MAKERERE UNIVERSITY

COLLEGE OF ENGINEERING, DESIGN, ART AND TECHNOLOGY (CEDAT)

SCHOOL OF ENGINEERING

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

CIV 4200: CIVIL ENGINEERING PROJECT II

COMPARISON OF VACUUM AND NON-VACUUM TECHNOLOGIES FOR EMPTYING FAECAL SLUDGE FROM INFORMAL SETTLEMENTS OF KAMPALA

BY

BAMUHIMBISE GILBERT 16/U/189

APIO SHEILLA CONSTANCE 16/U/106

Submitted in Partial Fulfilment of the Requirements for the Award of a Degree of Bachelor of Science in Civil Engineering

……………………………………….. ………………………………..

DR. SWAIB SEMIYAGA **DR. JOEL KINOBE**

MAIN SUPERVISOR **CO-SUPERVISOR**

FEBRUARY 2021

DECLARATION

We, the undersigned, declare that this final year project report has been fully undertaken and reviewed by us.
This report is submitted in partial fulfilment of the requirements for the award of a Degree of Bachelor of Science in Civil Engineering.

BAMUHIMBISE GILBERT 16/U/189

SIGN : ……………………………. Date :…………………………………

APIO SHEILLA CONSTANCE 16/U/106

SIGN : ……………………………. Date :…………………………………

DEDICATION

To our parents, Mr. and Mrs. Amutenda Salvatore and Mr. and Mrs. Onen Charles and supervisors, Dr. Swaib Semiyaga and Dr. Joel Kinobe.

ACKNOWLEDGEMENT

First and foremost, we thank the Almighty God for granting us the wisdom, health and abundant strength and guidance to enable us complete the project.

We would like to extend our sincere appreciation and gratitude towards our supervisors, Dr.Swaib Semiyaga and Dr. Joel Kinobe who continuously and selflessly guided us through the different steps during the implementation of this project.

We would like to thank our parents, who helped us financially and spiritually while executing this project.

We wish to extend our sincere gratitude to Mr. Matovu Jafari (Private Emptiers' Association Uganda), Mr. John Busigye (Gulper Association of Uganda) and Mr. Semukoteka Abubaker (Gulper Association of Uganda) for the useful information provided to us about the technologies.

We will not forget the people that were willing to participate in the survey, the vacuum and non-vacuum operators and the local leaders who provided information about their areas. We wish to acknowledge our fellow BSc students, Odong Vicent, Namboozo Jones, Mwanda Vincent and Nsubuga Emmanuel for the help rendered to us during the data collection especially availing to us the GPS device whenever we needed it.

We also thank the management of the Lubigi faecal sludge and wastewater treatment plant for the permission granted to us to access the facility and enable us carry out our research.

Lastly, we thank Mr. Bonny Balikuddembe Stema and Ms. Rita Nakazibwe for the help rendered to us during the Laboratory analyses of our samples.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BCR – Benefit-Cost Ratio

CBA – Cost Benefit Analysis

FSM – Faecal Sludge Management

GAU- Gulper Association of Uganda

GPS – Global Positioning System

KCCA - Kampala City Council Authority

MAPET – Manual Pit Emptying Technology

PEAU - Private Emptiers' Association Uganda

PVC – Polyvinyl Chloride

TVS – Total Volatile Solids

VIP – Ventilated Improved Pit Latrine

ABSTRACT

Pit latrines in slums fill up faster due to a high water table leaving emptying as the most viable solution. This study was aimed at comparing the vacuum and non-vacuum technologies used in emptying pit latrines in slums located in Kampala district. A total of thirty-seven (37) samples (20 for vacuum and 17 for non-vacuum technologies) were collected for analysis of moisture content, bulk density and total volatile solids. A total of one hundred eleven (111) questionnaires (78 for vacuum and 33 for non-vacuum) were used to obtain data such as vehicle capacities, costs, time estimates**.** The mean results were; 97.74% Moisture Content, 1004.39kg/m^3 bulk density and 66.04% TVS for vacuum technologies while 86.35% Moisture content, 1033.32 kg/m^3 bulk density and 59.86% TVS were obtained for non-vacuum technologies. The time estimates for setting up equipment, emptying the facility, dismantling the equipment and clean-up, travelling to the plant and discharging were 5, 16.5, 5, 32.92, 8.64 minutes respectively for vacuum technologies and 11, 120, 18, 35.61 and 33.58 minutes respectively for non-vacuum technologies. The solid waste content of the faecal sludge emptied by vacuum technologies was significantly lower than that of the non-vacuum technologies with the fraction obtained as 4.4% for the former and 22.85% for the latter. The sludge characteristics emptied were significantly different with vacuum technologies emptying more fluid sludge compared to the non-vacuum technologies. To promote more efficient emptying of facilities located in Kampala slums by the different technologies, there is need to set up more stringent policies to sensitize the public about the dangers of disposing solid waste into pit latrines, have an adjustable opening and closing time of the treatment plant in order to increase number of trips made per day by the technologies, provide more efficient solid waste handling tools to technology operators and designing a more efficient communication system between customers and technology operators.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Over 2.8 billion people worldwide rely on on-site sanitation facilities for their sanitation needs with approximately 1.77 billion people using pit latrines while in sub-Saharan Africa, over 80% of the urban population rely on these facilities (Naing et al., 2020; Seal et al., 2018; Strande et al., 2014). The facilities thus end up accumulating raw or partially digested slurry called faecal sludge (Strande et al., 2014). With the growing urban population, there is little space left to build new pit latrines, hence the most viable solution is emptying the pit latrines (Thye et al., 2011).

Pit latrines can be emptied using either vacuum or non-vacuum technologies. The vacuum technologies utilize atmospheric pressure or high rates of airflow to suck pit contents through a hose into a container under a partial vacuum (Thye et al., 2011). They include the vacuum tanker and UN-HABITAT Vacutug. The vacuum tanker has a capacity of 1 to $10m^3$ and is limited to only areas that are easily accessible (Thye et al., 2009; O'Riordan, 2009). This poses a challenge in slums where emptying is often inadequate due to poor accessibility (Semiyaga et al., 2015). In a bid to curb this challenge, smaller versions of conventional vacuum tankers, for example, the vacutug with a volume of 500-1000 litres have been developed to improve accessibility to high-density settlements (Mikhael et al., 2014). Vacutug-based emptying services were introduced and tested in Bangladesh but could not be sustained for a combination of reasons that include both technological inappropriateness and management limitations (Opel & Bashar, 2013). In Sub-Saharan Africa, the 500-litre Vacutug was proven in Nairobi, Mozambique and Tanzania (Still, 2002; O'Riordan, 2009). However, it proved not to be practical nor economical if the sludge must be disposed of more than a kilometer from the source (Still, 2002).

Non-vacuum technologies range from manual to semi-mechanized methods. They include the Manual Pit Emptying Technology (MAPET), the gulper and manual emptiers. The 200-litre MAPET and the gulper have been tested in Dar-es-Salaam. The gulper proved to be successful only on fairly liquid sludge (O'Riordan, 2009). Operation of the MAPET was not able to be sustained in Tanzania due to reliance on importation of key spare parts which could not be sourced locally (Mikhael et al., 2014). It is important to note that mechanical desludging methods are prone to failure and expensive hence most slum dwellers opt for cheaper alternatives like use of manual emptiers who usually dump faecal sludge in open environment (Eales, 2005; Murungi & van Dijk, 2014). In Kibera, Kenya, manual emptying is stigmatized and manual emptiers work inside pits at night on torch-light and are subject to abuse whereas, in Durban, South Africa, manual emptiers work in daylight and are provided with protective gear (Eales, 2005).

In Kampala, faecal sludge collection and transportation services are provided by Kampala City Council Authority (KCCA), the Private Emptiers' Association Uganda (PEAU) and the 2000 Trinity Agencies Limited (Murungi & van Dijk, 2014). Each of these associations has separate charges for emptying with each mainly based on distance, the capacity of the cesspool truck and solid waste content in the pit latrine (Murungi & van Dijk, 2014; Schoebitz et al., 2017). Currently, 900m^3/day of faecal sludge is generated in Kampala but the available desludging equipment is able to transport only 390 m^3/day (KCCA, n.d.). According to Nkurunzinza et al. (2017), in Kampala, each truck charges from USD 20 for 2.5m^3 to USD 50 for 10m^3 of faecal sludge and gulper charges a minimum of USD 9.00 per 200-litre barrel. This service is considered expensive in poor urban households in Kampala with an average daily income of USD 2. It is worth noting that the collection and transportation of faecal sludge from slums is costly due to lack of access, traffic congestion and long travel distances to treatment plants (Semiyaga et al., 2015). Sugden (2013) therefore emphasized that the best way to improve emptying efficiency is through optimizing unit transport costs that is transport speeds (including becoming stuck in traffic jams) and haul distances.

1.2 Problem Statement

In the deployment of emptying technologies in slums, little is known about certain aspects of the pit emptying process. These aspects manifest themselves in form of the time it takes a given technology to: negotiate the deal with the household, travel to and find the customer's sanitation facility, transport the waste to the treatment plant, set up the equipment before emptying and clean the equipment and latrine after emptying (Sugden, 2013). Cost similarly presents a challenge during emptying as it differs for different emptying technologies but many customers are not well versed with the type of facility they have hence may not know whether a technology they use is the most appropriate for their facility (Murungi & van Dijk, 2014).

The current research on pit emptying technologies has focused on their description, how deep they empty, challenges faced and comparison of capital costs (Kabange & Nkansah, 2019; Thye et al., 2011; O'Riordan, 2009; Mikhael et al., 2014; Thye et al., 2009). However, comparative studies on the technologies (in terms of emptying event time, sludge variation with solid wastes and benefit/cost) are scanty with the only research on sludge characteristics for vacuum tankers dated 30 years back (Bosch & Schenertenleib, 1985).

Since safe emptying and transportation of faecal sludge is extremely important for people's health and the environmental benefits it brings about, there is need therefore to identify the unknown parameters concerning it (Eales, 2005).

1.3 Main Objective

To compare vacuum and non-vacuum technologies for emptying faecal sludge from informal settlements of Kampala.

1.3.1 Specific Objectives

The specific objectives of the study are;

(i) To establish the functional existing vacuum and non-vacuum emptying technologies in slums.

(ii) To assess the time required for various emptying events using vacuum and non-vacuum technologies.

(iii) To determine the variation of the characteristics of faecal sludge emptied by the vacuum and non-vacuum technologies.

(iv) To evaluate the Cost-Benefit Analysis of the different technologies.

1.4 Justification

Basing on the problem statement, it was hoped that the results of this study would assist the Emptying Companies in optimizing the studied emptying technologies. Other benefits from the study included;

1. The actual time for the emptying event would reveal constraints that lengthen the process which can be optimized in order to increase the number of pits emptied.
2. Determining the variation in sludge characteristics would be important in knowing which technology can actually be used for emptying a given facility.

1.5 Scope of study

1.5.1 Content scope

The research was limited to;

1. Carrying out a detailed study on the type of emptying technologies used in informal settlements of Kampala.
2. Analyzing the variation in sludge characteristics with the vacuum and non-vacuum technologies. Emphasis was put on the physical and rheological properties of faecal sludge that mainly influence the type of sludge the technologies would empty.
3. Time as regards to the emptying procedures used by the different technologies.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter gives an extensive review of literature obtained from previous studies in order to assist in answering the research aims/objectives and in identifying gaps in the current information about the pit emptying technologies.

2.2 Technologies used in emptying pit latrines

Broadly, pit emptying technologies can be categorised either as vacuum or non-vacuum. The vacuum technologies are fully mechanized and rely on a vacuum created by atmospheric pressure or high rates of airflow to suck up pit contents through a hosepipe into the tanker (Thye et al., 2011; O'Riordan, 2009).

The non-vacuum technologies on the other hand consist of manual and semi-mechanized technologies that rely on application of manual power directly or indirectly through a mechanism in order to remove contents from the pit.

Manual systems involve application of manual power by use of hands. They are categorised into cartridge containment systems and direct lift methods as shown in Figure 2-1;

1) Cartridge containment: In this method, a cartridge containment (for example a 20 litre container) is built into the toilet system which is carried by collectors to a transfer station when full (GOAL, 2016).
2) Direct lift methods: This involves use of long handled buckets and shovels to lift sludge from the pit latrines and transfer it into containers which are taken to the transfer stations or treatment plants (Mikhael et al., 2014).

Figure 2-1: Cartridge containment (a) and long handled shovels (b) (adapted from Mikhael et al., 2014; GOAL, 2016)

Semi-mechanised systems involve use of human power transferred through some mechanisms with examples shown in Table 2-1.

Table 2-1: Examples of pit emptying technologies based on the form of power used (Mikhael et al., 2014; O'Riordan, 2009)

Manual systems	Semi-mechanized systems	Fully mechanized systems
Cartridge containment	Manual Pit Emptying Technology (MAPET)	Vacuum tanker
Direct lift	Gulper Nibbler	Micravac Vacutug Trash pump Motorised pit screw auger Gobbler

2.2.1 Vacuum Technologies

Vacuum technologies operate using a vacuum that can be created using four main techniques: the direct vacuum system and pneumatic systems, which comprise the constant air drag system, the air bleed nozzle and the plug drag system (Thye et al., 2011; Bosch and Shertenleid, 1985). The Figure 2-2 shows an illustration of the different techniques mentioned above.

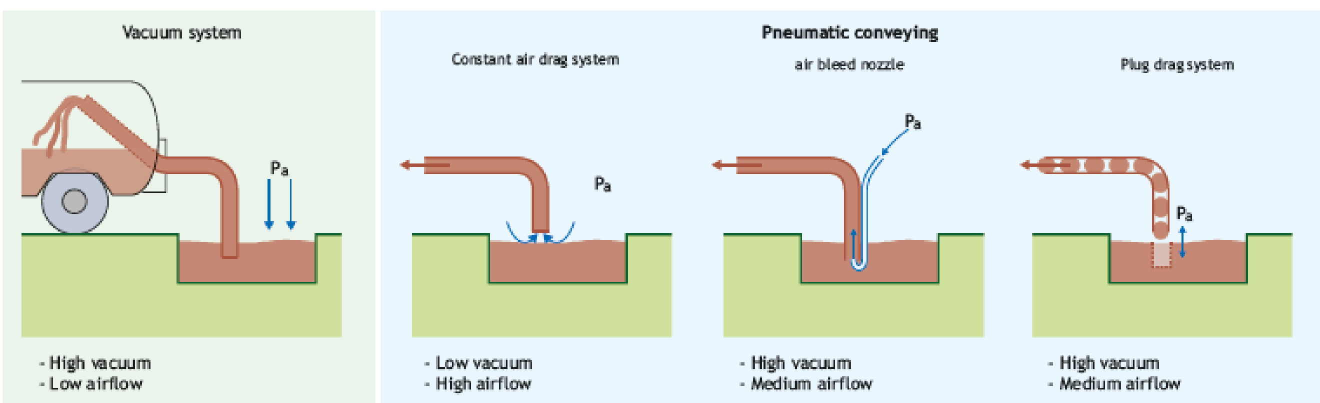


Figure 2-2: Sludge removal techniques (Bosch & Schenertenleib, 1985)

a) Vacuum system: Atmospheric pressure (Pa) acting on the surface forces the sludge along the hose into the holding tank. The hose is permanently submerged in the sludge, thus the material to be transported has to be liquid enough to flow limiting this type of system to liquid and thin sludges only (Thye et al., 2011).
b) Constant air drag system: The hose inlet is to be held a few centimeters above the surface of the sludge. Due to the very high velocity of air, particles of sludge are suspended in the

very high air stream and drawn along the hose into the holding tank. It, however, requires some operational skill and is very tiresome (Bosch & Schenertenleib, 1985).

c) Air bleed nozzle: Atmospheric pressure (Pa) forces air down the air bleedpipe and thus maintains the airflow necessary for the sludge particles.

d) Plug drag system: This relies on raising and lowering the hose inlet in and out of the sludge thus allowing time for the vacuum pump to create a new vacuum between each up and down movement. This ensures that each time the hose is out of the sludge, the vacuum inside the tank is released letting high velocity air stream rush in along with sludge particles.

2.2.1.1 Vacuum Tanker

These were initially developed and used in advanced countries for desludging septic tanks and vaults but may similarly be suitable for desludging wet pits with no bulky anal cleansing materials in the sludge (Kabange & Nkansah, 2019).

The conventional vacuum tanker is the most favoured technology where the plot is easily accessible because it ensures minimal contact with faecal sludge and offers improved sludge emptying efficiency than other alternatives (Thye et al., 2011; Eales, 2005). However, they are often characterized by high capital and maintenance costs (O'Riordan, 2009). They are likewise unsuitable because they cannot handle solid waste commonly found in pit latrines, have difficulty in handling compact sludge and are unable to service pits in high density housing areas (Kabange & Nkansah, 2019). Generally, the storage capacity of a vacuum truck ranges from 3 and 12 m^3 and can operate effectively up to about 60 meters from the pit latrine and to a 2 to 3 meter depth (Tilley et al., 2014). Most trucks are made in North America, Asia or Europe thus older trucks (age between 15 to 30 years) are often used with capital costs ranging between USD 50,000 to USD 80,000 (Strauss & Montangero, 2002; Mondal, 2018; Thye et al., 2009; Chowdhry & Kone, 2012).

In Kampala, Uganda, these trucks have been employed since the 1990s starting with about 5 private cesspool trucks (Wandera, 1999). This number has exponentially grown over the years to 27 in 2008 and by 2013, it had grown to 45 trucks, increased to 85 and 88 trucks in 2016 and 2017 respectively (Schoebitz et al., 2016; Nkurunzinza et al., 2017). This is due to the increase in companies such as the Private Emptiers' Association Uganda, Kampala Private Emptiers' Association, 2000 Trinity Agencies Limited. Generally, the emptying fee charged by these companies ranges between UGX 60,000 and UGX 150,000 for 1.8 m^3 to 10 m^3. This charge depends on a number of factors as shown in Table 2-2. Additional charges can arise when an extra pipe is to be used or when solid waste is to be emptied from the pit. A 'motivation fee' of between UGX 10,000 and UGX 30,000 is to be paid to the turn-man (Murungi & van Dijk, 2014).

Table 2-2: Breakdown of emptying fees charged

Emptying cost per trip	Factors considered in determining emptying costs			
	Fuel	Dumping	Turn-man	Operator's Fee
UGX 90,000 or more	UGX 30,000	UGX 10,000	UGX 10,000	UGX 10,000

(Source: Murungi & van Dijk 2014)

However, most of these trucks possess worn out hose pipes that are tied with clothes or polythene resulting into oozing and leaking of sludge during desludging leading to unhygienic conditions (Murungi & van Dijk, 2014; Mikhael et al, 2014). In addition, the vacuum pumps are old and are unable to completely remove the sludge from the containment system (Murungi & van Dijk, 2014).

Principle of emptying

The vacuum tankers use a vacuum system assisted by atmospheric pressure. The tanker works by having air trapped from a holding tank removed by a pump. The pump that receives power from the engine sucks air with a valve on the hose line closed, creating a pressure below the atmospheric pressure in the tank. This makes the trapped air to get so compressed and is exited through an exhaust valve while the hosepipe is immersed into the pit contents. The pit contents are then pushed up by atmospheric pressure to occupy the vacuum in the tank. With the hose pipe into the pit contents, a continuous flow is maintained into the tank (Runyoro, 1981).

2.2.1.2 Vacutug

Vacutug is a vacuum mounted on a truck that has a hose which runs from the unit into the hole. It typically takes 5 to 10 minutes to fill, working at a 2 to 3 meter depth (Mondal, 2018). Different developments have been made in recent years in order to come up with better versions of the vacutug. The Mark I Vacutug comprises a 500 litre steel vacuum tank with a sliding vane pump capable of -0.8 bar vacuum and is powered by a 4.1 kW Honda petrol engine (O'Riordan, 2009; GOAL, 2016). It bears a 3-inch diameter PVC vacuum hose pipe which is connected to the vacuum tank through which sludge is removed. The vacutug can empty a pit in a short time, but is difficult to maintain and is slow when it comes to movement to and from the facility to the disposal site (GOAL, 2016; Sugden, 2013).

Modifications were made to the Mark I Vacutug and the Mark II Vacutug was developed in Bangladesh. A comparsion of the two technologies is shown in Table 2-3. The Mark II Vacutug has a 1900-litre tank used in conjunction with a 200-litre satellite tank attached to the vacuum pump. The vacutug had advantages of safely removing waste from the facility, low odour and is faster than manual systems. However, its use failed to be sustained due to having a slow maximum speed of about 5 km/hr hence requiring a localised emptying point, high initial costs and access problems despite its small size (Thye et al., 2009).

Table 2-3: Comparison of Vacutug technologies

Technology	Vacutug MK1	Vacutug MK2
First application	Kibera slum, Nairoi, Kenya (1995)	Dhaka, Bangladesh (1999)
Components of system	500 litre tank, vacuum pump powered by small petrol engine with hose and handcraft	200 litre tank with a 1900 litre collection tank
Access width in meters	1.5	>1
Applying conditions	Areas with a high population density	Areas with poor accessibility and narrrow corridors between housing units
Current status	Still in use Kibera	In use in more than 10 cities in developing countries

(Source: Mondal 2018)

2.2.1.3 Micravac

The Micravac has a 2000-litre tank, a high-capacity vacuum pump which has a rate of 9000litres/minute and was introduced mainly for use on bumpy roads and areas that are not easily accessible. It was first designed in the 1980s to be used in Kibera, Kenya (Thye, Templeton, & Mansoor, 2011; O'Riordan, 2009).

2.2.1.4 Gobbler

The Gobbler was developed as an extra robust and efficient version of the Nibbler (O'Riordan, 2009). It is powered by an electric motor that turns a double chain drive which rotates a heavier gauge chain than that of the Nibbler (Mikhael et al., 2014). The Gobbler uses two chains to guide scoops up a pipe and over a bend in order to allow gravity to assist the sludge in exiting the pipe.

However, issues were encountered with sludge jamming in the sprockets, preventing the chains from rolling and lifting the scoops up the pipe (GOAL, 2016). In addition, the Gobbler's heavy weight made it difficult to move and set up and also due to its length which was not adjustable, it was difficult to empty containment systems of different depths (Mikhael et al., 2014).

2.2.1.5 Motorised pit screw auger

Motorised pit screw augers consist of an auger placed inside a plastic riser pipe and protruding by approximately 5 to 15cm from the bottom end of the pipe. A portion of the auger is exposed in order to direct the sludge into the pipe (GOAL, 2016). The Pit screw auger has an electric motor mounted on the top of the riser pipe where it connects to the auger (Mikhael et al., 2014). It has three blades at the bottom of the auger used to cut through rubbish and sludge, making it flow more easily up the pipe and is discharged through a downward angled spout at the top of the pipe.

Despite the fact that the auger is simple to use and reaches relatively high flow rates (40 – 50 litres/minute), it is very heavy, difficult to clean and has a fixed length (GOAL, 2016).

2.2.2 Non-Vacuum technologies

2.2.2.1 Sludge Gulper

The gulper is a technology that was initially developed to empty septic tanks but later introduced to pit latrines (Thye et al., 2011). The standard gulper will reach 1m-1.5m into the pit and the extendable gulper will reach up to 2m into the pit.

The sludge gulper is a mechanical sludge emptying device similar to a borehole pump (Nkurunziza et al., 2017). It consists of a PVC pipe, handle, hose, footstep and screen (Thye et al., 2011) shown in Figure 2-3. The PVC riser pipe contains two stainless steel 'non-return' butterfly valves. One valve, the 'foot' valve, is fixed in place at the bottom of the riser pipe and a second valve, the 'plunger' valve, is connected to a T-handle and puller rod assembly (Mikhael et al., 2014).

Operation

It is operated by one or two workers who move the handle on the gulper up and down causing the two valves to open and close in series, in turn causing the sludge to be lifted up and exited into a 50 L bucket (Thye et al., 2009; Mikhael et al., 2014). The gulper operates at approximately 30litres/minute.

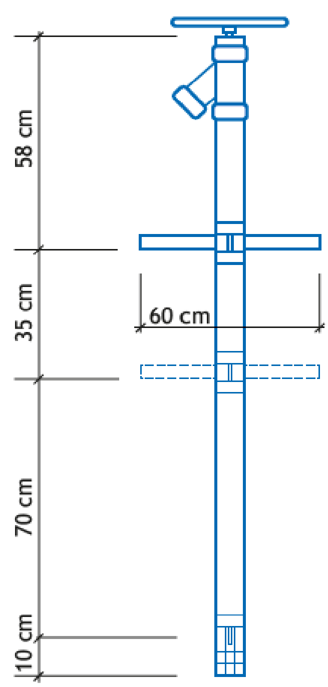


Figure 2-3: Schematic of the gulper (Mikhael et al., 2014)

The Gulper II (rammer) was developed as an improvement to the gulper and was designed to pump thicker sludge, is extendable hence goes deeper into the pit and can be dismantled, making it easier to clean (GOAL, 2016). The gulper is estimated to cost USD 100 to manufacture (O'Riordan, 2009). It has the advantage of not breaking the slab while emptying, having a low cost of about USD 160 to purchase and has enabled small independent entrepreneurs to enter the emptying business (GOAL 2016; Thye et al., 2011). However, the gulper is still limited to sludge of low viscosity and is prone to damage by solid waste in pit latrines (Mikhael et al., 2014).

2.2.2.2 Nibbler

The Nibbler was developed for faecal sludge that can be very thick especially in unlined pits located uphill (Malinga et al., 2016). The design consisted of a PVC pipe that housed steel disks welded onto a bicycle chain, which acted as scoops to lift the waste up and out of the pit. The sludge is scraped off the discs at the top of the pipe and directed through a Y-shaped pipe, discharging the sludge into a container for transport (GOAL, 2016). However, the Nibbler was not adopted by entrepreneurs on grounds that it removes little sludge and is so messy (Malinga et al., 2016).

2.2.2.3 Manual Pit Emptying Technology (MAPET)

A MAPET consists of a manually operated pump with a flywheel connected to a 200 litre vacuum tank mounted on a pushcart (Tilley et al., 2014). The 25 kg flywheel has an approximate diameter of 800 mm and a rotation speed of 40-60 rotations per minute (Thye et al., 2011). Trials proved that the MAPET is able to pump sludge from a depth of 3 meters at a rate of 10 to 40 litres/minute depending on the depth and viscosity of the sludge (Mikhael et al., 2014).

The method applied by the MAPET used an air vacuum in the sludge holding tank to suck up sludge through a hose pipe (4 meters long and 10 cm diameter) hence no need for breaking the squatting slab (GOAL, 2016). The sludge does not pass through the pump hence preventing blockages, wear and tear (Thye et al., 2011). The challenge however, was to find a vacuum pump appropriate to this task hence a piston pump with a leather piston in a 6-inch PVC cylinder was later introduced as the standard MAPET pump (O'Riordan, 2009).

The MAPET was durable under local conditions as the parts that wore and required replacement were affordable (GOAL, 2016). However, their lack of sustainability could be attributed to reliance on the importation of key spare parts (leather piston ring) which could not be sourced locally and the high costs incurred if the sludge must be disposed of more than a kilometer from the source (Mikhael et al., 2014; Still, 2002).

2.2.2.4 Manual Emptying

Manual emptiers play a crucial role in slums where large vacuum tankers cannot access (Schoebitz et al., 2017). However, they indiscriminately dispose of the sludge (Murungi & van Dijk, 2014).

Principle of emptying

In manual emptying, traditional hand tools like the shovels, spades, hammers and buckets are used to remove sludge from the pit (Thye et al., 2009). It involves destroying the squatting slab (since

5% of the latrines are built without access for emptying) and removing the sludge (Thye et al., 2009; Nakagiri et al., 2015).

Sometimes the roof of the pit latrine is removed to allow for easy movement of the long rods. The operators rarely use protective gear like gumboots and gloves since they cannot afford them hence opt for polythene bags (Eales, 2005; Murungi & van Dijk, 2014). After the sludge is removed from the pit, it is disposed of in streams, drainage channels or the street (Murungi & van Dijk, 2014).

Despite the activities of informal manual emptiers, their number remains unknown in Kampala (Schoebitz et al., 2016). However, their services are offered at a fee between UGX 30,000 and UGX 100,000 depending on different scenarios shown in Table 2-4. This charge is less than what vacuum trucks charge hence allows manual emptiers to remain in the emptying business (Murungi & van Dijk, 2014).

Table 2-4: Breakdown of Emptying costs by manual emptiers

Scenario	Factors considered in determining emptying costs									Approx. costs	
	Presence of materials in the facility		Presence or absence of a channel		Number of toilet stance	Cleanliness of the facility		Seasons		UGX	US$
	Less materials	More materials	Presence of a channel	Absence of a channel	Two stances	Clean from the outside	Dirty from the outside	Rainy season	Dry season		
1st scenario	✓		✓		✓	✓		✓		30,000–40,000	11.88–15.84
2nd scenario		✓	✓		✓		✓	✓		50,000–60,000	19.81–23.77
3rd scenario	✓			✓	✓	✓			✓	70,000–80,000	27.73–31.69
4th scenario		✓		✓	✓		✓		✓	90,000–100,000	35.65–39.61

(Source: Murungi & van Dijk 2014)

The choice on what technology to use depends on a number of factors based on their advantages and limitations. Table 2-5 summarizes the advantages and limitations of vacuum and non-vacuum-based emptying.

Table 2-5: Advantages and limitations of vacuum and non-vacuum based emptying

	Non-Vacuum based emptying	Vacuum based emptying
Advantages	• Accessibility • Local job creation and income generation • Can be made locally	• Fast and generally efficient • Minimizes health risk
Limitations	• Time-consuming • Health hazards for workers • Hard, unpleasant work • Requires a disposal point near to the emptied pit • Spillage and bad odours • Possible social stigma	• Low accessibility • Expensive, capital and O&M costs • Cannot pump thick, dry sludge

(Source: Thye et al., 2011; Mondal 2018)

2.3 Sludge parameters affecting flow of faecal sludge

In selecting a pit emptying technology, Thye et al. (2011) points out sludge characteristics as a parameter in the selection. Faecal sludge has been reported to vary widely locally thus investigation into its characteristics has been done in several studies (Strauss & Montangero, 2002; Niwagaba et al., 2014; Bassan et al., 2013; Zuma et al., 2015). The physiochemical characteristics such as total solids (TS), volatile solids (VS), moisture content (MC), ash content, pH, total phosphorus (TP), total nitrogen (TN) and potassium affect the design of pit emptying equipment, treatment and disposal of faecal sludge (Zziwa et al., 2016a; Niwagaba et al., 2014).

Despite the physiochemical characteristics, other characteristics that affect pit emptying include the rheological characteristics and solid waste content. Bosch & Schenertenleib (1985) reported that the flow behaviour of sludge could be determined from analysis of the moisture content and volatile solids content.

2.3.1 Physical characteristics

1) **Moisture content**

This is the amount of water in the faecal sludge expressed as a percentage of the dry portion of the sludge. The moisture content gives an indication of the age of the sludge as it decreases as decomposition takes place (Hawkins, 1982). Apart from the urine, rain water and household wastewater, refuse added to pit latrines impacts on the moisture content as it is high in organic content (Beukes, 2019). The moisture content affects the flow behaviour of the sludge by reducing the viscosity hence making the sludge flow more easily. This was reported by Radford et al. (2011) where they noted that increasing moisture content by order of 2 % reduced resistance to flow by 30-300 times. For thick sludge, water is added in a process called fluidization increasing the moisture content hence making the sludge easily flow in the hose pipe (Still & Foxon, 2012). Moisture content in Ventilated Improved Pit latrines has been reported to have averages of 92.4 and 83.4 % for lined and unlined pits respectively with a range of 60 % to 99 % (Semiyaga et al. 2016; Nabateesa et al. 2017). Pit latrine sludge high in moisture content is more fluid and is easily removed by vacuum technologies while non-vacuum technologies are more applicable to sludge with low moisture content (Beukes, 2019). Thus, generally vacuum tankers are reported to empty sludge of moisture content above 95 % (Gold et al., 2018).

2) Organic Content

This refers to the volatile portion of faecal sludge removed when it is heated above 500^{0}C (Niwagaba et al., 2014). Sludge with large variations in moisture content can exhibit similar flow due to changes in organic content. This is because in a sludge with high moisture content, the water is held in the microstructure of the organics increasing its resistance to flow while in one with low organic content, there would exist free water in the non-organic particles reducing its resistance to flow (Bosch & Schenertenleib, 1985). However, organics reduce with time due to digestion hence reducing fluidity of older pit latrine sludge (Hawkins, 1982).

2.3.2 Rheology of Sludge

Rheological properties of faecal sludge describe its flow and deformation. These include shear stress, shear rate, density and particle size distribution (AIT, 2012). The viscosity of the sludge affects its 'pumpability'; with a high viscosity sludge difficult to remove by pumping.

1) Bulk density

Bulk density is a measure of mass per unit volume (Reddy, 2013). The bulk density of faecal sludge has been reported to range between 970 kg/m^3 to 1700 kg/m^3 but can be as high as 2200 kg/m^3 in sludge with elevated sand content (Beukes 2019; Penn et al., 2018). However, it is highly variable like other faecal sludge parameters as shown by the mean values shown in Table 2-6. It is important for vacuum-based emptying systems as it determines the static head required to lift the sludge out of the pit, thus limiting the maximum emptying depth (Radford et al., 2015). Sludge with high bulk densities requires more suction power than less dense sludge (Bosch & Schenertenleib, 1985). Bulk density similarly affects the weight of sludge to be lifted manually by emptiers hence heavy sludge might be strenuous on them.

Table 2-6: Mean values of faecal sludge density from literature

Source	Mean value (kg/m^3)	Reference
VENTILATED IMPROVED PIT LATRINE (VIP)	1379.72	(Velkushanova et al., 2019)
VIP	1001	(Radford & Sudgen, 2014)
SEPTIC TANK	1120	(AIT, 2012)
VIP	1423	(Bosch & Schenertenleib, 1985)
VIP	1400	(Runyoro, 1981)

2) **Shear strength**

Shear strength of sludge is the maximum or limiting value that may be induced within its mass before the sludge yields. It is the resistance to flow of material in shearing. Bosch & Schenertenleib (1985) studied faecal sludge as a fluid using its viscosity. However, faecal sludge has been treated analogous to weak soil to describe its behaviour since it does not readily flow. Radford & Fenner (2013) converted viscosities reported by Bosch & Schenertenleib (1985) into shear strength values and reported the maximum as 400 Pa. Radford & Sudgen (2014) using a penetrometer, tested resistance to penetration in 30 pit latrines in Kampala, Uganda. They found 87% of the pits had weak sludge comparable to previously reported strength and 60% with sludge stronger than 400 Pa. A small percentage (7%), of the pits had strengths greater than the maximum value of 2 kPa the penetrometer could measure. However, extrapolated rheological data estimates the maximum shear strength at 10 kPa (Shafiq et al., 2020). In contrast to Buckley et al. (2008) model of four theoretical layers in faecal sludge shown in Figure 2-4 (a), it was further found that the strength varied along the pit depth with thick crustal layers frequently met as shown in Figure 2-4 (b) (Radford & Sudgen 2014; Seal et al., 2018). This poses a significant challenge for the current emptying technologies. Vacuum technologies can remove sludge of low strength of range 7.76 Pa to 400 Pa, 5 times weaker than the maximum directly measured strength of 2 kPa (Bosch & Schenertenleib, 1985; Radford & Sudgen, 2014). This limits these systems to removing only the liquid fractions of sludge near the surface leading to a build-up of unpumpable sludge at the bottom of the pit (Kwach, 2008; Shafiq et al., 2020). Radford et al. (2015) tested non-vacuum technologies (gulper I and gulper II) using faecal sludge simulants. Neither of the gulpers was able to pump the strongest simulant (2 kPa), with the gulper I being able to pump simulants of 100 Pa but not 500 Pa primarily due to the increase in shear strength of sludge. The plunger struggled to overcome the strength of the sludge and thus it was difficult for the simulant to enter into the column (Water for People, 2014). The gulper II was able to pump both 100 Pa and 500 Pa sludge.

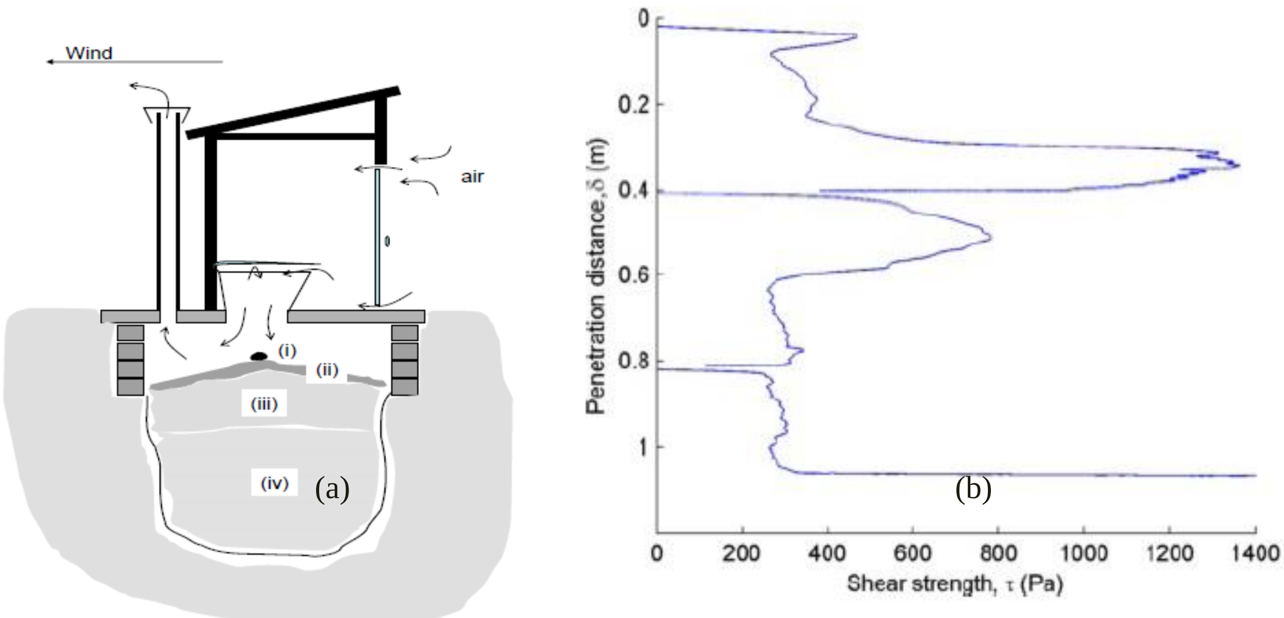


Figure 2-4: Theoretical model of pit latrine sludge according to Buckley et al. (2008) (a) and the sludge strength with depth Radford & Sudgen, (2014) (b)

2.3.3 Solid waste Content

In addition to faecal sludge, solid waste ranging from stones, wood, plastics, rags, cloth and glass is added to the pit (Still, 2002; Thye et al., 2011). One form of solid waste accustomed to pit latrines is menstrual waste. Its disposal covered in myth and need for secrecy leaves pit latrines as the 'only convenient' place to dispose them (Roxburgh et al., 2020; Crofts & Fisher, 2012). This leads to a high portion of waste that affects emptying technologies. This was evidenced by Tembo et al. (2019) who found the average precentage of solid waste in pit latrines as 31.1% in dry sludge (mass basis) and this was largely attributed to presence of mentrual waste and diapers in the latrines.

Solid waste increases the sludge accumulation rate on average by 15% reducing the useful life of the pit hence calling for regular emptying (Still, 2002). Secondly, it causes blockages of the pipe based emptying technologies; both the vacuum tanker and gulper leaving manual emptying with its shortcomings as the only viable option (Bosch & Shertenleid, 1985; Mikhael et al, 2014). Since manual emptiers rarely use protective clothing, they are prone to cuts from broken glasses and metal (Eales, 2005). Lastly, due to the added solid waste, larger storage and treatment volumes along with disposal space are needed at treatment plants (Zziwa et al., 2016b).

2.4 Duration of emptying

The pit emptying event starts with the customer contacting the emptying service providers up to when the pit is emptied. A pit emptying event thus involves activities right from negotiating a deal with the customer, travelling to and finding the customer's household, setting up the equipment, pit emptying, cleaning the equipment and finally transportation and disposal of the emptied sludge. In the design of pit emptying devices, technical aspects are so much considered in an attempt to reduce the actual pit emptying time neglecting the other time-consuming activities of the emptying event. Sugden (2013) suggested that the actual time of removing sludge from the pit has little impact on the number of latrines emptied per day since the most time-consuming events may not necessarily be the actual emptying, thus, for the comparison of the existing technologies, the following 'times' were considered.

I. Time taken to set up the equipment

This is the time it takes to prepare the equipment prior to emptying. Depending on the technology, this time may be insignificant or for the case of the manual emptiers, difficult to quantify. However, this time is not known for technologies used in emptying faecal sludge from slums in Kampala.

II. Time taken to lift sludge out of the pit

This is the time for the actual emptying, where sludge is removed from the pit. This time can be affected by the conditions of the technology as earlier stated such as in cases where worn-out pipes are used and in case of pipe bursts that need to be covered. In addition, blockages of the pipe by solid waste exceeding the pipe diameter can increase this time. It is important to note that there is limited information provided by literature on the actual time taken to empty pit latrines by the various technologies in Kampala.

III. Time taken to dismantle and clean the equipment

This is the time taken to clean the equipment before setting off for disposal. It involves cleaning the hose pipes, buckets, jerrycans and spiked rods used when emptying sludge from the pit latrines.

IV. Time taken for transportation and disposal

This is the time taken for the sludge to be moved from the slum to the treatment plant. This time is dependent on the road conditions like poor murram or proper tarmac roads and traffic jam. This ultimately affects the vehicle speed by limiting the maximum speed the driver can move at and increasing the time of travel. For the case of monitoring vehicle movement, GPS machines have been employed in moving trucks to map out their routes (Kinobe et al., 2015; Schoebitz et al., 2017). The GPS is capable of providing accurate data such as location, time of measurement, speed of movement and direction for which the speed and total time of measurement are important to this research project (Clifford & Zhang, 2008).

2.5 Cost Benefit Analysis (CBA) of the emptying technologies

Cost-Benefit analysis is carried out to estimate the economic benefits realised and costs incurred by each of the different technologies used for emptying faecal sludge in order to assess their viability (Hutton et al., 2007; Singh et al., 2017).

CHAPTER THREE: METHODS AND MATERIALS

3.1 Introduction

This chapter provides details on the methods and techniques used in the investigation into the pit emptying technologies. It covers the data collection and analysis techniques.

3.2 Data Collection

Various methods and techniques were used in obtaining data necessary for carrying out the research. These included; observation, questionnaires and interviews.

3.2.1 Observation

The functional existing technologies were identified through visual inspections (observation) in order to obtain information that differentiates them as shown in the observation checklist (Appendix D). The identified technology specifications were then described to show the various existing technologies and the techniques in which they function. Observations coincided with a household having their facility emptied.

3.2.2 Questionnaire and interviews

Questionnaires (n =111; n = 78 for vacuum and n =33 for non-vacuum) were administered to the operators of the technologies (Figure 3-1) who were arriving to the treatment plant in order to get information about different parameters concerning emptying for example equipment specifications such as the capacity of equipment, type of facility emptied, time estimates and costs for emptying as shown in the questionnaire (Appendix D). Interviews were held with local leaders, leaders of the Private Emptiers' Association Uganda and the Gulper Association of Uganda.

Figure 3-1: Administering questionnaires to technology operators

3.2.3 Time measurement

The time for setting-up, emptying, dismantling and discharging was measured using a timer. A hand-held GPS (Garmin Montana model 650) was then placed in the truck and configured to display the distance travelled, maximum speed, average moving speed and time spent moving, which were read off at the destination point (treatment plant) as shown in Figure 3-2.

Figure 3-2: GPS showing the measured parameters

3.3 Faecal Sludge Sampling

3.3.1 Overview

A total of thirty-seven (37) emptying events, seventeen (17) for non-vacuum technologies and twenty (20) for vacuum technologies were monitored during the period from February, 2020 to March, 2020 and October 2020 to January, 2021. The separation in periods of sampling was due to the impact of the COVID19 pandemic that led to a halt of the study.

The technologies were monitored in order to obtain samples and determine the different characteristics of faecal sludge. Prior to sampling, details on where emptying would take place were obtained from the operators of a particular technology. If the facility happened to be located in a slum then the emptying event would be monitored and faecal sludge samples obtained at the end of emptying. Thus, areas such as Bwaise, Kamwokya, Naguru, Ndeeba, Kabowa, Makerere Kivulu and Kibuye were the areas of study as shown in Figure 3-3.

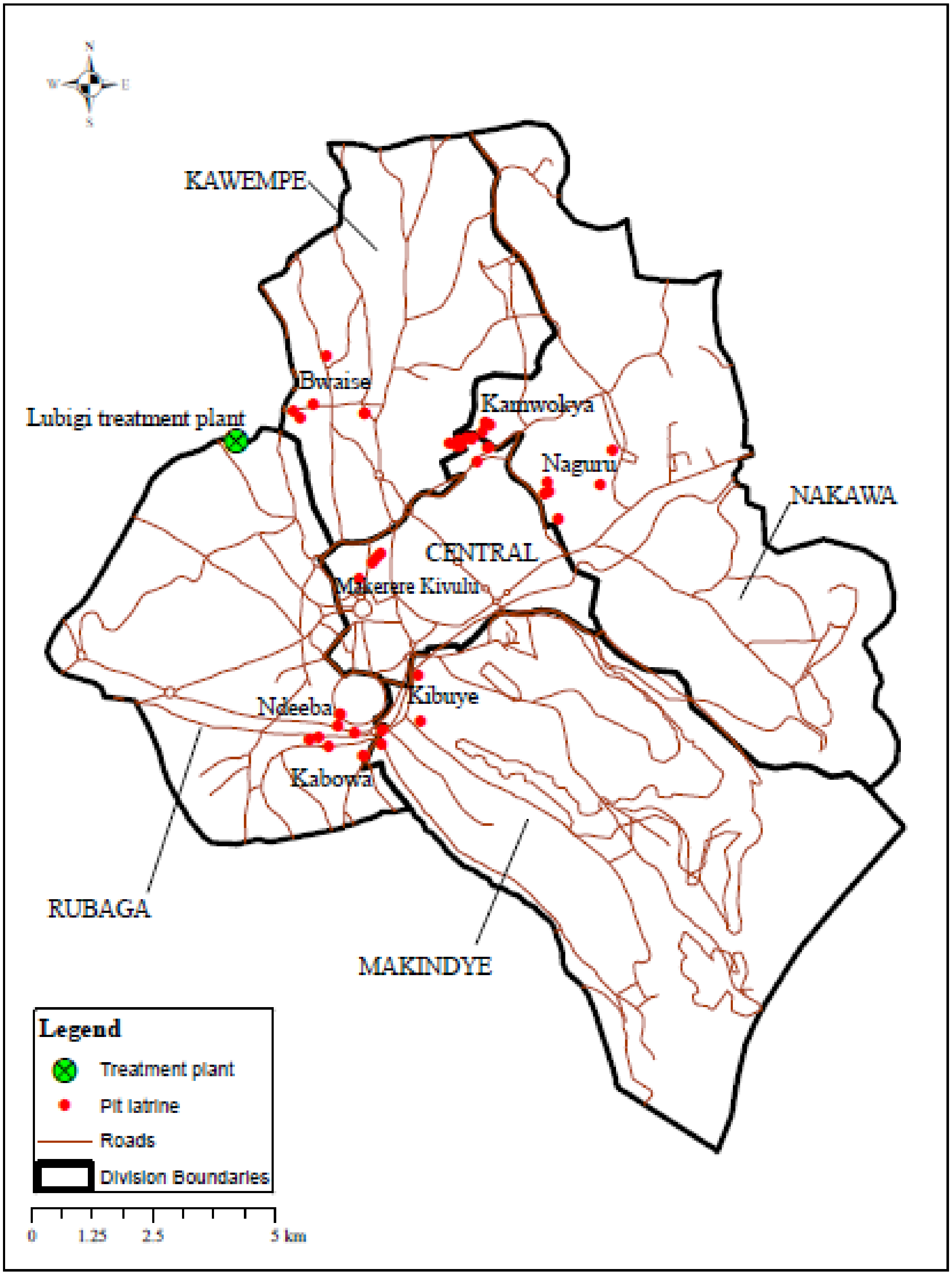


Figure 3-3: Map of Kampala showing pit latrines emptied during the different emptying events

3.3.2 Sampling Procedure

All samples were collected after a pit emptying event by either of the technologies as shown in Figure 3-4. Samples were collected using equipment and materials like buckets, samplers, scoops, disinfectants for cleaning and sanitizing purposes, weighing scales for weighing sludge and the respective components, a hosepipe to aid in washing of the sludge during the separation process, 5mm sieve and wire mesh for separation of solid waste, polythene sheets for storage of separated waste components and 250 mls plastic containers for collection of samples for laboratory tests.

a) Samples for moisture content, total volatile solids and bulk density tests

- Cesspool truck

A composite sample was made of four samples collected during discharge at the treatment plant (one at the beginning, two in the middle and one at the end) (Bassan et al., 2013), packed in a cooler box and transported to the Public Health and Environmental Laboratory at Makerere University for analysis.

- Barrels

A composite sample was made of samples collected from each of the barrels that were emptied on a given day. This ensured that a representative sample covering the full depth profile of the pit was obtained (Tembo et al., 2019). The samples were then packed in a cooler box and taken to the Public Health and Environmental Laboratory at Makerere University for analysis.

Figure 3-4: Sampling from barrels (a) and cesspool trucks during discharge at the treatment plant (b)

b) **Samples for solid waste;**

- Cesspool truck

During discharge at the treatment plant, the sludge sampled was collected in a bucket. The weight of the bucket with sludge was obtained. The components of the bucket were then sieved through a 5 mm sieve and the waste later air dried for two days before analysis was carried out.

- Barrels

Faecal sludge emptied from the pit was placed into a barrel of known weight, M_1. The weight of the barrel filled with sludge was obtained using a weighing scale and recorded as M_2. The sludge was then washed through a 5mm wire mesh to retain the solid waste. The solid waste was then air dried for two days and its mass obtained as M_3. Since the technologies worked on sludge of different moisture contents, for comparison purposes the solid waste content was obtained as a fraction of the dry sludge after correcting for the moisture according to Tembo et al. (2019) as shown below;

$$Total\ mass\ of\ sludge\ = M_2 - M_1$$

$$Total\ mass\ of\ dry\ solid\ waste\ = M_3$$

$$Mass\ of\ dry\ sludge\ (M_d) = \left(1 - \frac{MC}{100}\right) \times ((M_2 - M_1) - M_3) \qquad \text{Equation 3-1}$$

Where MC is the Moisture content of sludge obtained from the laboratory

Therefore, $Solid\ waste\ content\ (S\ as\ \%\ of\ dry\ sludge) = \frac{M_3}{M_d} \times 100\%$ Equation 3-2

3.3.3 Sample Preparation

The sludge samples collected were removed from the cooler box and left to attain room temperature. Non-homogenous debris larger than 5-mm sieve were then selectively removed by sieving (Septien et al., 2018).

3.4 Laboratory analysis

a) **Total Volatile Solids and Moisture Content**

The moisture content and Total Volatile Solids (TVS) were obtained using standard methods in accordance with APHA (2012). TVS was determined by taking the weight difference between oven-dried solids and the 2-hr muffle furnace-ignited sample at 550ºC and expressed as a percentage of Total solids.

b) Density Measurement

Density was measured according to Reddy (2013), 30 ml of sludge was weighed using a measuring flask. The weight of the sludge together with the flask was recorded as M_{sm}. The weight of the empty measuring flask was obtained and recorded as M_m. The density, ρ was calculated from;

$$\rho = \frac{M_{sm} - M_m\ (g)}{30\ (ml)} \times 1000\ kg/m^3 \qquad \text{Equation 3-3}$$

3.5 Shear Strength Prediction

In order to predict the shear strength of the samples, correlations used were obtained from a study by Septien et al. (2018) on faecal sludge in VIP latrines with comparable moisture content (77 % - 90 %) to our study.

$$\tau = K\gamma^n \quad R^2 > 0.95 \qquad \text{Equation 3-4}$$

$$K = 0.59 \times (MC)^{-30} \quad R^2 = 0.995 \qquad \text{Equation 3-5}$$

$$n = 1.2 \times (MC)^{13.5} \quad R^2 = 0.818 \qquad \text{Equation 3-6}$$

Where τ is shear stress (Pa), γ is shear rate (s^{-1}), MC is moisture content (%)

To compare our results with a previous study by Bosch & Schenertenleib (1985), a shear rate of 9.4 s^{-1} (Radford & Fenner, 2013) was used. This fell within the range (0.01–100 s^{-1}) of shear rate values used by Septien et al. (2018).

3.6 Data Analysis

Correlation and descriptive statistical analyses of the results obtained from the laboratory tests and time measurement for the different technologies were done to determine the averages, standard deviation and variances using SPSS version 26 and Microsoft Excel 2019. Pearson's correlation coefficient (R^2) at a 95 % confidence interval was used to analyse the relationship between solid waste fraction emptied by a given technology and the emptying time. The correlation was interpreted as 'negligible', 'low', 'moderate', 'high' and 'very high' using guiding value ranges provided by Mukaka (2012). The difference in faecal sludge characteristics emptied by the different technologies was evaluated using an independent samples Students' t-test at a significance level of 5 %.

3.7 Cost Benefit Analysis (CBA)

From the economic data obtained through questionnaires and interviews (Appendix B); a Cost Benefit Analysis was carried out to determine the viability of the different technologies using the Benefit Cost Ratio (BCR) and Net Present Value (NPV) methods.

a) Benefit Cost Ratio: This is a ratio of benefits of a project versus project costs.

$$BCR = \frac{\sum Equivalent\ Benefits}{\sum Equivalent\ costs}$$ (Panneerselvam, 2012) Equation 3-7

The benefits in a project may occur at different time periods of the activity hence for the purpose of comparison, they had to be converted into a common time base (present worth or future worth or annual equivalent). Similarly, since costs consist of initial investment, yearly operation and maintenance costs, they had to be converted to a common time base as done in equivalent benefits.

Therefore, the BCR was obtained from;

$$BCR = \frac{Bp}{P+Cp} = \frac{Bf}{Pf+Cf} = \frac{Ba}{Pa+C}$$ (Panneerselvam, 2012) Equation 3-8

Where;

Bp = Present worth of total benefits

Bf = Future worth of the total benefits

Ba = Annual equivalent of the total benefits

P = Initial investment

Pf = Future worth of the initial investment

Pa = Annual equivalent of the initial investment

C = yearly cost of operation and maintenance

Cp = Present worth of yearly cost of operation and maintenance

If BCR<1, the project should not proceed, if BCR =1, the project should be allowed to proceed but with little viability, if BCR>1, the project is justified.

a) Net Present Value (NPV)

The Net Present Value Method (NPV), also known as Present worth or Net Present Worth method refers to the difference between the present value of cash inflows and the present value of cash outflows over a given period of time. NPV is used in investment planning to analyze the profitability of a projected investment or project. Projects with positive NPV are considered to be viable hence the higher the NPV, the greater the calculated benefits of a project.

$$NPV = Bp - Cp - P$$ Equation 3-9

The following costs were considered for CBA analysis of the technologies;

- Capital costs (P_1): These were fixed, one-time expenses incurred in the purchase of a given technology.

- Operation and Maintenance costs: These include any costs associated with the smooth running of day to day activities and repair of a given technology. These costs included;
  - Cost of replacement of parts of a technology in case of breakdown (P_2).
  - Salary for the operators (driver inclusive) of a given technology (P_3).
  - Disposal charges at the dumping site (P_4)
  - Fuel costs (P_5)

Where the fuel cost (P_5) was given by (Anh et al., 2018);

$Fuel\ cost = (Travelling\ distance \times Fuel\ consumption) \times Fuel\ rate$ Equation 3-10

Where the travelling distance was determined as the average distance moved by the technologies. A fuel consumption rate of 13.73litres/100km (Banaga-Baingi, 2016) and a fuel rate of UGX. 3100 per litre (from petroleum station survey) were used.

The benefits were obtained as shown below;

$Revenues, P_a = N \times EF$ (Mbéguéré et al., 2010) Equation 3-10

Where N is the number of trips per year and EF is the emptying fee

To obtain Present Worth of the economic data obtained,

For initial investment costs;

$$Present\ Worth, P = Initial\ investment$$

For annual costs and benefits;

$Present\ Worth, P = A\ \frac{(1+i)^n - 1}{i(1+i)^n} = A(P/A, i, n)$ (Panneerselvam, 2012) Equation 3-11

Where; $(P/A, i, n)$ is called Equal-payment series present worth factor

P = Present Worth

A = Annual Equivalent payment

i = interest rate = 9% (Bank of Uganda, 2019)

n = Number of interest periods = 10 years

Therefore; Present Worth for annual benefits and costs, $P = A\ \frac{(1+0.09)^{10} - 1}{0.09(1+0.09)^{10}}$

$$P = A\ (6.4177)$$

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This section presents results obtained from the parameters analysed from each of the emptying technologies during the sampling period from the various slums in Kampala city. The parameters determined include; moisture content, Total Volatile Solids, Bulk density, solid waste content and time measurements for the different technologies monitored.

The analysed results for the mentioned parameters are provided in tables under Appendix A. Analysis was done using the methods proposed under the Methods and Materials chapter.

4.2 Functional pit emptying technologies

4.2.1 Vehicles used by the technologies

During the study, both the vacuum and non-vacuum technologies were encountered at the treatment plant. The vacuum technologies comprised of vacuum tankers of various capacities ranging from 2 m^3 to 14 m^3 (Figure 4-1 a). These were similar to 2m^3 to 10 m^3 (Nkurunzinza et al., 2017). A total of 78 emptying events were encountered with the highest percentage of trucks available mainly of size 3.6 m^3 (14.1%), followed by 3.7 m^3 (12.8%) and of the large sized trucks, the 10m^3 truck had the highest percentage (11.5 %). These trucks used hosepipes of common diameter 70 mm (50mm -100mm) and average hose length of 6.4m (2m -20m). The hosepipe dimensions were similar to (75 mm – 100 mm) diameter and (8 m to 40 m) hose length (Bosch & Schenertenleib, 1985). The trucks normally had 2 to 4 operators comprising a driver and turn-men who helped in emptying activities such as laying out the hosepipes and removing solid waste from containments. Most trucks (88.5 %) arriving at the treatment plant were full to capacity while 11.5 % carried fractions.

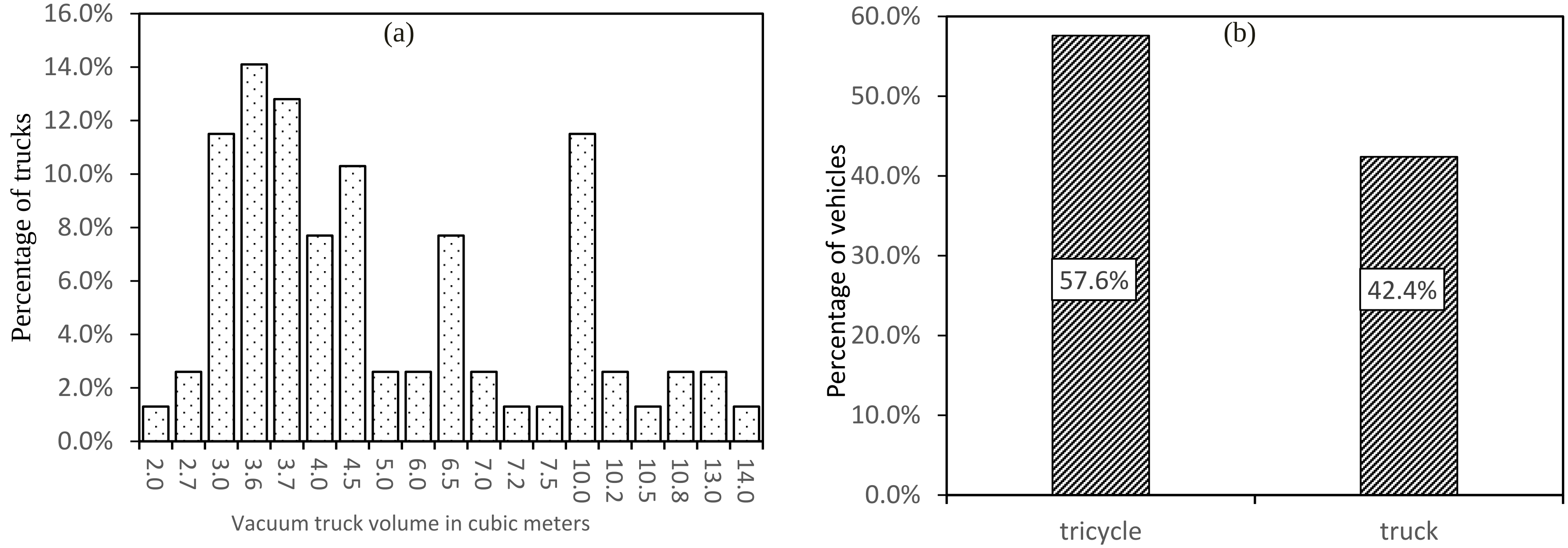


Figure 4-1: Vehicles used by the different technologies

The non-vacuum technologies included gulping or scooping the sludge out of the containments using a jerrycan. The removed sludge was transported in barrels to the treatment plant using either a tricycle or a truck. A large percentage (57.6%) of the operators mainly relied on tri-cycles that carried up to ten (10) barrels and the other 42.4% used trucks that carried a maximum of twenty-four (24) barrels (Figure 4-1 b). This is comparable to a study carried out by Seleman et al., (2019) where pick-up trucks and tricycles were reported as options used for transportation of faecal sludge. The high percentage of tricycles could be attributed to their low capital costs (UGX 7 million compared to a truck of UGX 18-50 million), ability to access all facilities and ease of maintenance in contrast to trucks. These technologies had an average of 3 operators (2 – 5 operators) who brought in on average 9 barrels (3 – 22 barrels) per trip. The volume of the barrels ranged between 160 litres and 200 litres. This is similar to what Nkurunzinza et al. (2017) reported that barrel sizes were 200 litres. However, the reason for variation in barrel volumes was mainly due to friction that could arise due to increment of emptying fees from UGX 30,000 to UGX 50,000. Therefore, the operators reduced the barrel size from 200litres to 160litres and maintained the price (J. Busigye, personal communication, 2020). The other explanation was that the operators used 180 litre barrels but simply reported them as 200 litres (Sanitech Engineering Operator, personal communication, 2020).

4.2.2 Ownership of the technologies

Ownership of the technologies was either on a company, individual or public basis. The study revealed that 100% of the non-vacuum technologies encountered in Kampala were managed on a company basis whereas vacuum technologies were operated on both individual (50%) and company basis (35.9%) as shown in Figure 4-2. Trucks owned on a public basis (14.1%) belonged to government entities like Kampala City Council Authority (KCCA) (5 trucks), Ministry of Water and Environment (4 trucks) and Uganda Police Force (1 truck). The public trucks were used to empty containments of schools, markets, prisons. All non-vacuum technology operators were strictly required to be registered due fear of them disposing of faecal sludge un-hygienically (S. Abubaker, personnel communication, 2020). However, having a company is more advantageous to non-vacuum operators since it allows for easy marketing and bidding for contractual emptying of containments compared to vacuum operators who own vehicles on an individual basis.

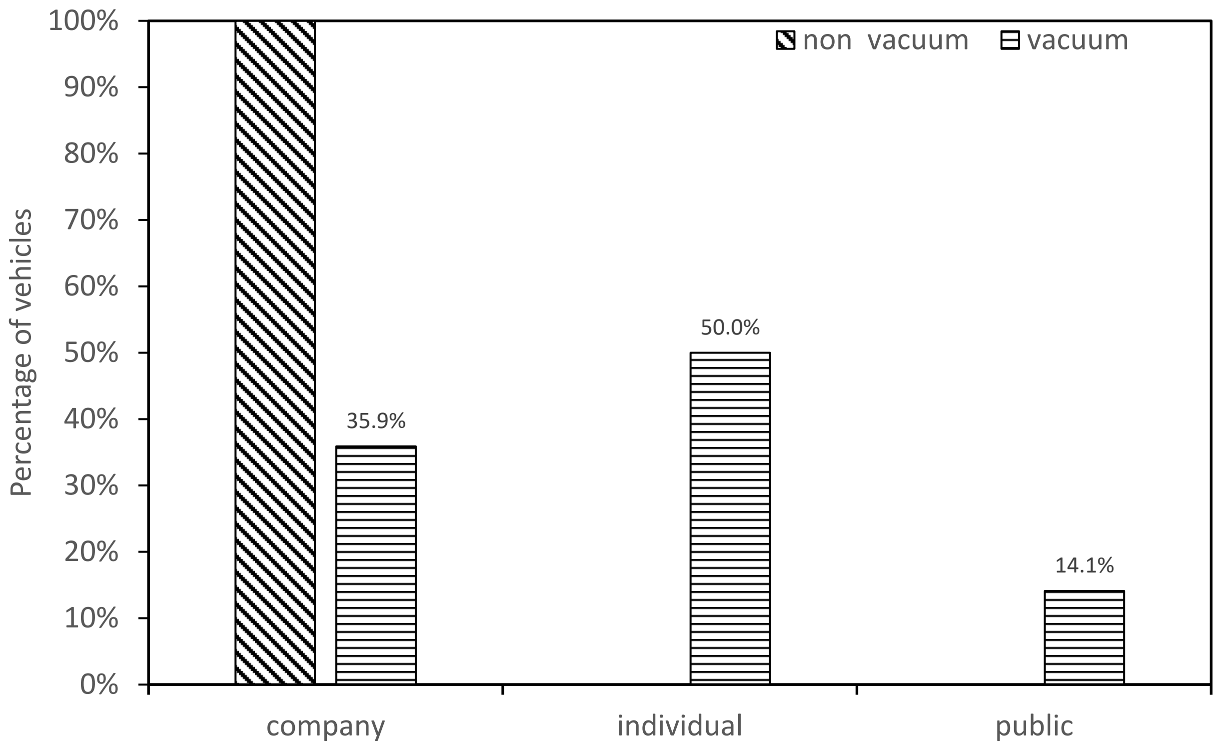


Figure 4-2: Vehicle ownership

4.2.3 Facilities emptied by the technologies

Both vacuum and non-vacuum technologies operated on both lined pit latrines and septic tanks. The vacuum technologies worked on 43.6% and 56.4% lined pits and septic tanks respectively as shown in Figure 4-3. The non-vacuum technologies on the other hand operated 34.5 % and 26.1 % less than the vacuum technologies on the lined pits and septic tanks respectively. This is because vacuum tankers are an effective choice of technology where septic tanks and pit latrines contain fairly liquid sludge (Still & Foxon, 2012). However, pit latrine sludge can be thick hence vacuum technologies do not satisfactorily empty pit latrines but remove the liquid portions of the sludge (Kwach, 2008). A high percentage (60.6%) of non-vacuum technologies operated on unlined pits and none of the vacuum technologies did. The vacuum technologies do not empty completely unlined pits because their suctioning runs a risk of damaging the unlined walls leading to collapse of the pit latrine (Pickford & Shaw, 1997; Jenkins et al., 2015).

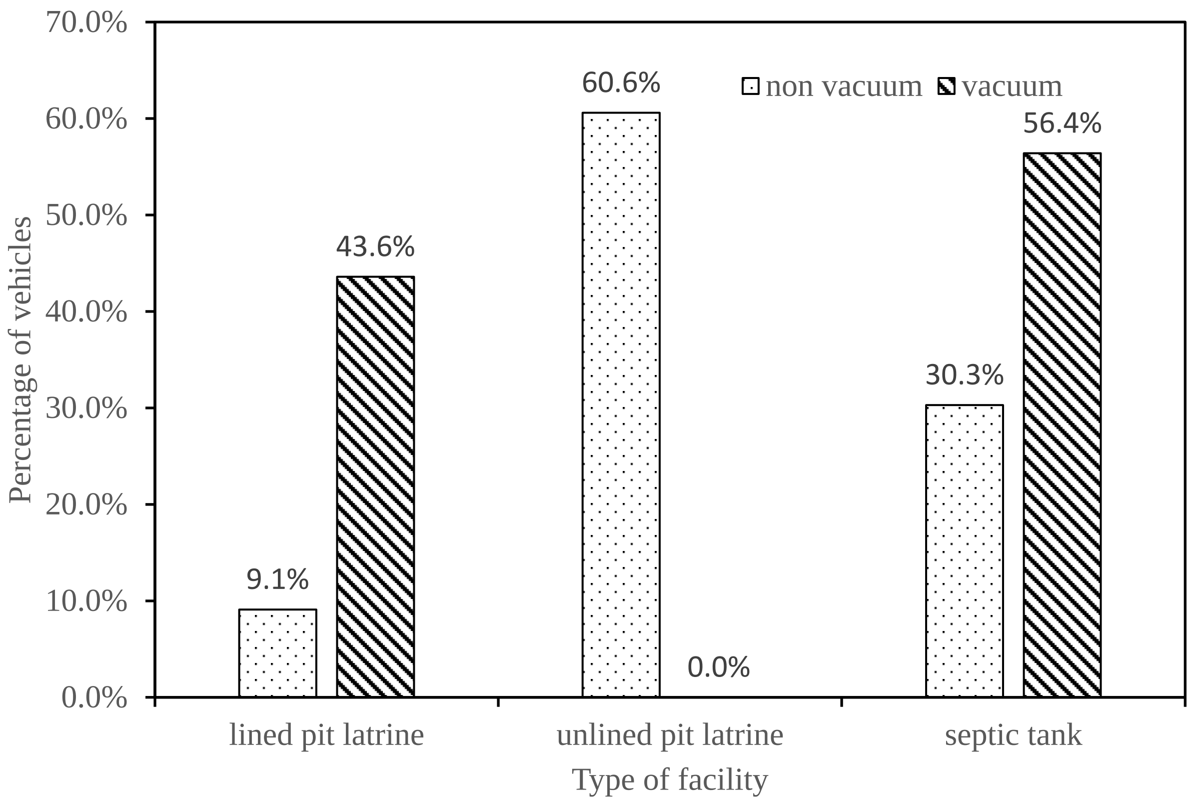


Figure 4-3: Facilities emptied by the technologies

4.2.4 Operation in slums

Of the 78 emptying events encountered within Kampala city, 38.5 % of the trucks with volumes ranging from $2m^3$ to $7m^3$ operated within slums. Of these, the most used truck for emptying in slums was of size 3.6 m^3 (10.3 %) (Figure 4-4). These are small in size and can maneuver through the narrow roads found in the slum areas. As the truck capacity increased from 7 m^3 to 14 m^3, these were found to mainly service outside slum areas. This could be attributed to their larger sizes that cannot access the small road network in slums. (Thye et al., 2009).

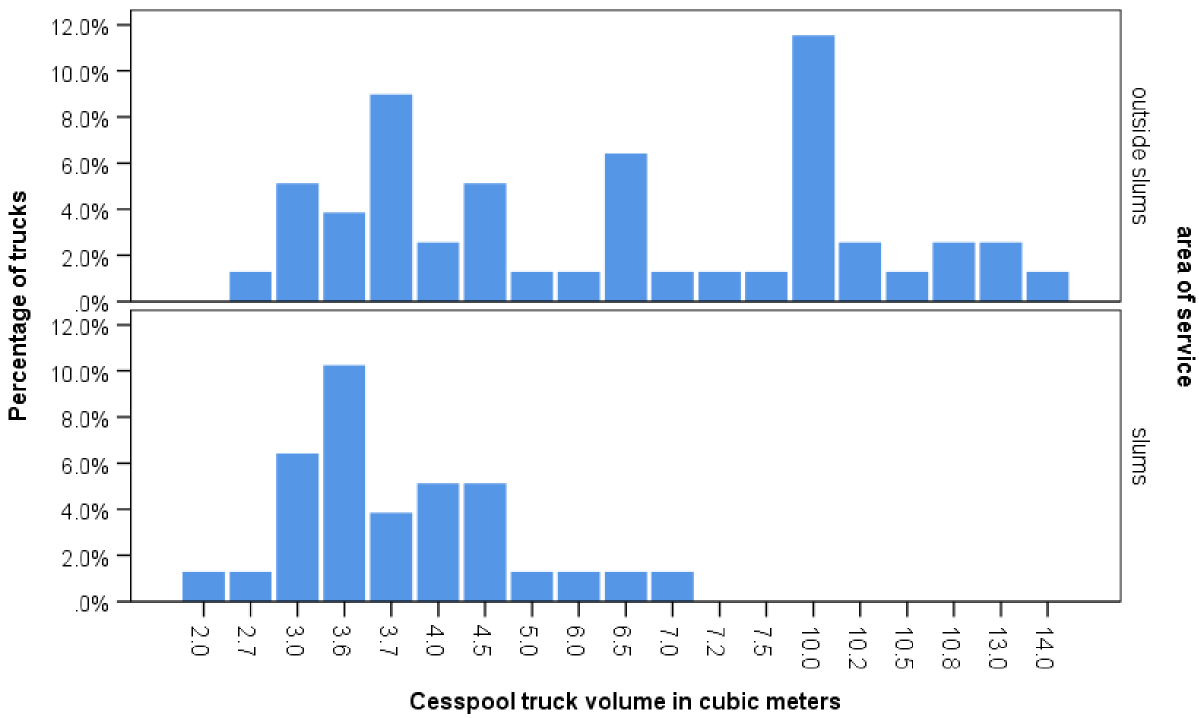


Figure 4-4: Vacuum tanker area of service distribution

The non-vacuum technologies operated in slums using both tricycles (33.3%) and trucks (27.3%) as shown in Figure 4-5. The higher percentage of tricycles in contrast to trucks could be attributed to their small size which allows them to navigate through the narrow paths found in these areas (Mikhael et al., 2014). Compared to vacuum tankers (38.5 %), the non- vacuum operators (60.6 %) worked 22.1 % more in slum areas. This discrepancy could be attributed to the type of containments used in slum areas. Most (78 %) of the latrines in these areas are either semi-lined or unlined compared to 22% that are fully lined (Schoebitz et al., 2016). Since non-vacuum operators worked mostly on unlined pits (Figure 4-3), their percentage of operation in slums was thus more compared to the vacuum technology operators.

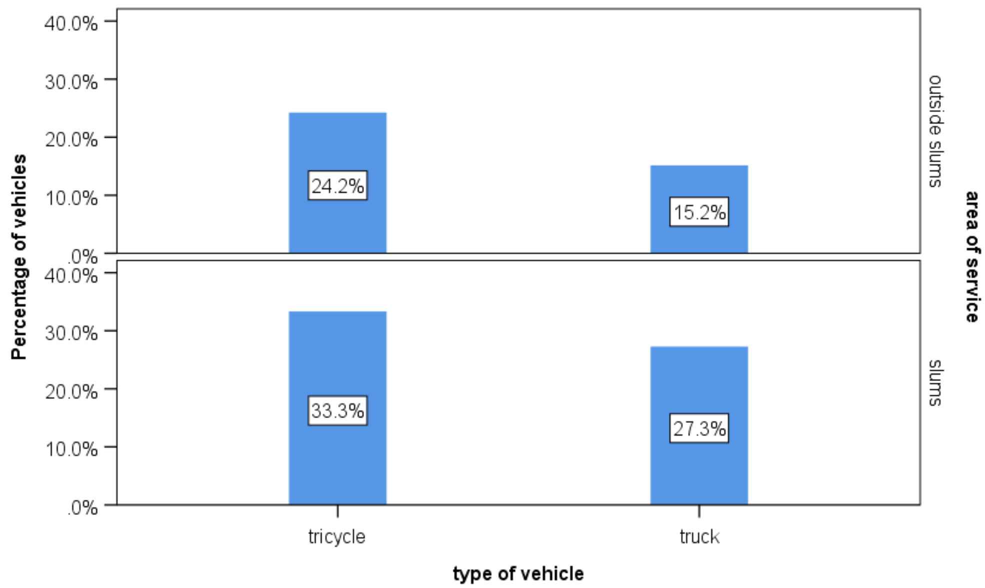


Figure 4-5: Non-vacuum technology areas of service distribution

4.3 Time taken for the emptying event

The time taken by the different technologies are indicted in Figure 4-6.

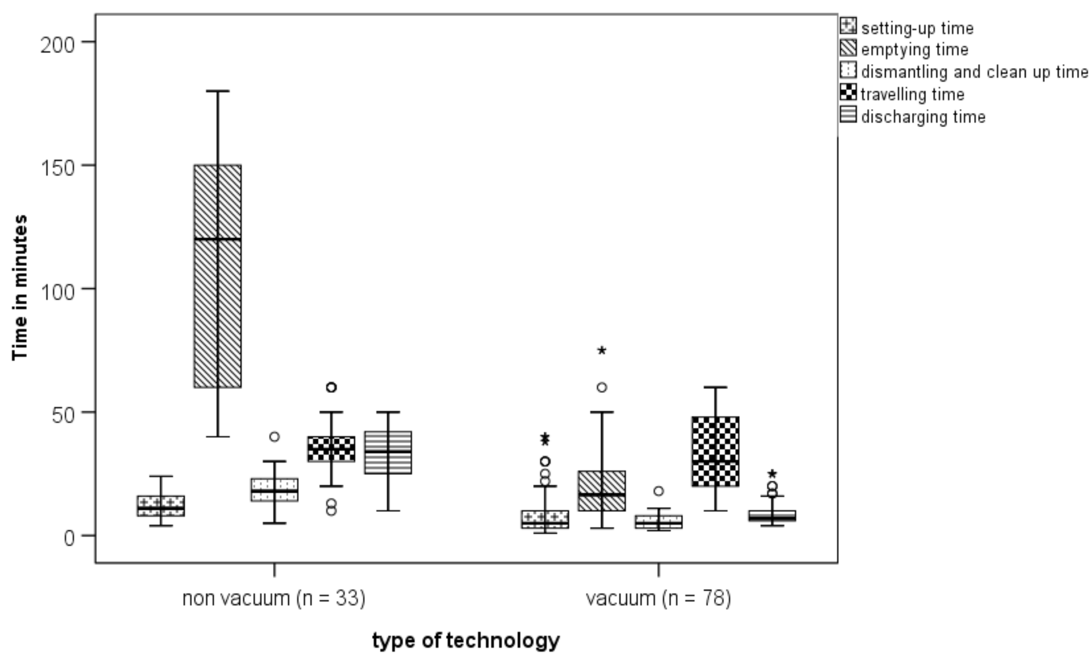


Figure 4-6: Time for the emptying event of each technology

4.3.1 Time for setting up

From Figure 4-6, the median setting up time was obtained as 5 and 11 minutes for the operators of the vacuum and non-vacuum technologies respectively. The former spent less time since setting up involved simply connecting the hose pipes to the required length needed to empty the pit. The outliers in the vacuum technology were due to delays caused by activities such as removing solid waste from the containment and setting up long pipes.

The operators of the non-vacuum technology spent time offloading the empty barrels, fetching water for cleaning, destroying the superstructure (widening the slab squat hole) (Zaqout et al., 2020). Such activities increased their time spent setting up contrary to that of the vacuum technologies.

4.3.2 Time for emptying

This took a median time of 16.5 and 120 minutes for operators of vacuum trucks and non-vacuum technologies respectively. The time spent by the latter was significantly higher than that of the former. This could be attributed to the inferior method of emptying (the direct lift method) used by some operators of non-vacuum technologies who operated at an average of 9.7 litres/minute (Appendix C) compared to vacuum trucks that worked between 150 and 300 litres/minute for a 5 m^3 truck and 14 m^3 truck respectively (Appendix C). This is comparable to 100 litres/minute for a truck emptying a 0.6m^3 pit latrine in 6 minutes (Bosch & Schenertenleib, 1985). The scooping method used by the non-vacuum operators involved to a greater extent, application of rudimentary tools like long spiked rods, long handled shovels, buckets and jerrycans to remove sludge from the pit latrines. Sometimes hammers were used by these operators to widen the squat hole and ensure that the pit was fully emptied.

Contrary to operators of non-vacuum technologies, the vacuum truck operators spent less time since they worked on non-thick sludge that avoided straining the pump. They were as well observed to remove or dodge solid waste that could end up blocking the hosepipe and consequently increase their emptying time. The outliers were brought about due to delays caused by blockage of the hose pipe by solid waste during emptying, long distance from truck to the facility being emptied, weak vacuum pump and variance in size of the facilities emptied hence more time was spent emptying.

4.3.3 Time for dismantling

This took a median time of 5 and 18 minutes for the operators of the vacuum and non-vacuum technologies respectively. Just like setting up, the vacuum truck operators spent little time packing to leave the pit site. The hosepipe was removed from the pit and dismantled, the portion of the pipe that was dipped into the pit was washed and packed up. Outliers here were mainly brought about by operators who had to remove the extra lengths of pipe connected or bury the removed solid waste from the containment hence spending more time.

Compared to vacuum technology operators, the non-vacuum technology operators had to clean the tools used, pit latrine floor, wash their gumboots and gloves and finally pack the tools onto the truck. In some cases, they had to place back the removed roof of the pit latrine. These activities relatively lengthened their packing time hence spending more time than vacuum truck operators on site.

4.3.4 Time for travelling

On average this was found to be 32.92 and 35.61 minutes moving at relatively similar average speeds of 30.28 and 28.95 km/hr for the operators of vacuum and non-vacuum technologies respectively (Table 4-1). Thus, the travel times were not significantly different due to similar road conditions. The average travel times are comparable to the average of 32.7 minutes reported in Accra, Ghana using vacuum tankers (Sagoe et al., 2019). Both technologies travelled similar distances which are less than 14 km considered financially sustainable in developing countries (Tayler, 2018).

Table 4-1: Showing speed and distance travelled by the different technologies

Category	Parameter	Unit	Vacuum (*n* = 20) Mean±SD	Non vacuum (*n* = 17) Mean±SD
Speed		km/hr		
	Maximum		65.31 ± 8.68	70.83 ± 6.83
	Average		30.28 ± 5.09	28.95 ± 5.97
Distance travelled		km	10.95 ± 2.78	9.00 ± 2.65

4.3.5 Time for discharging

The discharge time largely depended on the volume of the vacuum truck being emptied since larger trucks took a longer time compared to smaller trucks for example a vacuum truck of 10.8 m^3 took 10.25 minutes discharging while that of 2-5 m^3 took an average of 4.46 minutes. The discharging time is important since there are only three discharging points at the treatment plant. This could lead to delay of incoming trucks as shown in Figure 4-7.

Figure 4-7: Incoming trucks queue at Lubigi treatment plant

On average, vacuum trucks spent 8.64 minutes discharging while non-vacuum technology operators took 33.58 minutes. The large difference in time could be attributed to the fact that non-vacuum technology operators manually emptied sludge from their barrels into the holding facility (Figure 4-8) and took time cleaning the barrels and truck before heading out for the next trip. This is contrary to the vacuum truck operators who simply connected their hose pipes and mechanically emptied sludge from their trucks hence spending a shorter time discharging.

Figure 4-8: Holding facility for non-vacuum sludge discharge

4.4 Faecal sludge characteristics

The characteristics of the sludge obtained from the different technologies are presented in Table 4-2.

Table 4-2: Sludge characteristics obtained from cesspool and gulper operators

Parameter	Unit	Vacuum (n = 20) Mean ± SD	Non-vacuum (n = 17) Mean ± SD	p value
Moisture content	%	97.74 ± 1.50	86.35 ± 3.93	0000*
Total Volatile Soilds (TVS)	%TS	66.04 ± 13.64	59.86 ± 13.58	0.1778
Density	kg/m^3	1004.39 ± 46.96	1033.32 ± 29.20	0.0344*

*Significant difference between sludge characteristics from vacuum and non-vacuum technologies at $p = 0.05$ using an independent samples t-test

4.4.1 Moisture and Total volatile solids

From Table 4-2, the average moisture content obtained from the vacuum technologies (97.74%) was significantly higher (p = 0000) than that of non-vacuum technologies (86.35 %). This could be attributed to the behaviour of the vacuum truck operators as they were observed to ensure the lightest sludge got into the truck and moved the hosepipe around dodging solid waste with thick sludge. This is contrary to non-vacuum technology operators who simply removed whatever they encountered. The high moisture content of the vacuum technologies is similar to 95 % reported by Gold et al. (2018).

The average total volatile solids for operators of the vacuum and non-vacuum technologies were obtained as 66.04 % and 59.86 % respectively with no significant difference (p = 0.1778). This is because the amount of organic content in the pit latrine depends on the age of the sludge and decreases with time (Hawkins, 1982; Zziwa et al., 2016a). Since neither operator added organic materials during emptying, this meant the emptied sludge would have similar organics and affect the sludge fluidity in a similar way. However, the obtained values were within range (63.5 ± 11.5 %) of reported TVS in lined pits (Semiyaga et al., 2016).

4.4.2 Bulk density

The average density for the vacuum and non-vacuum technologies was 1004.39 kg/m^3 and 1033.32 kg/m^3 respectively. This meant that non vacuum technologies worked on significantly heavier sludge (p = 0.0344) than the vacuum technologies. The difference in densities could be attributed to the removal of top sludge by the vacuum technologies which is high in moisture content and less dense (Still & O'Riordan, 2012). Both the obtained densities are comparable to the average of 1001 kg/m^3 reported in pit latrines and within range (970 kg/m^3 to 1700 kg/m^3) (Radford & Sudgen, 2014; Beukes, 2019).

4.4.3 Solid waste

The mean solid waste fraction emptied by non-vacuum and vacuum technologies was 22.85 % and 4.4 % respectively as shown in Figure 4-9. The outlier in the non-vacuum technology solid waste fraction was due to presence of rubble (broken bricks) in some pits that made the composition heavier. From the solid waste fractions above, it can be seen that the vacuum technology handled far less solid waste (p = 0.0045) than the non-vacuum technology. This discrepancy could be attributed to the removal of solid waste by the vacuum truck operators from the hosepipe path or from the facility before emptying to ensure that little solid waste entered and blockage was avoided Figure 4-10 (a). This was analogous to a study carried out in Kampala where cesspool truck emptiers were noted to remove wastes from the facility before emptying (Murungi & van Dijk, 2014). However, the solid waste disposed at the treatment plant has no further treatment options and is piled up at the plant as shown in Figure 4.10 (b). The average solid waste fraction of the non- vacuum technology was in the range of 12 % - 54.5% in dry sludge as reported by (Tembo et al., 2019) since the sludge was removed using the same method (shovels, buckets).

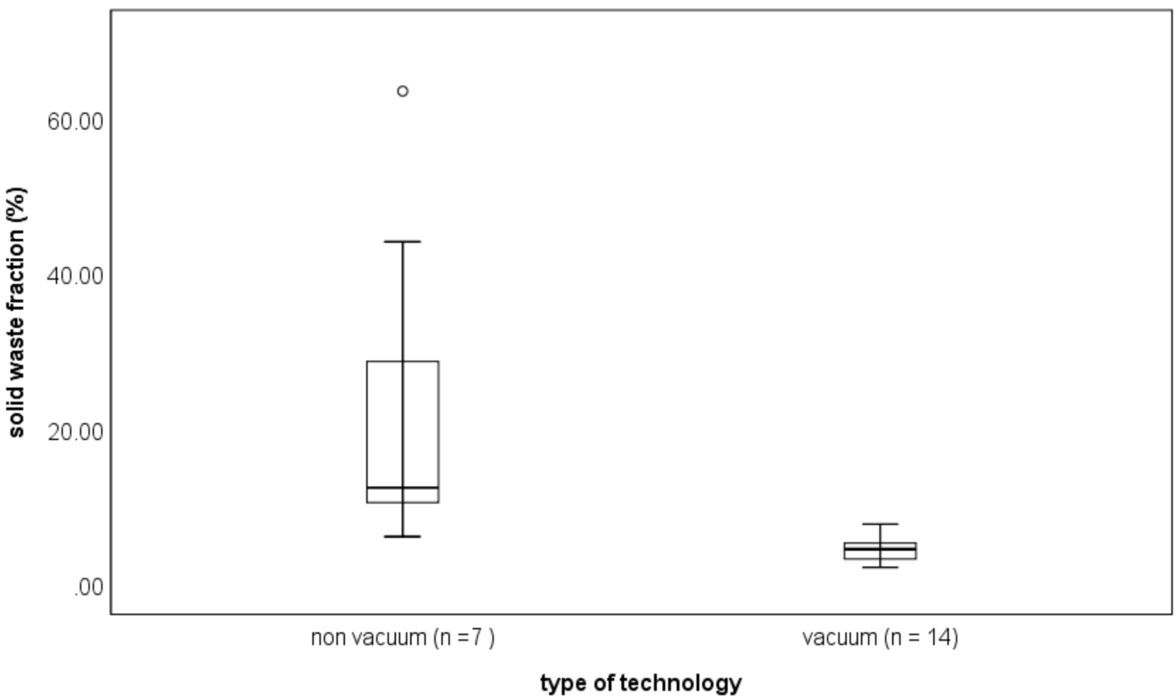
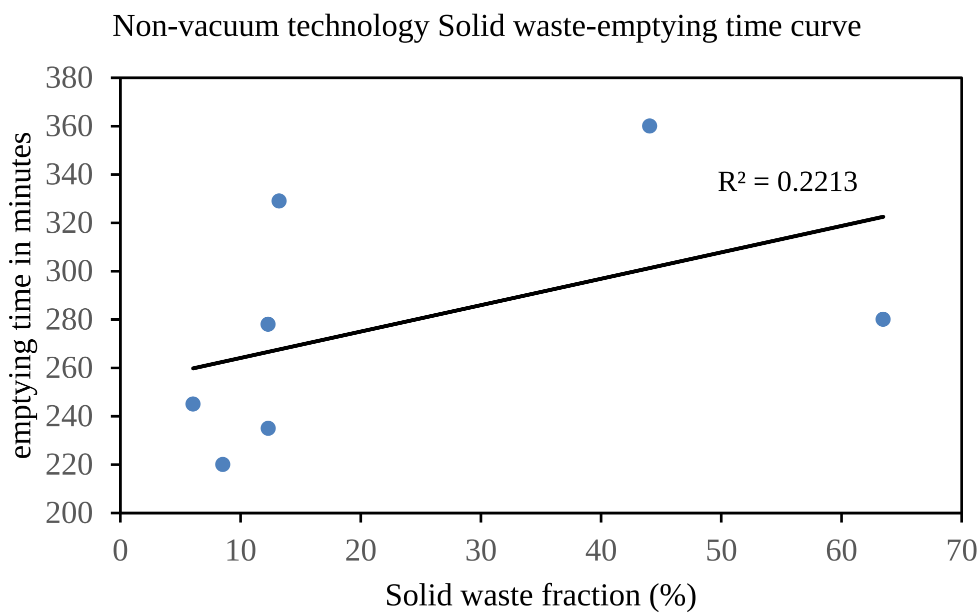


Figure 4-9: Mean solid waste fraction emptied by the different technologies

Figure 4-10: Vacuum truck emptier removing solid waste from the containment (a) and waste piled at Lubigi faecal sludge and wastewater treatment (b)

Correlation of the solid waste with emptying time taken by either technology revealed a positive relationship Figure 4-11. There was a non-significant low positive correlation ($R^2 = 0.2213$, $p = 0.287$) between the solid waste fraction and emptying time for non-vacuum technologies while it was a significant moderate positive correlation ($R^2 = 0.3746$, $p = 0.02$) between the solid waste and emptying time for vacuum technologies. This implied that for both technologies, the emptying time increased with the amount of solid waste emptied. However, this was significant for the vacuum technologies thus they are affected by the solid waste emptied compared to non-vacuum technology operators who easily handled the solid waste using hands to load it into the emptying bucket. The vacuum operators in contrast were observed to remove from the hose path or dodge it in order to reduce the solid waste that would get sucked up and cause blockages.



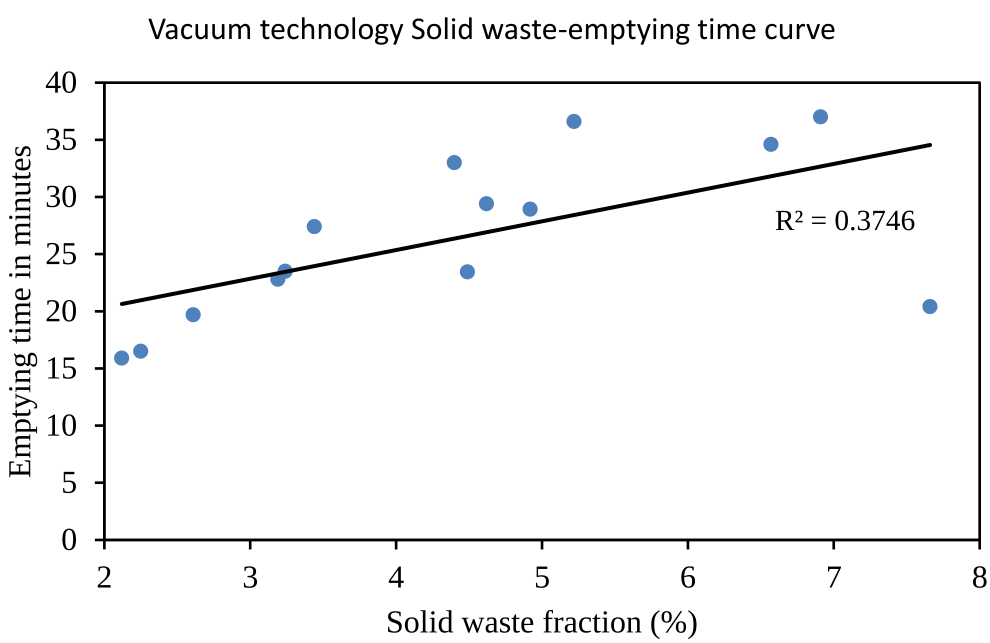


Figure 4-11: Variation of solid waste with emptying time

4.4.4 Shear strength

The maximum shear strength for the non-vacuum technology sludge was 6911.6 Pa (6.91 kPa) at 73.28 % moisture content (Appendix C) and for the vacuum technologies was 10.2 Pa at 95.26 %

moisture content (Appendix C). This shows that non-vacuum technologies worked on significantly stronger sludge (*p* = 0000) than the vacuum technologies.

This could be attributed to the high amount of water in vacuum truck sludge with an average moisture content of 97.74 % compared to that of non-vacuum technology sludge at 86.15 %. However, this is comparable with what Radford et al. (2011) noted that increasing the water content (by order of 2 %) could dramatically reduce resistance to flow by 30 times, thus increasing it from 73.28 % to 95.26 % (30 % increase) reduced the shear strength significantly by 600 times. The shear strength value for the vacuum technologies was on the lower end of the range 7.76 – 400 Pa (Bosch & Schenertenleib, 1985; Radford & Fenner, 2013) whereas the maximum value for the non-vacuum technologies was less than the estimated maximum value (10 kPa) of pit latrine sludge (Shafiq et al., 2020). This could be attributed to addition of water by the operators to ensure that they obtained simplied sludge that could be removed hence reducing its strength.

4.5 Cost Benefit Analysis

The total initial investments by the non-vacuum technology operators was obtained as UGX 19.17 million compared to vacuum technology at UGX 80 million (Table 4-3). Despite the fact that the initial cost of the non-vacuum technology was to a larger extent (93.9 %) composed of the cost of the vehicle used, the cost of a vacuum truck was much greater hence imposing a high start-up capital for vacuum-based businesses to commence. This is in line with findings of O'Riordan (2009) that vacuum based technologies have high capital costs. However, the operators of non-vacuum technologies incurred slightly higher annual operating costs (UGX 39.2 million) compared to those of vacuum technologies at (UGX 32.4 million). This could be attributed to the higher salary expenses incurred by the latter at UGX 29.6 million compared to the former at UGX 10.6 million. The higher expenditure in salary of the non-vacuum based business can be attributed to the higher number of operators who receive 10 % (UGX 3,000) of the emptying fee charged per barrel that is charged at UGX 30,000 (Sander, 2015).

Comparatively, both technologies incurred similar annual fuel costs at about UGX 1.4 million and UGX 5.1 million for the non-vacuum and vacuum technologies respectively. Thus, the fuel costs were 1.42 % and 5.2 % of the emptying cost for non-vacuum and vacuum technologies respectively.

Both technologies had high annual profits of UGX 98.6 million. This was due the high emptying fees and extra trips made by the vacuum technology operators as reported by Chowdhry & Kone, (2012) in order to make the same amount of money that the non-vacuum technology operators make in one trip.

Table 4-3: Showing Present worth of the economic data obtained

TECHNOLOGY	COSTS INCURRED (UGX)	PRESENT WORTH (P), (UGX)
NON-VACUUM TECHNOLOGY	**Initial investments;** 1. Cost of small truck – 18,000,000 2. Cost of 200litre barrels – 720,000 3. Cost of gulper-1 – 450,000 **Annual costs incurred;** 4. License of truck – 75,000 5. Repairs – 100,000 6. Servicing truck – 800,000 7. Fuel – 1,398,194.55 8. Payment of workers – 29,565,000 9. Cost for disposal of sludge-7,300,000	**P for initial investments;** 1. 18,000,000 2. 720,000 3. 450,000 **P for annual costs incurred;** 4. 481,327.5 5. 641,770 6. 5,134,160 7. 8,973,193.164 8. 189,739,300.5 9. 46,849,210
		∑P = 270,988,961.2
	BENEFITS OBTAINED	**PRESENT WORTH (P), (UGX)**
	Annual Benefits obtained; Emptying fee charged – 98,550,000	**P for annual benefits obtained** **632,464,335**
	COSTS INCURRED (UGX)	**PRESENT WORTH (P), (UGX)**

VACUUM TECHNOLOGY	**Initial investment;** 1. Cost of 3.6 m^3 vacuum truck – 80,000,000 **Annual costs incurred;** 2. Servicing the truck – 960,000 3. Licensing the truck – 90,000 4. Fuel costs – 5,103,411.75 5. Salary of workers; Driver; 7,300,000 Turnboy; 3,650,000 6. Discharge – 15,330,000	**P for initial investment;** 1. 80,000,000 **P for annual costs incurred** 2. 6,160,992 3. 577,593 4. 32,752,165.59 5. - 46,849,210 - 23,424,605 6. 98,383,341
		∑P = 288,147,906.6
	BENEFITS OBTAINED	**PRESENT WORTH (P), (UGX)**
	Annual Benefits obtained; Emptying fee charged – 98,550,000	**P for annual benefits obtained** **632,464,335**

Obtaining Benefit Cost Ratio (BCR)

$$BCR = \frac{\sum Present\ worth\ of\ benefits}{\sum Present\ worth\ of\ costs}$$

For non-vacuum technologies; $BCR = \frac{632,464,335}{270,988,961.2} = 2.33$

For vacuum technologies, $BCR = \frac{632,464,335}{288,147,906.6} = 2.19$

Since BCR for both technologies is greater than 1, it means that they are profitable.

Obtaining Net Present Value (NPV)

$$NPV = \sum Present\ worth\ of\ benefits - \sum Present\ worth\ of\ costs$$

For non-vacuum technologies;

$$NPV = 632,464,335 - 270,988,961.2 = Ugshs\ 361,475,373.8$$

For vacuum technologies, $NPV = 632{,}464{,}335 - 288{,}147{,}906.6 = Ugshs\ 344{,}316{,}428.4$

Since NPV for both technologies is positive, it means that they are both profitable with non-vacuum technologies having a greater NPV (UGX 361,475,373.8) than vacuum technologies (UGX 344,316,428.4) hence more profitable in the long run. This has been found elsewhere for example in Bangladesh where use of non-vacuum based methods were more profitable than vacuum based methods (Opel & Bashar, 2013; Zaqout et al., 2020).

4.6 Health

Health wise, the vacuum truck operators were not keen to put on overalls, nose masks, gumboots or gloves while emptying the facility (Table 4-4). They only put them on during discharge due to the strictness of the treatment plant manager who demanded working in proper Personal Protective Equipment (PPE). Although the vacuum tanker is considered to be more hygienic than the non-vacuum methods, the use of PPE remains vital to the operators (Thye et al., 2011). A recent study on air samples got during pit emptying using vacuum tankers revealed the possibility of pathogens being air borne with total coliforms and *E. coli* concentrations being as high as 790 CFU m^{-3} and 350 CFU m^{-3} respectively (Farling et al., 2019). The bio-aerosols emitted during emptying impose a health risk to the operators and the household owners.

Unlike the vacuum truck operators, the non-vacuum technology operators wore overalls, gloves and gumboots while emptying the latrines and were not keen about nose masks. The emptying procedure generally made the latrine dirty with sludge spilled all-over the floor and spills into the immediate outside environment as shown in Figure 4-12. Further contamination came from walking in the customer's compound with contaminated gumboots as Naidoo et al., (2016) noted.

Figure 4-12: Unhygienic manual emptying with sludge spills

Table 4-4: Health aspects of the technologies

Technology	Vacuum	Non-Vacuum
Operator similarities	• No nose masks	
Operator differences	Occasionally wear gloves, overalls at site	Always wear gloves, overalls and helmets at site
Technology health risks	• Sludge spills from pipes • Aerosolization of sludge microbes • Leaves removed solid waste on site	• Sludge spills from jerrycans • Contaminates customers' water taps • Often involves squat hole widening • Operator prone to fatigue, backaches and chest pains

Another aspect with the non-vacuum technology operators is the use of manual techniques that are tiresome. These make the operators prone to fatigue, backaches and chest pains. One operator explained that on using the gulper and the lifting of a jerrycan, they preferred the jerrycan to the gulper. This was attributed to the fatigue a gulper quickly builds in the operator compared to the jerrycan. Moreover, one operator could empty up to 20 barrels using a jerrycan but could only pump up to 3 barrels using a gulper. This explains the low usage of the gulper as shown in Figure 4.13.

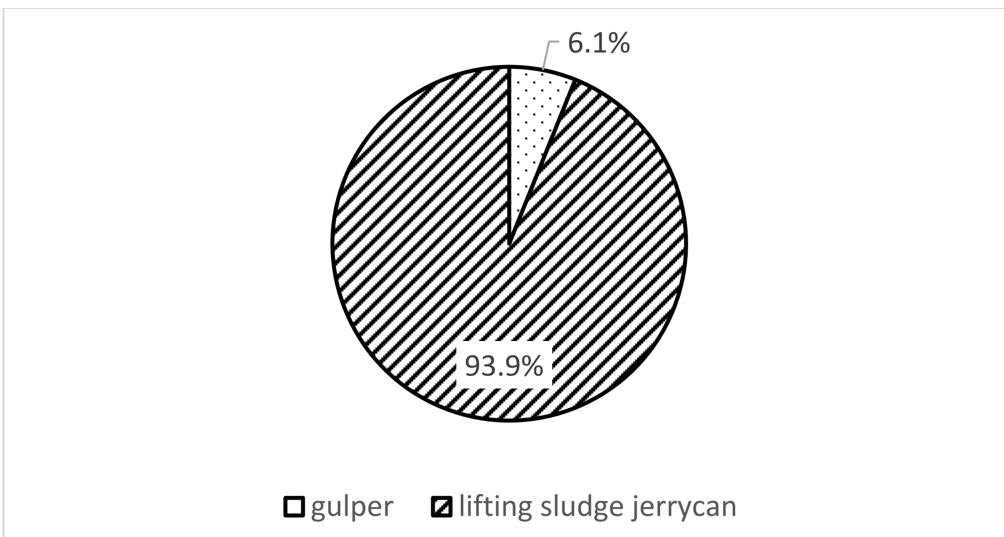


Figure 4-13: Usage of the gulper and lifting sludge jerrycan method of emptying

IMPLICATIONS OF THE RESULTS TO FAECAL SLUDGE MANAGEMENT

The results from the study have consequences on Faecal Sludge Management especially when it comes to emptying facilities. The study revealed that high presence of solid waste in pit latrines poses a major challenge to the technologies especially the vacuum technology that on average removed significantly less solid waste than the non-vacuum technologies. This implies that there is need to reduce the amount of solid waste disposed in pit latrines in order to ensure satisfactory emptying by the vacuum technologies. The amount of solid waste in the pit latrines increases the emptying time by the non-vacuum technologies hence effectively reducing the number of trips made per day.

The study revealed that 38.5% and 60.6% of the emptying events of the vacuum and non-vacuum technologies respectively occurred in slums areas. This implies that there is market for faecal sludge emptying in slum areas but is limited by factors such as narrow road access hence preventing large sized vehicles from accessing the areas.

The results show the need for water by the emptying technologies to carry out their operations. This means that the operators would require a lot more water to work on the pit latrine sludge during drier seasons since moisture content in the dry season is reported to average at 77.1% and 80.9% in lined and unlined pits respectively (Kimuli et al., 2016). This is 20.64% and 5.25% below the average working moisture content for the technologies.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- It was revealed that the non-vacuum technology operators worked more (22.1%) in slums compared to the vacuum technology operators because of a high prevalence of semi-lined and unlined pits in those areas.
- This study has demonstrated that the vacuum and non-vacuum technologies work on significantly different sludge with vacuum technologies working mainly on more watery and lighter sludge whereas the non-vacuum technologies work on both watery and thick sludge. This can be seen from the variation in faecal sludge characteristics of the two technologies with moisture content and bulk density obtained as 97.74% and 1004.39 kg/m^3 for vacuum technologies and 86.35% and 1033.32 kg/m^3 for non-vacuum technologies. The vacuum technologies worked on sludge that is 600 times weaker than that of the non-vacuum technologies. This can be seen from the shear strength values obtained for the different technologies, 6.91kPa for non-vacuum technologies and 10.2Pa for vacuum technologies.
- The study revealed that vacuum technologies generally take less time during different emptying events in contrast to non-vacuum technologies with the latter taking a total of 68.06 minutes and the former taking 218.09 minutes. This is mainly attributed to the efficiency of the mechanical method employed by vacuum technologies in emptying the pit in contrast to the tedious methods applied by non-vacuum technologies. The technologies had travel times that were not significantly different (32.92 and 35.61 minutes for vacuum and non-vacuum technologies respectively) due to similar road conditions.
- The study showed that both technologies are economically feasible with similar Benefit Cost Ratios above 1, (2.19 and 2.33 for vacuum and non-vacuum technologies respectively) and positive Net Present Values (UGX 344,316,428.4 and UGX 361,475,373.8 for vacuum and non-vacuum technologies respectively).

5.2 Recommendations

5.2.1 Recommendations for policy

- We recommend more stringent policies to be set up by concerned bodies in order to sensitize the public about the dangers of disposing solid waste into pit latrines. This will in turn shorten the emptying time taken by the technologies and further allow more pits to be emptied per day. Furthermore, energy recovery mechanisms for solid waste can be adopted by the authorities concerned in order to avoid piling the waste emptied from pits at the treatment plant.
- One major constraint to the number of trips made by either technology is the working hours permitted by the authorities of the treatment plant which runs from 8am to 6pm. Having an adjustable opening and closing time will increase the number of trips made per day

especially by the non-vacuum technology operators who were observed to make one trip per day. It will likewise avoid instances where technology operators have to store the emptied sludge overnight due to their failure to meet the closing time of the treatment plant.

- Provision of more efficient solid waste handling tools like the trash pump will help reduce the emptying time taken by non-vacuum technology operators.
- Basing on the information obtained from this research about the type of facilities emptied by the different technologies, a more efficient communication system can be designed by authorities where customers are encouraged to describe the facility they have before trucks are sent to the location to empty. This will avoid expenses incurred when trucks make trips to facilities they cannot fully empty.

5.2.2 Recommendations for further research

- We recommend that the solid waste for vacuum trucks should be determined by considering the entire truck volume and not only sampling using a bucket.
- We also recommend for further research to be carried out by sampling both from the pit before emptying by a given technology and also sampling what the technology has been able to remove. This will help in determining the variations in the sludge, both before and after emptying by a given technology.

REFERENCES

AIT. (2012). Assessment of Faecal Sludge Rheological Properties. Thailand.

Anh, T. H., Koottatep, T., & Polprasert, C. (2018). Business model analysis for faecal sludge collection and transport services in Thailand and Vietnam. Journal of Water, Sanitation and Hygiene for Development.

APHA, A. W. (2012). Standard Methods for the Examination of Water and Wastewater (23rd ed.).

Banaga-Baingi, G. (2016). The Fuel Efficiency Initiative In Uganda.

Bank of Uganda. (2019). Annual Report .

Bassan, M., Tchonda, T., Yiougo, L., Zoellig, H., Mahamane, I., Mbeguere, M., & Strande, L. (2013). Characterization of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. 36th WEDC International Conference, Nakuru, (pp. 1-5). Kenya.

Beukes, L. S. (2019). Pit latrines in a peri-urban South African community-a hygiene challenge and a health risk owning to curent desludging practices and biofilm forming, multi-drug resistant bacteria. PhD Thesis, University of Kwazulu-Natal.

Bosch, A., & Schenertenleib, R. (1985). Emptying On-Site Excreta Disposal Systems: Field Tests with Mechanized Equipment in Gaborone (Botswana). International Reference Center for Wastes Disposal, 21(17).

Buckley, C. A., Brouckaert, C. J., Rodda, N., Nwaneri, C., Balboni, E., Couderc, A., & Magagna, D. (2008). Scientific Support for the Design and Operation of Ventilated Improved Pit Latrines (VIPs) and the Efficacy of Pit Latrine Additives.

C.H.Burton. (2007). The potential contribution of separation technologies to the management of livestock manure. Livestock Science, 208-216.

Chowdhry, S., & Kone, D. (2012). Business Analysis of Fecal Sludge Management: Emptying and Transportation Services in Africa and Asia.

Chowdhry, S., & Kone, D. (2012). Landscape and Business Analysis for FSM Emptying and transportation in Africa and Asia.

Crofts, T., & Fisher, J. (2012). Menstrual Hygiene in Ugandan schools: An Investigation of Low-cost Sanitary Pads.

Eales, K. (2005). Sanitation Partnerships Series: Bringing pit emptying out of the darkness: A comparison of approaches in Durban, South Africa, and Kibera, Kenya.

Farling, S., Rogers, T., Kness, J. S., Tilley, E. A., Brown, J., & Deshusses, M. A. (2019). Bioaerosol emissions associated with pit latrine emptying operations. Science of the Total Environment (648), 1082-1086.

GOAL. (2016). Review of Manual Pit Emptying Equipment Currently in Use and Available in Freetown and Globally.

Gold, M., Harada, H., Therrien, J.-D., Nishida, T., Cunningham, M., Semiyaga, S., Strande, L. (2018). Cross-country analysis of faecal sludge dewatering. Environmental Technology, 39(23), 3077-3087.

Hawkins, P. M. (1982). Emptying On-Site Excreta Disposal Systems in Developing Countries: An Evaluation of the Problems.

Hutton, G., Haller, L., & Bartram, J. (2007). Global cost-benefit analysis of water supply and sanitation interventions. Journal of Water and Health.

Jenkins, M. W., Cumming, O., & Cairrncross, S. (2015). Pit Latrine Emptying Behavior and Demand for Sanitation Services in Dar Es Salaam, Tanzania. International Journal of Environmental Research and Public Health, 2588-2611.

Kabange, R. S., & Nkansah, A. (2019). A Review of Pit Latrine Emptying Technologies for Low-Income Densely-Populated Settlements of Developing Countries. Current Trends in Civil and Structural Engineering.

Kabange, R. S., & Nkansah, A. (2019). A Review of Pit Latrine Emptying Techologies for Low-income Densely-Populated Settlements of Developing Countries. Current trends in Civil and Structural Engineering.

KCCA. (n.d.). Improving faecal sludge management for on-site sanitation. Retrieved September 26, 2019, from https://www.kcca.go.ug/uDocs/Improving%20feacal%20sludge%20management%20for%20on-site%20sanitation.pdf

Kimuli, D., Zziwa, A., Banadda, N., Kabenge, I., Kiggundu, N., Kambugu, R., Kigozi, J. (2016). Quantification Of Physico-Chemical Characteristics And Modelling Faecal Sludge Nutrients From Kampala City Slum Pit Latrines. International Journal of Research in Engineering & Advanced Technology, 3(6).

Kwach, H. (2008). The UN-HABITAT Vacutug Development Project Updata. kenya.

Leeuwen, M. J., Sekeramayi, T., Martell, C., Feinberg, M., & Bowersox-Daly, S. (2017). A Baseline Analysis of the Katanga Slums; Informing Urban Public Policy In Kampala, Uganda. African Population Studies, 3(2).

Malinga, S., Atayo, H., & Atwijukye, O. (2016). Facilitating the emergence of sanitation technologies in developing economies. Water for People.

Mbéguéré, M., Gning, J. .., Dodane, P. H., & Kone, D. (2010). Socio-economic profile and profitability of faecal sludge emptying companies. Resources, Conservation and Recycling, 1288–1295.

Mikhael, G., Robbins, D. M., Ramsay, J. E., & Mbeguere, M. (2014). Methods and means for collection and Transport of faecal sludge. In L. Strande, M. Ronteltap, & D. Brdjanovic (Eds.), Faecal Sludge Management (pp. 67-74). London: IWA Publishing.

Mondal, S. (2018). Faecal Sludge Management in Khulna City: An Approach for Safe Emptying. Master Thesis, Khulna University of Engineering & Technology, Department of Civil Engineering.

Mukaka, M. M. (2012). Statistics Corner: A guide to appropriate use of Correlation coefficient in medical research. Malawi Medical Journal, 24(3), 69-71.

Murungi, C., & van Dijk, M. P. (2014). Emptying, Transportation and Disposal of feacal sludge in informal settlements of Kampala Uganda: The economics of sanitation. Habitat International, 69-75.

Nabateesa, S., Zziwa, A., Kabenge, I., Kambugu, R., Wanyama, J., & Komakech, A. J. (2017). Occurrence and survival of pathogens at different sludge depths in unlined pit latrines in Kampala slums. Water SA, 43(4).

Naidoo, D., Archer, C., Louton, B., & Rodda, N. (2016). Testing household disinfectants for the inactivation of helminth eggs on surfaces and in spills during pit latrine emptying. Water SA, 42.

Naing, W., Harada, H., Fujii, S., & Hmwe, C. S. (2020). Informal Emptying Business in Mandalay: Its Reasons and Financial. Environmental Management(65), 122–130.

Nakagiri, A., Kulabako, R. N., Nyenje, P. M., Tumuhairwe, J. B., Niwagaba, C. B., & Kansiime, F. (2015). Performance of pit latrines in urban poor areas: A case of Kampala, Uganda. Habitat International, 529-537.

Niwagaba, C. B., Mbeguere, M., & Strande, L. (2014). Faecal Sludge Quantification, Characterisation and Treatment Objectives. In L. Strande, M. Ronteltap, & D. Brdjanovic (Eds.), Faecal Sludge Management (pp. 19-44). London: IWA Publishing.

Nkurunzinza, A. G., Bateganya, N. L., Byansi, J. Z., Rokob, J., & Busingye, J. (2017). Leveraging FSM to Close the Urban Sanitation Loop in Kampala. Bill & Melinda Gates Foundation.

Opel, A., & Bashar, M. K. (2013). Inefficient technology or misperceived demand: the failure of Vacutug-based pit-emptying services in Bangladesh. Waterlines, 32(3), 214-220.

O'Riordan, M. (2009). Investigation into methods of Pit Latrine Emptying. Partners in Development, WRC Project, 1745.

Panneerselvam, R. (2012). Engineering Economics. New Delhi: PHI Learning Private Limited.

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, 222-240.

Pickford, J., & Shaw, R. (1997). Technical brief no. 54: Emptying latrine pits. Waterlines, 16(2), 15–18.

Radford, J. T., & Fenner, R. A. (2013). Characterisation and fluidisation of synthetic pit latrine. Journal of Water, Sanitation and Hygiene for Development.

Radford, J. T., & Sudgen, S. (2014). Measurement of faecal sludge in-situ shear strength and density. Water SA, 40(1).

Radford, J. T., Malinga, S., Drummond, G., Atayo, H., Whitesell, A. B., & Sugden, S. (2015). Latrine desludging pump development using a simple test for simulant strength: A case study from Uganda. Journal of Water, Sanitation and Hygiene for Development .

Radford, J. T., Underdown, C., Velkushanova, K., Bryne, A., Smith, D. P., Fenner, R. A., Whitesell, A. (2015). Faecal Sludge Simulants to Aid the Development of Desludging Technologies. Journal of Water, Sanitation and Hygiene for Development.

Radford, J., Manus, C., & Fenner, R. (2011). Developing a synthetic pit latrine sludge and a process for its fluidisation.

Reddy, M. (2013). Standard Operating Procedures.

Roxburgh, H., Hampshire, K., Kaliwa, T., Tilley, E. A., Oliver, D. M., & Quilliam, R. S. (2020). Power, danger, and secrecy—A socio-cultural examination of menstrual waste management in urban Malawi. PLoS ONE.

Runyoro, S. k. (1981). Pit latrine Emptying.

Sagoe, G., Danquah, F. S., Amofa-Sarkodie, E. S., Appiah-Effah, E., Ekumah, E., Mensah, E. K., & Karikari, K. S. (2019). GIS-aided optimisation of faecal sludge management in developing countires: the case of the Greater Accra Metropolitan Area, Ghana. Heliyon(5).

Sander, N. (2015). Sanitation as a business An analysis of community toilets and formal private pit emptying services in Kampala, Uganda. M.Sc. Thesis, Wageningen University.

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.

Schoebitz, L., Niwagaba, C. B., & Strande, L. (2016). SFD Promotion Initiative . Kampala.

Seal, D., Bown, R., & Parker, A. (2018). Penetrometer tests on 109 pit latrines in Kibera, Nairobi, Kenya. Water SA, 40, 459-463.

Seleman, A., Mbwette, T. S., Gabrielsson, S., & Kimwaga, R. (2019). Reviewing the Potential and Constraints of Modified Technology Options for Faecal Sludge Management in Dar es Salaam. Tanzania Journal of Engineering and Technology, 38(2), 245-259.

Semiyaga, S., Okure, M. A., 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, 109-119.

Semiyaga, S., Okure, M. A., Niwagaba, C. B., Nyenje, P. M., & Kansiime, F. (2016). Dewaterability of faecal sludge and its implications on faecal sludge management in urban slums. International Journal of Environmental Science and Technology.

Septien, S., Pocock, J., Teba, L., Velkushanova, K., & Buckley, C. A. (2018). Rheological characteristics of faecal sludge from VIP latrines and implications on pit emptying. Journal of Environmental Management, 228, 149-157.

Shafiq, Y., Haigh, S., Holm, R., & Parker, A. (2020). Re-evaluating the strength of pit-latrine faecal sludge from dynamic cone penetrometer test data. Water SA, 4(12), 638-644.

Singh, S., Mohan, R. R., Rathi, S., & Raju, N. J. (2017). Technology options for faecal Sludge management in developing countries: Benefits and revenue from reuse. Environmental Technology & Innovation, 203-218.

Still , D., & Foxon, K. (2012). Tackling the Challenges of full pit latrines Volume 1: Understanding sludge accumulation in VIPs and strategies for emptying full pits. Water Research Commision.

Still, D. A. (2002). After the pit latrine is full...what then? Effective Options for pit latrine management. Durban: Water Research Commission (WRC).

Still, D., & O'Riordan, M. (2012). Tackling the challenges of full pit latrines Volume 3: The development of pit emptying technologies. Water Research Commission.

Strande, L., Ronteltap, M., & Brdjanovic, D. (2014). Faecal Sludge Management Systems Approach for Implemantation and Operation (1st ed.). IWA Publishing.

Strauss, M., & Montangero, A. (2002). FS Management – Review of Practices, Problems and Initiatives. EAWAG/SANDEC.

Sugden, S. (2013). The importance of understanding the market when designing pit-emptying devices. Waterlines, 32(3), 200-212.

Tayler, K. (2018). Faecal Sludge ans Septage Treatment: A Guide for Low- and Middle- Income Countries. Practical Action Publishing.

Tembo, J. M., Matanda, R., Banda, I. N., Mwanaumo, E., Nyirenda, E., Mambwe, M., & Nyambe, I. A. (2019). Pit latrine faecal sludge solid waste quantification and characterization to inform the design of treatment facilities in peri-urban areas: A case study of Kanyama. African Journal of Environmental Science and Technology.

Thye, Y. P., Templeton, M. R., & Mansoor, A. (2009). Pit Latrine Emptying: Technologies, Challenges and Solutions.

Thye, Y. P., Templeton, M. R., & Mansoor, A. (2011). A Critical Review of Technologies for Pit Latrine Emptying in Developing Countries. Critical Reviews in Environmental Science and Technology.

Tilley, E., Ulrich, L., Luthi, C., Reymond, P., & Zurbrugg, C. (2014). Compendium of Sanitation Systems and Technologies. eawag aquatic research.

Velkushanova, K. V., Zuma, L., & Buckley, C. (2019). Mechanical properties of faecal sludge. Gates Open Research.

Wandera, B. (1999). Small scale independent providers of water and sanitation to the urban poor A Case of Kampala, Uganda.

Water for People. (2014). Report on the Gulper, Rammer and Nibbler Development. Kampala.

Zaqout , M., Cawood, S., Evans, B. E., & Barrington, D. J. (2020). Sustainable sanitation jobs: prospects for enhancing the livelihoods of pit-emptiers in Bangladesh. Third World Quarterly.

Zuma, L., Velkushanova, K., & Buckley, C. (2015). Chemical and thermal properties of VIP latrine sludge. Water SA, 41(4), 534-540.

Zziwa, A., Kabenge, I., Kayondo, H., Lugali, Y., Kambugu, R., & Wanyama, J. (2016b). Fractional content of non-faecal matter and its contribution to filling rates of pit latrines in Kampala slums. Glob. J. Eng. Sci. Res. Manag., 36-45.

Zziwa, A., Nabulime, M. N., Kiggundu, N., Kambugu, R., Katimbo, A., & Komakech, A. J. (2016a). A critical Analysis of physiochemical properties influencing pit latrine emptying and feacal sludge disposal in Kampala slums, Uganda. African Journal of Environmental Science and Technology, 10, 316-328.

APPENDIX

APPENDIX A: LABORATORY RESULTS AND GPS DATA

Appendix Table A-1: Showing analysis of vacuum truck data

No.	MCG (%)	TVSG (%TS)	Density (kg/m^3)	Solid waste fraction (%)	emptying (min)	setting-up(min)	Dismantling (min)	Discharge (min)	travel (min)	max speed (km/hr)	average speed (km/hr)	distance traveled (km)
1	96.26	67.53	935.36		32.00	6.00	7.00	5.90	26.26	69.90	23.40	10.24
2	99.21	64.41	1150.00		25.30	5.00	6.80	3.80	6.72	80.10	34.80	3.90
3	96.68	65.49	1050.00		30.20	6.20	7.40	4.70	12.41	78.20	20.30	4.20
4	98.91	39.10	1090.00		31.80	5.00	5.60	5.33	31.27	62.40	21.30	11.10
5	98.25	51.75	1015.17		26.00	5.40	6.00	3.70	23.35	71.70	31.60	12.30
6	98.03	70.98	1033.21		31.50	6.30	7.00	5.70	25.65	66.50	29.50	12.61
7	95.26	75.09	1000.00	7.66	20.40	6.50	6.60	2.07	27.76	54.80	24.90	11.52
8	99.18	64.98	977.90	6.57	34.60	7.00	8.00	6.00	11.66	67.00	35.00	6.80
9	95.37	80.39	1000.60	2.12	15.90	8.60	13.20	5.00	20.71	70.00	36.50	12.60
10	99.12	71.16	978.27	5.22	36.60	10.00	10.60	7.00	23.55	43.00	34.90	13.70
11	99.34	70.42	976.95	3.19	22.80	5.50	8.50	6.30	20.74	69.00	32.40	11.20
12	99.33	26.87	977.05	6.91	37.00	15.00	12.60	4.00	21.11	55.00	28.70	10.10
13	99.56	84.94	975.72	4.40	33.00	9.70	7.70	7.00	21.30	74.30	33.80	12.00
14	97.78	62.05	986.13	3.44	27.40	6.60	9.40	6.00	33.64	65.80	23.90	13.40
15	99.08	65.53	978.51	4.62	29.40	7.80	11.40	5.00	22.59	68.60	32.40	12.20
16	98.09	64.05	984.31	4.92	28.93	7.37	8.52	5.17	25.58	66.42	29.56	12.60
17	97.35	69.31	988.67	3.24	23.50	12.30	10.00	6.00	23.17	55.24	33.40	12.90
18	96.13	80.78	995.99	2.25	16.50	14.30	9.20	5.00	20.41	60.50	34.10	11.60
19	95.68	74.77	998.73	2.61	19.70	7.00	6.00	5.00	20.44	64.60	36.40	12.40
20	96.24	71.16	995.32	4.49	23.45	8.00	7.50	4.44	24.42	63.21	28.75	11.70

Appendix Table A-2: Showing analysis of data from non-vacuum technologies

No.	MCG (%)	TVSG (%TS)	Density (kg/m^3)	Solid waste fraction (%)	emptying (min)	setting-up(min)	Dismantling (min)	Discharge (min)	travel (min)	max speed (km/hr)	average speed (km/hr)	distance traveled (km)
1	73.28	18.87	1006.67		237.28	12.80	24.00	45.00	23.22	81.20	31.60	12.20
2	87.24	63.39	966.99		376.00	15.30	17.80	30.00	42.90	68.20	19.00	13.10
3	93.28	86.23	1013.46	63.47	280.05	28.08	29.03	50.00	15.23	77.50	37.50	9.50
4	85.43	64.96	1006.67	13.22	329.00	33.00	30.02	23.00	32.62	79.40	23.60	12.81
5	86.52	76.27	996.32	44.05	360.00	10.00	31.00	33.00	23.58	75.03	20.90	8.22
6	89.66	45.53	1022.00	12.30	278.00	14.00	35.00	39.00	7.10	59.60	33.80	4.00
7	84.41	60.77	1010.20	8.53	220.00	16.00	25.00	25.00	13.11	68.40	36.60	8.00
8	85.04	54.98	1030.76	6.06	245.00	14.16	22.50	44.00	9.10	60.44	30.40	4.60
9	88.86	61.30	1070.90	12.32	235.00	20.00	21.00	36.00	30.00	56.60	16.19	8.10
10	87.19	62.43	1052.52		289.00	18.45	27.41	22.00	18.00	72.98	29.00	8.70
11	85.75	57.21	1062.17		241.00	18.90	28.78	47.00	16.37	73.67	30.43	8.30
12	86.97	60.79	1053.98		185.00	19.78	29.46	25.00	25.58	72.59	30.26	12.90
13	86.80	59.91	1055.13		276.00	16.19	29.44	46.00	13.01	70.64	35.50	7.70
14	87.52	63.99	1050.33		305.00	22.30	25.21	36.00	16.97	76.58	27.93	7.90
15	86.86	60.86	1054.71		245.00	13.33	30.33	50.00	15.38	68.19	30.43	7.80
16	87.01	61.14	1053.72		287.00	18.32	27.88	35.54	16.95	72.73	29.73	8.40
17	86.08	59.03	1059.93		260.00	20.94	26.56	36.75	21.93	70.33	29.27	10.70

APPENDIX B: COST BENEFIT ANALYSIS (CBA)

A. For Gulper operators;

Appendix Table B-1: Gulper costs, income sources

Item	Value	Comment
Equipment		
Gulper- 1	450,000/= each	
Gulper-4	-	1 gulper of 4m in 2020
Truck	18 million	2014-2017
Truck	25 million	2017- to date
Rammer	700,000/=	1 rammer in 2017
200-litre barrels	80,000/= each	
Other expenses		
Repairs in a year	100,000/=	
Servicing in year	800,000/=	
License of truck in a year	75,000/=	
Payment to workers	3,000/= per barrel per day	
Fuel costs	30,000/= per day	
Disposal (old system)		
Tuku-tuku (tricycle)	15,000/=	A tricycle carries 5 barrels
Small truck	20,000/=	Maximum 20 barrels
Big truck	25,000/=	About 24 barrels

Disposal (new system)		
1-6 barrels	15,000/=	
6-14 barrels	20,000/=	
Over 14 barrels	25,000/=	
Charge at emptying		
Pit latrine	30,000/= per barrel	
Septic tank	25,000/= per barrel	

B. For Cesspool truck operators;

Appendix Table B-2: Emptying fees charged within Kampala

Truck Volume (m^3)	Emptying fees (UGX)
1.8 – 2	70,000 -80,000
3 – 3.7	90,000
4 – 4.5	100,000
5	140,000
6- 8	160,000
10	170,000 – 200,000
14 -15	220,000 – 250,000

Appendix Table B-3: Discharge fees for the different truck volumes

Truck volume (m^3)	Discharge fee (UGX)
1.8 – 3	10,000
3.5 – 4.5	14,000
5 and above	20,000

Appendix Table B-4: Truck costs

Item	Value	Comment
Costs		
2 – 3 m^3	UGX 45 – 50 million	
3.7 – 4.5	UGX 80 million	
7.2 – 8	UGX 120 million	
10	UGX 140 – 150 million	Good quality could be 170 million
14 – 15	UGX 170 – 180 million	
Servicing		
4 m^3	UGX 240,000	Per 3 months
7.2	UGX 500,000	Per 3 months
10	UGX 700,000	Per 3 months
License of truck		
4 m^3	UGX 90,000	
7.2	UGX 140,000	
10	UGX 150,000	
Fuel costs		
2 – 3 m^3	UGX 20,000	For 4 litres per day
3.7 – 4.5	UGX 25,000	For 4 litres per day
7.2 – 8	UGX 40,000	
10	UGX 50,000	
14 – 15	UGX 60,000	

Salary		
Driver	UGX 20,000	Per day
Turnboy	UGX 10,000	Per day

CONSIDERATIONS FOR CBA

1. Using gulper-1 and a 3.6 m^3 vacuum truck that frequents slums.
2. Operators of non-vacuum technologies make one trip per day and the 3.6 m^3 vacuum truck makes an average of 3 trips per day.
3. A truck that carries an average of 9 barrels per trip was considered for the non-vacuum technologies and the 3.6 m^3 vacuum truck was considered to be filled to capacity for every trip made.
4. The new system for disposal charges at the treatment plant was considered for gulper operators of non-vacuum technologies.

CALCULATIONS

NON-VACUUM TECHNOLOGIES

a) COSTS INCURRED

1. $Cost\ of\ small\ truck\ in\ 2014 \quad = \quad \boldsymbol{Ugshs\ 18,000,000}$
2. $License\ of\ truck\ per\ year \quad = \quad \boldsymbol{Ugshs\ 75,000}$
3. $Cost\ of\ each\ 200\ litre\ barrel \quad = \quad Ugshs\ 80{,}000\ \times\ 9$

   $= \quad \boldsymbol{Ugshs\ 720,000}$
4. $Cost\ of\ repair\ of\ truck\ in\ a\ year \quad = \quad \boldsymbol{Ugshs\ 100,000}$
5. $Cost\ of\ servicing\ truck\ in\ a\ year \quad = \quad \boldsymbol{Ugshs\ 800,000}$
6. $Cost\ of\ gulper - 1\ in\ 2014 \quad = \quad \boldsymbol{Ugshs\ 450,000}$
7. $Cost\ of\ fuel\ per\ year$

$$Fuel\ cost\ =\ (Travelling\ distance\ \times\ Fuel\ consumption)\ \times Fuel\ rate$$

From Section 4.3.4, table 4-1, the average distance travelled for non-vacuum technologies was obtained as 9km per trip, the fuel consumption rate is 13.73litres/100km (Banaga-Baingi, 2016) and the cost of a litre of fuel is UGX 3,100.

$$Therefore, fuel\ cost\ = 9\frac{km}{trip} \times \frac{13.73 litres}{100km} \times 3100\ \frac{shs}{litre}$$

$$= Ugshs\ 3,830.67\ per\ trip$$

$$Fuel\ cost\ per\ year\ = 3830.67\ \frac{shs}{trip} \times 1\ \frac{trip}{day} \times 365\ days$$

$$= \boldsymbol{Ugshs\ 1,398,194.55}$$

8. $Payment\ of\ workers\ per\ barrel\ per\ year$
$$= 3,000\ (shs/worker)/barrel \times 3 workers \times 9\ barrels/day \times 365\ days$$
$$= \boldsymbol{Ugshs\ 29,565,000}$$

9. $Cost\ of\ disposal\ for\ a\ truck\ per\ year\ st\ the\ treatment\ plant$
$$= Ugshs\ 20,000\ per\ trip \times 1\frac{trip}{day} \times 365\ days$$
$$= \boldsymbol{Ugshs\ 7,300,000}$$

b) BENEFITS OBTAINED

$$Charge\ for\ emptying\ a\ pit\ latrine\ in\ a\ year$$

$$= 30,000\frac{shs}{barrel} \times 9\frac{barrels}{trip} \times 1\ \frac{trip}{day} \times 365\ days$$

$$= \boldsymbol{Ugshs\ 98,550,000}$$

VACUUM TECHNOLOGIES

a) COSTS INCURRED

1. $Cost\ of\ truck\ \ (3.6\ m3\ operating\ in\ slums)$ $= \boldsymbol{Ugshs\ 80,000,000}$

2. $Cost\ (per\ year) of\ servicing\ truck\ every\ after\ three\ months$

$$= Ugshs\ 240{,}000 \times 4$$

$$= \boldsymbol{Ugshs\ 960{,}000}$$

3. $Cost\ of\ licensing\ truck\ per\ year \qquad = \boldsymbol{Ugshs\ 90{,}000}$

4. $Cost\ incurred\ in\ fuel\ per\ year$

$$Fuel\ cost\ = (Travelling\ distance \times Fuel\ consumption) \times Fuel\ rate$$

From Section 4.3.4, table 4-1, the average distance travelled for non-vacuum technologies was obtained as 10.95 km per trip, the fuel consumption rate is 13.73litres/100km (Banaga-Baingi, 2016) and the cost of a litre of fuel is UGX 3,100.

$$Therefore, fuel\ cost\ = 10.95\frac{km}{trip} \times \frac{13.73litres}{100km} \times 3100\ \frac{shs}{litre}$$

$$= Ugshs\ 4{,}660.65\ per\ trip$$

$$Fuel\ cost\ per\ year\ = 4{,}660.65\ \frac{shs}{trip} \times 3\ \frac{trip}{day} \times 365\ days$$

$$= \boldsymbol{Ugshs\ 5{,}103{,}411.75}$$

5. $Salary\ per\ year; \qquad Driver;$

$$= Ugshs\ 20{,}000\ per\ day \times 365\ days \qquad = \boldsymbol{Ugshs\ 7{,}300{,}000}$$

$$Turnboy;$$

$$= Ugshs\ 10{,}000\ per\ day \times 365\ days\ = \boldsymbol{Ugshs\ 3{,}650{,}000}$$

6. $Discharge\ fee\ for\ 3.6m3\ truck\ \ per\ year\ (by\ number\ of\ trips\ per\ year)$

$$= Ugshs\ 14{,}000\ per\ trip \times 3\ trips/day \times 365\ days$$

$$= \boldsymbol{Ugshs\ 15{,}330{,}000}$$

b) BENEFITS OBTAINED

$$Emptying\ fees\ per\ year;$$

$$= Ugshs\ 90{,}000\ per\ trip \times 3\ trips/day \times 365\ days$$

$$= \boldsymbol{Ugshs\ 98{,}550{,}000}$$

APPENDIX C: CALCULATIONS

Appendix C1: Shear strength values

Using the correlations

$\tau = K\gamma^n \quad R^2 > 0.95$ (Septien et al., 2018)

$K = 0.59 \times (MC)^{-30} \quad R^2 = 0.995$

$n = 1.2 \times (MC)^{13.5} \quad R^2 = 0.818$

Where τ is shear stress (Pa), γ is shear rate (s^{-1}), MC is moisture content (%)

Appendix Table C-1: Shear strength values of different moisture contents

Sample	MC (%)	type of technology	k	n	$\tau\ (Pa)$
1	96.26	Vacuum	1.852	0.717	9.2
2	99.21	Vacuum	0.749	1.078	8.4
3	96.68	Vacuum	1.624	0.761	8.9
4	98.91	Vacuum	0.820	1.035	8.3
5	98.25	Vacuum	1.002	0.945	8.3
6	98.03	Vacuum	1.073	0.917	8.4
7	95.26	Vacuum	2.535	0.623	10.2
8	99.18	Vacuum	0.755	1.074	8.4
9	95.37	Vacuum	2.446	0.633	10.1
10	99.12	Vacuum	0.769	1.065	8.4
11	99.34	Vacuum	0.719	1.098	8.4
12	99.33	Vacuum	0.722	1.096	8.4
13	99.56	Vacuum	0.674	1.130	8.5
14	97.78	Vacuum	1.156	0.887	8.4
15	99.08	Vacuum	0.779	1.059	8.4
16	98.09	Vacuum	1.052	0.925	8.4
17	97.35	Vacuum	1.319	0.836	8.6
18	96.13	Vacuum	1.926	0.705	9.3
19	95.68	Vacuum	2.221	0.661	9.8
20	96.24	Vacuum	1.861	0.716	9.3
21	73.28	non vacuum	6637.852	0.018	6911.6
22	87.24	non vacuum	35.466	0.190	54.3
23	93.28	non vacuum	4.755	0.469	13.6
24	85.43	non vacuum	66.484	0.143	91.6
25	86.52	non vacuum	45.468	0.170	66.5
26	89.66	non vacuum	15.579	0.275	28.9
27	84.41	non vacuum	95.346	0.122	125.2
28	85.04	non vacuum	76.354	0.135	103.2

29	88.86	non vacuum	20.420	0.244	35.2
30	87.19	non vacuum	36.021	0.189	55.0
31	85.75	non vacuum	59.379	0.151	83.2
32	86.97	non vacuum	38.852	0.182	58.5
33	86.80	non vacuum	41.240	0.177	61.4
34	87.52	non vacuum	32.170	0.198	50.2
35	86.86	non vacuum	40.349	0.179	60.3
36	87.01	non vacuum	38.347	0.183	57.8
37	86.08	non vacuum	52.897	0.159	75.5

Appendix C2: Vacuum technology work rate

$$vacuum\ tanker\ workrate = \frac{volume\ emptied}{time\ taken\ to\ empty}$$

$$5m^3 vacuum\ tanker\ workrate = \frac{5000\ l}{32\ minutes} = 156.25\ litres/minute$$

$$14m^3 vacuum\ tanker\ workrate = \frac{14000\ l}{46.02\ minutes} = 304.22\ litres/minute$$

Appendix C3: Non-vacuum technology work rate

Appendix Table C-2: Non vacuum technology work rate

pit	First hour	Second hour	Third hour	Average work rate (litres/min)
Pit 1 (5litre jerrycan used)	$no\ of\ lifts = 93$ $total\ sludge = 93 \times 5l$ $= 465\ litres$ $workrate = \frac{465}{60}$ $= \mathbf{7.75 litres/min}$	-	-	7.75
Pit 2	$no\ of\ lifts = 52$ $total\ sludge = 52 \times 10l$	$no\ of\ lifts = 23$	$no\ of\ lifts = 24$	8.11

(10litre jerrycan and 20litre bucket used)	$= 520\ litres$ $workrate = \frac{520}{60}$ $= \mathbf{8.67 litres/min}$	$total\ sludge = 23 \times 20l$ $= 460\ litres$ $workrate = \frac{460}{60}$ $= \mathbf{7.67 litres/min}$	$total\ sludge = 24 \times 20l$ $= 480\ litres$ $workrate = \frac{480}{60}$ $= \mathbf{8 litres/min}$	
Pit 3 (20litre jerrycan and 20litre bucket used)	$no\ of\ lifts = 50$ $total\ sludge = 50 \times 20l$ $= 1000\ litres$ $workrate = \frac{1000}{60}$ $= \mathbf{16.67 litres/min}$	$no\ of\ lifts = 39$ $total\ sludge = 39 \times 20l$ $= 780\ litres$ $workrate = \frac{780}{60}$ $= \mathbf{13 litres/min}$	$no\ of\ lifts = 30$ $total\ sludge = 30 \times 20l$ $= 600\ litres$ $workrate = \frac{600}{60}$ $= \mathbf{10 litres/min}$	13.22
				9.69

APPENDIX D: QUESTIONNAIRE AND OBSERVATION CHECKLIST

QUESTIONNAIRE

This is a questionnaire for a fourth year Civil Engineering Project titled 'Comparison of Vacuum and Non-vacuum technologies for emptying faecal sludge from pit latrines in informal settlements of Kampala'. Please kindly provide objective, truthful and complete responses in this questionnaire. Please note that your views on this topic are highly treasured and the responses you provide are completely anonymous and confidential. The research outcome and report will not include reference to any individuals.

A. VACUUM TECHNOLOGY

1. Discharging time; ………………..

2. What is the location of the facility you have emptied?

……………………………………………………………………………………..

3. What type of facility was it? (Provide a tick √)

a) Lined pit latrine: ………………………...
b) Unlined pit latrine: ………………………
c) Septic tank: ………………………………

4. Is this your first round today? If not, which round is this?

…………………………………………………………………………….............

5. What is the volume of your truck? (m^3)

……………………………………………………………………………………..

6. Was the truck full? (Circle the answer)

A. Yes
B. No

7. Estimate the time you took to;
   a) Setup at the facility: ………………………………
   b) Empty the facility: ………………………………..
   c) Dismantle the tools: ………………………………
   d) Travel from the facility to the treatment plant: …………………………….

8. How much do you spend on fuel per day?

………………………………………………………………………………………

9. How much did you charge to empty the facility? ……………………………..
10. Estimate the cost and age of your truck.

a) Cost: …………………………………………….
b) Age: ……………………………………………..

11. Is it a company truck or it is individually owned? How many more trucks do you have?

………………………………………………………………………………………………..

12. What is the length and diameter of hosepipe used? (measure)

a) Length: ……….. b) Diameter: …………….

B. NON VACUUM TECHNOLOGY

1. Discharging time: ……………

2. What is the location of the facility you have emptied?

……………………………………………………………………………………………….

3. What type of facility was it? (Provide a tick √)

a) Lined pit latrine: ………………

b) Unlined pit latrine: …………….

c) Septic tank: …………………….

4. Is this your first round today? If not, which round is this?

………………………………………………………………………………………………..

5. How many barrels did you empty?

………………………………………………………………………………………………...

6. How much did you charge to empty the facility?

…………………………………………………………………………………….....

7. Estimate the time you took to;
   a) Setup at the facility: ………………………………
   b) Empty the facility: ………………………………..
   c) Dismantle the tools: ………………………………
   d) Travel from the facility to the treatment plant: ………………………..

8. How much do you spend on fuel per day?

…………………………………………………………………………………………………..

9. Estimate the cost of your truck/tricycle:

………………………………………………..

10. Is it a company truck/tricycle or it is individually owned? How many more do you have?

…………………………………………………………………………………………………

OBSERVATION CHECKLIST

General Information

Location; ………………………….   Date; …………………

Weather; …………………

General Observation

Instruction; Provide a small cross or tick in the box where applicable (**X** or ✓)

1. Nature of the pit

Lined pit ☐

Unlined pit ☐

2. Condition of access to the property

Accessible to hand-carried emptying equipment only ☐

Reasonable access for small (manual or mechanized) emptying equipment ☐

Good access for medium/large size (mechanized) emptying equipment ☐

3. Type of emptying service provided

Mechanised / Vacuum technologies ☐

Semi-Mechanised / Non-vacuum technology (Specify) ………………………. ☐

4. Is the technology used operating under proper functioning conditions?

Yes ☐

No ☐

5. If no, what are the faults in the different technologies?

…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………

6. What is the blockage frequency of the technology used?

………………………………………………………………………………………………………

7. Does the emptying procedure leave fresh faecal sludge exposed in the compound?

Getting access results in significant amounts of faecal contamination of the surrounding area ☐

Getting access results in small amounts of faecal contamination of the surrounding area ☐

Others (specify) ……………………………………………………………………

8. Was the pit overflowing before emptying?

Yes ☐

No ☐

9. Was the pit latrine fully emptied by the technology?

Yes ☐

No ☐

10. What was the quantity of water added before emptying was carried out?

……………………………………………………………………………………………………

11. Does the sludge emptied contain solid waste?

Yes ☐

No ☐

12. If yes, what are some of the materials (solid waste) contained in the sludge?

………………………………………………………………………………………………………
………………………………………………………………………………………………………
………………………………………………………………………………………………………

13. What are the causes of the delays of the pit emptying process? (if any)

....

14. What is the number of crew members operating the technology (driver inclusive)?

…………………………………………………………………………………………………

Vacuum technology

15. What is the sludge removal technique applied?

Vacuum System ☐

Pneumatic Conveying System ☐

16. If Pneumatic Conveying system is used, what technique is used?

Constant air drag system ☐

Air bleed nozzle ☐

Plug drag ('suck and gulp') system ☐

17. What is the volume of sludge emptied by the vacuum tanker?

…………………………………………………………………………………………………
…………………………………………………………………………………………………

18. What is the length of the hose used?

………………………………………………………………………………………………..

Non-vacuum technology

19. What is the type of non-vacuum technology applied?

…………………………………………………………………………………………
…………………………………………………………………………………………

20. If gulper, what is the volume of the barrel used for collecting the faecal sludge?

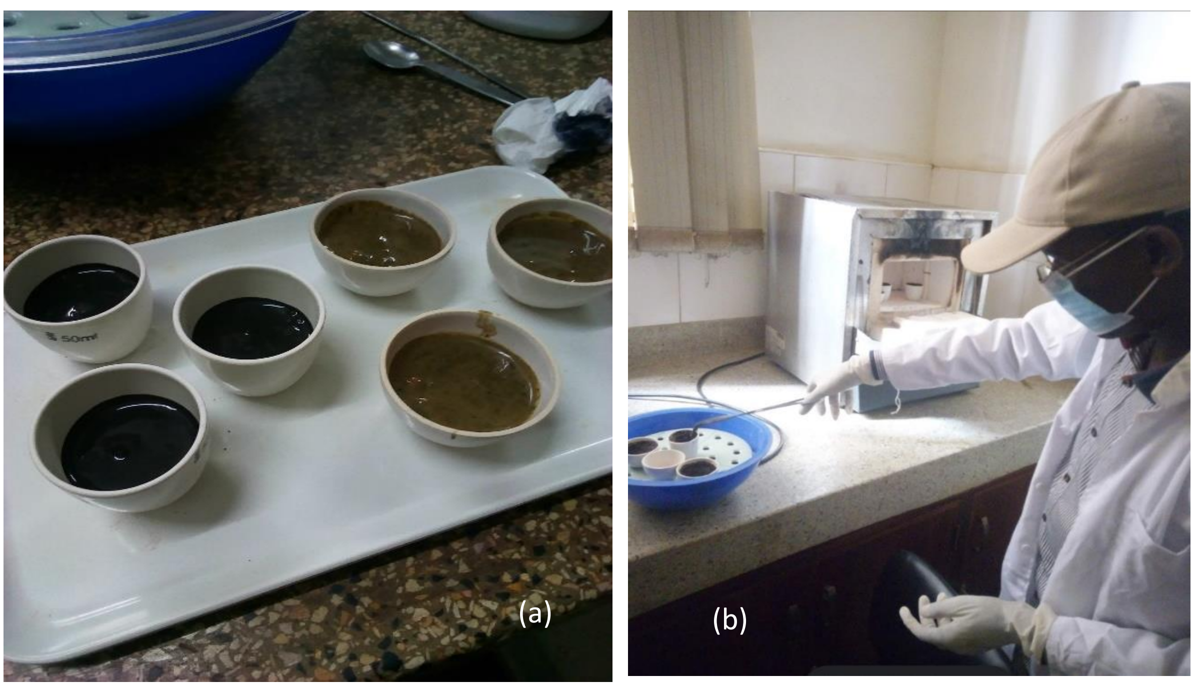
…………………………………………………………………………………………
…………………………………………………………………………………………

APPENDIX E: PICTORIAL EVIDENCE

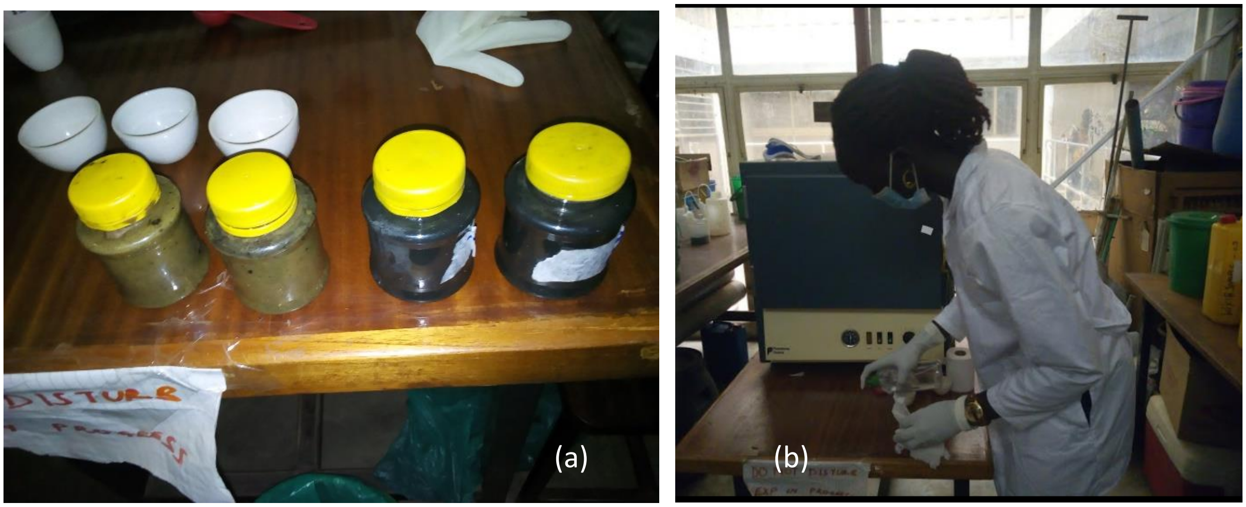
Appendix Figure E-1: Collecting feacal sludge sample (a) and sieving sample for solid waste (b)

Appendix Figure E-2: Barrels of faecal sluge (a) and collection sample from cesspool truck (b)

Appendix Figure E-3: Sorting solid waste and drying solid waste from non vacuum technology



Appendix Figure E-4: Samples for laboratory analysis (a) and using muffle furnance for Total volitale solids analyis (b)



Appendix Figure E-6: Samples for lab work (a) and analysis of samples (b)

Appendix Figure E-5: Taking GPS point at a pit latrine (a) and an interview with John Busingye a gulper entrepreneur (b)

NATIONAL WATER AND SEWERAGE CORPORATION

TELEGRAMS WATERS KAMPALA
Telephone: +256–414–315 000
+256–312–260414/5
Fax:0414 – 258 299/345531/346447
Email: info@nwsc.co.ug

HEAD OFFICE

P. O. BOX 7053
PLOT 3, Nakasero,
KAMPALA

Ref.: BSS/R&D/20-02

Date: 17th February 2020

=The Sen. Manager, Corporate Strategy & Investment Planning
=The Sen. Manager, Water Supply, KW

Re: PERMISSION TO CONDUCT RESEARCH IN NWSC

This is to introduce to you Bamuhimbise and Apio, final year Civil Eng. Students of Makerere University, who have been granted permission to conduct his research in NWSC. His study research is titled "***Comparison of non-vacuum and vacuum technologies for faecal sludge emptying in Kampala***"

The student would like to have access to the Lubigi ST Plant and interact with wastewater delivery truck drivers and discuss emptying technologies. It is expected that the findings from this research will be made available to NWSC and key recommendations beneficial to the corporation will be adopted to improve our operations. In this regard, you are kindly requested to accord them access to the required information to enable them successfully accomplish their research project.

This admission is valid up to end of May 2020.

Anticipating your usual cooperation.

Christopher Kanyesigye
Manager, Research and Development

Permission is extended to Dec. 15th 2020
4th/11/2020

Appendix Figure E-7: Permission letter requesting access to Lubigi Wastewater treatment plant