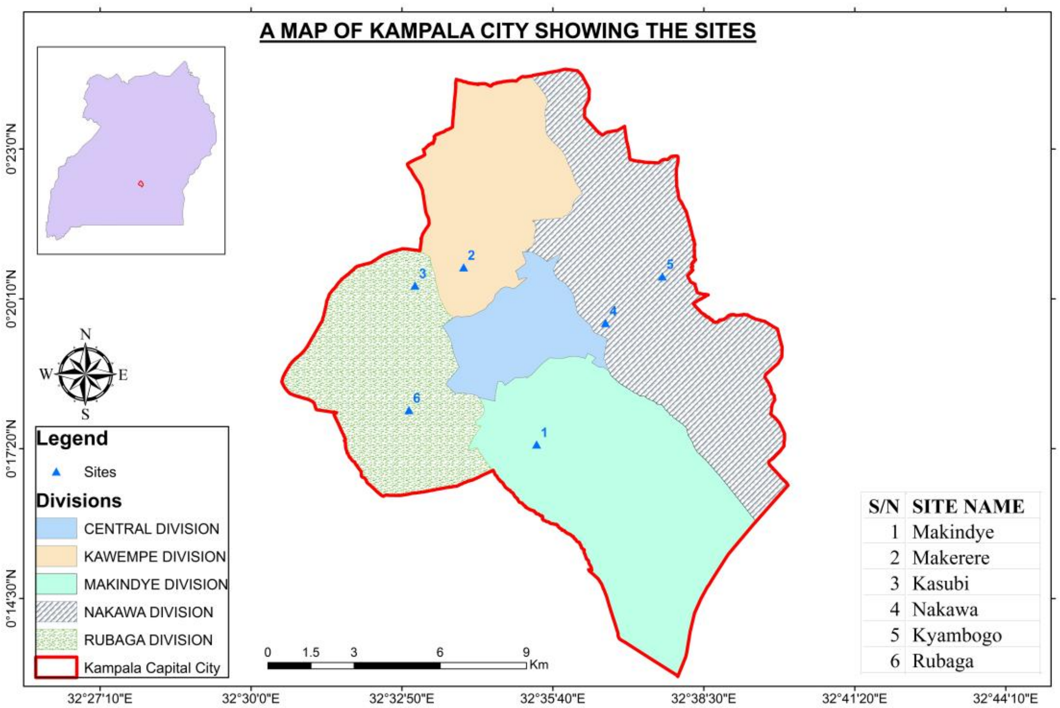

Figure 3-1: GIS map of Kampala showing the areas from which samples were collected.

3.3 Research Design

This research was a cross-sectional study which involved sample collection from various onsite septic tanks. Data was collected from different locations at a single point in time. The variables were also observed without influencing them.

Questionnaires and interviews were used to collect information such as frequency of emptying, number of users, and type of flush system.

Laboratory analysis of various parameters of scum and composite sludge, and dewaterability tests

This study was grouped into research activities as explained below.

3.3.1 Research Objective 1: Quantification of FSS and FS from Septic tanks.

The quantity of FSS and FS in each septic tank was measured using an L-stick (Velkushanova, Strande, Ronteltap, et al., 2021) and Volasor. The L-stick has calibrated indentions which enable it to measure the depth of both the FSS and the FS from a septic tank, while the Volasor instrument was used to measure the surface area of the tank. For measurement of scum depth, the stick was dipped into the scum, rotated 90°, and raised until the 'L' touched the bottom of the scum layer. To determine the depth of FS, the L stick was lowered till it touched the bottom of the tank, and the measurements were read from the calibrations. The Volasor instrument however was placed inside the septic tank without touching the FSS surface and rotated through 180º to capture the dimensions of the septic tank, which were stored on a mobile smart phone The use of both the L-stick and the Volasor instrument are shown in **Figure 3-2**. The quantities of both FSS and FS were both determined from their depths and surface area using **Equation 3-1**.

$$Volume\ of\ FSS/FS = Depth\ of\ FSS/FS \times surface\ area\ of\ the\ septic\ tank \ldots\ldots\ldots \quad (3.1)$$

Figure 3- 2: Measurement of depth of both FS and FSS using L-stick (a) and (b) surface area of the septic tank using the Volasor.

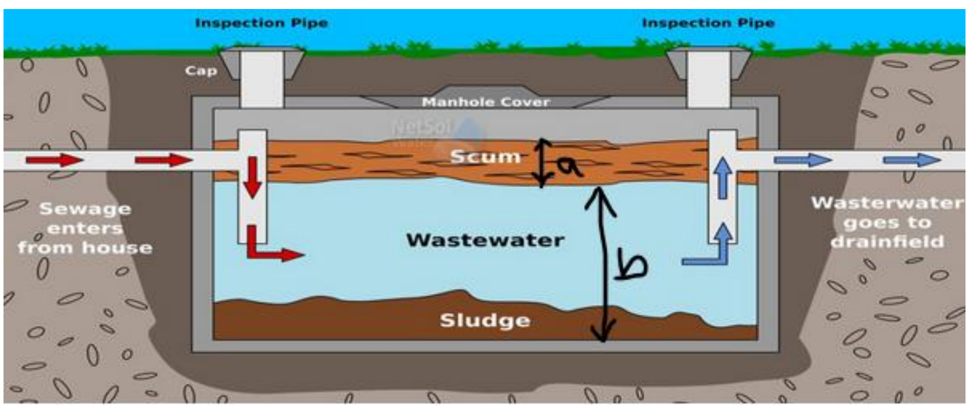

Figure 3-3: Illustration of septic tank showing the depths of FSS and FS as a and b respectively (Ronteltap, et al., 2021).

Alongside sample collection, technical and demographic data regarding the containment units and its users were gathered using a questionnaire. The data collected with this tool included type of establishment and containment type, level of income, type of toilets, age of scum, type of cleansing material and detergents used. The questionnaire is attached in APPENDIX A.

3.3.2 Research Objective 2: Physio-chemical characteristics of FSS and FS

3.3.2.1 Sampling of FSS and FS

The FS and FSS samples were collected from 35 sites using the grab sampling method (Velkushanova, Strande, Ronteltap, et al., 2021) during the period of March 2022 to August 2022 from selected septic tanks in all the five divisions of Kampala city in order to obtain a representation of the city. The selection of septic tanks was based on expert knowledge of the area by the team who have sampled containments in past studies The samples were collected from septic tanks belonging to various categories of users such as: Commercial (Restaurant and shopping mall), Industry, Public toilet, Markets, Church/Mosques, Petro stations, Schools, Household (single & multiple from Formal and informal areas).

Ahead of the sampling, measurements of the scum, middle and sludge layers was determined using the calibrated L-stick.

Grab sampling technique was used to manually obtain both FS and FSS. FSS was obtained from the surface of settling-thickening tank using a scooping spoon while FS was obtained using an improvised long-handled container (**Figure 3-4**). For both the FS and FSS samples to be representative, at the time of sampling, grab samples were obtained at the surface, middle and bottom of both scum layer and the septic tank respectively, and these were thoroughly mixed to obtain composite samples. At this point, a potable meter (Hach HQ30d flexi model) was used to measure the pH, temperature, electrical conductivity (EC), and oxidation reduction potential (ORP) of theFS and FSS sample (Semiyaga et al., 2017a). Thereafter, both the FS and FSS samples were each put in the plastic containers, kept in a 4°C cool box and sent to Makerere University's Public Health and Environmental Engineering Laboratory for examination. The samples were kept at 4°C for a maximum of 24 hours prior to analysis. They were taken out of the refrigerator and allowed to come to room temperature before analysis (Semiyaga et al., 2017a) .

Figure 3- 4: Sampling of FSS from the surface of septic tank using a scooping spoon (a) and (b)FS using improvised long-handled container.

3.3.2.2 Sample preparation

Before analysis, the scum samples were prepared by removing large extraneous materials that can affect analysis. This was done by passing the samples through a 5-mm sieve (Gold et al., 2017). An electric blender was used to homogenize the scum samples for evaluation of COD, TS, TVS, and dewatering extent. Since particle structure affects these characteristics, non-homogenized samples were used to determine the capillary suction time (CST) (Gold et al., 2017)

3.3.2.3 Sample analysis

The collected samples of both FSS and FS were analyzed for Electro conductivity (EC), Oxygen reduction potential (ORP), pH, density, Total Solids (TS), Total Volatile Solids (TVS), Moisture content(MC), Total Suspended Solids (TSS), Ortho-phosphates, Chemical Oxygen Demand (COD), Total Phosphorous, Dewaterability rate and extent were ascertained using techniques of Faecal sludge analysis (Velkushanova, Strande, Ronteltap, et al., 2021).

The pH, ORP, and EC were measured using the Hach HQ 30d flexi pH and EC meters respectively. The density was measured using the mass and volume measurement method where a 5 mL measuring spoon was used to scoop both FS and FSS into a crucible of determined weight. The weight of both the crucible and the known volume of either FS or FSS was determined from which the weight of samples was determined by subtraction, and the density determined by dividing the weight of the sample by the known volume.

By calculating the oven-dried sample's weight as a percentage of the wet sample volume and keeping it at 105 °C for 24 hours, the TS concentration was calculated gravimetrically. TVS is calculated as a percentage of TS by calculating the weight difference between the solids that were dried in an oven and the sample that was ignited in a muffle furnace for two hours at 550°C. By deducting the percentage of TS from 100%, the moisture content was found.

In order to determine TSS, a glass fiber filter, dried and pre-weighed was vacuum filtered through the measured volume of a sample that has been well mixed. After drying the filters and residue at 103–105 °C to a constant weight, the increase in filter weight indicated the total amount of suspended solids. The closed reflux colorimetric method was utilized to calculate COD using a COD reactor, Camlab 156 Hach and the readings were taken from a spectrophotometer (APHA/AWWA/WEF, 2014). Both Orthophosphates and Total Phosphorous were measured using the spectrophotometric method (APHA/AWWA/WEF, 2014).

3.3.3 Research Objective 3: The solid- liquid separation performance of FS and FSS

Centrifuged percent cake solids and capillary suction time (CST) were used to calculate the dewaterability extent and rate, respectively (Semiyaga et al., 2017a). As per the standard procedure, Using a CST instrument, CST values were measured three times (Type 304 M, Triton, England, UK) fitted with chromatography paper and an 18-mm reservoir funnel (APHA/AWWA/WEF, 2014). A centrifuge (MISTRAL1000 type, UK) was used to measure the cake solids (Semiyaga et al., 2017a). The 50 mL FS and FSS sample was centrifuged for 20 minutes at 3000 rpm (Jin et al., 2004). Following the standard procedure, the weights of the wet and oven-dried (105 0C) cakes were analyzed to determine the percent solids content (wet basis) in the centrifuged cake after the supernatant was decanted off (APHA/AWWA/WEF, 2014). To confirm the reproducibility of the experiment's findings, each sample was examined twice (Semiyaga et al., 2017a).

Figure 3-5: A capillary suction timer during the measurement the dewaterability rate of a sample.

3.3.4 Research Objective 4: The influence of FSS on the solid- liquid separation of FS

Data obtained from testing individual samples of FSS and FS were recorded and compiled. Correlations between the FS and FSS mixture were run against the physical chemical properties of the mixture. These were then compared with the correlations of the properties and dewaterability of FS alone to assess the influence of FSS on the properties and their overall influence on solid-liquid separation of FS.

Analysis of samples was done using the percentages of FSS against the different parameters measured. Their relationship was assessed using correlation analysis and visualized using scatter plots.

3.4 Data Analysis

Data from interviews, questionnaires and observations was manually entered and analyzed using STATA version 15, while analysis of both FSS and FS parameters was done using Microsoft Excel. Descriptive statistics (mean,median standard deviation and range) were used to describe the characteristics of FSS and FS. The influence of FSS on the solid- liquid separation of FS was assessed using the One-way Analysis of Variance (ANOVA) and Pearson's correlation coefficient (r) was utilized to assess the nature and magnitude of the association between dewaterability and the key contributing variables. Significant statistical correlations were were determinedat the 5 % level of significance.To ascertain whether FSS has any discernible impact on the solid-liquid separation of FS, linear regression analysis was employed.

3.5 Ethical considerations

The Department of Civil and Environmental Engineering, Faculty of Engineering, Kyambogo University provided an introduction letter to help with clearance from KCCA and Government Analytical Laboratory to grant approval and consent. During data collection, the participants were given information sheets explaining the study's objectives and this was translated to their preferred languages during engagement. Participants who gave their consent were informed about the study, and the respect and confidentiality of the participant were highly valued.

CHAPTER FOUR : RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents and discusses the findings of the study. It starts with the description of FSS from different onsite containment units and then proceeds to characterize the physico-chemical properties of FS and FSS.

4.2 Quantification of Faecal sludge scum from septic tanks

The depth of faecal sludge scum (FSS) from the containments in this study varied from none to 50cm, with a median value of 0.05mm. The median thickness of faecal sludge scum (FSS) from household establishments was 0.05 mm. Also, the median thickness of FSS obtained from public/commercial place and schools was 0.05 mm and that from schools was 0.07mm. Analysis of variance (Kruskal-walls) showed that the thickness of FSS from the different establishments was not statistically different (p=0.9275).

The scum depth in this study ranged from 2 to 18 % of the overall depth of FS in the containment (Figure 4-1 b). A higher depth was noted in household establishments especially multiple households, followed by single households compared to public/commercial and school septic tanks The allowable scum accumulation space during design of septic tanks is 30% (Mahon et al., 2022).

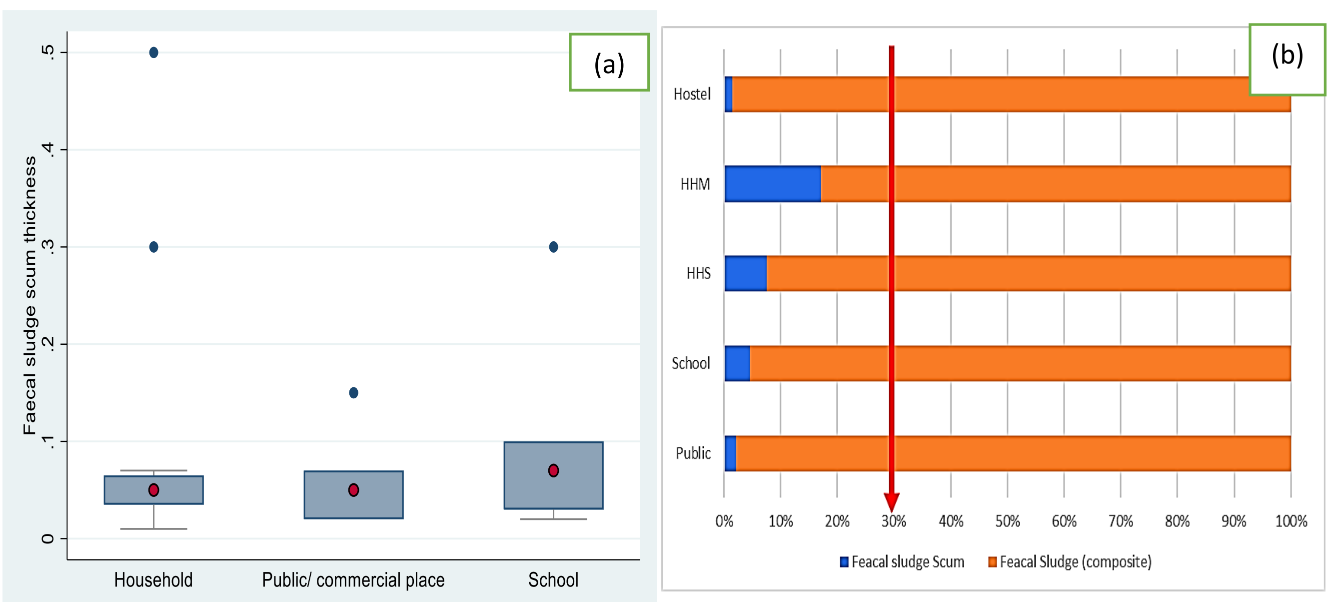

Figure 4.1: Occurrence of faecal sludge scum in septic tanks (a) thickness in different establishments (b) percentage depth of scum layer in faecal sludge.

The line inside the box indicates the median, the whiskers indicate the minimum and maximum, and the box itself represents 50% of the data points. The red line indicates the percentage depth of scum in design guidelines.

4.3 DET aspects

To understand the occurrence of FSS in the containments in this study, the demographic environmental and technological (DET) aspects of areas where the septic tanks were located was assessed as explained below.

4.3.1 Nature of establishment.

The nature of establishment was determined by its use and number of users. Establishments with fewer users had higher percentages of FSS and those with more users had lower values of percentages of FSS. Single households registered the highest mean FSS% of 9.63 and the mall had the lowest percentage of 0.50. With these results, it can be concluded that more users contributed to quicker filling of the septic tanks and subsequent emptying. Therefore, the percentage of FSS increases with age of sludge.

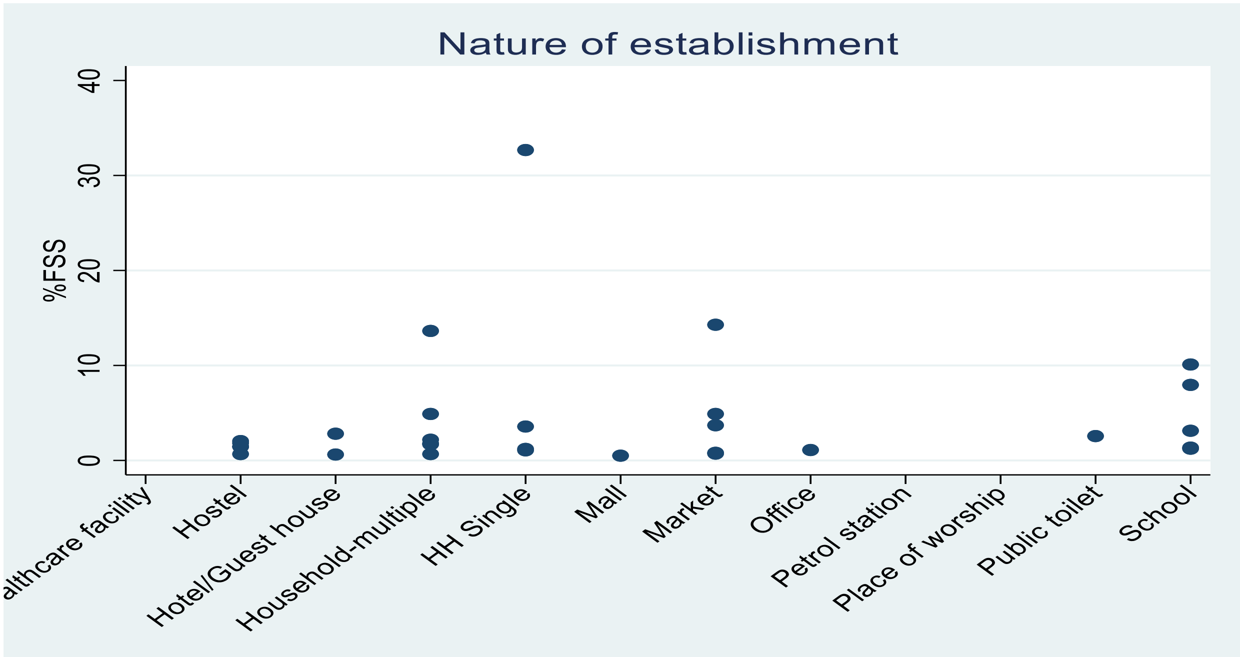

Figure 4.2: Occurrence of FSS vs nature of establishment

4.3.2 No of users and emptying time

As illustrated in Figure 4.3, the percentage of FSS reduces as the number of users increases. There was a weak negative correlation between the percentage of FSS and the number of users 0.5342

Also, the percentage of FSS increases with the time taken before emptying which affects the formation of more scum and vice versa. The mean percentage of FSS was 0.96 for FS that had been emptied two weeks before the study and 6.58 for that which had not been emptied for a year. It can therefore be concluded that the percentage of FSS increases with age of FS. It was reported that the height of the scum layer increased with time in the thickening tank (*Settling-Thickening Tanks and Enhancing Its Drying*, 2022).

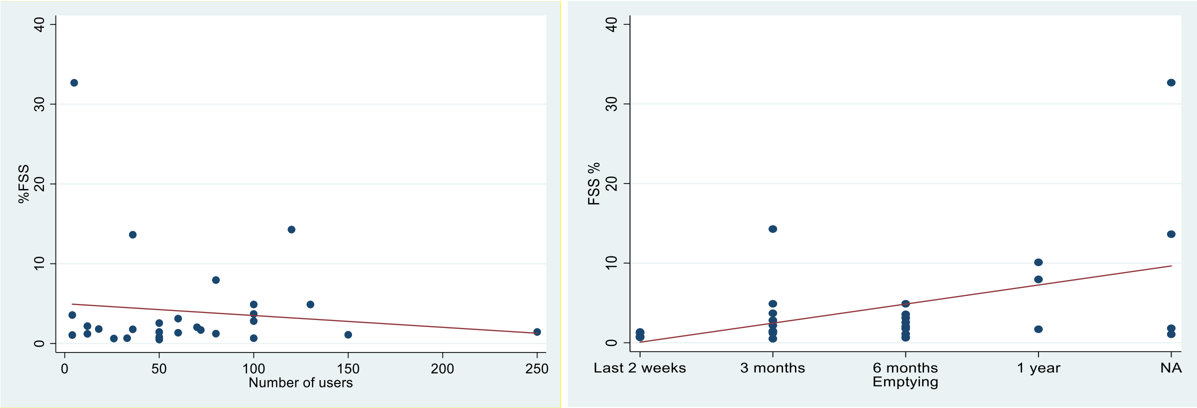

Figure 4.3: %FSS by number of users and emptying time

4.3.3 Flushing method

The method of flushing was found to mainly affect the amount of water used hence the moisture content of the FS. The findings in Table show that the percentage of FSS ranged from 0.6 to 32.7% (median=1.4) in cistern flush and 0.5 to 14.3% (median=1.8). Therefore, in a pour flush system where less water is used, the percentage of FSS in FS was found to be higher than when more water was used in the cistern flush method.

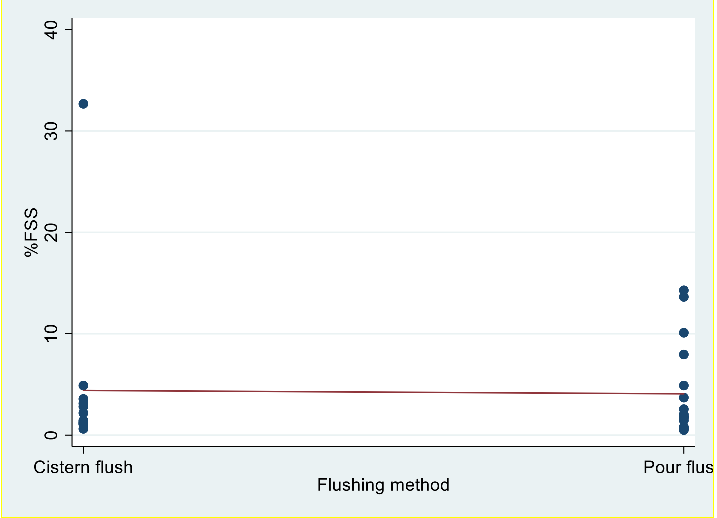

Figure 4.4: Flushing type and %FSS

Table 4.1: %FSS by type of flushing

Flush	Mean	Std. Dev.	Median	Minimum	Maximum
Cistern flush	4.41	8.58	1.45	0.63	32.68
Pour flush	4.08	4.58	1.82	0.50	14.29

4.3.4 Level of income

The level of income was associated with the percentage of faecal sludge scum in FS. As indicated in Figure 4.5 and Table 4.2 and the median percentage of FSS was 3.34% for FS collected from low income establishments and 1.77% FSS from middle-high income establishment.

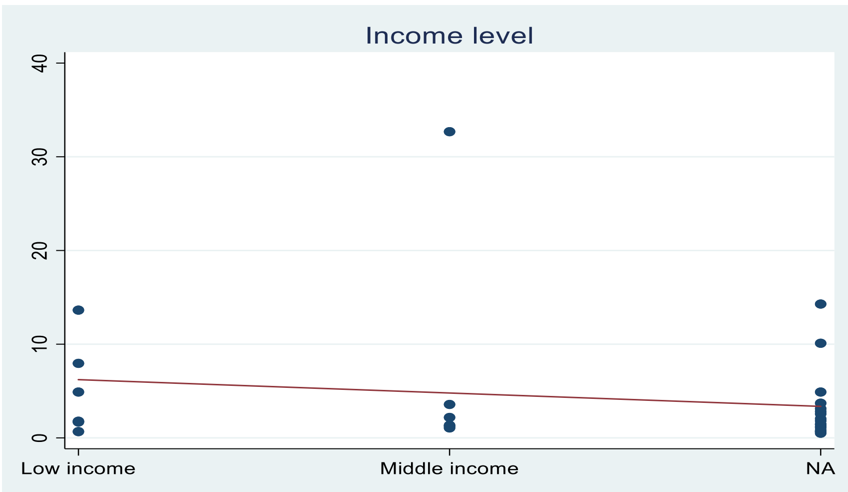

Figure 4.5: Level of income and %FSS

Table 4-2: %FSS by level of income

Income level	Mean	Std. Dev.	Median	Minimum	Maximum
NA	2.99	3.62	1.63	0.50	14.29
Low income	5.11	4.97	3.34	0.67	13.64
Middle-High income	7.01	12.61	1.77	1.06	32.68

4.4 Characteristics of Faecal Sludge Scum (FSS) and Faecal Sludge (FS)

4.4.1 Characteristics of FSS

Table 4.3 shows that the median TS of FSS was 12.77 g/l and ranged from 1.68 to 24.11 g/l. Higher concentrations of total solids in FS of 8.9–58 g/l were reported in (Seck et al., 2015). The median for TVS in FSS was 68.89 with a standard deviation of 13.0 and values ranging from 41.99 to 92.6. The median TSS was found to be 31500 with values ranging from 1270 to 288000. The median MC was 87.23 with values ranging from 75.89 to 98.32. The median of density was 1.242g/ml with a considerably low standard deviation of 0.159.

The findings in Table 4.1 show that the mean value of TP in FSS was 2207.0 with a very high standard deviation of 6810.8. This was higher than the content in FS. The average value of orthophosphates was 280.9 with a standard deviation of 461.0 and a range of 16 to 1523.

The EC values ranged from 16 to1523 with a mean of 126.0 and standard deviation of 401.4. ORP had values ranging from -187.6 to -30.2, and a median of -153.3. The mean pH was 7.7 with a significantly low standard deviation of 0.6 with values ranging from 5.6 to 8.39. There is no significant difference with the range of 6.7 to 8.5 that was reported by (Penn et al., 2018) while reviewing faecal sludge for wastewater and sanitation research. In addition, the median COD of FSS was 6100 with a range of 104.36 to 385000, and a very high standard deviation of 70679. The COD values of the samples were much higher than those reported in a review in which COD in faecal sludge was estimated to be between 46 and 96 g/cap.day (Penn et al., 2018).

Nitrogen values ranged from 0.23 to 1196.36 with a standard deviation of 214.0 and a median of 3.753. The mean of Magnesium was 470.1 and the SD was 801.1. The average value of Calcium was 322.9 and the SD was 410.0 with the lowest value being 0.32 and the highest as 1751.2.

The highest value of crude protein was 7.84 and the lowest was 2.01. The median was 4.74 with a standard deviation of 1.3. The average ash content was 27.8 and the SD was 12.3. Values of fat content varied from 2.6 to 11.11 with a median and SD of 3.86 and 1.82 respectively. Fibre content values had a mean of 10.2 and SD of 1.8. The average of the values for carbohydrate content was 44.7 and values ranged from 18.69 to 56.9.

Table 4.3: Characteristics of FSS

Parameter	**Units**	**FSS (n=31)**	
		Mean ± SD	Median (Range)
Total volatile solids (TVS)	% of TS	69.1 ± 13.0	68.89(41.99,92.6)
Chemical oxygen demand (COD)	mg/L	29225.03 ± 70679	6100(104.36, 385000)
Electrical Conductivity	µs/cm	126.0 ± 401.4	5.38(16,1523)
Total solids (TS)	g/L	11.0 ± 6.4	12.77(1.68,24.11)
Total Suspended Solids (TSS)	mg/L	46085.16 ± 54981.57	31500(1270,288000)

Density	g/ml	1.238 ± 0.159	1.242(0.964,1.603)
pH		7.7 ± 0.6	7.79(5.6,8.39)
Moisture content	%	89.0 ± 6.4	87.23(75.89, 98.32)
Total Phosphorus (TP)	mg/L	2207.0 ± 6810.8	472.6(83.6,37500)
Oxygen reduction potential (ORP)	mv	-149.9±31.9	-153.3(-187.6, -30.2)
Ortho phosphates (OP)	mg/L	280.9 ± 461.0	82 (16,1523)
Nitrogen (N)		43.6 ± 214.0	3.753 (0.23, 1196.36)
Magnesium (Mg)		470.1 ± 801.1	146.09 (2.45, 4068.75)
Calcium (Ca)		322.9 ± 410.0	192.33 (0.32, 1751.2)
		FSS (n=30)	
Crude protein		4.9 ± 1.3	4.74(2.01,7.84)
Ash content		27.8 ± 12.3	22.31(16.41,54.66)
Fat content		4.33± 1.82.3	3.86(2.6,11.11)
Fibre content		10.2 ± 1.8	10.4(6.52,15.05)
Carbohydrate content		44.7 ± 12.5	49.12(18.69, 56.9)

FSS- Faecal sludge scum; SD- Standard deviation

4.4.1.1 Color and texture quantification

Analysis of color and texture (Fig. 4-2) showed that most scum found in the containments of this study (77.4%) was a solid mass, with only 22.3% of the containments having a foaming watery scum layer. It was most likely to find a thick grey-black scum layer in every 5 of 10 containments within the study area compared to 23% that had scum made of fresh faecal matter although this difference was found not to be statistically significant (x^2 = 5.601, df=1, *p=0.467*). More solid yellow scum was noted in public facilities (25%) than schools (20%) and households (10%).

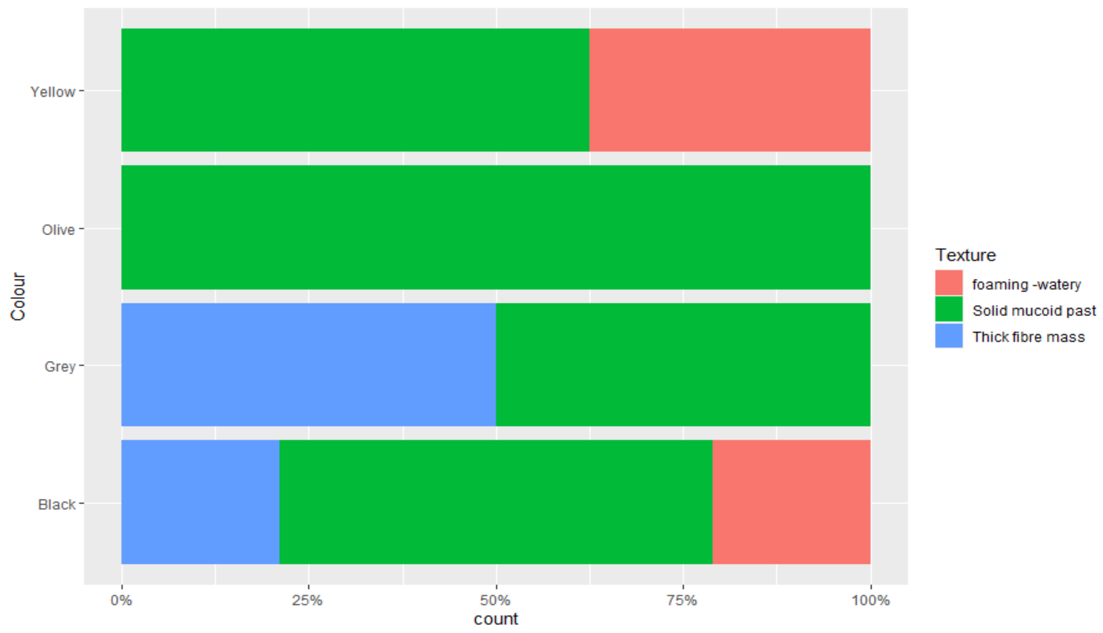

Figure 4.6: Color and texture of FS and FSS

4.4.2 Characteristics of FS

The findings indicate that the mean of TVS in Faecal sludge was 67.9 with a range of 18.89 to 99.17 and a standard deviation of 16.4. These findings show a small deviation from the mean TVS of 63.5 and SD of 11.5 that were found in a study on the dewaterability of faeces and its effects on the management of faeces in Ugandan urban slums (Semiyaga et al., 2017a). Unlike Fanyin-Martin et al., 2017 who recorded a mean TS as 4.68 and SD of 2.57 in pit latrines in a study conducted in Ghana, this study had the mean TS in FS was 3.7 with SD of 5.6 and a range of 0.08 to 27.08. It is important to note that the volume of TS in FS was lower than in FSS. The median TSS was found to be 3300 with a range of 20, to 9000 mg/L. In addition, the median MC was 98.49 with values ranging from 72.98 to 99.92. The median MC was reasonably higher than the MC in FSS. This study finds that the mean and standard deviation of density was 1.162g/ml and 0.149 g/ml, and values ranged from 0.8816 to 1.5005 g/ml. This is comparable to the range of 1.0 to 2.2 reported in an analysis for wastewater and sanitation research using synthetic human excrement and faecal sludge (Penn et al., 2018). The table shows that the density of FSS was even higher.

In Table 4.1, the mean value of Total Phosphorus in FS was 302.5 mg/L with a standard deviation of 360.4. This was much lower than the TP in FSS. A study conducted in Ghana showed that the mean phosphorous content was found to be 521.07 mg/L and a standard deviation of 207.58 in pit latrines (Fanyin-Martin et al., 2017). The average value of orthophosphates was 62.7 mg/L with a standard deviation of 79.6 and a range of 3.387 to 400. This was lower than an average concentration of 97.6 mg/L in the raw sludge in planted Sludge Drying Beds in Treatment of Faecal Sludge from Ouagadougou (Joceline et al., 2016).

Nitrogen values ranged from 1.87 to 14241.38 with a mean of 1194.1, standard deviation of 2971.9 and a median of 70.909. This differs from the computed mean and standard deviation of nitrogen in FS collected from private septage of 649.40 and 484.52mg/L respectively, in a study conducted in Ghana (Fanyin-Martin et al., 2017). The mean of Magnesium was 94.9 and the SD was 217.0. The average value of Calcium was 1205.1 and the SD was 4961.8 with the lowest value being 2.37 and the highest as 29429.25.

Table 4.4 indicates that the median of EC of FS was 6.23µs/cm and ranged from 2.23 to 2148 µs/cm. Despite the presence of outliers, most EC results in this study lie within the same range as 2.2 to 14.6µs/cm reported in a review of faeces sludge and synthetic human faeces for wastewater and sanitation research (Penn et al., 2018). The median EC of FSS was 5.38 and ranged from 0.19 to 1822. Also, the median Nitrogen content of FS was 70.909 with a range of 1.87 to 14241.38. The mean and median of the COD in FS was 4777.9 and1670 mg/l, and the values ranged from 29.76 to 25600 mg/l. Fanyin-Martin et al., 2017 reported that COD in FS was between 9495 and 45611mg/L in Ghana. The mean of COD in this study is also lower than the mean COD of 23,657.82 mg/l that was reported by Atwijukye et al., 2016 and much higher than the averaged COD of 9.3 in unthickened sludge in faecal sludge drying beds reported by Seck et al., 2015. ORP had values ranging from - 224.3 to -69.7, and a median of -160.5. The mean pH was 7.9 with a significantly low standard deviation of 0.5, with a range of 6.3 to 9.0. During the chemical characterization of faecal sludge conducted in Kumasi, the pH of the FS from all sources was found to range from near-neutral to slightly alkaline (Fanyin-Martin et al., 2017). A study conducted in Uganda also that found a pH range of faecal sludge of 6.84-9.1 (Atwijukye et al., 2016).

The study findings also indicate that the median carbohydrate content of FS was 47.45 and ranged from 15.12 to 68.79. Table 4-2 indicates that the median ash content of FS was 23.57 with a range of 7.54 to 53.73. With the highest value of crude protein as 8.93 and the lowest as 1.28, the median was 4.38 with a 7-point standard deviation. The average ash content was 24.9 and the SD was 11.2. Values of fat content varied from 1.62 to 9.62 with a median and SD of 4.59 and 1.5 respectively.

Fibre content values had a mean of 10.2 and SD of 1.8. The average of the values for carbohydrate content was 44.7 and values ranged from 18.69 to 56.9.

Table 4.4: Characteristics of FS

Parameter	**Units**	**FS (n=35)**	
		Mean ± SD	Median (Range)
Total volatile solids (TVS)		67.9 ± 16.4	68.68(18.89, 99.17)
Chemical oxygen demand (COD)		4777.9 ± 6730.8	1670(29.76,25600)
Electrical Conductivity		453.4 ±695.5	6.23(2.23, 2148)
Total solids (TS)		3.7± 5.6	1.51(0.08,27.08)
Total Suspended Solids (TSS)	mg/L	11701.86± 17124.16	3300(20,69000)
Density	g/ml	1.1542± 0.152	1.154 (0.882,1.500)
pH		7.9 ± 0.5	7.91(6.3, 9.04)
Moisture content		96.3 ± 5.6	98.49(72.98, 99.92)
Total Phosphorus (TP)		302.5 ± 360.4	149.08(12.022, 1225.8)
Oxygen reduction potential (ORP)		-161.5±28.8	-160.5(-224.3, -69.7)
Ortho phosphates (OP)		62.7 ± 79.6	29.54(3.387,400)
Nitrogen (N)		1194.1 ± 2971.9	70.909 (1.87,14241.38)
Magnesium (Mg)		94.9 ± 217.0	25.6(5.99,1195.3)
Calcium (Ca)		1205.1 ± 4961.8	95.58 (2.37, 29429.25)
		FS (n=33)	
Crude protein		4.6 ± 7	4.38 (1.28,8.93)
Ash content		24.9 ± 11.2	23.57 (7.54, 53.73)
Fat content		4.6 ± 1.5	4.59 (1.62,9.62)
Fibre content		10.0 ± 1.0	10.2(8.05,11.8)
Carbohydrate content		47.8 ± 11.1	47.45 (15.12,68.79)

FS: Faecal sludge; SD: Standard deviation

4.4.3 Comparison of characteristics of FS and FSS

The findings in Table 4.5 indicate that except for total volatile solids, pH, total phosphates, oxygen reduction potential, calcium, crude protein, ash content, fat content, fiber content and carbohydrate content, the characteristics of faecal sludge and faecal sludge scum were significantly different. The study shows that the chemical oxygen demand was significantly greater in FSS than in FS

(P=0.046). Similarly, total solids (TS) in FSS were higher than those in FS ($P<0.001$); the density of FSS was higher than that of FS, (P=0.032); FSS had more orthophosphates than FS (P=0.008); and FSS had a higher magnesium content than FS (P=0.010). On the hand, the conductivity of FS was higher than that of FSS (P=0.025); the moisture content of FS was higher than that of FSS ($P<0.001$); and FS had higher Nitrogen content than FSS (P=0.003).

Table 4.5: Variation in characteristics of FS and FSS

Parameter	**P-value**
Total volatile solids (TVS)	0.727
Chemical oxygen demand (COD)	***0.046***
Electrical Conductivity	***0.025***
Total solids (TS)	***<0.001***
pH	0.152
Moisture content	***<0.001***
Total Phosphates (TP)	0.103
Oxygen reduction potential (ORP)	0.125
Ortho phosphates (OP)	***0.008***
Nitrogen (N)	***0.036***
Magnesium (Mg)	***0.010***
Calcium (Ca)	0.328
Crude protein	0.426
Ash content	0.332
Fat content	0.557
Fibre content	0.555
Carbohydrate content	0.293

4.5 Solid-liquid separation performance of FS

Two (02) samples of FSS and 1 sample of FS were not dewatered because they were too solid. Their respective moisture contents were 84%, 90.13% and 89.32%, and their respective total solid contents were 15.85, 9.87 and 10.68. Alternative methods of dewatering samples with similar characteristics include belt filter press (BFP), centrifuge, screw and rotary press and pressure filters (Dentel & Qi, 2013). Table 4-3 shows that the capillary suction time (CST) in FSS and FS was significantly different (p=0.04). The capillary suction time was higher (163.5) in the faecal sludge scum sample than in the faecal sludge sample (59.5). This shows that the dewaterability rate of FSS was higher than that of FS. The mean cake solids in FS was 11.4% while that of FSS was 12.8%. While the higher percent cake solids of FSS indicate higher dewaterability extent of faecal sludge scum relative to faecal sludge, the dewaterability extent for FS and that of FSS were not significantly different (P=0.485) at the 5% level of significance. The box plots in Figure 4.7 show the graphical representation of the explained results.

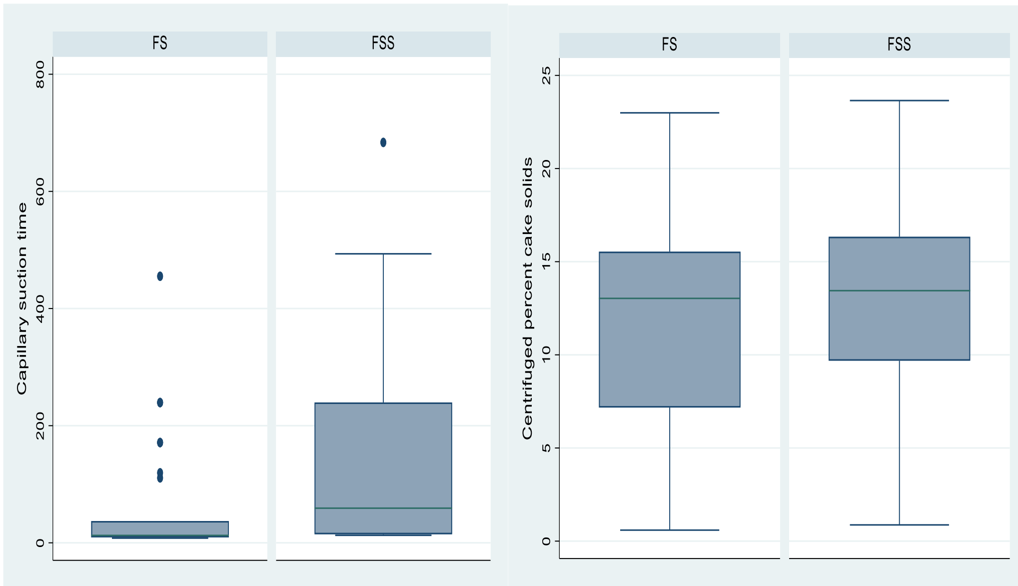

Figure 4.7: Box plots showing the dewaterability rate and extent of FS and FSS

The results in Table 4.6 show that faecal sludge scum (FSS) was less dewaterable and had a higher percentage of cake solids than faecal sludge (FS). The statistical analysis, however, indicates that the difference in dewaterability extent between FS and FSS was not statistically significant.

Table 4.6: Dewaterability rate and extent of FS and FSS

Descriptive	**Capillary suction time**		**% Cake solids**	
	FS	**FSS**	**FS**	**FSS**
Mean	59.5	163.5	11.4	12.8
Standard deviation	100.6	223.4	5.4	6.2
Frequency	31	12	27	12
P-value	***0.040***		0.485	

Furthermore, the results in the scatterplots in Figure 4.8 show that the capillary suction time and the percentage cake solids for both FS and FSS were positively correlated. However, the correlation was stronger in FS (r= 0.6174) than in FSS (r= 0.2431). The greater the percentage of cake solids in a sample, the higher the capillary suction time.

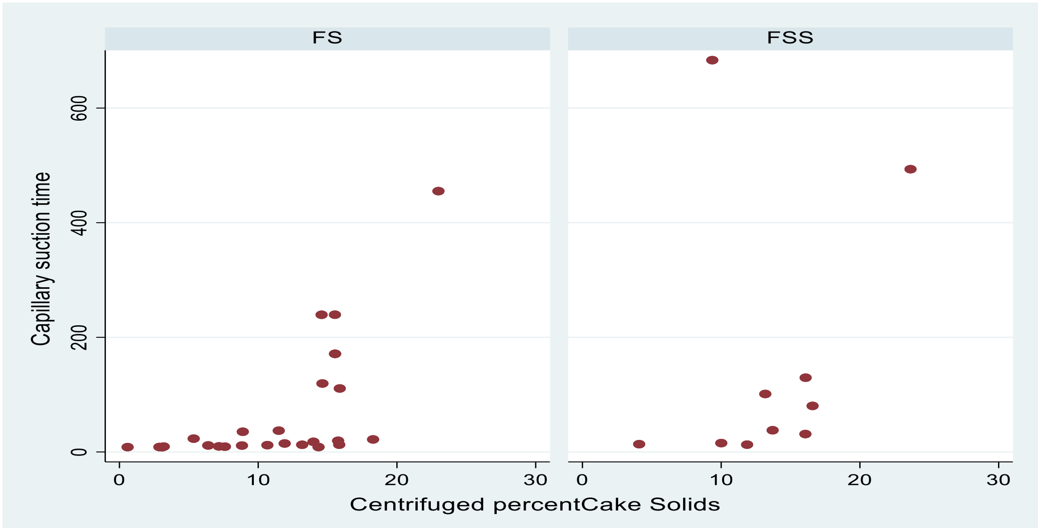

Figure 4.8: Plotted representation of capillary suction time vs centrifuged percent cake solids

4.6 Influence of FSS on the solid- liquid separation of FS

The influence of FSS on the solid-liquid separation of FS was assessed using correlation, which was found to be a weak positive association as shown in the scatter plot presented in Figure 4.9. However, the percent of faecal sludge scum in faecal sludge showed a stronger positive association with the capillary suction time (r= 0.3573) than its association with the percent cake solids was relatively weaker (r= 0.1164).

The amount of scum present in FS has a greater impact on the time it takes for water to be drawn out through capillary action than on the solids content of the dewatered sludge cake. As scum content increases, CST also tends to increase indicating slower dewatering. However, the scum has little influence on how solid or dry the final sludge cake becomes. In simpler terms, more scum in the sludge slows down the dewatering process but does not significantly affect the dryness of the resulting cake.

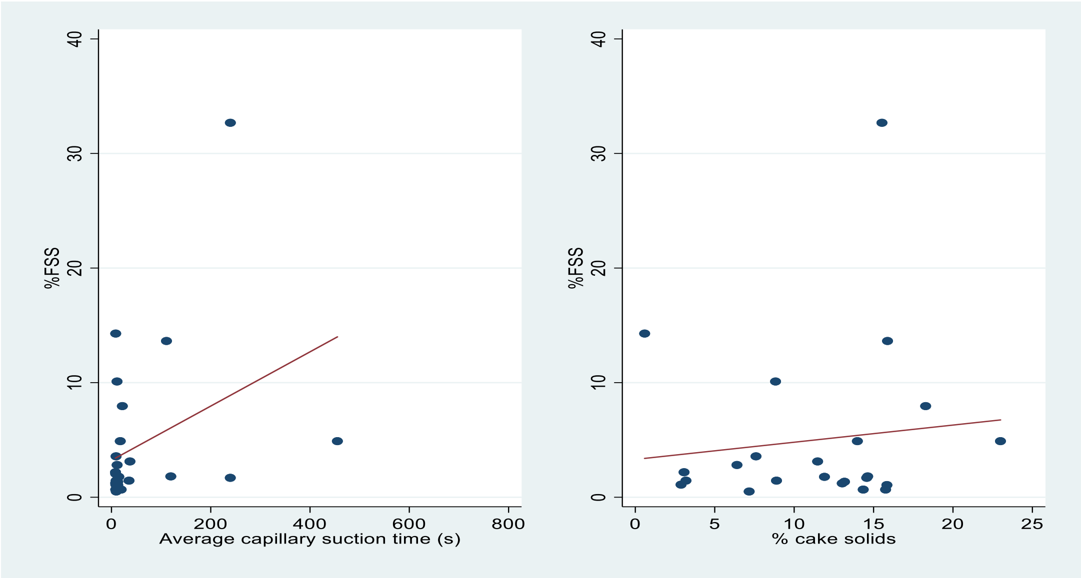

Figure 4.9: %FSS vs capillary suction time and percent cake solids

In the scatter plot shown in Figure 4.10, the findings demonstrate that the percentage of FSS was positively associated with the capillary suction time of FS. This implies that an increase in the percentage of FSS in FS would result in an increase in the capillary suction time. On the other hand, the association between quantity of faecal sludge and capillary suction time was significantly negative (r=-0.3245, p=0.0337). This implies that the average capillary suction time is not affected by the quantity of FS.

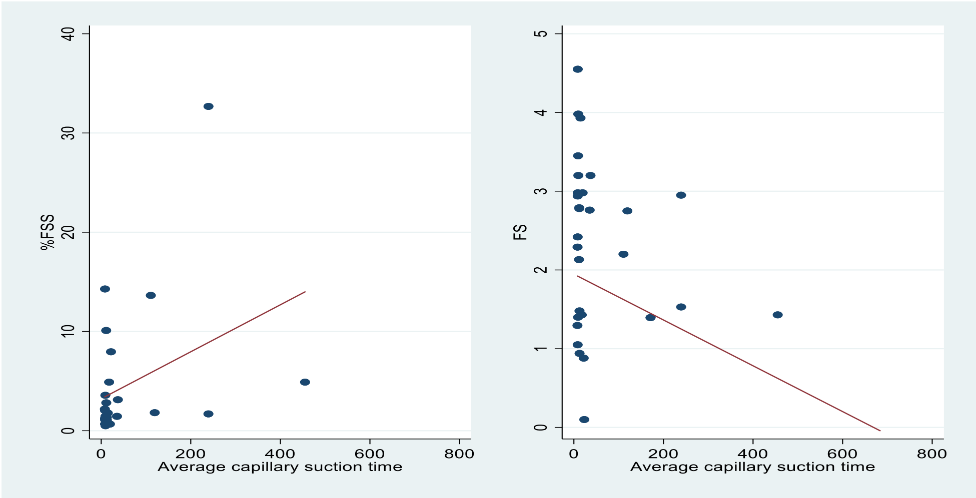

Figure 4.10: Relationship of %FSS and FS versus capillary suction time

In the scatter plot presented in Figure 4.11, the findings show that the percentage of FSS had a weak positive association with the percent cake solids of FS. This implies that an increase in the percentage of FSS in FS would result in slight increases in the percent cake solids formed. On the other hand, the association between the quantity of faecal sludge and the percent cake solids formed was negative (r= -0.2142). This implies that the percent cake solids formed is not determined by the quantity of FS.

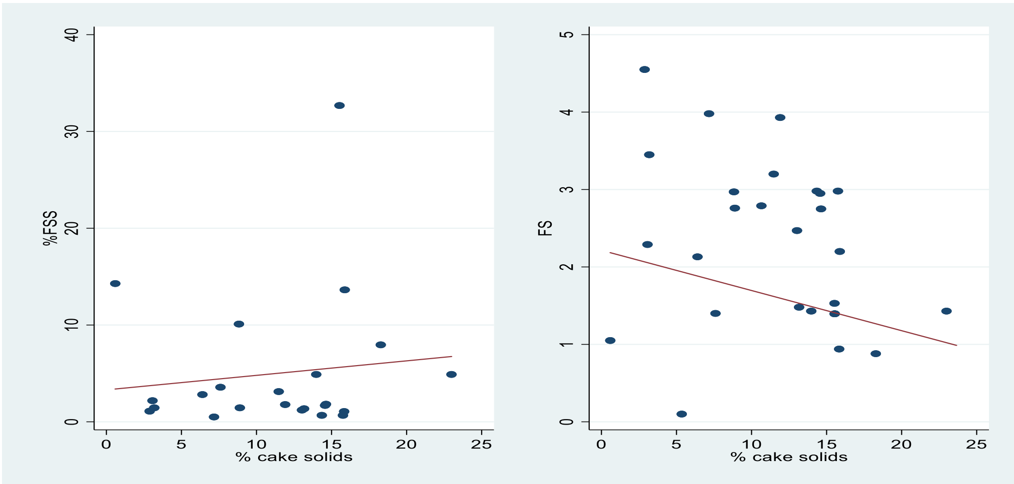

Figure 4.11: Relationship of %FSS and FS versus %cake solids

4.6.1 Physicochemical properties and Dewaterability rate of FS

The physicochemical properties FS were tested for their association with the dewaterability rate. The dewaterability rate was significantly associated with COD, TS, MC, OP, and sludge depth. The results in Table 4.7 indicate a strong positive correlation (r=0.550) between the chemical oxygen demand (COD) and the capillary suction time. Similarly, total solids (r=0.45) and orthophosphates (r=0.577) were found to have influence on the dewaterability rate. However, moisture content, N, Mg, Ca, and depth of sludge had a negative relationship on the dewaterability rate, which indicates that they were independent of each other.

Table 4.7: Correlation of physicochemical properties and dewaterability rate of FS

Parameter	Correlation coefficient	p-value
COD	0.550	<0.001
EC	-0.090	0.568
TS	0.450	0.003
MC	-0.450	0.003
Density	0.109	0.489
OP	0.577	<0.001
N	-0.061	0.699
Mg	-0.053	0.737

Ca	-0.074	0.635
Depth of FS	-0.325	0.034

4.6.2 Physicochemical properties and Dewaterability extent

Table 4.8 shows the relationship between the parameters and dewaterability extent. Total solids had a weak but significantly positive influence on the percent cake solids. Nitrogen and Magnesium had much weaker correlations (correlation coefficients of 0.1 and 0.144 respectively), but were not significant (p-values of 0.543 and 0.384 respectively). On the other hand, the moisture content had a weak negative but significant correlation with the percent cake solids. Therefore, only moisture content and total solids were found to have influence on the dewaterability extent of faecal sludge. The more MC in a sample, the less percent cake solids and the higher the TS, the higher the percent cake solids.

Table 4.8: Correlation of physicochemical properties and dewaterability extent of FS

Parameter	Correlation coefficient	p-value
COD	-0.199	0.225
EC	-0.240	0.142
TS	0.374	0.019
MC	-0.374	0.019
Density	0.026	0.876
OP	-0.205	0.211
N	0.100	0.543
Mg	0.144	0.384
Ca	-0.135	0.414
Depth of FS	-0.214	0.190

4.6.3 Association between physicochemical properties of faecal sludge and dewaterability rate

Using Pearson correlation coefficients, the correlation between the physicochemical characteristics of faecal sludge and the dewaterability rate was examined. The results in Table 4.9 indicate that the capillary section time was not correlated with the depth of sludge. The table indicates that there was a weak positive correlation between capillary suction time and the total volatile solids. Similarly, electrical conductivity showed a weak negative relationship with the capillary suction time of FS.

The results also show that the capillary suction time of FS had a very weak positive relationship with the pH while total phosphates showed a weak positive association with the capillary suction time which was significant at 5%. Oxygen reduction potential had a very weak negative correction with the capillary suction time of faecal sludge, but this correlation was not significant at the 5% level of significance. The results also show that density had a very weak positive association with the capillary suction time while Nitrogen content had a very weak negative relationship with the capillary suction time of FS.

Table 4.9 shows that Magnesium in FS content had a very weak negative relationship with the capillary suction time of FS. The dewaterability rate had a strong positive correlation with the chemical oxygen demand (r=0.705) and this association was significant at the 5% significance level (p<0.001).

Table 4.9 also shows that total solids had a strong positive relationship with the dewaterability rate (r=0.532). The results also indicate that the moisture content was negatively correlated with the dewaterability rate (r=-0.532) and this correlation was significant (p=0.002). There was a fairly strong positive correlation (r=0.634) between orthophosphates (OP) and the dewaterability rate which was significant at the 5% level of significance (p<0.001). Calcium had a very weak negative influence on the capillary suction time of faecal sludge and this association was not significant at 5%.

COD had a fairly strong positive association (r=0.696) with the dewaterability rate of FSS which was significant (p=0.012). Also, ORP was strongly correlated (r=0.804) with the dewaterability rate of FSS and the correlation was significant. Table 4.9 also shows that there was a significant (p=0.037) strong positive correlation (r=0.606) between TSS and the dewaterability rate.

Table 4.9: Correlation of physicochemical properties and dewaterability rate of FS and FSS

	FS		**FSS**	
Property	**Correlation coefficient, r**	**p-value**	**Correlation coefficient, r**	**p-value**
COD	**0.705**	***<0.001***	**0.696**	***0.012***
EC	-0.249	0.177	0.247	0.439
TS	**0.532**	***0.002***	0.269	0.397
MC	**-0.532**	***0.002***	-0.269	0.397
Density	0.049	0.793	0.021	0.948
OP	**0.634**	***<0.001***	0.511	0.089
N	-0.019	0.918	-0.219	0.495
MG	-0.047	0.801	-0.178	0.580
CA	-0.070	0.710	-0.187	0.560
ORP	-0.011	0.952	**0.804**	***0.002***

TP	**0.422**	***0.018***	0.261	0.412
TVS	0.310	0.090	0.408	0.189
TSS	**0.766**	***<0.001***	**0.606**	***0.037***
Protein	0.131	0.497	-0.035	0.914
Fat	0.061	0.755	0.012	0.972
Fibre	0.027	0.889	0.432	0.161
Ash	**-0.444**	***0.016***	-0.145	0.654
Carbohydrate	**0.424**	***0.022***	0.233	0.233

4.6.4 Association between physicochemical properties of faecal sludge and Dewaterbility extent of FS

The results in Table 4.10 indicate that the dewaterability extent was fairly correlated in a positive way with total solids (r=0.565) and this association was significant at the 5% significance level (p=0.002). The findings also show that the moisture content was negatively correlated with the dewaterability rate (r=-0.565) of faecal sludge and this correlation was significant (p=0.002). The dewaterability extent of FS was also significantly correlated with; TP (p=0.036), TVS (p=0.017) and TSS (p=0.008). The correlation coefficients between TP (r=0.406), TVS (r=0.454) and TSS (r=0.498) were positive which implied that the properties positively influenced the dewaterability extent of FS.

Table 4.10: Correlation of physicochemical properties and dewaterability extent of FS

Property	**Correlation coefficient, r**	**p-value**
COD	0.372	0.056
EC	-0.266	0.180
TS	**0.565**	***0.002***
MC	**-0.565**	***0.002***
Density	-0.185	0.356
OP	0.373	0.055
N	0.159	0.428
Mg	0.096	0.633
Ca	-0.144	0.474
ORP	0.167	0.404
TP	0.406	***0.036***
TVS	0.454	***0.017***
TSS	0.498	***0.008***
Protein	0.370	0.068
Fat	-0.131	0.533
Fibre	0.161	0.442
Ash	-0.227	0.274
Carbohydrate	0.190	0.362

Table 4.11 shows the associations between the physical-chemical properties of FSS and the dewaterability extent. The results indicate that of all the FSS properties, only TP had a significant (p=0.041) correlation with the dewaterability extent. TP had a negative correlation (r=-0.596) with the dewaterability extent of FSS.

Table 4.11: Correlation of FSS properties and dewaterbility extent

Property	**Correlation coefficient**	**P-value**
COD	-0.573	0.052
EC	-0.140	0.664
TS	-0.012	0.971
MC	0.012	0.971
Density	0.403	0.194
OP	-0.544	0.067
N	0.262	0.412
MG	0.182	0.571
CA	-0.301	0.342
ORP	-0.148	0.646
TP	-0.596	***0.041***
TVS	-0.517	0.085
TSS	-0.527	0.079
Protein	-0.234	0.488
Fat	0.564	0.071
Fibre	-0.061	0.859
Ash	-0.284	0.398
Carbohydrate	0.095	0.781

4.6.5 Relationship of %FSS, CST and EXT

The findings in Table 4.12 indicate that COD had a very weak positive association with percentage of FSS in FS and a weak negative association with the percent cake solids. However, it had a strong and significant positive relationship ((r=0.550, p<0.001) with the capillary suction time. The results in the table also reveal that EC was negatively linked to the % FSS, CST and EXT but the correlations were not significant.

TS had significant positive association with both capillary suction time (r=0.450, p=0.002) and the percent cake solids (r=0.374, p=0.019). MC had significant negative association with both capillary suction time (r=-0.450, p=0.002) and the percent cake solids (r=-0.374, p=0.019). Also, OP had a strong positive and significant correlation (r=0.577, p<0.001) with only the dewaterability rate. ORP was found to be significantly correlated with the dewaterability rate only.

The study findings show that only fat was significantly associated (r=0.595, p=0.001) with the %FSS.

Table 4.12: Correlation of properties with %FSS, dewaterbility rate and extent

Properties	%FSS		CST		EXT	
	r	**p-value**	**r**	**p-value**	**r**	**p-value**
COD	0.043	0.821	0.550*	***<0.001***	-0.199	0.225
EC	-0.321	0.084	-0.089	0.568	-0.240	0.142
TS	0.226	0.229	0.450*	***0.002***	0.374*	***0.019***
MC	-0.226	0.229	-0.450*	***0.002***	-0.374*	***0.019***
Density	0.091	0.632	0.109	0.488	0.026	0.876
OP	-0.051	0.790	0.577*	***<0.001***	-0.205	0.210
N	-0.182	0.337	-0.061	0.699	0.100	0.543
MG	-0.113	0.551	-0.053	0.737	0.143	0.384
CA	-0.048	0.800	-0.074	0.635	-0.135	0.414
ORP	-0.121	0.523	0.451*	***0.002***	0.061	0.712
TP	0.298	0.109	0.286	0.063	-0.242	0.138
TVS	-0.079	0.680	0.318*	***0.038***	0.246	0.131
TSS	0.162	0.392	0.661*	***<0.001***	-0.157	0.339
Protein	0.050	0.799	0.084	0.600	0.269	0.112
Fat	0.595*	***0.001***	0.056	0.728	0.173	0.313
Fibre	0.132	0.503	0.251	0.113	0.072	0.676
Ash	-0.115	0.560	-0.292	0.064	-0.241	0.156
Carbohydrate	0.027	0.891	0.289	0.067	0.153	0.374

*** Shows significance at p<.05**

4.7 Implications of this study

This study identifies variations between FS and FSS properties and their implications on dewatering performance. It highlights the impact of various factors on the composition of faecal sludge and faecal sludge scum and hence their dewaterability rates and extents. There were significant differences in the characteristics of FSS and FS as well as their dewaterability. FSS had higher dewaterability rate and extent values than FS. The capillary suction time of the FSS (163.5s) was higher than that of FS (59.5s). The mean cake solids in FS was 11.4% while that of FSS was 12.8%. Therefore, results in this study show that the presence of scum and its quantity in FS have an effect of on the dewaterability of faecal sludge.

The dewaterability of scum is highly influenced by the characteristics of FS. Parameters such as COD, ORP, fat, total solids (TS), and orthophosphates (OP) have a significant impact on capillary suction time (CST), with increases in these parameters generally leading to longer dewatering times. In contrast, moisture content (MC) shows an inverse relationship, where higher MC is associated with faster dewatering and shorter CST. This conclusion is based on the physiochemical properties of the sludge collected from septic tanks within Kampala district.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter summarizes the conclusions made from this study under each specific objectives and details the proposed recommendations.

5.2 Conclusions

Specific Objective 1: Quantification of FSS from different septic tanks.

This study focused on characterizing Faecal sludge scum and determining its influence on the dewaterability faecal sludge collected from septic tanks. The samples analyzed were collected from 32 household establishments, 24 public/commercial place establishments and 10 schools. Samples were collected from 31 Cistern flush sites and 35 pour flush sites. The median thickness of FS was 2.47 with a range of 0.1 to 4.55 while that of FSS was 0.08 with a range of 0.01 to 0.50. The mean thickness of FSS from household establishments was 1.29 with a standard deviation of 1.35. Relatedly, the mean thickness of FSS obtained from public/commercial place was 1.35 with standard deviation of 1.48. The mean thickness of FSS obtained from schools was 1.15 with 1.28 standard deviations. There was however no evidence to suggest the mean thickness of FSS from the different establishment units was statistically different ($p=0.9275$) at the 5% level of significance. The mean thickness of FSS from cistern flush sites was 1.24 with 1.29 standard deviations while that of FSS obtained from pour flush sites was 1.33 with 1.45 standard deviations.

Specific Objective 2: Characterization of the physical and chemical properties of FSS and FS.

The study revealed that faecal sludge (FS) and faecal sludge scum (FSS) exhibit distinct physicochemical characteristics, with statistically significant differences observed in most parameters analyzed. Notably, parameters such as total volatile solids, pH, total phosphates, oxidation-reduction potential (ORP), calcium, crude protein, ash content, fat content, fiber content, and carbohydrate content did not differ significantly between FS and FSS. However, significant differences were found in key treatment-relevant parameters, indicating that FSS is compositionally distinct from the underlying sludge.

The chemical oxygen demand (COD) of FSS was significantly higher than that of FS ($p = 0.046$), suggesting a greater concentration of biodegradable organic matter in the scum. Similarly, total solids (TS) and density were significantly higher in FSS than in FS ($p < 0.001$ and $p = 0.032$, respectively), implying that FSS is more concentrated and physically denser. Higher orthophosphate ($p = 0.008$) and magnesium ($p = 0.010$) levels in FSS further point to elevated nutrient accumulation in the scum layer.

In contrast, FS demonstrated significantly higher electrical conductivity ($p = 0.025$), moisture content ($p < 0.001$), and nitrogen content ($p = 0.003$) compared to FSS. These differences suggest that FS contains a greater proportion of dissolved salts and retains more water, which may influence its dewaterability and treatment requirements.

Overall, these findings underscore the importance of treating FSS as a distinct fraction of faecal sludge in terms of characterization and management. Understanding these differences is crucial for optimizing treatment processes, particularly in systems where scum accumulation is common and may affect operational performance and efficiency.

Specific Objective 3: Investigation of the solid- liquid separation performance of FS

The study demonstrated that faecal sludge (FS) and faecal sludge scum (FSS) exhibit statistically significant differences in their dewaterability rates. FSS samples recorded a substantially higher mean capillary suction time (CST) of 163.5 seconds compared to 59.5 seconds for FS, indicating slower water release from FSS during dewatering. Despite this, FSS exhibited a slightly higher mean cake solids content (12.8%) than FS (11.4%), suggesting a marginally better dewaterability extent. However, this difference was not statistically significant ($p = 0.485$) at the 5% level, indicating that the overall dryness of the sludge cake produced was comparable between the two.

Correlation analysis revealed that the dewaterability rate of FS was significantly and positively associated with COD, TS, OP, and TP, suggesting that these parameters play a key role in influencing how quickly FS can be dewatered. Conversely, moisture content (MC) was negatively correlated with the dewaterability rate, implying that higher water content in FS slows down the dewatering process. Additionally, the dewaterability extent measured by cake solids content was positively and significantly correlated with both TS and TP, further emphasizing the importance of these parameters in achieving a drier sludge cake. The relationship between MC and dewaterability extent, while negative, was relatively weak.

These findings highlight the complex interplay between sludge characteristics and dewatering performance, suggesting that targeted management of key parameters such as solids content and nutrient concentrations could improve the efficiency of sludge treatment processes.

Specific Objective 4: Investigate the influence of FSS on the solid- liquid separation of FS.

Findings established that nitrogen (N) and magnesium (Mg) exhibited weak and statistically insignificant correlations with the dewaterability extent of faecal sludge (FS), suggesting a limited role in influencing the final solids content of the dewatered sludge cake. In contrast, moisture content (MC) and total solids (TS) were found to significantly impact dewaterability extent. Specifically, higher moisture content was associated with lower percentages of cake solids, while increased total solids corresponded to higher cake solids content. This implies that moisture and solids concentrations are key determinants of how effectively FS can be dewatered.

With respect to dewaterability rate measured using capillary suction time (CST), the results revealed significant associations with several physicochemical parameters, including COD, TS, MC, OP, and sludge depth. COD, TS, and OP showed strong positive correlations with CST, indicating that increased concentrations of these parameters lead to a slower dewatering rate. This suggests that high organic and solid loads, as well as the presence of oil and grease, increase resistance to water removal. On the other hand, MC, N, Mg, calcium (Ca), and sludge depth were negatively correlated with CST, indicating an inverse relationship. However, the negative correlations particularly those involving N, Mg, and Ca were not strong, suggesting that these parameters are relatively independent and exert minimal influence on the dewaterability rate of FS.

These findings underscore the importance of specific sludge characteristics particularly TS, COD, OP, and MC in determining both the rate and extent of faecal sludge dewatering. Targeted control and conditioning of these parameters could lead to improved sludge handling and treatment efficiency.

5.3 Recommendations

From findings: FSM systems should integrate targeted strategies for the separate collection and treatment of faecal sludge scum (FSS) and faecal sludge (FS). The significant differences in key physicochemical properties suggest that treating these components as a single entity may reduce the overall efficiency of dewatering and drying processes. Therefore, future designs of sludge treatment facilities should incorporate specialized infrastructure or processes to address the distinct characteristics of FSS. Additionally, the negative correlation between moisture content and dewaterability underscores the need for pre-treatment technologies that enhance water release, such as the use of coagulants, flocculants, or mechanical thickening systems. Lastly, research into the resource recovery potential of FSS given its high organic and nutrient load should be prioritized to support the development of sustainable and circular sanitation solutions.

To address policy: Ministries, Departments, and Agencies (MDAs) should strengthen regulation concerning the disposal and management of FS. The presence of environmentally sensitive substances such as nitrogen, magnesium, TP, and orthophosphates (OP) highlights the need for stringent controls to prevent their accumulation and adverse impacts on environmental and public health. These institutions should actively support and invest in research initiatives aimed at investigating FSS. Providing adequate funding, infrastructure, and technical support to researchers will facilitate the generation of knowledge necessary for effective and sustainable FSM. Such research could also inform innovative approaches to resource recovery from FS and FSS, contributing to the development of circular sanitation solutions and environmentally sound waste management practices.

For further research: While this study provides valuable insights into the physicochemical characteristics and dewaterability of FS and FSS, further research will deepen understanding of additional influencing factors. Future studies should explore the biological properties of FS and FSS, including microbial activity, as well as the effects of temperature and environmental conditions on scum formation and behavior within containment units. Investigating these parameters will help elucidate the mechanisms underlying scum accumulation and transformation, which remain inadequately understood. Additionally, there is a need to examine how these biological and environmental factors interact with physical and chemical characteristics to influence dewatering performance. Particular attention should be given to identifying the specific mechanisms by which sludge and scum properties affect water retention and release, in order to guide the design of more efficient and cost-effective treatment technologies. Such research is critical for optimizing faecal sludge management practices and enhancing resource recovery potential.

5.4 Limitations

The gap in the participants' knowledge on the accurate number of users per establishment, knowledge of emptying cycle and other DET factors may have introduced potential biases in the data collected thereby influencing the accuracy and reliability of the findings and conclusions drawn from this study.

The study solely focused on faecal sludge samples collected from only septic tanks and this may limit the full understanding of the physiochemical characteristics of FSS that affect dewaterability of FS.

REFERENCES

Adhikari, J. R., & Lohani, S. P. (2019). Design, installation, operation and experimentation of septic tank–UASB wastewater treatment system. *Renewable Energy*, *143*, 1406–1415.

Ahmed, I., Ofori-Amanfo, D., Awuah, E., & Cobbold, F. (2019). 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. *Journal of Renewable Energy*, *2019*, 1–11. https://doi.org/10.1155/2019/8696058

Akumuntu, J. B., Wehn, U., Mulenga, M., & Brdjanovic, D. (2017). Enabling the sustainable Faecal Sludge Management service delivery chain—A case study of dense settlements in Kigali, Rwanda. *International Journal of Hygiene and Environmental Health*, *220*(6), 960–973. https://doi.org/10.1016/j.ijheh.2017.05.001

Andrade, C. F., Sperling, M. Von, & Manjate, E. S. (2017). Treatment of septic tank sludge in a vertical flow constructed wetland system. *Engenharia Agrícola*, *37*, 811–819.

APHA/AWWA/WEF. (2014). APHA (2005), Standard Methods for the Examination of Water and Wastewater, Washington DC: American Public Health Association. Ahmad, SR, and DM Reynolds (1999), Monitoring of water quality using fluorescence technique: Prospect of on-line process control,. *Dissolved Oxygen Dynamics and Modeling-A Case Study in A Subtropical Shallow Lake*, *217*(1–2), 95.

Atwijukye, O., Nimanya, C., Sugden, S., Pillay, S., Otaka, G., & Pietruschka, B. (2016). Development of low-cost decentralised faecal sludge treatment system for resource recovery. *Ensuring Availability and Sustainable Management of Water and Sanitation for All*, 1–6.

Basamykina, A., Kharlamova, M., & Mada, S. Y. (2020). Dewatering as a primary treatment of faecal sludge in individual residential sector (a technologies review). *E3S Web of Conferences*, *169*. https://doi.org/10.1051/e3sconf/202016902008

Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, I., Mbéguéré, M., & Strande, L. (2013). *Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso*.

Berendes, D. M., Sumner, T. A., & Brown, J. M. (2017). Safely Managed Sanitation for All Means

Faecal Sludge Management for at Least 1.8 Billion People in Low and Middle Income Countries. *Environmental Science and Technology*, *51*(5), 3074–3083. https://doi.org/10.1021/acs.est.6b06019

Bolto, B., & Gregory, J. (2007). Organic polyelectrolytes in water treatment. *Water Research*, 41(11), 2301–2324. https://doi.org/10.1016/j.watres.2007.03.012

Bounds, T. R. (1997). Design and performance of septic tanks. *ASTM Special Technical Publication*, *1324*, 217–234.

Butte, G., Niwagaba, C., & Nordin, A. (2021). Assessing the microbial risk of faecal sludge use in Ugandan agriculture by comparing field and theoretical model output. *Water Research*, *197*, 117068. https://doi.org/10.1016/j.watres.2021.117068

Chandana, N., & Rao, B. (2022). A critical review on sludge management from onsite sanitation systems: A knowledge to be revised in the current situation. *Environmental Research*, *203*(April 2021), 111812. https://doi.org/10.1016/j.envres.2021.111812

Changara, M. C., Bangira, C., Sanyika, W. T., & Misi, S. N. (2018). Characterisation of pit latrine sludge from Shackleton, a Peri-urban residential area of Zimbabwe. *Journal of Water Sanitation and Hygiene for Development*, *8*(3), 568–577. https://doi.org/10.2166/washdev.2018.041

Cockrell, P. (2011). *2011 Water Environment & Technology All rights reserved*. *April*, 48–53. https://doi.org/https://www.jstor.org/stable/i40159976

Cofie, O. O., Agbottah, S., Strauss, M., Esseku, H., Montangero, A., Awuah, E., & Kone, D. (2006). Solid-liquid separation of faecal sludge using drying beds in Ghana: Implications for nutrient recycling in urban agriculture. *Water Research*, *40*(1), 75–82. https://doi.org/10.1016/j.watres.2005.10.023

Delaire, C., Peletz, R., Haji, S., Kones, J., Samuel, E., Easthope-Frazer, A., Charreyron, E., Wang, T., Feng, A., Mustafiz, R., Faria, I. J., Antwi-Agyei, P., Donkor, E., Adjei, K., Monney, I., Kisiangani, J., MacLeod, C., Mwangi, B., & Khush, R. (2021). How Much Will Safe Sanitation for all Cost? Evidence from Five Cities. *Environmental Science and Technology*, *55*(1), 767–777. https://doi.org/10.1021/acs.est.0c06348

Dempsey, B. A., Wilderer, P. A., & Reuter, M. (2018). Sludge dewatering in wastewater treatment: A review. *Journal of Environmental Engineering*, 144(5), 04018019. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001363

Dentel, S. K., & Qi, Y. (2013). 3.12 Management of Sludges, Biosolids, and Residuals. *Comprehensive Water Quality and Purification, 3*, 223–243. https://doi.org/10.1016/B978-0-12-382182-9.00049-9

Dentel, S. K., & Qi, Y. (2014). Management of Sludges, Biosolids, and Residuals. In *Comprehensive Water Quality and Purification* (Vol. 3, pp. 223–243). Elsevier. https://doi.org/10.1016/B978-0-12-382182-9.00049-9

Diener, S., Semiyaga, S., Niwagaba, C. B., Muspratt, A. M., Gning, J. B., Mbéguéré, M., Ennin, J. E., Zurbrugg, C., & Strande, L. (2014). A value proposition: Resource recovery from faecal sludge - Can it be the driver for improved sanitation? *Resources, Conservation and Recycling*, *88,* 32–38. https://doi.org/10.1016/j.resconrec.2014.04.005

Eliyan, C., Vinnerås, B., Zurbrügg, C., Koottatep, T., Sothea, K., & McConville, J. (2022). Factors influencing physicochemical characteristics of faecal sludge in Phnom Penh, Cambodia. *Journal of Water Sanitation and Hygiene for Development*, *12*(1), 129–140. https://doi.org/10.2166/washdev.2021.193

Fanyin-Martin, A., Tamakloe, W., Antwi, E., Ami, J., Awarikabey, E., Apatti, J., Mensah, M., & Chandran, K. (2017). Chemical characterization of faecal sludge in the Kumasi metropolis, Ghana. *Gates Open Research*, *1*, 12. https://doi.org/10.12688/gatesopenres.12757.1

Fuhrimann, S., Winkler, M. S., Kabatereine, N. B., Tukahebwa, E. M., Halage, A. A., Rutebemberwa, E., Medlicott, K., Schindler, C., Utzinger, J., & Cissé, G. (2016). Risk of Intestinal Parasitic Infections in People with Different Exposures to Wastewater and Faecal Sludge in Kampala, Uganda: A Cross-Sectional Study. *PLoS Neglected Tropical Diseases*, *10*(3), 1–19. https://doi.org/10.1371/journal.pntd.0004469

Fuhrimann, S., Winkler, M. S., Schneeberger, P. H. H., Niwagaba, C. B., Buwule, J., Babu, M., Medlicott, K., Utzinger, J., & Cissé, G. (2014). Health risk assessment along the wastewater and faecal sludge management and reuse chain of Kampala, Uganda: a visualization.

Geospatial Health, *9*(1), 241. https://doi.org/10.4081/gh.2014.21

Ge, D., Yuan, H., Xiao, J., & Zhu, N. (2019). Insight into the enhanced sludge dewaterability by tannic acid conditioning and pH regulation. *Science of the Total Environment*, *679*, 298–306. https://doi.org/10.1016/j.scitotenv.2019.05.060

Gold, M., Harada, H., Therrien, J. D., Nishida, T., Cunningham, M., Semiyaga, S., Fujii, S., Dorea, C., Nguyen, V. A., & Strande, L. (2018). Cross-country analysis of faecal sludge dewatering. *Environmental Technology (United Kingdom)*, *39*(23), 3077–3087. https://doi.org/10.1080/09593330.2017.1374472

Gold, M., Harada, H., Therrien, J., & Nishida, T. (2017). Cross-country analysis of faecal sludge dewatering. *Environmental Technology*, *0*(0), 1. https://doi.org/10.1080/09593330.2017.1374472

Hafford, L. M., Ward, B. J., Weimer, A. W., & Linden, K. (2018). Faecal sludge as a fuel: Characterization, cofire limits, and evaluation of quality improvement measures. *Water Science and Technology*, *78*(12), 2437–2448. https://doi.org/10.2166/wst.2019.005

Harada, H., Strande, L., & Fujii, S. (2016). Challenges and Opportunities of Faecal Sludge Management for Global Sanitation. *Towards Future Earth: Challenges and Progress of Global Environmental Studies*, 81–100. https://www.eawag.ch/fileadmin/Domain1/Abteilungen/sandec/publikationen/EWM/General_FSM/challenges_opportunities_fsm_global.pdf

Harper, J., Bielefeldt, A., Javernick-Will, A., Dickinson, K., Veasna, T., Kozole, T., & Nicoletti, C. (2021). Household Preferences for Rural Faecal Sludge Management Services in Cambodia: A Discrete Choice Experiment. *Environmental Science and Technology*, *55*(3), 1832–1841. https://doi.org/10.1021/acs.est.0c04636

Houghton, J. I., Quarmby, J., & Stephenson, T. (2000). The impact of digestion on sludge dewaterability. *Process Safety and Environmental Protection*, *78*(2), 153–159. https://doi.org/10.1205/095758200530547

Jin, B., Wilén, B.-M., & Lant, P. (2004). Impacts of morphological, physical and chemical properties of sludge flocs on dewaterability of activated sludge. *Chemical Engineering*

Journal, *98*(1–2), 115–126.

Joceline, S. B., Koné, M., Yacouba, O., & Arsène, Y. H. (2016). Planted Sludge Drying Beds in Treatment of Faecal Sludge from Ouagadougou: Case of Two Local Plant Species. *Journal of Water Resource and Protection*, *08*(07), 697–705. https://doi.org/10.4236/jwarp.2016.87057

Junglen, K., Rhodes-Dicker, L., Ward, B. J., Gitau, E., Mwalugongo, W., Stradley, L., & Thomas, E. (2020). Characterization and prediction of Faecal sludge parameters and settling behavior in informal settlements in Nairobi, Kenya. *Sustainability (Switzerland)*, *12*(21), 1–14. https://doi.org/10.3390/su12219040

Klingel, F., Montangero, A., Koné, D., & Strauss, M. (2002). Faecal sludge management in developing countries. *A Planning Manual. EAWAG: Swiss Federal Institute for Environmental Science and Technology SANDEC: Department for Water and Sanitation in Developing Countries*.

Krueger, B. C., Fowler, G. D., & Templeton, M. R. (2021). Critical analytical parameters for faecal sludge characterisation informing the application of thermal treatment processes. *Journal of Environmental Management*, *280*. https://doi.org/10.1016/j.jenvman.2020.111658

Lugali, Y., Nimanya, C., Achiro, B., Maiteki, J., & Asimwe, J. (2022). Faecal sludge briquettes production as a viable business in Kampala: a case study of a partnership between Water for People and National Water and Sewerage Corporation. *International Journal of Biological and Chemical Sciences*, *15*(7), 66–75. https://doi.org/10.4314/ijbcs.v15i7.7s

Mahon, J. Mac, Knappe, J., & Gill, L. W. (2022). Sludge accumulation rates in septic tanks used as part of the on-site treatment of domestic wastewater in a northern maritime temperate climate. *Journal of Environmental Management*, *304*(July 2021), 114199. https://doi.org/10.1016/j.jenvman.2021.114199

McConville, J. R., Kvarnström, E., Maiteki, J. M., & Niwagaba, C. B. (2019). Infrastructure investments and operating costs for Faecal sludge and sewage treatment systems in Kampala, Uganda. *Urban Water Journal*, *16*(8), 584–593. https://doi.org/10.1080/1573062X.2019.1700290

Metcalf, L., & Eddy, H. P. (2003). *Wastewater engineering–treatment and reuse, 4th edn. Handbook*. McGraw-Hill, New York.

Mrimi, E. C., Matwewe, F. J., Kellner, C. C., & Thomas, J. M. (2020). Safe resource recovery from faecal sludge: Evidence from an innovative treatment system in rural Tanzania. *Environmental Science: Water Research and Technology*, *6*(6), 1737–1748. https://doi.org/10.1039/c9ew01097a

Muspratt, A. M., Nakato, T., Niwagaba, C., Dione, H., Kang, J., Stupin, L., Regulinski, J., Mbéguéré, M., & Strande, L. (2014). Fuel potential of faecal sludge: Calorific value results from Uganda, Ghana and Senegal. *Journal of Water Sanitation and Hygiene for Development*, *4*(2), 223–230. https://doi.org/10.2166/washdev.2013.055

Nikiema, J., Cofie, O., & Impraim, R. (2014). Technological options for safe resource recovery from Faecal sludge. In *Technological options for safe resource recovery from Faecal sludge*. https://doi.org/10.5337/2014.228

Novak, J. T., & O'Brien, J. H. (1975). Polymer conditioning of chemical sludges. *Journal (Water Pollution Control Federation)*, 2397–2410.

Novozymes. (2021). *A quick and easy guide to septic systems. Take a closer look at how septic tanks work*.

Otoo, M., Drechsel, P., & Hanjra, M. A. (2015). Wastewater. In P. Drechsel, M. Qadir, & D. Wichelns (Eds.), *Wastewater: Economic Asset in an Urbanizing World*. Springer Netherlands. https://doi.org/10.1007/978-94-017-9545-6

Pan, J. R., Huang, C., Cherng, M., Li, K.-C., & Lin, C.-F. (2003). Correlation between dewatering index and dewatering performance of three mechanical dewatering devices. *Advances in Environmental Research*, *7*(3), 599–602.

Parkinson, J., Luthi, C., & Walther, D. (2014). Sanitation 21. *Thinking*, *September*.

Penn, R., Ward, B. J., Strande, L., & Maurer, M. (2018). Review of synthetic human faeces and faecal sludge for sanitation and wastewater research. *Water Research*, *132*, 222–240. https://doi.org/10.1016/j.watres.2017.12.063

Philip, H., Maunoir, S., Rambaud, A., & Philippi, L. S. (1993). Septic tank sludges: accumulation rate and biochemical characteristics. *Water Science and Technology*, *28*(10), 57–64.

Rohilla, S. K., Agyenim, F. B., Luthra, B., Padhi, S. K., Quashie, A. S., & Yada, A. (2019). Integrated Wastewater and Faecal Sludge Management for Ghana Integrated and Faecal Sludge Management. *Draft Guidelines*.

Sam, S. B., Ward, B. J., Niederdorfer, R., Morgenroth, E., & Strande, L. (2022). Elucidating the role of extracellular polymeric substances (EPS) in dewaterability of Faecal sludge from onsite sanitation systems, and changes during anaerobic storage. *Water Research*, *222*, 118915.

Samal, K., Moulick, S., Mohapatra, B. G., Samanta, S., Sasidharan, S., Prakash, B., & Sarangi, S. (2022). Design of faecal sludge treatment plant (FSTP) and availability of its treatment technologies. *Energy Nexus*, *7*(March), 100091. https://doi.org/10.1016/j.nexus.2022.100091

Sarkar, B., Mandal, S., Tsang, Y. F., Vithanage, M., Biswas, J. K., Yi, H., Dou, X., & Ok, Y. S. (2019). Sustainable sludge management by removing emerging contaminants from urban wastewater using carbon nanotubes. In *Industrial and Municipal Sludge: Emerging Concerns and Scope for Resource Recovery*. Elsevier Inc. https://doi.org/10.1016/B978-0-12-815907-1.00024-6

Schoebitz, L., Bischoff, F., Lohri, C. R., Niwagaba, C. B., Siber, R., & Strande, L. (2017). GIS analysis and optimisation of faecal sludge logistics at City-Wide Scale in Kampala, Uganda. *Sustainability (Switzerland)*, *9*(2), 1–16. https://doi.org/10.3390/su9020194

Seck, A., Gold, M., Niang, S., Mbéguéré, M., Diop, C., & Strande, L. (2015). Faecal sludge drying beds: Increasing drying rates for fuel resource recovery in sub-saharan africa. *Journal of Water Sanitation and Hygiene for Development*, *5*(1), 72–80. https://doi.org/10.2166/washdev.2014.213

Seleman, A., Gabrielsson, S., & Kimwaga, R. (2021). Faecal sludge containment characteristics and their implications on safe desludging in unplanned settlements of Dar es Salaam, Tanzania. *Journal of Environmental Management*, *295*(October 2020), 112924. https://doi.org/10.1016/j.jenvman.2021.112924

Semiyaga, S., Okure, M. A. E., Niwagaba, C. B., Katukiza, A. Y., & Kansiime, F. (2015). Decentralized options for faecal sludge management in urban slum areas of Sub-Saharan Africa: A review of technologies, practices and end-uses. *Resources, Conservation and Recycling*, *104*, 109–119. https://doi.org/10.1016/j.resconrec.2015.09.001

Semiyaga, S., Okure, M. A. E., Niwagaba, C. B., Nyenje, P. M., & Kansiime, F. (2017a). Dewaterability of faecal sludge and its implications on faecal sludge management in urban slums: Faecal sludge pre-treatment by dewatering. *International Journal of Environmental Science and Technology*, *14*(1), 151–164. https://doi.org/10.1007/s13762-016-1134-9

Semiyaga, S., Okure, M. A. E., Niwagaba, C. B., Nyenje, P. M., & Kansiime, F. (2017b). Optimisation of centrifuge operating conditions for dewatering physically conditioned faecal sludge from urban slums. *Environmental Technology and Innovation*, *8,* 28–39. https://doi.org/10.1016/j.eti.2017.03.005

Septic Max. (2021). *What Are the Septic Tank Layers?*

Septien, S., Mirara, S. W., Makununika, B. S. N., Singh, A., Pocock, J., Velkushanova, K., & Buckley, C. A. (2020). Effect of drying on the physical and chemical properties of faecal sludge for its reuse. *Journal of Environmental Chemical Engineering*, *8*(1), 103652. https://doi.org/10.1016/j.jece.2019.103652

Settling-Thickening Tanks and Enhancing Its Drying. (2022). *July*.

Simiyu, S., Chumo, I., & Mberu, B. (2021). Faecal Sludge Management in Low Income Settlements: Case Study of Nakuru, Kenya. *Frontiers in Public Health*, *9*(October), 1–8. https://doi.org/10.3389/fpubh.2021.750309

Smith, R., Novak, J., & Lee, S. (2019). Advances in sludge dewatering technologies: A review. *Environmental Technology Reviews,* 8(2), 56–74. https://doi.org/10.1080/21622515.2019.1599345

Soil Resolution Technologies. (2019). *Septic Tank Design*.

Standards. (1985). *Code of Practice for Installation of Septic Tanks: Part 1 Design Criteria and Construction.(Part–I), I S 2470*. Bureau of Indian Standards New Delhi.

Strande, L. (2014). The Global Situation: Faecal Sludge Management: Systems Approach for Implementation and Operation. *IWA Publishing*, 1–14.

Strande, L., & Brdjanovic, D. (2014). *Faecal sludge management: Systems approach for implementation and operation*. IWA publishing.

Strande, L., Schoebitz, L., Bischoff, F., Ddiba, D., Okello, F., Englund, M., Ward, B. J., & Niwagaba, C. B. (2018). Methods to reliably estimate faecal sludge quantities and qualities for the design of treatment technologies and management solutions. *Journal of Environmental Management*, *223*(June), 898–907. https://doi.org/10.1016/j.jenvman.2018.06.100

Velkushanova, K., & Strande, L. (2021). Faecal sludge properties and considerations for characterisation. In *Methods for Faecal Sludge Analysis*.

Velkushanova, K., Strande, L., & Ronteltap, M. (2021). Methods for Faecal Sludge Analysis. In K. Velkushanova, L. Strande, M. Ronteltap, T. Koottatep, D. Brdjanovic, & C. Buckley (Eds.), *Methods for Faecal Sludge Analysis*. IWA Publishing. https://doi.org/10.2166/9781780409122

Velkushanova, K., Strande, L., Ronteltap, M., Koottatep, T., Brdjanovic, D., & Buckley, C. (2021). Methods for faecal sludge analysis. In *Methods for Faecal Sludge Analysis*. https://doi.org/10.2166/9781780409122

Wanda, C., Kengne, E. S., Wafo, G. V. D., Nzouebet, W. A. L., Nbendah, P., Ngandjui, Y. A. T., Zapfack, L., & Noumsi, I. M. K. (2021). Quantification and characterisation of faecal sludge from on-site sanitation systems prior the design of a treatment plant in Bangangte, West Region of Cameroon. *Environmental Challenges*, *5*(August), 100236. https://doi.org/10.1016/j.envc.2021.100236

Wang, B., Wu, D., Zhang, X. L., Mackey, H. R., & Chen, G. H. (2018). Sludge flotation, its causes and control in granular sludge upflow reactors. *Applied Microbiology and Biotechnology*, *102*(15), 6383–6392. https://doi.org/10.1007/s00253-018-9131-1

Ward, B. J., Nguyen, M. T., Sam, S. B., Korir, N., Niwagaba, C. B., Morgenroth, E., & Strande, L. (2023). Particle size as a driver of dewatering performance and its relationship to stabilization in Faecal sludge. *Journal of Environmental Management*, *326*(PB), 116801.

https://doi.org/10.1016/j.jenvman.2022.116801

Ward, B. J., Traber, J., Gueye, A., Diop, B., Morgenroth, E., & Strande, L. (2019). Evaluation of conceptual model and predictors of faecal sludge dewatering performance in Senegal and Tanzania. *Water Research*, *167*, 115101. https://doi.org/10.1016/j.watres.2019.115101

Zhou, Y., Li, J., Li, J., & Wei, S. (2011). Dewaterability of aerobic granular sludge. *Applied Mechanics and Materials*, *90–93*, 2944–2948. https://doi.org/10.4028/www.scientific.net/AMM.90-93.2944

Ziebell, F., Gold, M., Matovu, J., Maiteki, J., Niwagaba, C., Strande, L., & Water, N. (2016). Dewatering of faecal sludge with geotextiles : Results from laboratory and bench-scale experiments in Kampala , Uganda. *Sludge to Energy Enterprises in Kampala (SEEK)*.

FSS thickness by establishment and flush methods

Unit	Faecal sludge (FS)				Faecal sludge scum (FSS)		
	Category	**Mean ± SD**	**n**	**P-value**	**Mean ± SD**	**n**	**P-value**
Establishment	Household	2.49±0.81	16	0.233	0.09±0.13	16	0.027
	Public/commercial place	2.27±1.30	14		0.06±0.05	10	
	School	2.19±0.99	5		0.10±0.11	5	
Nature of establishment	Healthcare facility	1.30±0.00	1	0.329			<0.001
	Hostel	2.98±0.28	5		0.04±0.01	6	
	Hotel/ guesthouse	2.67±0.76	2		0.04±0.03	2	
	Household Multiple	2.63±0.86	6		0.09±0.10	6	
	Household Single	1.83±0.77	5		0.15±0.24	4	
	Mall	3.98±0.00	1		0.02±0.00	1	
	Market	2.36±1.19	5		0.08±0.07	5	
	Office	4.55±0.00	1		0.05±0.00	1	
	Petro Station	1.40±0.00	2				
	Place of Worship	0.10±0.00	1				
	Public toilet	1.95±0.00	1		0.05±0.00	1	
	School	2.19±0.99	5		0.10±0.11	5	
Flush	Cistern flush	2.20±0.98	17	0.329	0.08±0.12	14	0.230
	Pour flush	2.51±1.08	18		0.09±0.09	17	