EXAMINATION OF PIT SLUDGE MANAGEMENT AND PHYSICO-CHEMICAL CHARACTERISATION. THE CASE STUDY OF NTOPWA, BLANTYRE, MALAWI

MPhil. (ENVIRONMENTAL SANITATION) Thesis

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UNIVERSITY OF MALAWI

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MPhil (Environmental Sanitation) Thesis

By

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Declarations

This study represents the original work done by the author and fellow research group members in a sanitation research project which was funded by the Water Research Commission (WRC) and the Malawi Polytechnic. This work has not been submitted to any academic institution with the intentions of getting an academic paper. Where other researcher's materials have been mentioned in study, it has been duly acknowledged.

DARLINGTON CHIMUTU

Signature ______________________________________

Date ______________________________________

Certificate of Approval

We, the undersigned, certify that we have read and hereby recommend for acceptance by the University of Malawi a thesis titled '*Examination of Pit Sludge Management and Physico-chemical Characterisation. The Case Study of Ntopwa, Blantyre, Malawi*.'

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Head of Department : ______________________________

Signature : ______________________________

Date : ______________________________

Dedication

This work is dedicated to my two children who have brought joy, happiness and meaning in my life. Also dedicated to my best friend and life partner, Josephine Butao Chimutu, for being there for me throughout the entire period.

Acknowledgements

A special acknowledgement to Dr. B. Thole and Dr. E. Chikwenda for an opportunity given that I can never repay in any way. You guidance, friendship, and most of all your patience in entrusting me with different task during this study were very important and critical to my study, thank you so much.

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Most of all, Glory to God.

Executive Summary

Urbanisation in most major cities around the world often results in overpopulation and inadequacy of public sanitation facilities and infrastructure. Similarly, in most developing countries inclusive Malawi, almost all unplanned urban settlements are not connected to a municipal sanitation facility and residents utilize onsite sanitation facilities with both traditional pit latrines and improved pit latrines (VIP) being the most commonest and popular types. While pit latrines and VIP's have and continue to be the simplest and hygienically acceptable onsite facility, they present two major problems: a) filling up and risk of contaminating the surrounding environment; and b) Once a pit latrine is full, it has proven to be a great challenge to manage full pit latrines especially in unplanned settlements where there is space limitation for emptying equipment to properly navigate to targeted pits to empty it and for disposal of the emptied material. Regardless of these challenges, residents often times abandon the filled pit and develop a new pit for use. It is against this background that motivated this study to understand the Physico-Chemical characteristics of the pit latrine contents in filled up pit latrines and VIPs.

At the onset of the study, a survey was conducted to understand user practices of the pit latrines with an emphasis of understanding how many users use an individual pit, what kind of domestic waste users dump in the pits and any special chemicals or additives use for cleaning the latrines, odor reduction and pest control. While the study had expected to find a relationship between user practices of the pit latrine and the different Physico-chemical characteristics of the sludge, no attempt was made to see if there would be any relationship between the actual results of the laboratory analysis of the sampled pit latrines and the user practices since the survey had reviewed that most pit latrines were shared among several families and had different practices on how they make use of the latrine. Ten pit latrines in Ntopwa Township, an informal peri-urban settlement were selected for sampling after inspecting them to have a satisfactory amount of sludge that enabled for multiple point height sampling (at the surface, 0.5 meters, 1.0 meters and 1.5 meters) within the pit latrine were randomly selected for sludge sampling for laboratory analysis for various Physico-Chemical characterisation. The Physico-Chemical characterisation included pH, moisture content, Chemical Oxygen Demand (COD), Ammonia, Total Solids (TS), Total Volatile Solids (TVS), Fixed Solids (FS), Total Kjeldahl Nitrogen (TNK), Phosphorus (P), potassium (K).

The survey revealed that the majority of the residents (61.5%) had access to an onsite sanitation facility with a minimal percentage practicing open defecation. The average number of users per pit latrine was more than five with two or more families utilizing a single pit latrine. The majority (55.2%) of users were also aware of the relationship between pit latrine management and water quality with some making a direct link to groundwater contamination and disease outbreaks.

The Physico-chemical characterisation results for COD and TVS from the ten pit latrines showed that in unlined pit latrine, sludge from the bottom layers still needs further additional degradation for it to be fully stabilized and to ascertain its biological safety. It was also observed that there were variation in trend for the different parameters from pit latrine to pit latrine ($p<0.001$). Only COD values from different depths were significantly different ($p=0.01$). While macro-nutrient (NPK) were detected at the different depths, there is a need to ascertain its biological safety since the study had shown that there is a need for further degradation and stabilization of the sludge as this is an indication of low microbial load due to natural die-off.

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Abbreviations and Acronyms

ANOVA	Univariate analysis of variance
AOAC	Association of Analytical Communities
APHA	American Public Health Association
BS	British standard
COD	Chemical Oxygen Demand
FS	Fixed Solids
K	Potassium
KAP	Knowledge Attitudes and Practices
MAPET	Manual Pit emptying Technology
MDGs	Malawi Development Goals
MICS	Malawi Indicator Cluster Survey
MS	Moisture Content
NSO	National statistical Office
P	Phosphorus
pH	Power of Hydrogen
SPSS	Statistical Package of Social Scientist
TN	Total Nitrogen
TS	Total Solids
TVS	Total Volatile Solids
UDDT	Urine Diverting-dry Toilets.
VIP	Ventilated Improved latrine
WHO	World Health Organization

Chapter One: Introduction

1.1 Background

Malawi is a landlocked country located in the southern part of Africa having a total surface area of 118,000 km^2 and 20% of the total area is covered by fresh water bodies. The 2008 Malawi housing and population census enumerated a total population of 13, 077, 160 people with an annual inter-censual growth rate of 3.3% (National Statistical Office (NSO), 2008). Current estimates put the country's population in the region of 16 million people. The same census in 2008 revealed that 84.7% of the population lives in the rural areas with the remaining 15.3% in the urban areas. The urban growth rate as of 2008 was 5.2% of which rural to urban migration was noted as the main factor for the growth. The report also points out that over the years most urban areas have developed without proper planning.

As of 2014, access to improved sanitation was at 47% with 88.2% having access to basic sanitation facility including traditional pit latrines (Malawi Indicator Cluster Survey (MICS), 2006). The adopted 2015 MDGs put the target for access to improved sanitation at 86.2%, of which the document stipulates to be very unlikely to be met. A 2009 report by Manda indicated that connection to sewer system for the two major cities in Malawi namely Blantyre's and Lilongwe's is only 10% and 9% of population respectively. The study found that an ordinary pit latrine was the dominant type onsite sanitation facility with a representative percentage of 94% among the households surveyed.

Kaluwa (1997) report concluded that in Malawi, sanitation systems do not feature prominently in urban households as a critical service and that most households use an onsite sanitation facility. A site visit to many unplanned settlements within Blantyre collaborated the fact that most households are not connected to the cities municipality sewer system but instead employ an onsite sanitation facility with septic tanks and pit latrines being the dominant ones. The NSO, (2008) Malawi census also showed that 78.1% of the urban dwellers use traditional pit latrines with only 3.8% utilizing a VIP.

While a pit latrine offers a simple onsite sanitation facility, sustainable operation of a pit latrine is difficult in an unplanned settlement. Pit emptying after it fills up is often not possible due to economic reasons; space availability for empting equipment to navigate through the settlement to the pits; and space availability for safe disposal of the sludge. In the end, the common practice and cheaper option employed by many users is to bury the old pit latrine and construct a new pit latrine. It is against this back ground that this research seeks to understand what happens to pit latrine contents physically and chemically after it has been filled.

The primary focus of this study was to understand the physico-chemical characteristics of the pit latrine sludge with respect to time, at the same time to find out the stabilisation and degradation extent of the organic matter content of the sludge. This study adapted the theoretical approach proposed by Buckley et al. (2008) which theorizes that in a pit latrine, sludge stabilizes and degrades with increasing depth (with respect to time). The pit sludge sampled in this study was sampled from unlined pit latrines in Ntopwa Township located in Blantyre district. Ntopwa is one of the most popular unplanned urban settlements which is part of a bigger township called Bangwe located in the east of Blantyre district. Bangwe has a population of 170,350 having 41,456 households (Kaonga et al., 2013). At the onset of the study, it was planned that sampling would be done in lined pits to conform to initial proposed Buckley et al. (2008) theory, but actual sampling was done on non-lined pits since lined pits were not available in this township. Sampling was done on 10 pit latrines after assessing that they had more than two meters of sludge accumulation for the primary purpose of multiple depths sampling within the pit latrine. The research findings in this study have been submitted (at time of write up of this thesis) for journal publication consideration with the following titles: "Sanitation Facility Access KAP study of Ntopwa, A Peri Urban settlement, Blantyre, Malawi." (2015). D. Chimutu, B. Thole and E. Chikwenda; and "Chemical and Bilogical Pit sludge Characterisation; A case study of Ntopwa and Milare Townships, Blantyre, Malawi." (2015). D. Chimutu, B. Thole and E. Chikwenda.

1.2 Research Objective

The aim of the research was to determine the management practices of pit-latrines and potential trends in Physico-Chemical degradation of pit sludge in Ntopwa.

1.3 Specific Objectives

The specific objectives were:

i. Investigate the level of knowledge, attitudes and practices on faecal sludge management among residents of Ntopwa.
ii. Determine the Physico-Chemical degradation of pit sludge through characterisation of the levels of Chemical Oxygen Demand (COD), Total Solids (TS), Total Volatile Solids (TVS), Fixed Solids (FS), Moisture content and Ammonia from different depths.
iii. Detecting the concentration of Total Nitrogen (TN), Phosphorus (P) and Potassium (K) in the faecal sludge.

1.4 Significance of Research

With the global increase in population, many urban unplanned settlements continue to face numerous social amenities deficiencies including the availability of sanitation facilities and their sustainable operation. Numerous research studies have been undertaken to see the effectiveness of traditional pit latrines as an onsite sanitation facility with the primary focus on disease prevention and have proven to be effective in areas where there are no conventional sanitation systems. However it's been noted that dealing with (full) latrines poses several challenges, some of which are:

- Potential contamination of the environment especially groundwater.
- Difficulty in safe emptying and disposal of the pit sludge.
- Difficulty in deployment of current emptying techniques to effective empty full pits in unplanned settlements.
- Public health considerations during emptying.

In this regard, this study will save as a blue print on unlined pit latrine sludge Physico-Chemical characteristics to inform on future interventions on effective faecal sludge management and policy formulation for unplanned urban settlements both locally and other development African countries.

1.4 Dissertation Outline

The outline of this thesis is as follows:

- CHAPTER ONE: INTRODUCTION

  This chapter outlines the general content of the study including study objectives, the theory, the methodology used in brief and the outline of thesis.

- CHAPTER TWO: LITERATURE REVIEW

  The literature in this thesis is divided into five main sections. Section 2.1 deals with a general description of what a pit latrine is and its associated problems; Section 2.2 briefly discusses the general expected contents of a pit latrine; Section 2.3 discusses the physical and biological processes that occur in a pit latrine; Section 2.4 discusses the potential value of pit sludge as organic agricultural manure; a synthesis of key research studies from literature and research gap identification is presented section 2.5

- CHAPTER THREE: RESEARCH METHODOLOGY

  This chapter presents the methods that were used in this study. It includes the description of the social survey, sampling, the laboratory experimental work and data treatment.

- CHAPTER FOUR: RESULTS AND DISCUSSION

  This chapter presents the results of the study. Section 4.1 presents the results and a discussion of the social survey. Section 4.2 presents the results and subsequent discussion of the Physico-Chemical characterisation for the laboratory analysis. Study limitations are also presented in this chapter.

- CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

  This chapter presents the conclusions and recommendations regarding the results obtained. Recommendations for further studies are also discussed in this chapter.

Chapter 2: Literature Review

2.1 Introduction

Traditional pit latrines are a common onsite sanitation facility for a majority of households in developing countries. However, they have several disadvantages; they emit a lot of bad odour, they serve as a breeding ground for flies and other disease carrying insects and are potential ground water contamination source. A ventilated improved pit latrine (VIP) however is globally accepted as a minimum sanitation facility at household level (World Health Organization (WHO), 2008). The major advantage of a VIP over a traditional pit latrine is that there is control of odor and insects. This review focuses on: a) what traditional pit latrines and VIPs are; b) associated problems with latrines; c) and the general pit latrine management practices that are currently being employed in addressing the highlighted problems and the impacts of pit latrines on the surrounding environment including ground water quality. In the end, a conclusion will be presented highlighting the major discoveries that have been made in physico-chemical analysis of pit latrine sludge.

2.2 Ventilated Improved Pit Latrines (VIP)

A pit latrine is a simple onsite sanitation facility used for storage of urine, faecal matter and other household generated waste. It basically consists of a dug out pit covered with some form of material on top (having a hole for passage of waste), be it logs, concrete slab of even metal bars to protect users from falling into the pit. Besides these, usually a four sided superstructure is built using a variety of materials including plastic, cardboard, bricks, grass and others materials to provide some protection from different environmental elements and to provide privacy to the users (Grimason et al., 2000). The major difference between a traditional pit latrine and a VIP is that a VIP has a vent pipe which is used as an exhaust of bad smell emanating from the pit which is also used as a trap for flies and other insects (Mara, 1984).

2.2.1 Problems Associated with Pit Latrines and VIP

While a pit latrine and VIP's offer a simple and cheap onsite sanitation solution, pit latrines have several problems, such as easily; filling up, requiring frequent emptying and they are potential biological threat to both ground water and the surrounding environment. The foregoing text explains these problems in brief.

2.2.1.1 Pit Filling

The rate of filling up of a pit latrine is determined by several factors including number of users, additional refuge being deposited into the pit, anal cleansing material, extent and rate of aerobic and anaerobic processes for the biodegradation of the waste in the pit, design and construction of the pit lining, introduction of non-biodegradable solid waste and the geophysical and climate factors (Still et al., 2012). While drainage of liquids into and from the surrounding environment also affects the rate of pit filling; the number of users of the pit latrine is the primary factor in determining the filling rate of pit latrine (Buckley et al., 2008 and Still et al., 2012). The maturing age of a pit latrine (life span) is a factor of the amount of biodegradable and non-biodegradable organic matter being introduce into the pit latrine, anal cleansing material (both degradable and no biodegradable), physical size of the pit latrine, substrate and soil type. However, Still et al. (2012) estimated that a pit latrine is filled up in an average space of 5 – 9 years.

2.2.1.2 Pit Emptying

In most communities, the practice as regards to a filled up pit latrine is basically to destroy the superstructure or to salvage it for reuse after burying the pit. Several emptying technologies have been developed (and some still in development) and tested in several countries. The most widely used and most convenient is the use of a vacuum tanker which sucks the sludge into a tanker and then transports the pit sludge to a proper disposal site (Yoke et al., 2009). Several designs which make use of vacuum suction have been fully developed and have been effectively tested regardless having several constraints. These include the MAPET, the Gulper, the Micravac and the Dug Beetle (Still et al., 2012). Most manual and mechanized emptying technologies at the moment are in the development and testing stage. The most notable ones are the Gobbler which has a chain mechanism with scopes, and the Screw Auger which uses a screw to move the sludge along a pipe (Still et al., 2010). The biggest challenges so far in mechanical technologies are the weight and the presence of a lot of moving parts which often times jam during operation.

Since vacuum related emptying technologies involve the use of a tank for the sludge storage and transport, its usage in unplanned urban settlements is difficult as access to the pits is difficult (Still et al., 2010). In addition to the high cost for the provision of the service, most residents either prefer to use manual emptying or just to bury the pit. Manual emptying involves hiring several people to scoop the sludge out of the pit and dispose it somewhere else. This method poses greater health risks to both the people doing the job and the surrounding environment.

2.2.1.3 Ground Water Contamination

Ground water contamination is highly associated with pit latrines in areas where pit latrines are in close proximity with groundwater sources. Contamination of the water arises due to a rise in the water table leading to pit flooding (Chaggu, 2004). A poorly lined pit and poor filtration characteristics of the surrounding soils also results in ground water contamination since liquids may flow from the pit latrine to the surrounding environment (Mara, 1984).

2.3 General Contents of a Pit Latrine and VIP

A pit latrine is primarily designed to be a safe holding tank for faecal matter and urine. Since pit latrines are also used as a disposal point for a wide range of waste, including waste paper, plastics, glass, rags and other household waste, the composition of a pit latrine vary from house hold to house hold (Bakare et al. 2012). In this regard, a pit latrine would generally contain both biodegradable and non-biodegradable materials.

2.3.1 Primary Pit Latrine Contents and Its Characterisation

Primarily, a pit latrine or a VIP is designed to act as storage and a sanitation facility for human faeces and urine. 70-80% of human faeces is water and 20-30% is solid matter with 84% of the solid mater being organic in nature (Torondel, 2010). Zavala. 2002 characterized human feces and showed that 80% of human faeces is made up of slowly biodegradable organic matter and the remaining 20% is biological inert material. Urine on the other hand is made up of urea, slats, organic compounds and dissolved materials which account for 5% by weight. However, human excreta differ from person to person and from country to country due to difference in dietary needs, health and age of individuals (Torondel, 2010 & Zavala et al., 2002). That said, several research studies have looked at faeces characteristics from different parts of the word in which user social patterns, diet and habits were not considered as a factor to the characteristics of the faeces. Table 1 presents a summary done by Bakare (2014) of several (parameters of interest) characteristics of faeces from various studies.

Table 1. Feacal Sludge Characteristics of Fresh Faeces (Bakare, 2014)

Parameter	Units	Almeida (1999)	Lopez (2002)	Nwaneri (2009)
Source of sample		Fresh faeces	Fresh faeces	Fresh faeces
Moisture	% of wet mass	79.2	81.8	78
Volatile solids	% g VS/g TS	-	84.4	84
Total COD	Mg COD/g dry mass	1 380	1 450	1 130
Biodegrability	% mg COD/mg COD	-	80	74

A comparison of fresh faeces and pit latrine faecal sludge however differs in composition with fresh faeces showing higher values than the pit latrine faecal sludge indicating that there are Physical, Biological and Chemical changes that the faecal sludge undergo in a pit latrine (Nwaneri, 2008). While there is limited scientific literature to show these differences between fresh faeces and faecal matter in pit latrine, several studies in pit sludge characterisation have showed that pit sludge undergoes some level of degradation and stabilization even though there are variations in data between pits and within an individual pit itself.

Of interest is a study that was funded by the Water Research Commission in 2008 in which amongst other objectives there was an investigation on physico-chemical characterisation of the pit sludge at different depth and Biodegradation of the pit contents at different depths. The data from this study have been used by several researchers for academia and publication purposes, notably by Bakare et al. (2012) and Bakare et al. (2014), Buckley et al. (2008), Mwaneri et al. (2008) and Mwaneri et al. (2009). Data from an earlier study by Magagna (2006) was also included in this study for analysis. Mwaneri et al. (2009) also made further investigations on pit sludge characterisations. The study by Buckley et al. (2008) had conceptualized on what happens to pit sludge over time and theorized that in a pit latrine, the faecal sludge could be divided into four sections. The top most layer (i) where fresh faecal matter is deposited as users are using the pit. The expected processes on this layer are aerobic digestion of the faecal matter since there is presence of oxygen from the direct contact with the surrounding air; the second layer (ii) which is just below the first layer where limited aerobic digestion of the faecal matter is happening due to limited presence of the oxygen due to the overlying layer; the third layer (iii) where theoretically there is no presence of oxygen and it is expected that the faecal matter is undergoing anaerobic degradation and the last bottom layer (iv) where in theory we expect to find faecal matter that has been fully degraded and has stabilized and no further degradation can take place, Figure 1 illustrates. What are the key issues learnt from above literature which will be used in your study.

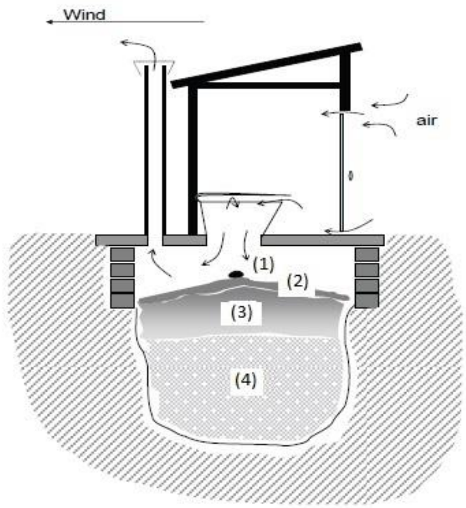

Figure 1. Theoretical Layers Depiction in a Pit Latrine as Proposed by Buckley et al. (2008)

While the study had several hypothesis under investigation, of interest is the hypothesis that was linked directly to degradation and stabilization of sludge. It was hypothesized that the amount of COD and TVS (used as a measure of degradation and stabilization) decreases with depth and age of the pit indicating the degradation of oxidisable organic matter and that it is expected that the concentration of COD and TVS would be lower at the bottom of the pit in comparison with the upper layers. Other parameters that were investigated for the purposes of determining the degradation and stabilization of the sludge were moisture content, total solids, and fixed solids.

The earlier study by Magagna (2006) investigated four (4) VIP's in which five samples were collected at 5 different points. Three samples were collected at different heights between the surface (starting point of the sludge) and 300 millimeters below obtained from the center of the pit, below the pedestal hole and two samples were collected from about 50 millimeters to 200 millimeters below the surface at the side of the pit. Figure 2 illustrates the sampling points.

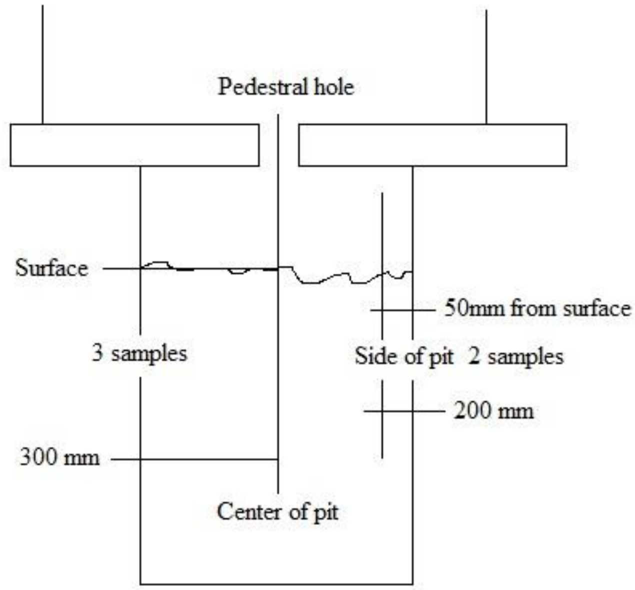

Figure 2. Magagna (2006) Study Sampling Points

This study analyzed moisture content, total solids, organic solids, inorganic solids (IS) and COD in VIP 1 and VIP 2 while methanogenic (methane production) test were done on VIP 3 and VIP4. Table 2 summaries the results for VIP 1 and VIP 2.

Table 2. Pit Latrine Sludge Characteristics (Magagna, 2006)

Parameter		MS (% g /g)	TS (% g /g)*	OS (% g /g)*	IS (% g /g)*	COD (mg /g)*
VIP1	Top center	78 ± 0.20	22 ± 0.20	39 ± 5	61 ± 4.64	599 ± 52
	Middle center	80 ± 0.05	20 ± 0.05	42 ± 1.5	58 ± 1.5	475 ± 31
	Bottom center	79 ± 0.11	21 ± 0.11	40 ± 0.12	60 ± 0.12	497 ± 10
	Top side	80 ± 0.80	20 ± 0.80	42 ± 2.00	58 ± 2.00	232 ± 16
	Bottom side	69 ± 1.00	31 ± 1.00	33 ± 4.00	67 ± 4.00	287 ± 15
VIP 2	Top center	30 ± 3.00	70 ± 3.00	6 ± 1.00	94 ± 1.00	71 ± 7.96
	Middle center	N/A	N/A	N/A	N/A	N/A
	Bottom center	47 ± 4.00	53 ± 4.00	15 ± 2.00	85 ± 2.00	146 ± 14
	Top side	29 ± 3.00	71 ± 3.00	7 ± 1.00	93 ± 1.00	156 ± 10
	Bottom side	44 ± 3.00	56 ± 3.00	11 ± 1.00	89 ± 1.00	110 ± 8

* test done on dry sample.

Based on the results that were obtained for VIP1, it was observed that there were no significant differences in the moisture content amongst the three different sampled points. However, the results showed a significant different in moisture values for the sample drawn below the surface at the side of the pit in comparison with the other points. Moisture content values for VIP2 were considerably lower (12% - 33%) than those in VIP1 reportedly to the fact that sampling for VIP1 was done on a day it was raining heavily and sampling for VIP 2 was done during a period of dry weather. For the inorganic solids components, it was observed that there were no significant differences amongst the different sampling points for VIP1, but for VIP2 higher values were observed and reportedly suspected that there might be some introduction of foreign inorganic material into the pits such as sand and other unusual materials. For VIP1, the study found that there was a significant difference in COD values between samples at the side of the pit and those in the middle of the pit with samples taken at the side having higher values than those at the center. While for VIP2, it was observed that there was a correlation between the

COD values at the sides of the pit, and COD values at the sides in the lower side sample taken at the center of the pit. Due to the high inorganic solids values obtained in the VIP2, it was summarized that this could be the reason why VIP2 had lower COD values on a total solid base.
Samples from VIP1 and VIP2 were subjected to a Serum bottle test primarily to see if there could be methane production as an indication of effective anaerobic degradation of the organic material in the sample. Samples from VIP1 showed an inhibitory effect on anaerobic digestion after 90 day period of which the inhibition was attributed to the chemical agents added in the pit by the householders (reportedly householders admitted to adding some chemicals to control smell but could not identify what kind of additive they had used). For VIP2, four samples that were subjected to the Serum bottle test did not show any inhibitory effects after 45 day incubation, thus they all produced positive results producing methane meaning that there was biodegradability on the organic materials in the sample. Biodegradability ranged from 23% to 43%.

For the methanogenic activity test that were done on VIP3 and VIP4, there was methane gas production in samples from VIP3 with an estimated 1% - 5% of the COD being converted to methane gas over a period of 21 days at 35^{0}C. Since the observed values were relatively small, it was summarized that it was not possible to ascertain any significant differences between the values obtained for the sample which was at center and the sample sampled at side of the pit. In VIP4, it was estimated that 1% - 21% of the COD was converted to methane for samples that were taken from the centre of the pit, while samples that were taken from the sides of the pit, it was estimated that between 1% - 2% of the COD was converted to methane. In terms of radio position of the sample, it was observed that 3 of the 4 sampled central point's showed higher values than samples taken from the side of the pit. It was then concluded that for methanogenic activity, it is expected to have generally higher values for samples taken from the center than samples taken from the side of the pit.

Buckley et al. (2008) study had similar sampling paten in terms of vertical sampling points. In study, samples were taken at three different points; at the surface (0.0 meters), where fresh faecal matter is constantly being deposited; at the center of the pit (about 0.5 – 1 meter depth) and at the bottom of the pit latrine (1 – 1.5 meter depth). There is no indication as to at what radio poeition were the sampled taken. It should be noted that these results were for only three pit latrines and an allowance was made for the small sample size (n=3) by reading off the probability from the t-table in calculating the confidence limit. Table 3 summaries the results for the study.

Table 3. Pit Latrine Sludge Characteristics Buckley et al. (2008)

Parameter	MS (%g /g)	TS (% g/g)	OS (% g OS/g)*	IS (% g IS/g)*	COD (mg COD/g)*
Top	80 ± 0.07	20 ± 0.07	62 ± 5	38 ± 5	738 ± 0.0
Middle	73 ± 2	27 ± 2	53 ± 2	47 ± 2	733 ± 0.0
Bottom	66 ± 4	34 ± 4	42 ± 2	58 ± 2	503 ± 0.0

* Dry solid sample.

In the study, it was observed that moisture content decrease with increasing pit depth. Likewise the COD and organic solids also reduced with increasing depth although it was concluded that these were not a direct measure of biodegradability of the pit sludge. It was also observed that the COD and organic solids values of the top layer sludge were almost half in comparison with COD values of fresh faeces which is an indication that the sludge does undergo aerobic biological degradation already before being covered by another layer of fresh faeces. By comparing the COD values of fresh faeces and the top layer COD values in this study, it was observed that at least 49% of the COD had already been reduced with samples from the bottom layer having been reduced by almost 61%.

Nwaneri et al. (2009) study made an additional investigation on physico-chemical characteristics of sixteen pit latrines looking at COD, Moisture Content, Organic solids and biodegradability tests. The results for the sixteen pit latrines showed that the mean COD values obtained for the top layer (0.54mg COD/mg dry sample) were less than the COD values of fresh faeces (1.13mg COD/mg dry sample) like what was observed in Buckley et al. (2008) study conforming that some sort of biodegradation had already taken place at the top layers. Moisture content values showed a decrease with increasing depth. However, there was a distinctive difference in moisture content from the top layer (0.5m) to the middle layer (1.0m) with no further change from 1.0

meter to 1.5 meter layer. For organic solids, it was also observed that the average percentage of the organic solids at the surface (58%) was less than that measured for fresh faeces (84%). The organic solids for the layers under the first layer were even less in comparisons with the first layer which was expected since fresher material was being deposited at this layer (first). She went further to do biodegradability test using the serum bottle test in which the production of methane gas was an indicator of anaerobic digestion of the organic matter present in the sample. Only sample from one VIP (amongst the samples from the 16 VIPs) usefully yielded positive results (gas production) and it was concluded that the other fifteen samples had perhaps undergone biodegradation already prior to sampling. In her conclusion however, she pointed out that the serum bottle test is not a suitable test for biodegradability for VIP sludge.

2.3.2 Other Waste

Since VIPs are also used for dumping of other household refuse, the contents differ from household to household. Studies done by Buckley (2008) and Bakare et al. (2012) found that a variety of materials such as newspapers, magazines, broken glass, bottles, rags, plastics, dead animals and other waste are found in a pit latrines which agrees with earlier studies (Cotton et al. 1995; Franceys et al., 1992; Mara, 1984; Still, 2002).

2.4 Theoretical Processes Inside a VIP

There are two basic processes that occur inside a pit latrine, these are physical and biological processes. The physical processes involve the addition of materials in the pit and the transport mechanisms of the soluble pit constituents into and from the surrounding environment. The biological process involves the degradation of the organic matter constituents aerobically and an aerobically.

2.4.1 Physical Processes

The rate at which materials are added into a pit latrine primarily determines the life span of the pit. Rubbish represents 5 – 10% in volume of the total materials entering a pit and in a space of ten years, rubbish makes 25% of the total volume (Still, 2012). The overall filling rate of a pit latrine also depends on the transfer of liquids in and out of the pit in which there is transportation of soluble constituents in and out of the pit. However, transportation of the soluble constituents in and out of the pit is a factor of soil characteristics of the surrounding pit, pit lining and ground water lateral travel and subsurface geology (Nwaneri, 2009).

2.4.2 Biological Processes

2.3.2.1 Aerobic Digestion

For aerobic biodegradation to occur, the biomass (micro-organisms and waste substrate) needs a supply of oxygen for cell metabolism in the micro-organisms which produces energy. The energy produced is used by the micro-organisms to produce new cells and carbon dioxide (Nwaneri, 2009). With Buckley et al. (2008) proposition that in a pit latrine there are four theoretical categories in which the top most layer is supplied with fresh faecal matter and there is presence of oxygen from the surrounding environment, (as explained earlier) aerobic digestion is expected to be taking takes place at this layer.

2.4.2.2 Anaerobic Digestion

Anaerobic digestion involves the breaking down of degradable organic matter in anaerobic conditions by micro-organisms leading to the formation of biogas (a mixture of carbon dioxide and methane) and biomass (Kelleher, 2002). Anaerobic digestion however is a complex process that involves a number of strongly interacting groups of microorganism (Torondel, 2010). For an anaerobic digestion to take place, there are four key biological and chemical stages that take place. These are as follows; a) Hydrolysis; where long-chain macromolecules are hydrolyzed to short-chain compounds; b) Acidogenesis; where the soluble substrate produced in hydrolysis is degraded by fermentative acidogenic bacteria to form organic acids; c) Acetogenesis; where simple molecules created in acidogenesis are further digested by acetogens to produce primarily acetic acid as well as carbon dioxide and hydrogen further reducing them to form acetate and sometimes butyrate (Giot, 1992); and d) Methanogenesis; where there is conversion of the intermediate products from acetogenesis phase into methane, carbon dioxide and water (Torondel, 2010). However the successfulness of the microbes to anaerobically digest organic matter relies on a number of complex environmental variables including pH, temperature, homogenitality, nutrient availability, toxicity inhibition, ammonia levels, volatile fatty acids

(VFAs), oxygen presence and ability of micro-organisms to thrive (Haran & Mara, 2003 and Speece, 1996).

Since Ammonia and pH are parameters of interest in this study, the foregoing is a mini review on the role Ammonia and pH plays in anaerobic digestion.

Ammonia is a by-product in the biological degradation of nitrogenous matter in the form of urea and proteins (Chen et al., 2008). In anaerobic digestion, the ammonia substance is found in two forms as an ionized ammonia (NH^{+}_{4}), or as free ammonia (NH_{3}) in which they directly inhibit methane production (Kayhanian, 1999; Sprott & Patel, 1986). The free ammonia is reportedly to be toxic because of its capability to penetrate cell membranes causing proton imbalance and/or potassium deficiency leading to reactor upset and failure (de Baere et al., 1984; Kroeker et al., 1979; Sung & Liu, 2003). Since there is a wide range of micro-organisms involved in anaerobic digestion in the different stages during anaerobic digestion, their tolerances to toxicity and other inhibitors also differ (Chen et al., 2008).

Ammonia presence in anaerobic digestion is inhibited by other factors including; pH, temperature, presence of other ions, its perpetual concentration, and acclimation. pH and temperature are the commonest factors that have been researched on as a factor in ammonia inhibition studies in anaerobic digestion.

pH affects the growth of micro-organisms as well as the composition of total ammonia nitrogen (Hansen et al., 1999; Hashimoto, 1983; Hashimoto, 1984 and Kroeker et al., 1979). An increase in pH result in increased toxicity since it triggers a shift to a higher free ammonia to ionized ammonia ratio in the micro-organisms cells (Borja et al., 1996b). This instability causes accumulation of volatile fatty acids which again leads to a decrease in pH and affecting concentration of free ammonia. Several studies have looked at pH in different anaerobic digestion and have different results (different substrate sources). The general consensus in different studies is that the optimum pH range for anaerobic digestion is 6.5 – 8 (Benabdallah et al., 2009; Braun et al., 1981; Haran & Mara, 2003; and Zeeman et al., 1985).

Temperature affects microbial growth rates and free ammonia concentrations with general increase in temperature resulting in an increase on metabolic rate, resulting in higher concentration of free ammonia (Chen et al., 2008). However, studies that have looked at effects of temperature on biogas production have concluded that in anaerobic digestion under mesophilic (low temperature) and thermophilic (high temperature) conditions, the thermophilic flora tolerates ammonia toxicity twice than the mesophilic flora depending on acclimation of temperature and pH (Angelidaki & Ahring, 1994; Gallert & Winter, 1997; Sung & Liu, 2003). Since pit latrines generally are not covered digesters per se, the expected temperature would be from 0 to 30^{0}C, hence we expect mesophilic digestion to dominate (Buckley et al., 2008).

2.5 Pit Sludge as an Organic Manure

Application of human faeces as a nutrient resource for crop production has been in practice in a number of countries. The leading countries and regions include China, Japan, Korea, South America, some countries in Africa and countries in Northern Europe and the Northern Atlantic also known as the Nordic countries (Malkki, 1999). With an estimated annual toilet waste of 520kg/person, using human waste as a cheap nutrient resource is as an effective sustainable way of dealing with human waste. Out of the annual 520kg/person human waste, 7.5kg consist of Nitrogen, Phosphorus and Potassium and some useful macro-nutrients for plant production in which it can enable the production of a single person annual grain needs of 250 kg (Wolgast, 1993).

Sewage sludge usage is practiced in different parts of the world regardless the fact that sludge is a poor in other macro-nutrients since its nutrient balance does not correspond well to the nutrient needs of different crops coupled with the presence of heavy metals which remain in the soil and undergo biomagnifications in the food chain (Levinen, 1991). Regardless of these facts, sludge is still favoured due to its long-lasting effect of slow release of Nitrogen and Phosphorus into the soil together with the presence of high organic matter which improves the structure and water economy of the soil (Makela-Kurtto, 1994). While many communities do use human excreta as a fertilizer in their field, most do it with the ignorance of the health hazards they may be exposed to and the focus is rather placed on the basic outcome of the crop when it matures. This section looks at a glance some of the potential benefits of applying human excreta as a fertilizer and not the potential health risks.

2.5.1 Characteristics of Human Excreta as a Fertilizer

2.5.1.1 Urine

Urine contains 98% Nitrogen, 65% Phosphorus and 80% Potassium excreted by the human being (Malkki, 1999) and its fertilising effects are comparable to nitrogen-rich chemical fertilisers (Kirchman & Petterson, 1995). Some of the advantages of using urine as a potential nutrient source are that the nitrogen is in the form of ammonia nitrogen of which it is usable by plants and urine is microbiologically clean when passed by a health human being (Claesson & Steineck, 1996 and Kirchmann & Pettersson, 1995). However it can easily be contaminated with faecal material. The drawback of using urine as a nutrient resource is mainly the high pH of urine (8.6 – 9.2) which increases ammonia loses during storage and after application becoming an environmental problem in the process.

Large scale field testing and application of urine in agriculture currently has not been accepted in some parts of the world. However, several practical research studies have shown the effectiveness of using urine as a fertilizer. Typical examples include the following (in chronological order): Johanssson et al. (2001) and Rodhe et al. (2004) study in which 90% of equal amount of nitrogen in urine corresponded to 100% of equal amount of ammonium fertilizer in barley production in Sweden; Guadarrama et al. (2001) study in which urine was tested as fertilizer to greenhouse lettuce in Mexico and the results showed that urine gave the best yield of lettuce in comparison with a combination of urine and compost mixture and no fertilizer application; Morgan (2003) and (2008) study in Zimbabwe where vegetables grown in cement basins with a 3:1 water/urine ratio applied showed an increase in production than the control; Simons and Clemens. (2004) study in which there were no difference in yield in plots which was applied with acidified urine in comparison with plots with fertilizer applied in Germany; Mkeni et al. (2006) study in South Africa in which the urine was diluted in a 1:3 ratio with water resulting in higher yields in cabbage and spinach as compared to goat manure (maize response to the urine being equal to urea fertilizer); Germer et al. (2006) study in Ghana in which urine and compost applied to sorghum as a supplement to fertilizer with phosphorus and potassium increased yield by 3.5 times; Pradhan et al. (2007) study in Finland where urine was applied to cabbage in comparison with industrial fertilizer and non fertilizer treatment and it was concluded that urine could be used as a fertilizer for cabbage and that the mature cabbage had no significant hygienic threats and different flavor; Sridevi (2009) study in India where recommended nitrogen needs for cereal was applied to the soil from human urine and a significant increase in nitrogen, phosphorus and potassium content of the plant was observed and Jeyabaskaran (2010) study in India where urine was being applied to bananas through a drip irrigation system (different application rates and supplement ratios were involved) and the results showed that urine application resulted in high yield of banana fruits per bunch than the control (with no urine applied).

With the promotion of UDDT in most developing countries by different governments and sanitation organizations coupled with actual scientific evidence of benefits of using urine as a fertilizer, it is yet to be seen how urine will effectively change the agricultural sector.

2.5.1.2 Faeces

A person produces approximately 0.4kg of faeces every day of which approximately 80-90% of it is organic matter (Still & Foxon, 2012). Looking at faeces alone as a nutrient resource, human faeces are a poor source of nutrients (Malkki, 1999) and contains a rich ecosystem of different micro-organisms including bacteria, viruses, protozoa and fungi which are both a health and an environmental problem. Composting however by far is the best way to deal with the different hazardous pathogens in faecal matter even thought it must take at least six months (and at least in the summer months) to effectively minimize the presence of microbes (Malkki, 1999). A comparative analysis of compost and synthetic fertilizers however has shown that the nutrient content in compost is low as compared synthetic fertilizers but compost is still favoured since it is usually applied at greater rates and therefore nutrient contribution can be significant

The big advantage of using faecal sludge in composted or dry form is its ability to act as a soil conditioner due to the increased presence of organic matter and its capability of providing nutrients slowly into the soil over time. Composted human faeces alone however has little nutritive value, but when done with urine, human faeces become a great nutrient resource since the presence of urine makes the compost to have up to 90% nitrogen, up to 50% phosphorus and up to 70% potassium available to plants for use for a longer period of time, (Richert et al., 2010).

2.5 Potential Ground Water Contamination

There are numerous studies that have looked at chemical and microbial contamination of ground water in relation to pit latrines. Graham et al. (2013) reviewed 24 studies (globally) which had accessed chemical and microbial contamination of ground water in which human excreta was the main input to pit latrines on the quality of ground water. The review concluded that most researchers who looked for groundwater contamination from pit latrines frequently detected it. Locally, same observations have also been done by Kanyerere et al. (2012); Kaonga et al. (2013); Muruka et al. (2012) and Msilimba et al. (2013).

2.6 Research Gap

A review of key aspects related to pit latrine sludge composition, associated problems with pit latrines and VIPs, potential environmental problems associated with pit latrines and VIPs, latrine contents and processes that occur in latrines had been presented. This section presents a synthesis of existing scientific research information and identification of gaps that drove to this study.

Limitation of Scientific Information

Understanding to what happens and how to safely handle pit latrine sludge is of fundamental importance considering the land demand that is arising with population growth in various communities. The literature reviewed in the preceding sections has demonstrated the limitation in scientific information in this area of pit sludge characterisation. So far a few coherent research studies done by Buckley et al. (2008) and Magagna (2006), which was later extended by Mwaneri et al. (2009), have been conducted in this study area although the areas of focus varied between the studies. The data from these research studies have been further refereed, synthesized and summarized by Bakare et al. (2012 and 2014). Looking at Nwaneri et al. (2009) study, the study had three samples for analysis in which the sample was too small for statistical analysis and for a coherent generalization. Similarly, Magagna (2006) study only looked at four VIPs in which VIP1 and VIP2 were subjected to a group of different parameters, VIP3 and VIP4 were subjected to another group of test of which it was not possible to make comparison on the different parameters for the four VIPs. Furthermore, Buckley et al. (2009) recommended that a similar study be conducted for a statistically significant number of VIPs to further develop additional significant information on pit sludge characterization.

Variations of Data from Available Research Studies

Looking at Magagna (2006) study, the results showed variations when parameters of interest were compared from different depths within the pit and from pit to pit. Same trend was also observed by Bakare et al. (2012) and Nwaneri et al. (2009) studies. Arguments could be made that sampling must have been made at different times of the year, climatic condition and geological conditions. However these studies were conducted in an area having the same climatic and geological formations (eThikwini Municipality, Durban, South Africa) with sampling time/period (no indicative season) as the only differentiating component. Magagna (2006) study had sampled four VIPs in which VIP 1 was sampled on day it was raining heavily and VIP2 was sampled during a period of dry weather. Sampling for VIP3 and VIP4 was done on a day preceding a day it had rained heavily and the samples from these VIPs were subjected to methanogenic activities only. Looking at how the sampled from these four VIP were subjected to different parameters if interest, obviously the results from VIP1 and VIP2 had variations since the conditions were different, samples of VIP1 registered higher moisture values throughout the different vertical and radial positions compared to VIP2 which was sampled in a period of dry weather hence these two VIPs were not comparable. VIP3 and VIP4 which were sampled at the same time and the samples subjected to methanogenic activities only also yielded results which were not comparable as well. It was estimated (combined from all the four triplicates, one from center and one from side) that between 1% - 5% of the COD in VIP3 had been converted to methane gas while in samples from VIP4, 1% 21% of COD had been converted to methane from samples from the center, and between 1% - 21% of the COD converted to methane from sampled from the side, again making the two VIPs results having variations in the results.

Having the above discussed limitations in both scientific research data and knowledge, there is a need for continued scientific investigation on what happens to pit sludge over time. Thus the present study investigated the Physico-Chemical status of faecal sludge in pit latrines. The area under study was chosen to be of similar social characteristics as eThekwini Municipality taking into consideration the population dynamics of an urban unplanned settlement.

Chapter Three: Research Methodology

3.1 Introduction

This chapter outlines the research methods that were used in this study. It presents a brief description of the study area, site visit, research approach and design, sample preparation and the principles and analytical methods for the parameters that were of interest. Detailed questionnaire used during site visit is in Appendix A. This study followed the following methodology:

- A review of literature of key research studies that describe what happens in pit latrines.
- Social behavior data collection from users of the pit latrines in the targeted area through a survey.
- Selection of randomly chosen pit latrines that had a minimum of two meters of sludge for sampling.
- Physico-chemical analysis of the sampled sludge sampled from four different depths within the pit latrine.
- Summary and an attempt to compare the results with other key research studies in literature.

3.2 Study Area

This study was conducted in Ntopwa Township, an unplanned peri urban settlement. It is part of a bigger location called Bangwe located to the southeast of Blantyre city with approximately 5 hectares of land. It has a population of 3,789 people with 500 households (UN-Habitat, 2011).

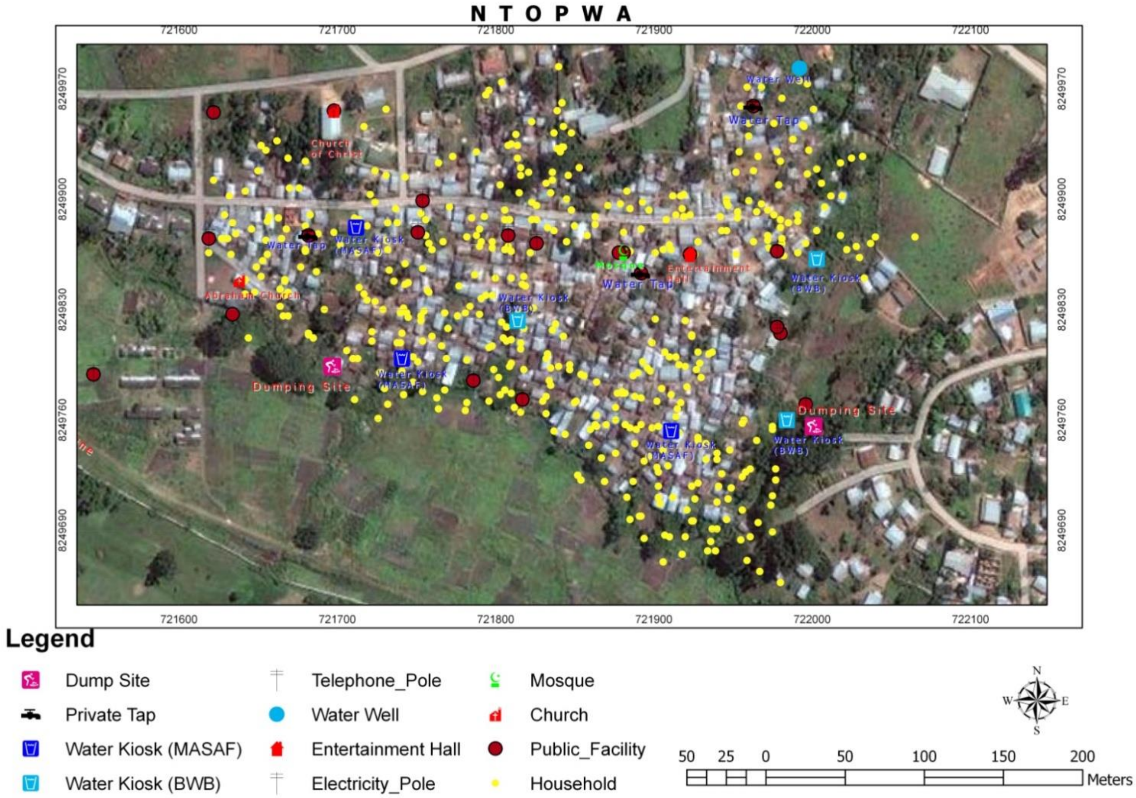

Figure 3. Public and Private Amenities in Ntopwa Township (Source of information)

The main economic activities in Ntopwa are facilitated by various formal employments offered in a nearby town called Limbe and to a certain extent Blantyre including various small scale businesses within the settlement. Being part of Blantyre city, Ntopwa generally have similar to almost identical climatic conditions to that of Blantyre as a whole. Typically Ntopwa experiences three distinctive seasons; a warm-wet season that stretch from November to April; a cool-dry winter season from May to August and a hot-dry season from September to October.

The study followed both a qualitative and quantitative approach.

3.3 Research Approach and Design

3.3.1 Qualitative Approach

A semi-structured questionnaire questioner was administered to collect qualitative data with the intention of trying to understand the general user knowledge, attitudes and practices of faecal sludge management of the pit latrines. The administered questions were designed to get information ranging from social and financial status, level of access to sanitation, knowledge on faecal sludge management and attitudes towards faecal sludge management.

3.3.2 Quantitative Approach

Quantitative approach was achieved through sampling of faecal sludge from pit latrines at different depths to quantify the different Physico-Chemical parameters that were of interest.

3.3.2.1 Sampling – Pit Sludge

Sampling of the pit latrine sludge was done in April 2014, just after the rainy season. Initially the plan was to sample sludge from 20 pits at four different depths in each pit. Due to financial and time limitations the sample size was reduced from 20 pit latrines to 10 pit latrines. The initial thinking at the onset of the study was to sample lined pits in the target area, however during the survey it was discovered that the target area had unlined pits only.

Sampling was done using a motorized vacuum pump. The vacuum hose was measured and marked at 0.5 meters, 1.0 meters and 1.5 meters along its length with the tip of the horse representing the surface when sampling. After identifying a latrine that was at least 2 meters full, the vacuum horse was inserted into the pit, vacuuming the sludge at that layer into the holding tank where the sample was then collected into a 500 ml plastic bottle. After collection the sludge at a specific depth, the whole system was then pressure washed using water to flush the sludge from the holding tanks and the horses (into a separate waste holding bucket and not in the pit latrine) before commencing on another depth. No water was added in the pit latrine to fluidize the sludge at any depth. In total 40 samples were collected, put in cooler boxes and transported to the laboratory for analysis where each parameter of interest at every depth was done in triplicates.

3.3.2.2 Analytical Methods

All the samples that were collected were analyzed for different parameters as depicted in table 4.

Table 4. Parameters of Interest and Their Reasons for Inclusion

Category	Parameter	Reason for inclusion
Pit latrine chemical environment status	pH Ammonia	Interchangeably affects each other effecting anaerobic digestion processes
Physico-chemical characterisation	Chemical oxygen demand (COD)	A measure of oxidisable organic matter
	Total volatile solids (TVS)	A measure of organic matter
	Moisture content (MS)	A measure used to relate biodegradability
	Total solids (TS)	A measure of inorganic solids
	Fixed solids FS)	A measure of non-organic solids
Nutrient potential for agricultural use (macro nutrients)	Total Nitrogen (TN) Total phosphorus (P) Total potassium (K)	

3.3 Methods of Test for the Different Parameters of Interest

Solids (MC, FS, TS, and TVS) and pH were determined using standard methods (APHA. 1998). Total Nitrogen, Total potassium, Total phosphorus and Ammonia were determined using AOAC. 2000 standard methods. Chemical Oxygen Demand was determined using the British standard (BS 6068 Section 2.34:1998).

3.5 The KAP Study

The study area had a population of 500 households and 221 households were purposively sampled using Krejcie and Morgan (1970) sample size calculation formulae for proper statistical representation of the population (required sample was 217). The sample size was calculated at 95% confidence level with a margin error of 5%.

3.6 Statistical Data Analysis

Data from the Knowledge Attitudes and Practices survey was first cleaned and compiled in SPSS version 16. (2008) in which descriptive analysis was done on the responses. Data from the laboratory analyses was also compiled in SPSS 16 and Microsoft Excel 2007 version where graphical representation were made to visualize the trends between depth and the different means of the different parameters of interest. Polynomial trend lines order of 4 were added to show how well the data was fitting with the added line in which $R^2 = 1$ indicated a perfect match with $R^2 =$ 0.7 -1.0 indicating a strong relationship and 0.4 – 0.7 indicating a moderate linear relationship. Values within 0.4 – 1.0 were indication that the data can be used to make predictions. ANOVA using the post-hoc Scheffe test was used to determine if there were any differences between the different physico-chemical parameters of interest between pit latrine and pit latrine and differences in the values of different parameters of interest between depth within a pit latrine. Correlation analysis (SPSS 16. 2008) was also done to determine the relationships between the different physico-chemical parameters under investigation with depth.

Chapter Four: Results and General Discussions

4.1 Introduction

This chapter presents the study findings in detail. The first section deals with the survey results and the last section reports on the results of the analytical work. General discussions are presented together with the results.

4.2 The KAP Study

The study was carried out with the primary goal of establishing a qualitative indication in the user's knowledge, attitudes and practices in regard to on site sanitation access and management. Frequency tables for the different questions are in Appendix D.

4.2.1 Social and Financial Overview of Ntopwa Residents

The survey revealed that the average household income per day is US$2.32/day with income ranging between US$0.24/day to US$5.88/day. The main income comes from small scale business, 59.7%, which is typical in high density informal human settlements followed by 32.1% in a formal employment, 4.5% involved in small scale farming and 3.6% in large scale farming.

A majority of the households are male headed, 68% with 27.7% households being female headed. Few households are child or elderly headed as depicted in Figure 6. A majority (67.4%) of the household are owned by landlords with the remainder, 32.6% of the respondents being tenants.

4.2.2 Access to an Onsite Sanitation Facility

The survey showed that 92.8% of the households have latrines on their premises, Figure 4.

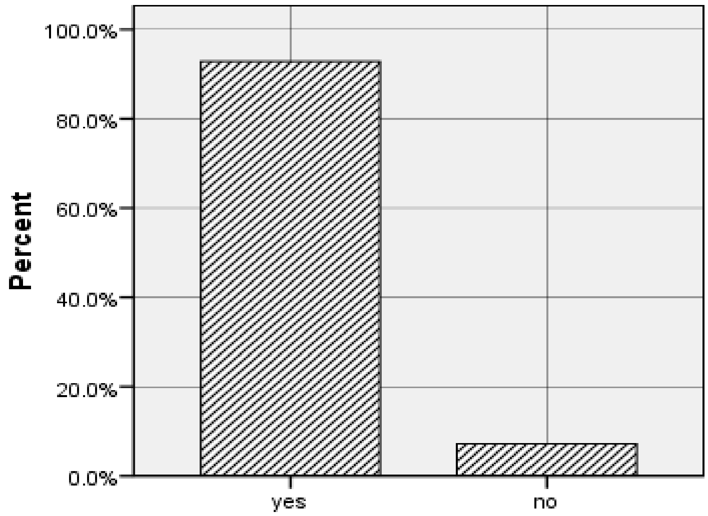

Figure 4. Latrine Ownership

Traditional pit latrines were the most used type, 61.5%, followed by improved traditional pit latrines, 13.2%, VIP 8.8%, temporal pit latrine, 8.8% and Ecosan latrines 7.3%. The qualities of the pit latrines themselves were poor in nature as expected. The superstructure of the pit latrines ranged from unburnt brinks, 49.8%, burnt brinks 29%, raw earth 9.5% and other unspecified materials 5.0%. Likewise, the materials used for the floor of the pit latrines ranged from aggregated earth with logs 53.8%, concrete slab 35.7%, burnt bricks 2.3% and 1.4% accounting for other materials such as railway – line metal bars, old vehicle chassis and some unrecognizable worn out metals. For residents who did not have a pit latrine; 73.7% indicated making use of the neighbour's latrine, 10.5% indicated using the bush and 15.8% did not specify how they fulfill their ablution needs, Figure 5.

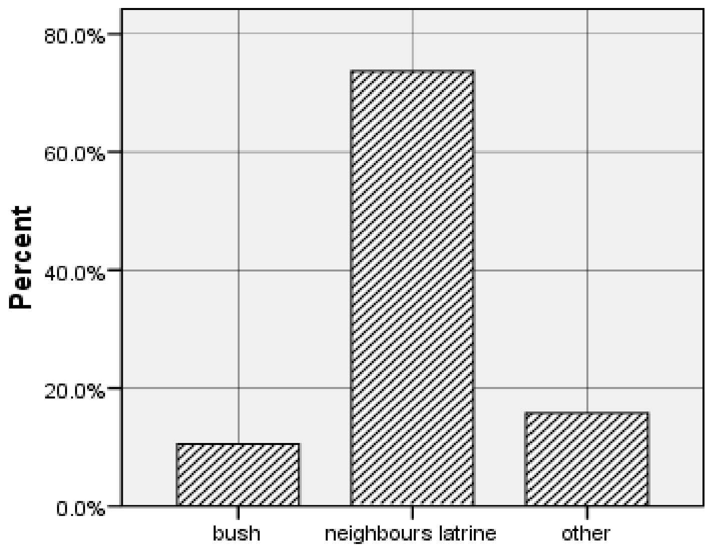

Figure 5. Alternatives for Those without Toilets

While some residents who have no toilets cited the reason for not having a toilet as no one being available to dig a latrine for them, this reason seem to be a scapegoat since hired labour constitutes to 48.7% for construction of the available latrines followed by self build, 31% and labour sourced from relatives 11.7%. A majority of respondents indicated that they allow other users access to their pit latrines, 63.2%, some selectively allow other users, 13.5% with 23.4% indicating that they don't allow other users. However, for those who allow access, some do so at a fee and some at no cost. Likewise for those who selectively allow do so at a fee and some at no cost.

This has an implication for those who do not own latrines in that their use of a latrine is subject to the choice of the owner. Some owners indicated that they actually charge a fee for the use of their toilets. In some instances the owner chooses who to allow access even at a fee meaning that apart from one having the ability to pay one has to be in a cordial relationship with such an owner to be allowed to have access and still the right to access is at the discretion of the latrine owner.

The survey identified that the average household had 5 members. This implies that for the toilets used by an additional one family, additional two families or more than two additional families the numbers per toilet are 10, 15 or more than 15 people. 65.2% of the toilets were used by more than three families, that is the respondent household and more than two additional households.

4.1.3 Pit Age and Site Selection

Respondents who had indicated to have a pit latrine were asked as when they had decided to have a pit latrine so as to determine the current age of the pit latrine in use. 44.3% of the respondents indicated to have used the latrine for at least over two years, 18.4% for two years, 18.9% for over a year and 18.4% for less than a year.

Random site selection for pit latrine construction was the most indicated choice, 65.9%, 23.9% indicated constructing a pity latrine as a distance from a dwelling house (unspecified distance), 6.3% chose site at a lower altitude from a water source and 3.9% had no proper indication, Figure 6.

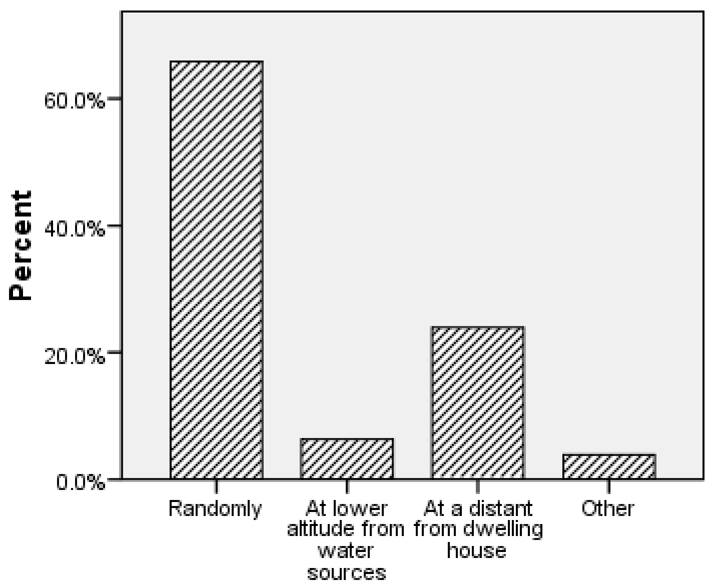

Figure 6. Site Selection for Pit Latrine Construction

4.1.4 Sanitation and Pit Sludge Management

Majority of respondents indicated using old newspapers for anal cleansing, 31.9% followed by 30.5% who indicated using water and 20.7% use commercial toilet tissue with a small percentage of the respondent using cobwebs and other unspecified materials.

Nearly half of the population in Ntopwa is aware of use of dehydrant chemicals for pit sludge management (43.4%) but very few are conversant with pit emptying (11.6%) as a pit sludge management techniques. Some are aware of use of pit sludge as organic fertilizer (23.2%). There was observation that pit emptying is very rarely practiced in Ntopwa and abandonment of full pit latrines is fairly represented (22.7%), figure 7.

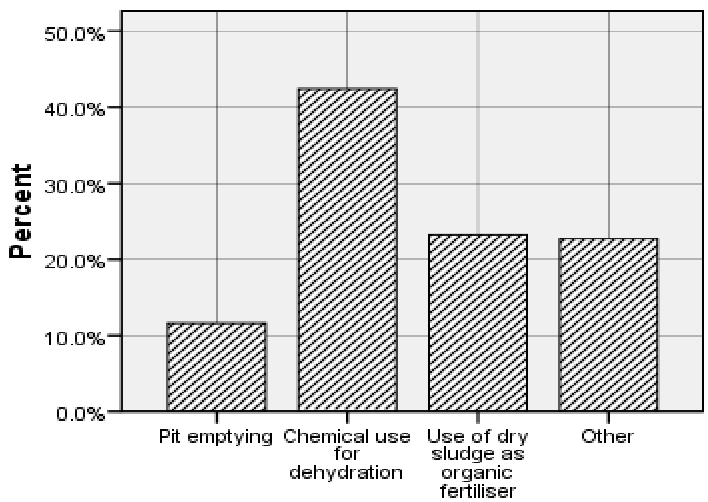

Figure 7. Methods of Pit Sludge Management Known in Ntopwa by Residents

For the few respondents who indicated that they empty there pit latrines when full, 31.8% indicated that they empty the pit latrines themselves, 24.0% employ hire manual labour, 17.1% employ pit emptying services at a cost and 27.1% did not specify how (tenants).

As regard to what they use the sludge once they empty it from the pit latrines, the responses were numerous with the notable ones being the use of the sludge as manure 53.8%, (no indication as in its raw form or after composting), 6.9% just abandon the sludge. A bigger percentage, 55.2% in the study responded that there is a relationship between pit sludge management and water quality. Out of the 44.8% who respondent to no existence of relationship between pit sludge management and water quality, 15.8% indicated virtually to having no idea

Satisfaction levels for the different pit sludge management employed in Ntopwa varied from very satisfied (30.0%) to very dissatisfy (21.1%) to very dissatisfied (21.1%), while those satisfied ranged from very satisfied (30.0%) to satisfied (23.5%). Interesting to note was that there were others who did not care about sludge management (12.7%), Figure 8.

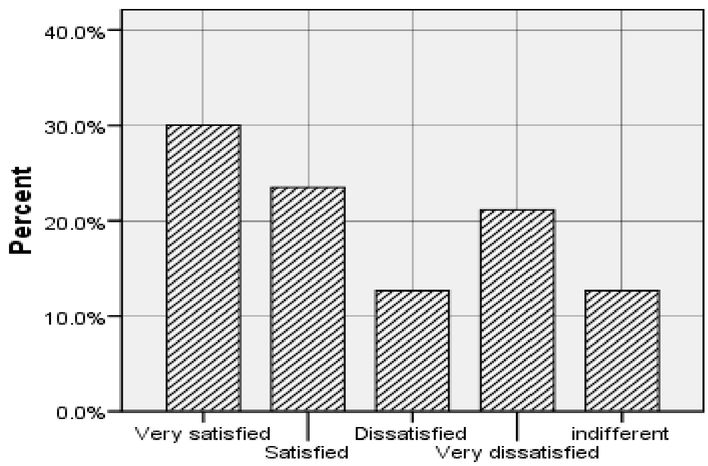

Figure 8. Level of Satisfaction about Pit Sludge Management Employed in Ntopwa

4.2.5 Summary

Access to an onsite sanitation facility in Ntopwa Township in this study is very dominant with 92.8% having access to an onsite sanitation facility either with ownership of pit latrines by households being at 96%, 86.9%, 80.0% and 75% for male, female, elderly and child headed households respectively. However, most of the pit latrines are of poor quality with the majority, 57% being traditional pit latrines and the majority of the materials used for construction of the pit latrines floor and superstructure are temporal in nature. This is typical of high density urban unplanned areas where most residents are low income earners and that translates to the quality of structures as well. Open defecation is in practices in Ntopwa although the percentage of user are minimal, 10.5%.

The study revealed that pit latrines can be used as a source of income to other households since they let other people who have no pit latrines to use them at a fee. An attempt to link household headship and tolerance to allow other users access to their pit latrines showed that child headed households were tolerant to other users for free and at a fee in equal measure unlike other household headed by other members of the family. Household headed by elderly members were the most tolerant, Table 5 below illustrates the linkage.

Table 5. Tolerance Level of Household Head

Head of household	Do you allow neighbours/visitors use of your toilet?					
	Yes and for free	Yes at a fee	Selectively for free	Selectively at a fee	Not at all	% Total
Male headed	53.9	5.7	10.6	4.3	25.5	100
Female headed	57.7	15.4	5.8	1.9	19.3	101
Child headed	33.3	33.3	33.3	0	0	99.9
Elderly headed	50	0	25	0	25	100
Total	54.5	8.5	10.0	3.5	23.5	100

Money was the most cited reason as to why some residents do not have a pit latrine. An attempt to link such residents as those who practice open defecation was not done in this study to ascertain that they were not the ones who were paying their neighbour for them to have access to their pit latrines. It was established that the majority (65.2%) of the pit latrines were being used by an average of more than ten people from more than two households which is a typical setup in high density urban unplanned areas where land is scares for individual pit latrine construction.

Many people in the study area are aware of some form of pit sludge management with 43.2% being aware of use of a dehydrant chemical (there were no indication of which chemicals in the study) and 23.2% knowing that pit sludge can be used as an organic manure. However, no one reported having to have used the actual pit sludge as organic manure, but the majority, 53.8%

just abandon a filled up pit latrine a practiced widely employed in different communities. A majority (55.2%) of the respondents indicated that they know the existence on the relationship between pit latrine and general hygiene with some making a direct link to cholera and groundwater contamination. However, a majority (65.9%) of the respondents indicated that site selection for pit latrine in relation to a water source was random which implies that knowledge in this area need to be highlighted to the residents since proper site selection for pit latrines deters the potential of groundwater contamination.

4.3 Results from the Laboratory Analysis

This section is divided into four sub-sections as follows; a) first presenting the results on the chemical environment status of the pit latrines; b) the second presenting on the degradation and stabilization indicators; c) the third presents results on nutrient potential of the sludge for agricultural use; and d) the fourth presents results for microbial contamination on water samples in the surrounding environment.

4.3.1 Pit latrine chemical environment

4.3.1.1 pH

The acidity and alkalinity condition of the pit sludge registered a mean value of 7.40 ± 0.07. A pictorial vertical analysis of the pH values showed that there was a considerable rise in pH from the top layer to the 0.5 meter layer, and a continues slow rise in pH from the 0.5 meter to the bottom 1.5 meter layer, Figure 9.

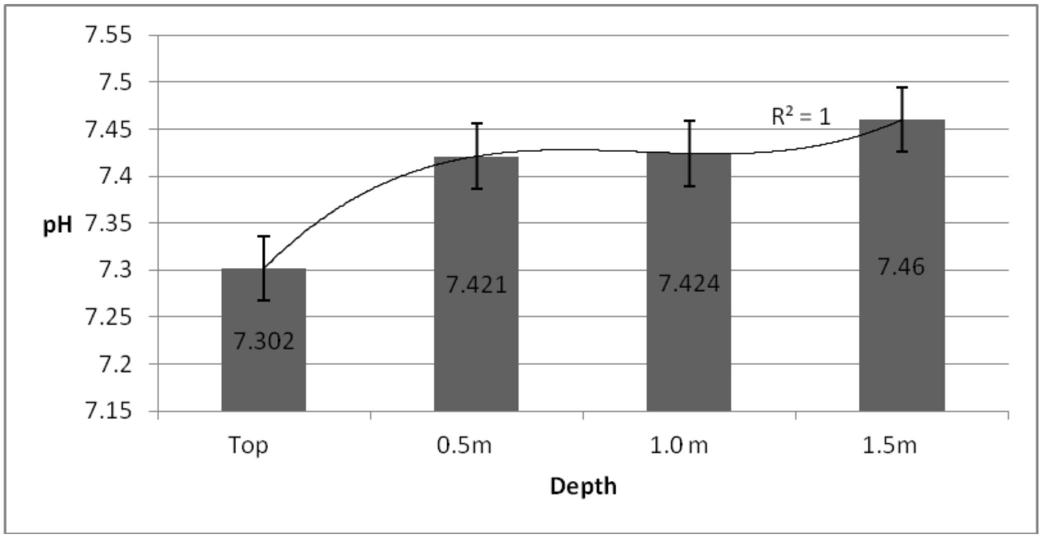

Figure 9. Mean pH Values at Four Different Depths (n = 40)

The pH values were all within values in literature (Batstone et al., 2002; Benabdallah et al., 2009; Braun et al., 1981; Haran & Mara, 2003; Henze et al., 1997 and Zeeman et al., 1958) in which these are the conditions considered to be ideal for anaerobic digestion. These values gave confidence that one of the conditions for anaerobic digestion to take place was met and the expectation was to see the extent of degradation of the organic matter on the lower layers. One way ANOVA showed that there were significant variations in the pH values from pit latrine to pit latrine ($p<0.001$) with no significant differences in the values between depths ($p>0.95$). The Pearson correlation was used to assess the relationship between depth and the pH values and showed that there was no significant correlation relationship ($r=0.895$, $p>0.05$).

4.3.1.2 Ammonia

The mean ammonia content was 0.02±0.02 mg/g sample. There were variations in trends between pit latrine and pit latrine, Figure 10, ($p<0.001$). On the other hand there were no significant difference between the mean ammonia values at different depths ($p=0.88$).

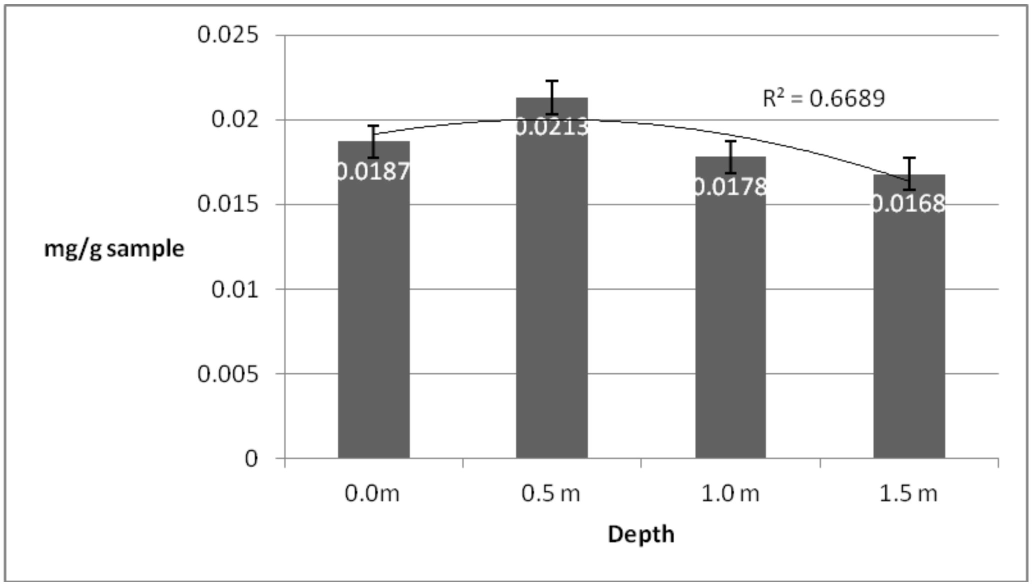

Figure 10. Mean Ammonia Content at Four Different Depths (n = 40)

The ammonia content was highest at the 0.5 m depth, with a gradual decrease from this layer to the 1.5 meters depth, Figure 10. While there is no literature capturing ammonia levels in ***pit latrines*** with regards to different depths, there was no general trend expectation with respect to depth since ammonia is present in urine and at the same time we expect ammonia or ammonium from the process of anaerobic digestion on the lower layers. In an ideal digestion reactor where we would be controlling the different parameters that affects anaerobic digestion, would expect the ammonia or ammonium levels to be consistent for maintenance of ideal environment in order to prevent ammonia build up to toxic or inhibitor levels. While different studies have varying toxicity and inhibitory levels of ammonia in anaerobic digestion, the mean values in this study (0.02±0.02 mg/g) is below observable literature values that cause toxicity and inhibitory effects in mesophilic conditions. A Study by Gallert & Winter (1997) have shown that for mesophilic conditions at pH7.6, 0.22 – 0.28 mg/g of free ammonia causes a 50% reduction in methane production (substrate was organic fraction of household waste). Likewise a study by Garcia & Angenent (2009) also showed that an increase of ammonia from 4mg/g reduces methane production by 45% (substrate was pre-acidified brewery wastewater).

Linking this observation with the pH values which is within range for anaerobic degradation to take place, it can be speculate that pH and ammonia conditions for anaerobic digestion to take place in the pit latrines was not at toxic or inhibitory levels. The Pearson correlation showed that there was an insignificant negative correlation relationship between the two (r=-0.93, p=0.07) which is expected and as observed for in mesophilic digestion conditions in literature (Benabdallah et al., 2009).

4.3.2 Degradation and Stabilization Indicators

4.3.2.1 Moisture Content

The mean moisture content for the sampled ten pit latrines was 73.39±2.93%. The mean moisture content value is within range with values in studies bone by Magagna (2006) and Mwaneri. (2009) which were 78.97±1.1% and 70.08±5.38% respectively. This mean value also supports the existence of favorable conditions for microbial activity since its way above the required 50%-60% moisture content range requirement (Bakare et al., 2012 and Bazrafshan et al., 2006). However a comparison of fresh faeces moisture content from literature (Almeida, 1999; Lopez, 2002 and Nwaneri, 2009) were 79.2%, 81.8% and 78% respectively with the results in this study shows that the results from this study are relatively lower supporting the theory that once faecal matter enters a pit latrines it undergoes some form of degradation within a short period of time (Buckley et al., (2008). A graphical plot of the mean moisture content values versus the depth shows a rise in moisture content from the surface layer to the 0.5 meters depth, and then a decrease from the 0.5 meter to the 1.0 meter depth to the 1.5 meter depth, Figure 11, supporting the ideology of expected decrease in moisture content with increasing depth (Bakare et al., 2012; Buckley et al., 2008 and Nwaneri, 2009). However, ANOVA analysis showed that these differences were statistically insignificant (p=0.83).

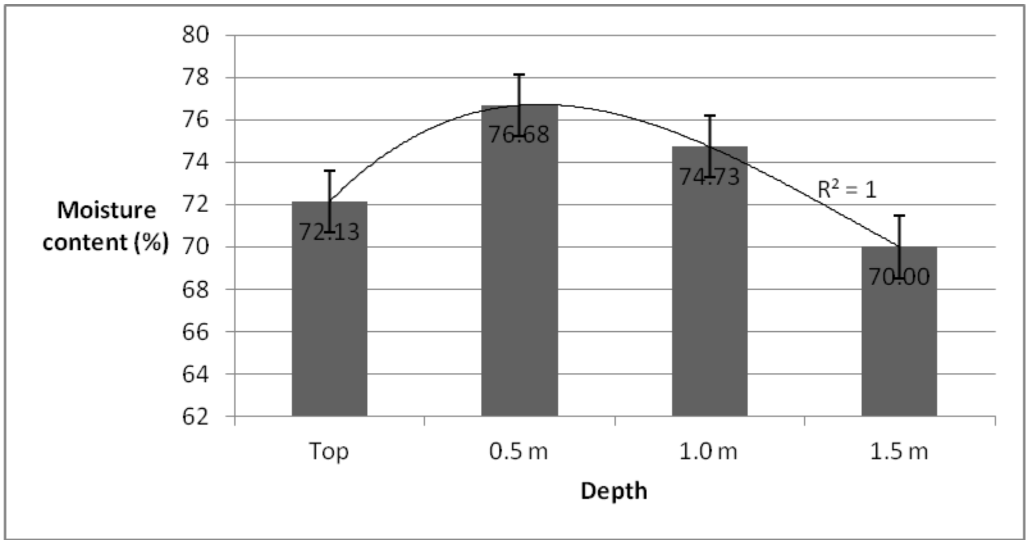

Figure 11. Mean Moisture Values at Four Different (n = 40)

There were variations however of the moisture content between pits ($p<0.001$), Figure 23. It was observed that all except pit latrine code PL10 exhibited an upward trend of moisture content values when moving from the surface to the 0.5 meter depth while PL10 exhibited a downward trend at this level. Moving from the 0.5 meter to 1.0 meter depth, PL02, PL04, pL05 and PL06 exhibited a downward trend till the 1.5 meter depth. The other pit latrines had various trends, Figure 12.

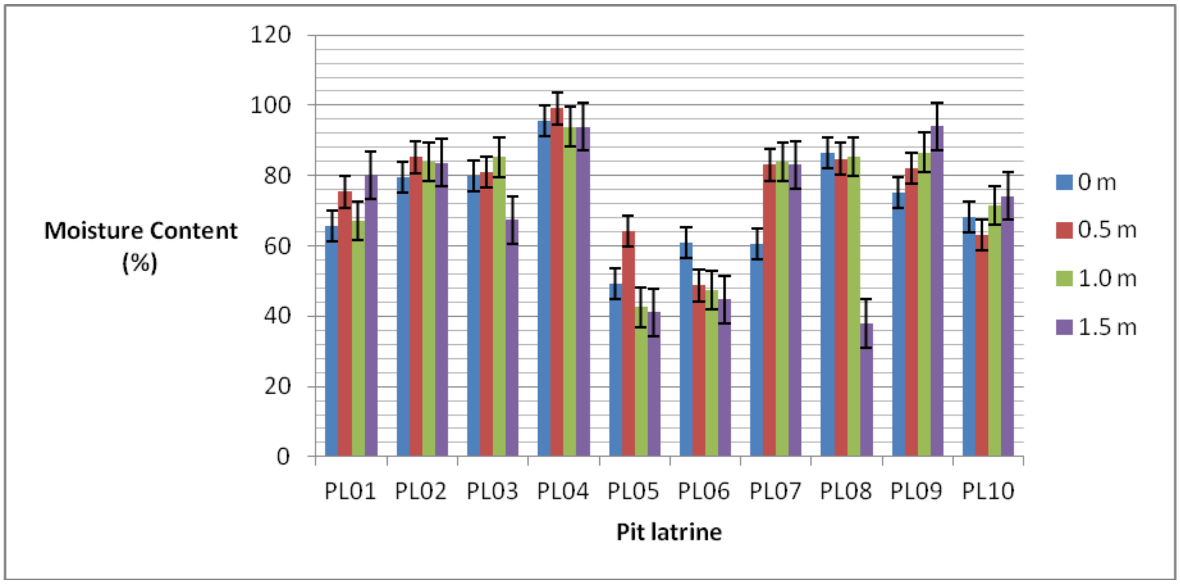

Figure 12. Individual Pit Latrine Moisture Content Trend with Depth

PL09 which exhibited an upward trend all from the surface to the 1.5 meter layer. Literature suggests this phenomenon being an introduction of water from the surrounding environment into the pit be it from ground water or leaking tap nearby (Nwaneri, 2008; Mara, 1984 and Still, 2012). In the case PL09, the pit was also being used a dumping site for grey water from nearby shack bathrooms which were being used by five household on the premises (a row of building with five households two toilets and two bathrooms noted). This continued dumping of the grey water contributed to this general increase of moisture content throughout the different depths.

4.3.2.2 Total Solids, Fixed Solids and Volatile Solids

The Total Solids content results showed that there were significant variations in trends between pit latrines, Figure 23, ($p<0.001$). Three pit latrines, PL03, PL09 and PL10 notably showed the expected pattern of decrease of total solids with increasing depth with the rest of the pit latrines portraying different trends.

However, the mean total solids content appear to increase with increase depth from the surface to the 0.5 meter depth with an increase from the 0.5 meter depth to the 1.5 meter depth. There was no statistical difference among the mean total solid contents of sludge from different depths (p=0.83). Similar observations were also made for Fixed Solids. There were variations in trend amongst pit latrines (p<0.001), Figure 25. Only PL01 exhibited a decrease in fixed solid content with increasing depth. The rest of the pit latrines exhibited different patterns.

The mean Fixed Solids content showed a decrease from the surface to the 1.0 meter depth with an increase from the 1.0 meter depth to the 1.5 meter depth which is a contradiction with what was expected. There was no statistical differences among the fixed solid contents of sludge from different depths (p=0.96)**.**

Despite the fact that the results for the Total Solids in terms of trend are contrarily to expectations (decrease with increase in depth) the mean values are within the values found in literature. The Mean Total Solids in studies by Magagna (2006) was 79 ± 0.58 %/ gram sample for VIP1 (sampled on a rainy day) and 25 ± 13.74 %/ gram sample for VIP2 (sampled on a day with dry weather) while in studies done by Nwaneri (2009) the mean Total Solids was 27.00±4.01 %/gram sample. In this study the mean Total Solids content was 26.62±1.46 %/ gram sample. For fixed solids, this study mean was 64.82±2.08 %/ gram sample which is above the mean found by Magagna (2006), VIP1 59.67±1.53 %/ gram sample and VIP2 59.67±51.87 %/ gram sample and Nwaneri (2009) mean fixed solid value of 47.67±10.02 %/ gram sample (n=3).

For relatively dry pits coupled with at Buckley et al. (2008) hypothesis of processes in a pit latrine, the expectations are that the amount of faecal sludge being deposited at the surface layers undergoes degradation of the ready-biodegradable components rapidly once they are deposited in a pit latrine (Bakare et al., 2012). In this regard, the expectation is that the amount of fixed solids (an indication of the amount of inorganic solids) and total solids at the lower end of the pit should be less in comparison with the upper. In this study however, there was an increase in the lower layers in comparison with the upper layers. A plausible explanation for these observations is that there was an introduction of inorganic solids at some point into the pit latrines. Most household users had indicated using the pit latrines for waste disposal of household refuse and other things. The design of the latrines themselves also is suspected to have played a role. In this study, all the pit latrines under investigations were not lined pits, meaning that the chances of introducing inorganic materials from the walls of the pit itself were inevitable especially soil carvings from the walls of the pit latrines getting mixed with the sludge. At the onset of the study during the sampling phase, it was noted that some latrines had a complete mixture of sludge and soil on the surface of the latrine, of which such latrines were discarded for sampling.

The mean Volatile Solid (an indicator for organic matter) content for the ten sampled pit latrine was 35.12±2.08 %/ gram sample. There were varying volatile solids content trend ($p<0.001$) from pit latrine to pit latrine with no definite expected pattern observed of decrease in volatile solid content with increasing depth, Figure 13.

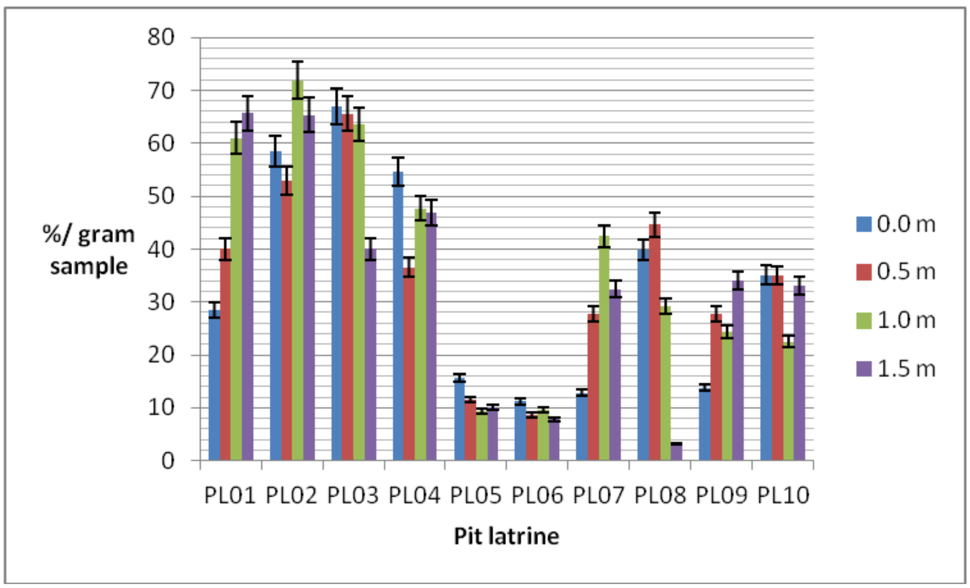

Figure 13. Individual Pit Latrine Volatile Solid Content

The mean volatile solid content showed an increase from the surface layer to the 1.0 meter depth with a decrease from the 1.0 meter to the 1.5 meter depth, Figure 14. ANOVA analysis showed that the mean volatile solids values for the different depths were statistically not different ($p = 0.96$).

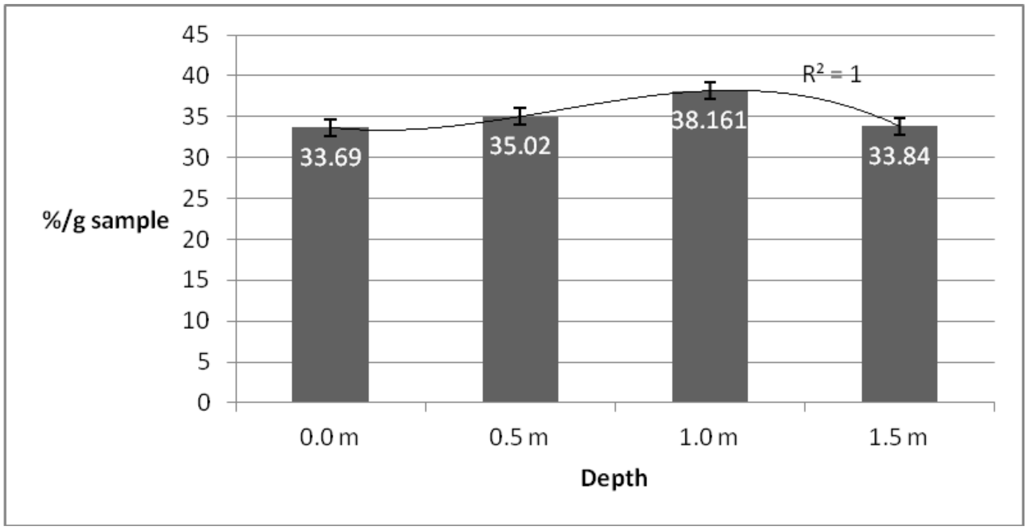

Figure 14. Mean Total Volatile Solids Content at Four Different Depths (n = 40)

A comparison of literature values from other studies shows that the mean value of 35.12±2.08 %/ gram sample from this study was within range with Magagna (2006) mean total solids content of 40±1.53 %/grams dried sample and that of Mwaneri (2009) study of 52±10.02 %/grams dry sample. However, Magagna (2006) study showed that the total volatile solid content values were increasing with increasing depth unlike Nwaneri (2009) which showed a decrease with increasing depth. Again looking at the hypothesis of Buckley et al. (2008), the expected and logical explanation of processes in a pit latrine is that we expect the amount organic material to be decreasing with increasing depth as the amount of degradable organic matter decreases leading to the accumulation of non-biodegradable materials at the bottom layers. In this study however, the bottom layers had a higher value of organic matter content, 38.161%/grams sample for the 1.0 m depth and 33.84%/grams sample for the 1.5 m depth in comparison with the surface layer (33.69%/gram sample). With this scenario, one may deduce that the bottom sludge might have accumulated without undergoing any form of degradation and there was accumulation of the organic matter at the point of this study in comparison with the surface layer. This school of thought would be in conflict with expected both aerobic and anaerobic degradation (Buckley et al. 2008) that would be expected to have been undergoing. Coupling these results with the fixed solid results above, which also showed high values on the bottom layer than the surface layer, a logical explanation would also be that of an introduction of organic material from the surrounding environment of the pit latrine since these pit latrines were not lined.

4.3.2.3 Chemical Oxygen Demand (COD)

The individual trends for COD (indicator for oxidisable organic matter) amongst the ten pit latrines varied from pit to pit ($p=0.50$), Figure 15. An analysis of the mean COD versus depth showed that there was a decrease in COD from the surface layer to the 0.5 meter depth, and then a gradual increase from the 0.5 meter layer to the bottom 1.5 meter layer, Figure 16. This trend is contrary to expectation of decrease in COD with increasing depth. However, ANOVA indicated that there were significant differences of the mean COD values between the different depths ($p=0.01$). The Pearson correlation used to assess the relationship between depth and the COD values showed that there was a positive significant correlation relationship between the two ($r=1$, $p<0.001$).

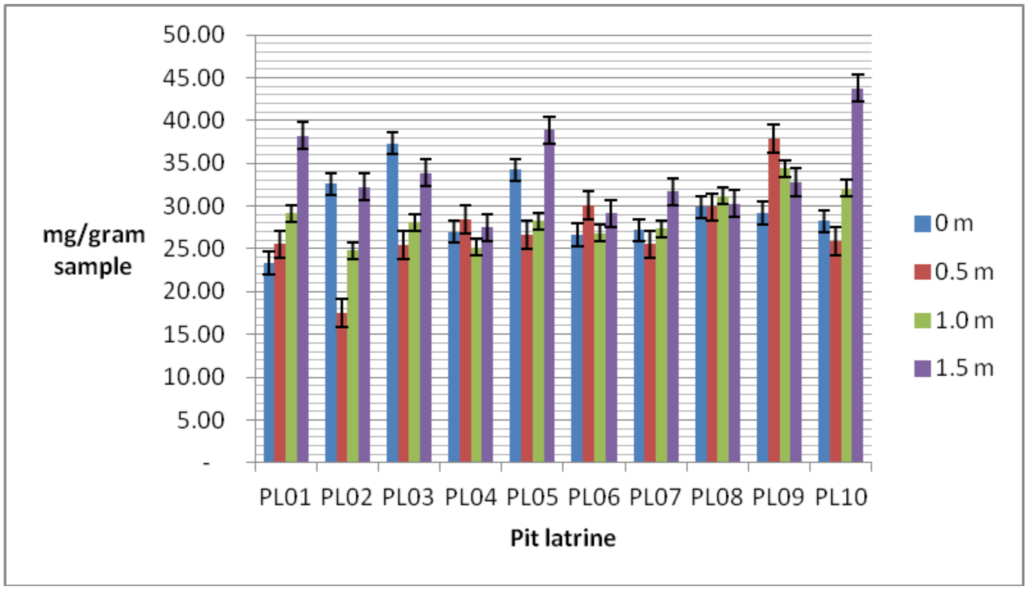

Figure 15. Individual Pit Latrine COD Values

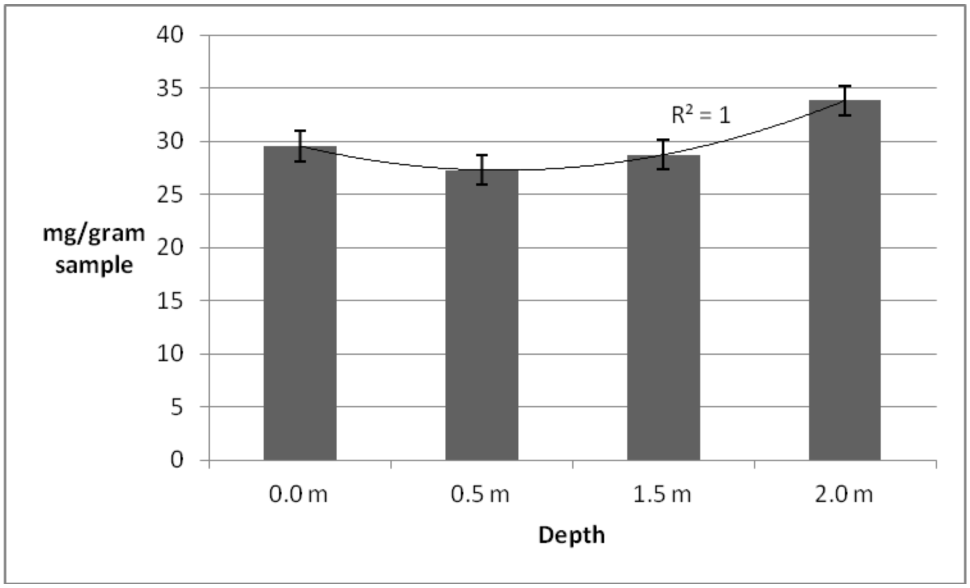

Figure 16. Mean COD Content at Four Different Depths (n = 40)

Observation of great importance is the COD values in this study are too low in comparison with other similar studies. This study mean was 29.85±2.82 mg/g sample while that of Magagna (2006) study was 523.67±66.16 mg/g sample for samples from VIP1 which was samples on a day it was raining, and 108.00±53.03 mg/g sample for samples from VIP2 which was sampled on a day with dry weather. Nwaneri (2009) study had mean COD values of 173.67±24.54 mg/g wet sample with the same sample on a dry basis producing 658.00±134.26 mg/g. These were sample from 3 VIPs only (n=3). She further made an analysis of 48 samples from 16 pits in which the mean COD value was 362.50±151.23 mg/g dry sample.

The COD results from literature are two fords, one; COD done on wet sample and two; COD done on a dry sample. A look at Nwaneri (2009) study, it can be noted that the same sample subjected to the same test produced different COD values when done on a wet and dry basis. This is due to COD fractionation (distribution) within the pit latrine. Ideally, the readily and slowly biodegradable organic matter in pit latrine is normally soluble and either seep away into the surrounding environment with the available water in the pit which is either used by microbes for energy production or accumulates at the bottom of the pit for slow degradation either aerobically or an aerobically (Mwaneri, 2009). In this regard, total COD (tCOD) of organic matter is divided into two; total soluble COD and total particulate COD (Rossle & Pretorius, 2001) which is further divided into slowly biodegradable COD and an biodegradable COD for the total particulate COD and readily biodegradable COD and an biodegradable soluble COD for the soluble COD (Dold & Marais, 1986). With the foregoing COD fractionation theory from literature, it can be deduced that there was a need to investigate soluble COD and particulate COD in this study to make proper COD estimations since this study only investigated COD of a mixed liquor of the sludge from the pit latrines in which there is suspected heavy soluble COD dilution into the surrounding waters. The low COD values found in this study are therefore not ideally proper COD values that should be compared with COD values from other studies unless in studies that were done in pit latrines which were not lined, (unlike in Nwaneri (2009) case which were lined) and COD done on a mixed liquor of sludge.

4.2.3 Macro Nutrients (NPK) Detection

The mean Total Kedjal Nitrogen content (TKN) for the ten pit latrines was 20.225±3.61 mg/g sample. There were significant variations of the TKN content from pit latrine to pit latrine ($p<0.001$). The TKN content decreased from the surface layer to the 1.0 meter depth with an increase from the 1.0 meter depth to the 1.5 meter depth. However ANOVA showed that these differences were not significant ($p=0.51$). The Pearson correlation showed no significant relationship between depth and the TKN values ($r=0.23$, $p=0.77$).

For phosphorus, there were significant variations in trend from pit latrine to pit latrine ($p=0.01$) with the mean content being 0.42±0.11 mg/g sample for the ten sampled pit latrines. A well defined trend of decrease of the mean phosphorus content with increasing depth was observed. However, an ANOVA test reviled that these differences in phosphorus content amongst the different depths were insignificant ($p=0.13$). The Pearson correlation showed a negative insignificant relationship between depth and the phosphorus values ($r=- 0.97$, $p=0.29$).

The mean Total Potassium content for the different depth exhibited similar trend paten as TKN of decrease with increasing depth from the surface layer to the 1.0 meter depth with an increase from the 1.0 meter depth to the 1.5 meter depth. The means at the different depths were however insignificantly different ($p=0.72$). Similarly, there were different variations in trend for the total potassium content amongst different pits ($p<0.001$). The Pearson correlation showed no significant relationship between depth and the total potassium values ($r=-0.40$, $p=0.54$).

With urine being the largest contributor of nitrogen, the trend observed in this study in which the nitrogen content in the faecal sludge was decreasing with increasing depth is as expected since the upper layers would hold a bigger percentage of the urine being deposited into the pit latrine than the lower layers over time. The same applies for phosphorus and potassium in which the main source of the two is largely the faeces itself. Since the sludge would be undergoing biodegradation with increasing depth, the expected content for phosphorus and potassium as well would be a decrease since as we are going down into the pit latrine no additional fresh faecal matter is being added to contribute to new or additional source for the phosphorus and potassium.

With scientific research literature regarding nutrient levels on ***raw pit latrine sludge*** at different depths being very limited and none existent, this study did not do any comparative analysis of nitrogen, phosphorus and potassium with other known studies. However, several studies have been done that have looked at the potential and practical effectiveness of composted human waste as a nutrient source for agricultural use. A typical study for comparison would be a study by Tare and Yadav (2009) done in India in which they were looking at effects of composting on different physico-chemical parameters in sludge from pit latrines. The nitrogen content of the raw pit latrine sludge was 41.0±4.0mg/g sample, phosphorus was 11.0±2.0mg/g sample and potassium was 23.0±17mg/g sample of which in comparison with the results from this study, (mean nitrogen content was 20.225±3.61 mg/g sample, phosphorus 0.42±0.11mg/g sample and potassium 17.63±2.53mg/g sample) shows that there are variations. The variations in that study and the present study conforms to the ideology that the amounts of nutrients found in faeces vary from person to person and from region to region depending on the nutrient content of the food consumed by the person (Vinnerås & Jönsson, 2002).

4.3.5 Study Limitations

The major limitation in this study was the nature of the sample itself. With some latrines receiving grey water from near bay bathrooms, samples in the upper layers were mostly watery in nature as observed in high moisture content of PL09 and PL10. It is possible that a parameter of interest which might have been detected and captured at a certain depth might have been capture at another depth due to dilution and percolation within the pit latrine. Again due to the fact that the pit latrines were not lined, the samples from the bottom of the pits were observably being a mixture of sludge and soil meaning that there were high chances of both soluble and insoluble particulates to have moved either from the surrounding environment into the sludge or from the sludge into the surrounding environment as evidenced by higher COD and TVS values in the bottom layers.

Another limitation of this study could have been the multiple users from multiple families per single pit latrine. The variations in the different parameters under study from pit latrine to pit latrine could be attributed to observed usage of the pit latrines from multiple family members with different user practices and different diets unlike in a situation where by a single family uses a single pit and observable practices can be observed.

The study also noted that different pit latrines had different ages in which the rate and extent of degradation of the biodegradable organic matter might have been different. Obviously a pit latrine with a higher age would have had more time for the biodegradable organic matter to decompose in comparison with a relatively younger pit latrine considering other factors being equal.

Chapter Five: Conclusion and Recommendations

5.1 Introduction

The results in this study have generated information regarding knowledge, attitudes and practices by users in Ntopwa Township, a peri urban unplanned settlement and the physico-chemical characteristics of pit latrine sludge in unlined pit latrines. This chapter presents conclusions and recommendations that have arisen from this research work coupled with the objectives laid out in Chapter 1.

5.2 Conclusions

5.2.1 The KAP study

The first objective of this study was to investigate the level of knowledge, attitudes and practices amongst the residents of Ntopwa. With 221 households being sampled out of the 500 households against the required 217 households in the area, the survey results are a statistical representation of the whole population and the data obtained is sufficient to indicated knowledge, attitudes and practices for the whole population qualitatively. Therefore, the following conclusions can be made from this study:

- In urban unplanned settlements, it is expected to find the majority of users to have access to an onsite sanitation facility either owned by the household or owned by their neighbor and it is expected that the majority of the pit latrines would be temporal in nature and of poor quality.

- It is also expected to find minimal pockets of users who still practice open defecation

- In urban unplanned settlements, the expected number of user per pit latrine exceeds five people with at least two families making use of a single pit latrine.

- Financial problems is the most expected reason why some residents have no pit latrines in urban unplanned areas, which is typical putting into perspective that in such settlements a majority of the residents are low income earners.

- It is expected that residents in such areas would be ware of some form of pit sludge management regardless the fact that they would not be practicing it with some having the knowledge in the relationship between pit latrines, general sanitation and ground water quality.

- General acceptance for using sludge as a source of organic fertilizer would be minimal.

5.2.2 Physico-chemical Characteristics of Pit Sludge

The results obtained from the laboratory analysis of the various parameters for the physico-chemical characterisation of the sludge from the ten pit latrines in Ntopwa had variations when compared from pit latrine to pit latrine. There were also variations of results between depths in the different pit latrines. This leads to the following conclusions as regards to pit latrines sludge from ***unlined*** pit latrines:

- There was a general decrease in moisture content with increasing depth as expected and as reported in literature (Bakare, 2012; Buckley, 2008; Magagna, 2008 and Nwaneri, 2009).
- Also contrary to expectations, the COD values in this study did not depict a definite decrease in COD with increasing depth from the surface layer to the bottom layer (1.5 meter depth), however, the study acknowledges some degree of degradation and stabilization of the organic matter from the surface layer to the 0.5 meter depth supporting Buckleys et al. (2008) theory.
- Macronutrients essential to different crops were detected in the sludge at different depths, but there biological safety was not tested at the different depths.
- This study has shown than no two pit latrines can be identical to one another in case of unlined pit latrines hence looking at Buckleys et al. (2008) theory, the ideology of

decrease of biodegradability of organic matter with increase in depth has been confirmed for unlined pit latrines.

The physico-chemical characteristics results in this study can be used as a technical model/blueprint for of sludge in ***unlined*** pit latrines with respect to urban unplanned settlement both local and other developing African countries. This would help in making proper decisions and policy on how to handle and manage the pit latrine sludge while protecting users and the environment in cases where pit latrines are full. The degradation and stabilization indicators, COD and TVS in this study has showed that in ***unlined*** pit latrines, the bottom layers (1.5 meter depth) sludge needs further digestion when in comparison with the upper layers. With no microorganism load potential done in this study for the sludge at different depths, a conclusion can still be made about the biological safety of the sludge putting into perspective that microorganisms are linked to the degree of stability of pit latrine contents in which greater extent of stability is linked to significant die-off of harmful micro-organisms (Nwaneri, 2008). Therefore, it can be concluded that pit sludge from unlined pit latrines have greater potential of higher micro-organisms load across the different depths.

User education on importance of site selection for pit latrine construction should be enhanced in such areas since it was established that site selection is basically chosen randomly regardless the fact that a majority of users do have the knowledge of the relationship between pit latrine and its potential ground water contamination.

5.3 Recommendations

The study presented in this thesis have generated data on physico-chemical characteristics of pit sludge in unlined pit latrines from urban unplanned settlements as presented in **chapter 4**. The study have revealed that pit sludge from unlined pits have no definite stabilization and degradation pattern with respect to depth and the sludge from the different depths might be a biological hazard both to users and the environment. The thesis then recommends the following:

- Relevant authorities to enhance public health education regarding the relationship between pit latrines and sanitation.
- Pit sludge from unlined pit latrines should be handled with extreme care since the sludge might not have attained full stabilization and it can be a biological hazard regardless of depth where the sludge has been sourced.
- Pit latrine users should be encouraged to be constructing lined pit latrines though various sanitation programs to decrease the likelihood of contaminating the surrounding environment.

5.4 Recommendations for Future Research Work

The study recommends the following for future research:

- Development of a diet-pit latrine sludge characteristics model to highlight the quality of the sludge for it after use.
- Developments of a model to predict pit latrine sludge microbial die-off of pathogens from full, buried and abandoned ***unlined*** pit latrines
- In depth assessment of sludge as a source of organic fertilizer in agricultural space.

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Appendices

Appendix A: Questionnaire used in the Knowledge Altitudes and Practices study

QUESTIONNAIRE ON DELIVERABLE ONE

Water Research Commission

Polytechnic

Review of pit sludge management and emptying practices

A research entitled "Characterisation of pit sludge management, sludge biochemical degradation, and respective impacts on public health in unplanned settlements of Malawi" is currently underway. This questionnaire intends to identify what people know, their perception about pit sludge management and what they do in managing their pit sludge. We therefore request your kindness to respond to some questions below. Your privacy is respected and the information given will only be used for research.

QUESTIONNAIRE NO.	Date :
Name of location : Mtopwa	City : Blantyre
Name of Household:	Name of interviewer:

Instruction: Please circle appropriate option/options!

NO	QUESTIONS AND INSTRUCTIONS	RESPONSE	CD
1.	Who is the head of the household?	Male headed household	1
		Female headed household	2

		Child headed household	3
		Elderly headed household	4
2.	What do you do for your living?	Small scale farming	1
		Large scale farming	2
		Business	3
		Employed	4
		Other (specify):	5
3.	In what capacity do you find yourself at this premise?	Landlord	1
		Tenant	2
4.	What is your average household income (estimate per day or month or year)		
5.	How many people live in this house?	One to 3	1
		Four to six	2
		More than six	3
6.	Do you have a latrine at this household?	Yes	1
		No	2
7.	If no, where do you go to help yourself?	Bush	1
		Neighbours latrine	2
		Other …………………………	3
8.	Why is it that you do not have a latrine	No one to dig the latrine	1
		It's not important	2
		No money to buy building materials	3
		Other (specify):	4
9.	What efforts have you tried to have a latrine?		
10.	Who builds your toilet	Self	1

		Other relative	2
		Hired labour	3
		Other	4
11.	How is the site for building a pit latrine chosen?	Randomly	1
		At lower altitude from water sources	2
		At a distant from the dwelling house	3
		Other (Specify)	4
12.	If you have a toilet, do you allow neighbours or passers-by use of your toilet?	Yes & for free	1
		Yes at a fee	2
		Selectively for free	3
		Selectively at a fee	4
		Not at all.	5
13.	What type of toilet is it? (Please observe and check type)	Flush toilet	1
		Traditional pit latrine	2
		Improved traditional pit latrine (with sanplat or dome slab)	4
		Ventilated Improved latrine (VIP)	5
		Temporary latrine	6
		Ecosan latrine	7
		Other :	8
14.	What material is the substructure made of?	Earth	1
		Unburnt bricks	2
		Burnt bricks	3
		Other	4
15.	What material is the floor made of?	Earth and logs	1
		Concrete slab	2

		Other (specify)	3
16.	When did you decide to have one?	Less than a year ago	1
		One year ago	2
		Two years ago	3
		More than two years ago	4
17.	Why do you have a latrine?		
18.	What materials do you use for anal cleaning after using latrine?	Commercial tissue paper	1
		Old newspapers	2
		Any other waste paper	3
		Water	4
		Cobwebs	5
		Other.	6
19.	Which methods of pit-sludge management do you know?	Pit-emptying	1
		Chemical use for dehydration	2
		Use of dry sludge as organic fertiliser	3
		Other	4
20.	How much does it cost to empty a filled up latrine?		
21.	What do people do with pit sludge when it is emptied from the pit?		
22.	Are you satisfied with how pit sludge is managed in this settlement?	Very satisfied	1
		Satisfied	2
		Neutral	3

		Dissatisfied	4
		Very dissatisfied	5
23.	Is there any problem in pit sludge management in this settlement?	Yes	1
		No	2
24.	What do you consider a major problem in pit sludge management in this settlement?		
25.	Do you think there are any relationships between pit sludge management and water quality? Would you explain with an example?		
26.	If you use a pit latrine, what do you do when your pit latrine is full?		
27.	If you empty your pit when it is full, how is that done?	Hired machine pit emptying service	1
		Hired manual labour	2
		Self manual emptying	3
		Other	4
28.	Who builds your pit latrine?	Self	1
		Other relative	2
		Hired labour	3
		Other	4

Thank you for your time and cooperation.

Research Team

Bernard Thole, Edward Chikhwenda, Adamson Thengolose, Khumbo Kalulu, Darlington Chimutu

Appendix B: Degradation and stabilization laboratory analysis determination

Chemical oxygen demand

COD determination was done using the BS: 6068: Section 2.43:1988 titrimetric method.

The principle of the method is that the concentration of oxygen is equivalent to the amount of dichromate consumed/reduced by dissolved and suspended organic matter in the sample. The remaining excess dichromate is then titrated with ammonium iron sulphate and the COD value is calculated from the amount of dichromate. Reduction of the dichromate is given by:

$$Cr_2O_7^{2-} + 14H^+ + 6e^- \longrightarrow 2Cr^{3-} + 7H2O$$

The remaining dichromate is titrated with a standard ammonium iron (II) sulphate solution:

$$Cr_2O_7^{2-} + 6Fe^{2+} + 14H^+ \longrightarrow 6Fe^{3+} + 7H2O + 2Cr^{3+}$$

The equivalent point is indicated by a sharp color change from blue-green to red as the ferroin indicator undergoes reduction from iron (III) to iron (II) complex.

Reagents, solutions and materials used

Standard potassium dichromate solution $K_2Cr_2O_7$, **(digestion solution: 0.0167M)**

Solution was made by dissolving 11.768g of potassium dichromate, $K_2Cr_2O_2$, which was previously dried at 103^0C for two hours in distilled water and diluted to 1000 ml.

Sulphuric acid (4 mol/L)

220 ml of sulphuric acid, H_2SO_4 was added to 500 ml of distilled water slowly and in portions after which the volume was made to 1 liter with additional distilled water.

Sulfuric acid H_2SO_4/Silver-Sulphate Reagent Ag_2SO_4 (COD Reagent)

The 10g of silver sulfate was added to concentrated l000 ml sulphuric acid and mixed properly and left for two days for complete dissolution.

Standard Ferrous Ammonium Sulfate $Fe(NH_4)_2(SO_4)_2.6H_2O$: (0.12M)

The 47.0g of Ferrous ammonium sulfate was dissolved in distilled water in which 20 ml of concentrated sulphuric acid, H_2SO_4 was added and the contents diluted with 1000 ml distilled water. The solution was standardized daily against standard potassium dichromate $K_2Cr_2O_7$ solution.

Ferroin Indicator

Ferroin indicator was made by dissolving 1.50g of 1-10 phenanthroline monohydrate, together with 0.70g of ferrous sulphate ($FeSO_4.7H_2O$) in 100 ml of distilled water.

Standardization

The standard solution was made by diluting 10 ml of potassium dichromate to 100 ml distilled water with 4M sulphuric acid (COD reagent) with 3 drops of ferroin indicator added titrated with 3 drops of ferroin indicator.

Determination

The 0.4g of mercury (II) sulphate was added to 10 ml of sample in round bottomed flask and swirled thoroughly. A volume of 5.0 ml of potassium dichromate solution was added with a few granules of anti bumping granules. 15 ml of silver sulphate - sulphuric acid solution was slowly added while swirling the flask in an ice bath to prevent loss of volatile organic matter.

The flask was then attached to a condenser and the mixture refluxed for two hours after which the contents were allowed to cool. The inside of the condenser was then washed down with a few volume of distilled water to wash down any material on the inside into a flask. The flask was then removed, the mixture diluted to about 75 ml with distilled water and cooled at room temperature.

The excess dichromate in the digestive mixture was then titrated with 3 drops of standard ferrous ammonium sulphate indicator, titrating from sharp blue-green to red-brown end point.

Calculation

The COD was expressed in milligrams of oxygen per liter given by the formulae:

$$COD\ as\ mgO_2/g = \frac{\left((blank - titration) X\ morality\ of\ (NH_4)2Fe\ (SO_4)_2.6H_2O\ X\ 8000\right)}{ml\ sample\ X\ 1000}$$

Where:

8000 = mill equivalent weight of oxygen x 1000 ml/L

$$Morality\ of\ (NH_4)2Fe\ (SO_4)_2 \cdot 6H_2O = \frac{(Volume\ 0.0167M\ \ K2Cr2O7, solution\ titrated, ml)}{Volume\ (NH4)2Fe\ (SO4)2 \cdot 6H2O\ used\ in\ titration, ml}$$

Total solids

Total solids (same as total volatile and fixed solids) were determined through a gravimetric method. Well labeled Aluminum dishes were placed in a muffle furnace at a temperature of 550 ^{0}C for 1 hour after which there were placed in a desiccator for 15 minutes for the dishes to cool. The dishes were then weighed on an analytical balance and data was recorded accordingly. Carefully weighed 25 grams of thoroughly well mixed sample was then added to the dish and placed in an oven to dry overnight at 103 ^{0}C. The dish with the sample was then placed in a dessicator to allow the sample to cool. The dish was then re-weighed and the final masses recorded.

Calculation

The final percentage of the total solids in the sample was worked out using the following formulae;

$$Total\ Solids, \% = \frac{Weight_{dish\ \&\ sample(dry)} - Weight_{Dish}}{Weight_{dish\ \&\ sample\ (wet)} - Weight_{Dish}}\ X\ 100$$

All masses were measured in grams

Moisture content

Moisture content of the sample was the loss in weight of the sample after to the dish and sample was placed in an oven to dry overnight at 103 ^{0}C.

Calculation

The final percentage of the total moisture content in the sample was worked out using the following formulae;

$$Total\ Moisture\ content, \% = \frac{Weight_{dish\ \&\ sample\ (dry\ overnight)}}{Weight_{dish\ \&\ sample\ (wet)}}\ X\ 100$$

All masses were measured in grams.

Total volatile solids

For the total volatile solids, the dry contents (plus dish) from the total solids determination were placed in a muffle furnace at a temperature of 550 ^{0}C for 1 hour until all black matter (organic matter) was burnt off leaving behind a visible white material in the dish. The dish was then removed from the furnace, partially cooled on an asbestos tile and placed in the dessicator for complete cooling. The cooled dish was then re-weighed on an analytical balance and the masses recorded. The ignition was repeated, dishes cooled and weight again until constant weights were obtained.

Calculation

The final percentage of the total volatile solids in the sample was worked out using the following formulae;

$$Total\ volatile\ solids, \% = \frac{Weight_{dish\&sample\ (dry)} - Weight_{dish\ \&\ sample\ (ignited)}}{Weight_{dish\ \&\ sample\ (dry)} - Weight_{dish}}\ X\ 100$$

All masses were measured in grams

Fixed solids

For the fixed solids, the remaining sample after total volatile solid determination above represented the fixed solids in the sample.

Calculation

The final percentage of the fixed solids in the sample was worked out using the following formulae;

$$Fixed\ solids, \% = \frac{Weight_{residual\ \&\ dish\ (after\ ignition)} - Weight_{dried residue\ \&\ dish}}{Weight_{dried residue\ \&\ dish} - Weight_{dish}}\ X\ 100$$

All masses were measured in grams

Ammonia

The principle behind ammonia determination is through titrimetry with standard sulphuric acid and a mixed indicator after the sample have been distilled into a solution of boric acid in a specific pH environment with a borate buffer.

Reagents, solutions and materials used

Ammonia free water

Since ammonia is present in distilled water, the trace ammonia in the distilled water under use was eliminated by adding 0.1 ml sulphuric acid to 1000 ml distilled water and redistilled.

Borate buffer solution

Borate buffer solution was made by adding 88 ml of 0.1M of sodium hydroxide, (NaOH) to 500 ml of 0.025M di-sodium tetra –hydrous, $Na_2B_7 . 10H_2O$ solution and diluted to 1000 ml.

Mixed indicator solution

The mixed indicator was made by combining 200 mg methyl red indicator dissolved in 100 ml ethyl alcohol and 100 mg methylene blue in 50 ml ethyl alcohol.

Indicating boric acid solution

Indicating boric acid was made by dissolving 20g of boric acid H_3BO_3 in ammonia free distilled water together with 10 ml of mixed indicator solution diluted to 1000 ml.

Standard sulphuric acid titrant, 0.02N

The solution was made by first dissolving 0.5 ml concentrated sulphuric acid in distilled water and diluted to 1000 ml which was then titrated with a solution of sodium carbonate which was prepared after dissolving 1.325g of anhydrous sodium carbonate dried at 270^0C in a 250 ml volumetric flask with distilled water with bromocresol green-methyl mixed indicator.

Normality of the sulphuric acid was calculated as follows;

$$Normality\ of\ H_2SO_4 = \frac{25\ X\ 0.1N}{Volume\ \ of\ H_2SO_4\ used\ X\ 1000\ ml}$$

All volumes were in millimeters

Preparation of distillation apparatus

The distillation apparatus was first prepared to get rid of any traces of ammonium. This was achieved by first adding 100 ml of ammonia free water and 20 ml of borate buffer to the distillation flask and pH adjusted to 9.5 with 6N sodium hydroxide, NaOH solution. This mixture was then steamed out of the distillation apparatus until the distillate showed no traces of ammonia.

Determination

The 70 ml of sample was added to the distillation flask followed by 25 ml of borate buffer of which the mixture was pH adjusted to 9.5 using 6N sodium hydroxide, (NaOH). The contents were then distilled for 5 minutes of which 100 ml of the distillate was collected into the 50 ml indicating boric acid solution. This distillate was then titrated with standard 0.02N sulphuric acid until the indicator turned from green to grey to pale lavender. A blank was carried through all the steps of the procedure except in cases where distilled water was used instead of the sample.

Calculation

The ammonia in the sample was then calculated using the following formulae;

$$mg\ NH_3 = \frac{Volume_{H_2SO_4,\ titrated\ for\ sample,ml}\ X\ 280}{ml\ sample}$$

Total Nitrogen

The total nitrogen determination was based on the conversion of nitrogen of nitrogenous substances into ammonia by boiling with concentrated sulphuric acid, which is fixed by excess of the acid as ammonium sulphate. The latter was determined by adding an excess of caustic alkali to the solution after digestion with the acid and distilling off the liberated ammonia into boric acid after which it was quantified by titration.

Reagents, solutions and materials used

Boric acid – 4%

The 4% boric acid was made by dissolving 40g of Boric acid acid in 1000 ml.

Sodium hydroxide - 50%

The 50% sodium hydroxide was made by dissolving 500g NaOH in 1000 ml of distilled water.

Mixed indicator

The mixed indicator was made by combining methyl red (20mg) and bromocresol green (100ml)

Determination

Digestion stage

The 1g of well mixed sample was mixed with 10g of potassium sulphate, 0.5g of anhydrous copper sulphate, 1g of salicylic acid, 1g of zinc dust in a 50ml Kjeldahl flask together with anti bumping granules. This mixture was mixed thoroughly with 25ml of concentrated sulphuric acid. A blank was then prepared under the same conditions but without the sample. The sample was placed on the digestion set and heated at low heat until sample started to boil. The heat was increased slowly while mixing time to time in order to remove charred matter from the walls. After fuming had ceased and the boiling mixture was clear (till color changed from blue to dark green to colorless), digestion was allowed to proceed for additional 30 minutes. Then the heating mantle was switched off and the flask was allowed to cool. The content was then diluted with 100 ml of distilled water.

Distillation stage

The distillation unit was first prepared by warming it up with ammonia free distilled water for a few minutes. A 50 ml flask containing 10 ml 4% boric acid solution plus 3 drops of the mixed indicator was placed under the condenser steam for collection of the distillate with the tip of the condenser positioned below the surface of the boric acid. 5 ml of the sample was pipette and slowly poured into the unit in which 10 ml of 50% sodium hydroxide was added and rinsed through with distilled water and closed. Distillation was then allowed to run for 5 minutes. The distillation was then repeated with the blank.

Titration stage

The titrate was then titrated with standard 0.05M hydrochloric acid solution until the end point was reached, thus, a color change from green to wine-red. The volume was then recorded.

Calculations

The percentage total nitrogen (% *N)* was calculated using the following formula:

$$\% N = \frac{((a)(b)(14)(100)V_0)(10)}{C \ X \ 1000 \ X \ V_1}$$

Where: ***a*** is concentration, ***b***, volume of standard acid used (ml) for sample minus blank, V_o. is final dilution after digesting the sample, V_1 is aliquot used during distillation and ***C*** is sample weight

Total phosphorus

Total phosphorus determination was done based on the reaction of orthophosphate ions in sulfuric acid reacting with molybdate ions to form molybdophosphoric acid which is latter reduced to phosphomolybdenum blue (PMB) with ascorbic acid that is then determined photometrically.

Reagents, solutions and materials used

Ammonium molybdate solution

This solution was made by dissolving 25g ammonium molybdate in 300 ml warm distilled water and cooled.

Ammonium metavanandate

This solution was made by dissolving 1.25g ammonium metavanadate in 300 ml boiled distilled water, cooled and 250 ml of concentrated nitric acid (HNO_3) added.

Color solution

The color solution was made by mixing the prepared Ammonium molybdate solution and the prepared Ammonium metavanandate solution in which the volume was made to 1000 ml.

Standard P solution

The standard P solution was prepared by dissolving 0.219g of dried potassium di-hydrogen phosphate in distilled water which was then acidified with 25 ml of 7N sulphuric acid and the volume made to 1000 ml.

Determination

Digestion

The 5g sample was dried in an oven at 105^0C for 2 hours which was later digested in a muffle furnace at 550^0C for 2 hours and 30 minutes. 2 ml of nitric acid was then added and the contents were evaporated to dryness on a hot plate. The contents were once again ignited at 550 ^{0}C for 1 hour to obtain a clear ash. 10 ml of 1N HCl was then added to the clear sample while heating on a hot plate to dissolve the ash. The content was then diluted to 100 ml with distilled water.

Analysis

The 10 ml of the digested sample was placed in a 50 ml volumetric flask in which 10 ml of the color solution was added to the mixture and diluted to 50 ml. for the standard solutions; 1ml, 2 ml, 3 ml, 4 ml, and 5 ml of the 50mg/1P solution were transferred into 50 ml volumetric flasks of which 10 ml of the prepared color solution was added to each flask and the volumes made up to the 50 ml mark.

A calibration curve of the standards was then constructed and the concentration of P in the samples calculated after reading the absorbance of the standard and samples were read after 10 minutes at a wavelength of 420nm. Dilution factor was 400 times.

Appendix C: KAP study sample size calculation

The sample size formula for the calculation was as follows;

$$n = \frac{X^2 * N * P * (1 - P)}{(ME^2 * (n - 1) + (X^2 * P * (1 - P))}$$

Where n = sample size

X^2 = Chi – square for the specific confidence level at 1 degree of freedom

N = Population size

P = Population proportion (0.50)

ME = desired Margin of error (expressed as a proportion)

Appendix D: Raw and mean data for the different parameters from the laboratory analysis

Raw data

		pH	*COD*	*NH_3-N 2*	*TKN*	*P*	*K*	*TVS*	*TS*	*FS*	*MC*
	Depth			*mg/g sample*					*%/ g sample*		*%*
PL01	**0.0 m**	7.85	23.32	0.09	19.3	0.577	28.9	28.40	34.40	71.60	65.60
	0.5 m	7.87	25.54	0.13	17.6	0.558	16.7	40.00	24.60	60.00	75.40
	1.0 m	7.67	29.16	0.12	12.2	0.561	19.7	61.00	33.00	39.00	67.00
	1.5 m	7.68	38.22	0.11	18.8	0.512	15.4	65.70	19.70	34.30	80.20
PL02	**0.0 m**	7.65	32.60	0.09	13.3	0.54	25.1	58.50	20.50	41.50	79.50
	0.5 m	7.32	17.50	0.10	3.3	0.541	21.4	52.90	14.80	47.10	85.20
	1.0 m	7.28	24.81	0.09	18.9	0.449	19.7	71.90	16.10	28.10	83.90
	1.5 m	7.53	32.24	0.13	15.5	0.029	20.6	65.30	16.40	34.70	83.60
PL03	**0.0 m**	5.88	37.31	0.11	23.5	0.513	29.2	67.00	20.00	33.00	80.00
	0.5 m	5.85	25.48	0.10	19.9	0.513	18.2	65.60	19.00	34.40	81.00
	1.0 m	6.37	28.07	0.11	26.5	0.458	29.4	63.60	14.90	36.40	85.20
	1.5 m	6.67	33.87	0.10	32	0.376	31.4	40.00	32.60	60.00	67.40
PL04	**0.0 m**	7.14	26.99	0.83	9.1	1.282	4.8	54.60	4.50	45.40	95.50
	0.5 m	7.04	28.44	0.43	11	0.148	5.7	36.50	0.85	63.50	99.20
	1.0 m	7.24	25.18	0.38	6.7	0.101	5.8	47.70	6.10	52.30	93.90
	1.5 m	7.15	27.53	0.45	26.5	0.112	5.5	46.90	6.20	53.10	93.80
PL05	**0.0 m**	6.83	34.23	0.06	41	0.668	4.9	15.70	50.60	84.30	49.40
	0.5 m	7.71	26.62	0.02	13.3	0.694	19.7	11.50	35.80	88.50	64.20
	1.0 m	7.35	28.25	0.02	6.7	0.654	1.5	9.40	57.50	90.60	42.50
	1.5 m	7.41	38.88	0.02	11.1	0.566	4.78	10.00	58.90	90.00	41.10
PL06	**0.0 m**	7.75	26.62	0.02	9.1	0.45	12.8	11.20	39.00	88.80	61.00
	0.5 m	7.65	30.07	0.02	28	0.368	1.07	8.60	51.30	91.40	48.70
	1.0 m	7.81	26.81	0.02	9.9	0.489	22.3	9.60	52.50	90.40	47.50
	1.5 m	7.64	29.17	0.02	6.7	0.289	13.9	7.80	55.30	92.20	44.70
PL07	**0.0 m**	7.27	27.17	0.03	7.8	0.176	27.8	12.80	39.50	87.20	60.50
	0.5 m	7.56	25.54	0.06	6.7	0.209	6.25	27.70	16.90	72.30	83.10
	1.0 m	7.60	27.35	0.06	5.5	0.108	6.25	32.40	16.20	67.20	83.80
	1.5 m	7.54	31.70	0.06	19.3	0.109	7.5	32.40	16.90	67.60	83.10

	0.0 m	7.70	29.89	0.21	25.3	0.419	43.7	39.80	13.40	60.20	86.60
PL08	**0.5 m**	7.67	29.89	0.17	19	0.34	39.6	44.60	15.20	55.30	84.80
	1.0 m	7.97	31.15	0.13	15.8	0.354	31.2	29.20	14.50	70.80	85.50
	1.5 m	8.07	30.25	0.14	49	0.391	41.7	3.20	62.10	96.80	37.90
PL09	**0.0 m**	8.39	29.16	0.13	55.3	0.099	28.4	13.80	24.90	86.20	75.10
	0.5 m	8.29	37.85	0.12	43	0.144	18.2	27.80	17.90	72.20	82.10
	1.0 m	8.24	34.41	0.10	42.7	0.075	18.6	24.30	13.40	75.70	86.60
	1.5 m	8.33	32.78	0.13	37.9	0.102	29.9	34.00	5.90	66.00	94.10
PL10	**0.0 m**	6.56	28.25	0.03	12.5	1.02	5.4	35.10	31.90	64.90	68.10
	0.5 m	7.25	25.90	0.03	23	0.743	7.8	35.00	36.90	65.00	63.10
	1.0 m	6.71	32.06	0.02	17.8	0.546	6.2	22.50	28.60	77.50	71.40
	1.5 m	6.58	43.74	0.02	28.5	0.558	8.1	33.10	25.90	66.90	74.10

Mean data for the different parameters

Mean pH values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	7.30	7.42	7.42	7.46
Standard Deviation	0.73	0.65	0.57	0.55
Standard Error	0.23	0.21	0.18	0.17
Minimum	5.88	5.85	6.37	6.58
Maximum	8.39	8.29	8.24	8.33
Confidence Level (95.0%)	0.52	0.47	0.41	0.39

Mean COD in mg/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	29.55	27.28	28.73	33.84
Standard Deviation	4.12	5.11	3.05	5.00
Standard Error	1.30	1.62	0.96	1.58
Minimum	23.32	17.50	24.81	27.53
Maximum	37.31	37.85	34.41	43.74
Confidence Level (95.0%)	2.95	3.66	2.18	3.58

Mean Total Ammonia in mg/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	0.16	0.12	0.11	0.12
Standard Deviation	0.24	0.12	0.11	0.13
Standard Error	0.08	0.04	0.03	0.04
Minimum	0.02	0.02	0.02	0.02
Maximum	0.83	0.43	0.38	0.45
Confidence Level (95.0%)	0.17	0.09	0.08	0.09

Mean Total Nitrogen in mg/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	21.62	18.48	16.27	24.53
Standard Deviation	15.60	11.39	11.40	12.88
Standard Error	4.93	3.60	3.60	4.07
Minimum	7.80	3.30	5.50	6.70
Maximum	55.30	43.00	42.70	49.00
Confidence Level (95.0%)	11.16	8.15	8.15	9.21

Mean Total Phosphorus in mg/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	0.57	0.43	0.38	0.30
Standard Deviation	0.36	0.22	0.21	0.21
Standard Error	0.11	0.07	0.07	0.07
Minimum	0.10	0.14	0.08	0.03
Maximum	1.28	0.74	0.65	0.57
Confidence Level (95.0%)	0.25	0.16	0.15	0.15

Mean Total Potassium in mg/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	21.10	15.46	16.07	17.88
Standard Deviation	13.31	11.05	10.49	12.70
Standard Error	4.21	3.49	3.32	4.02
Minimum	4.80	1.07	1.50	4.78
Maximum	43.70	39.60	31.20	41.70
Confidence Level (95.0%)	9.52	7.90	7.50	9.09

Mean TVS in %/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	66.31	64.97	62.80	66.16
Standard Deviation	20.79	17.42	22.55	22.11
Standard Error	6.58	5.51	7.13	6.99
Minimum	33.00	34.40	28.10	34.30
Maximum	88.80	91.40	90.60	96.80
Confidence Level (95.0%)	14.87	12.46	16.13	15.82

Mean TS in %/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	27.87	23.33	25.28	29.99
Standard Deviation	13.81	14.37	17.48	21.45
Standard Error	4.37	4.54	5.53	6.78
Minimum	4.50	0.85	6.10	5.90
Maximum	50.60	51.30	57.50	62.10
Confidence Level (95.0%)	9.88	10.28	12.50	15.34

Mean FS in %/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	66.31	64.97	62.80	66.16
Standard Deviation	20.79	17.42	22.55	22.11
Standard Error	6.58	5.51	7.13	6.99
Minimum	33.00	34.40	28.10	34.30
Maximum	88.80	91.40	90.60	96.80
Confidence Level (95.0%)	14.87	12.46	16.13	15.82

Mean Moisture content in %/g sample values from 4 different depths of the 10 pit latrines (n = 40)

Depth	0.0 m	0.5 m	1.0 m	1.5 m
Mean	72.13	76.68	74.73	70.00
Standard Deviation	13.81	14.37	17.48	21.44
Standard Error	4.37	4.55	5.53	6.78
Minimum	49.40	48.70	42.50	37.90
Maximum	95.50	99.20	93.90	94.10
Confidence Level (95.0%)	9.88	10.28	12.51	15.34

Appendix E: Frequency tables for data in the KAP study

Means of livelihood

		Frequency	%	Valid %	Cumulative %
	small scale farming	10	4.5	4.5	4.5
	large scale farming	8	3.6	3.6	8.1
Valid	Business	132	59.7	59.7	67.9
	Employed	71	32.1	32.1	100.0
	Total	221	100.0	100.0	

Head of household

		Frequency	%	Valid %	Cumulative %
Valid	Male headed	150	67.9	68.2	68.2
	Female heade	61	27.6	27.7	95.9
	Child headed	4	1.8	1.8	97.7
	Elderly headed	5	2.3	2.3	100.0
	Total	220	99.5	100.0	
Missing	System	1	.5		
Total		221	100.0		

Latrine ownership

		Frequency	%	Valid %	Cumulative %
Valid	yes	205	92.8	92.8	92.8
	no	16	7.2	7.2	100.0
	Total	221	100.0	100.0	

Relationship between pit sludge management and water quality

		Frequency	%	Valid %	Cumulative %
Valid	yes	122	55.2	55.2	55.2
	no	99	44.8	44.8	100.0
	Total	221	100.0	100.0	

Type of latrine present

		Frequency	%	Valid %	Cumulative %
Valid	Flush toilet	1	.5	.5	.5
	Traditional pit latrine	126	57.0	61.5	62.0
	Improved traditional pit latrine	27	12.2	13.2	75.1
	Ventilated improved pit latrine	18	8.1	8.8	83.9
	Temporal pit latrine	18	8.1	8.8	92.7
	Ecosan latrine	15	6.8	7.3	100.0
	Total	205	92.8	100.0	
Missing	System	16	7.2		
Total		221	100.0		

Access options for those with no latrines

		Frequency	%	Valid %	Cumulative %
Valid	bush	2	.9	10.5	10.5
	neighbours latrine	14	6.3	73.7	84.2
	other	3	1.4	15.8	100.0
	Total	19	8.6	100.0	

Missing	System	202	91.4		
Total		221	100.0		

Reasons for not having a latrine

		Frequency	%	Valid %	Cumulative %
Valid	no one to dig the pit	14	6.3	50.0	50.0
	no money to buy material	9	4.1	32.1	82.1
	no land on which to build latrine	3	1.4	10.7	92.9
	other	2	.9	7.1	100.0
	Total	28	12.7	100.0	
Missing	System	193	87.3		
Total		221	100.0		

Source of labour for pit construction

		Frequency	%	Valid %	Cumulative %
Valid	Self	61	27.6	31.0	31.0
	Other relative	23	10.4	11.7	42.6
	Hired labour	96	43.4	48.7	91.4
	other	17	7.7	8.6	100.0
	Total	197	89.1	100.0	
Missing	System	24	10.9		
Total		221	100.0		

Latrine access for other users

		Frequency	%	Valid %	Cumulative %
Valid	Yes and for free	110	49.8	54.7	54.7
	Yes at a fee	17	7.7	8.5	63.2
	Selectively for free	20	9.0	10.0	73.1
	Selectively at a fee	7	3.2	3.5	76.6
	Not at all	47	21.3	23.4	100.0
	Total	201	91.0	100.0	
Missing	System	20	9.0		
Total		221	100.0		

Number of families per pit latrine

		Frequency	%	Valid %	Cumulative %
Valid	None	14	6.3	6.7	6.7
	One	24	10.9	11.4	18.1
	Two	35	15.8	16.7	34.8
	More than two	137	62.0	65.2	100.0
	Total	210	95.0	100.0	
Missing	System	11	5.0		
Total		221	100.0		

Estimated age of pit latrine

		Frequency	%	Valid %	Cumulative %
Valid	Less than a year ago	37	16.7	18.4	18.4
	One year ago	38	17.2	18.9	37.3
	Two years ago	37	16.7	18.4	55.7
	More than two years ago	89	40.3	44.3	100.0
	Total	201	91.0	100.0	
Missing	System	20	9.0		
Total		221	100.0		

Site selection for pit latrine construction

		Frequency	%	Valid %	Cumulative %
Valid	Randomly	135	61.1	65.9	65.9
	At lower altitude from water sources	13	5.9	6.3	72.2
	At a distant from dwelling house	49	22.2	23.9	96.1
	Other	8	3.6	3.9	100.0
	Total	205	92.8	100.0	
Missing	System	16	7.2		
Total		221	100.0		

Materials used for anal cleansing

		Frequency	%	Valid %	Cumulative %
Valid	Commercial tissue paper	44	19.9	20.7	20.7
	Old newspaper	68	30.8	31.9	52.6
	Any other waste paper	28	12.7	13.1	65.7
	Water	65	29.4	30.5	96.2
	Cobwebs	4	1.8	1.9	98.1
	Other	4	1.8	1.9	100.0
	Total	213	96.4	100.0	
Missing	System	8	3.6		
Total		221	100.0		

Known pit sludge management techniques

		Frequency	%	Valid %	Cumulative %
Valid	Pit emptying	23	10.4	11.6	11.6
	Chemical use for dehydration	84	38.0	42.4	54.0
	Use of dry sludge as organic fertiliser	46	20.8	23.2	77.3
	Other	45	20.4	22.7	100.0
	Total	198	89.6	100.0	
Missing	System	23	10.4		
Total		221	100.0		

Level of satisfaction of known pit sludge management techniques

		Frequency	%	Valid %	Cumulative %
Valid	Very satisfied	64	29.0	30.0	30.0
	Satisfied	50	22.6	23.5	53.5
	Dissatisfied	27	12.2	12.7	66.2
	Very dissatisfied	45	20.4	21.1	87.3
	indifferent	27	12.2	12.7	100.0
	Total	213	96.4	100.0	
Missing	System	8	3.6		
Total		221	100.0		

Pit emptying methods

		Frequency	%	Valid %	Cumulative %
Valid	Hired machine pit emptying services	22	10.0	17.1	17.1
	Hired manual labour	31	14.0	24.0	41.1
	Self manual emptying	41	18.6	31.8	72.9
	Other	35	15.8	27.1	100.0
	Total	129	58.4	100.0	
Missing	System	92	41.6		
Total		221	100.0		