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ASSESSMENT OF USER ACTIVITIES ON PERFORMANCE OF PIT LATRINES SERVING LOW INCOME SETTLEMENTS IN NAKURU COUNTY, KENYA

FREDRICK OWINO GUDA

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A Thesis Submitted to the Graduate School in Partial Fulfilment of the Requirements for the Award of the Degree of Master of Science Degree in Environmental and Occupational Health of Egerton University

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DEDICATION

To my late father for his love of education that has made me press on.

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My greatest gratitude goes to God for making this research work possible. I would like to acknowledge Egerton University and the entire staff for their support throughout this study. I also thank my supervisors Dr. Wilkister Nyaora Moturi and Dr. Steve Omondi Oduor for their guidance and special gratitude to Mr. Edward Muchiri for giving me an opportunity in the research project. Special gratitude goes to the late Dr. Jeroen Ensink of London School of Hygiene and Tropical Medicine for guiding me in shaping the study and supervising my work. I appreciate the invaluable assistance given to me by my fellow graduate students Emmanuel Amuok and Pauline Macharia during laboratory analysis. I further appreciate the assistance given by Mr. Silus Nyakundi of NAWASCO laboratory and Mr. Lewis Mungai of Biological Science laboratory, Egerton University. Further, I thank my research assistants; Joseph Maira, Christopher Oluoch and Samuel Macharia. Gratitude also goes to all the study respondents, the community guides who supported us throughout the study and households that accommodated our interruptions as we sampled their facilities. In the same strength, I extend my sincere appreciation to the Bill and Melinda Gates Foundation (BMGF) through the Sanitation Research Fund for Africa (SRFA) and Water Research Commission (WRC), South Africa for financing the study without which the research would not have been done. Finally, I thank my family for their inspiration throughout the study especially my wife Deborah and loving daughter Marie-Becka for their prayers and support.

ABSTRACT

Proper disposal of human excreta plays a vital role in the provision of primary health care. Developing countries such as Kenya face a problem of human excreta disposal due to inefficient or low coverage of sewerage systems. Most people in the developing countries use pit latrines as the main means of excreta disposal. However, pit latrines are posing health risks because of numerous failures and inefficient management practices. Nakuru and Njoro sub-counties has experienced rapid population growth that has caused mushrooming of unplanned settlements. Such settlements have no connection to municipal sewerage lines, and are mostly served by pit latrines. The objectives of this study were to investigate management practices, fill up rates, and physicochemical properties of pit latrine contents. It involved a survey of the user management activities, undertaking bi-monthly monitoring of fill up rates and laboratory analysis of the physicochemical properties of the pit contents along the pit depth. The laboratory analysis was conducted using standard methods for the analysis of wastewater; pit latrine fill up rate determination was done using laser technology while the pit latrine users activities and household information was obtained through a questionnaire and an observation schedule. Descriptive statistics, one way ANOVA, Fisher's Exact Test and Pearson's Correlation were used to analyse the data at 95% confidence limit. The result showed significant differences in the management activities across units of the study, while the physicochemical characteristics of the pit contents varied significantly within units and between study locations at $p<0.05$. The mean individual contribution of faecal sludge was 42 L/p/yr with the highest accumulation rates documented in Kaptembwo. The total organic load of the sludge reduced by 59.9% from the surface to 3M depth, the reduction was significant and showed negative correlation with the volatile solids. Not only does the result show variability of pit latrine content and performance, but it also shows the significance of incorporating pit latrine management to ensure efficient performance. Property owners need to understand the relationship between the number of users and the pit fill up rates to effectively plan for duration of use and post fill up management programs.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
CBOs	Community Based Organizations
CLTS	Community Lead Total Sanitation
COD	Chemical Oxygen Demand
DWA	Department of Water Affairs
FS	Faecal Sludge
JMP	Joint Monitoring Program
MC	Moisture Content
MDG	Millennium Development Goals
MoPHS	Ministry of Public Health Services
NEMA	National Environmental Management Authority
NETWAS	Network for Water and Sanitation
NGO	Non-Governmental Organization
ODF	Open Defecation Free
SDG	Sustainable Development Goals
SRFA	Sanitation Research Fund for Africa
TS	Total Solids
UN	United Nations
WHO	World Health Organization
VIP	Ventilated Improved Pit (latrine)
VS	Volatile Solids

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Sanitation has a fundamental role in shaping people's health, economic wellbeing, dignity, and quality of the local environment (Streeten *et al.*, 1981; Deen, 2010). Adequate and proper sanitation enhance good health and act as a preventive intervention to disease breakouts (Barreto *et al.*, 2007; Carolini, 2012). According to Faechem and Cairncross (1978), proper disposal of human excreta has more significance than the provision of safe water since it significantly lowers the possibility of faecal contamination of water hence reduction of related disease incidence (Kallon, 2008; Govender, *et al.* 2011). Poor sanitation facilities lead to higher costs of health services, reduced workers' productivity, low education enrolments, and decline in school retention especially of girls, and deprive people of dignified living (Green, 2006).

Globally, 2.4 billion people do not have access to improved sanitation in spite of the fact that from 1990 to 2014, 2.1 billion people gained access to improved sanitation facilities (WHO/UNICEF, 2015). There are significant sanitation gaps in regards to services offered to rural and urban populations, gender inequalities, and exclusion of the poor from water and sanitation services (Onda *et al.*, 2012, WHO/UNICEF, 2015). According to Joint Monitoring Program (JMP), between 1990 and 2015, the least developed countries failed to meet the sanitation targets. Only 27% of their current populations gained access to improved sanitation facilities. In Sub-Saharan Africa, less than 20% of the current population have access to improved sanitation facilities. Southern Asia made greater strides providing 32% improved sanitation to its current population. Sub-Saharan Africa has the greatest share of people practicing open defecation and recorded an increase since 1990 whereas all other regions of the world have recorded decrease. Open defecation is still being practiced by almost one billion people (WHO/UNICEF, 2015).

Kenya has a population of 40 million and 21 million people use non-improved facilities while 5.6 million people have no pit latrines hence practice open defecation (WSP, 2012). Poor sanitation services have economic impacts on the country (Amnesty International, 2009). It is estimated that Kenya losses KSH. 32,400 million annually as e result of poor sanitation (GoK, 2010). Access to improved sanitation facilities in Kenya from 1990 to 2015 have increased from

25% to 30%. However, the change is considered as limited progress according to the JMP classification (WHO/UNICEF, 2015).

Generally, rural and urban populations in the country have different sanitation challenges. Approximately 60% of the urban dwellers live in peri-urban settlements characterized by inadequate water supply and sanitation facilities (Collignon and Vezina, 2000; Nilsson and Nyanchaga, 2008). On-site sanitation facilities in low-income settlements are inadequate while the available ones are overstretched (European Aid, 2005; Kimani-Murage & Ngindu, 2007). Rapid urbanization associated with economic constraints has led to expansion of low-income urban settlements characterised with poor sanitation facilities. Pit latrines are used widely in these areas but they pose management and operational constraints (Osumanu, 2008; Templeton and Mansoor, 2011; Afrane and Adjei-Poku, 2014). The sanitation provision task does not end at the point of pit latrine construction. There is a need to understand that on-site sanitation systems will eventually get full hence require plans for post fill up management and budget support (Still and Foxon, 2012).

Many low-income settlements and rural areas in Kenya face barriers of installation and maintenance of sewerage systems because of high cost and the need for constant flow of water (Collignon and Vezina, 2000). In such settlements on-site disposal of excreta, majorly pit latrines offer affordable and hygienic sanitation solutions (Franceys *et al.*,1992; Lawrence and MacDonald, 2001). When the on-site facilities fill up, they lead to the management burden of either emptying or building a new pit latrine. Where emptying is concerned, this pose health risks and occupational hazards associated with sludge disposals (Faechem and Cairncross, 1993; Buttenheim, 2008). Unlike in rural Kenya, where new pit latrines can be dug to replace the filled up facilities because of available space, emptying is the most appropriate management option in urban areas due to limited space. The pit latrine emptying costs vary with municipalities and technologies. However, in most urban settlements, manual emptying is the most common technology and costs about $2.6 per foot of the emptied content (Eales, 2005). This presents an economic and environmental sanitation constraint creating a significant health safety challenge to property owners and the government.

The generally high population growth observed in Kenyan low-income settlements has put pressure on sanitation facilities with faster rate of pit latrines fill up (Otieno, 2010).

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Theoretically, stabilization or content leaching should be equal to the filling rates (Buckley *et al.*, 2008). However, the decrease in degradation enhances fill up rate of the vault. In South Africa, studies on pit fill up rates reported increase in pit latrine contents associated with an increase in inert material, dilution of biologically active fraction with household waste and the introduction of biocides into the vault (Nwaneri, 2009). The user management practices affect content characteristics determining degradation of the sludge.

1.2 Statement of the Problem

Increasing population in low-income settlements in Nakuru municipality and surrounding settlements has led to increased use of on-site sanitation facilities, especially pit latrines. Most of such settlements in peri-urban areas have no connections to the functional sewerage system, hence pit latrines offer basic excreta disposal to the inhabitants. Full pit latrines can no longer serve users sanitation needs. This may be because the vault is completely full hence, no materials can be added. Unsustainability of these facilities pose greatest health challenge since they are the basic means of disposal of human excreta in such settlements. When abandoned or poorly used, they provide breeding sites for disease causing microorganisms. Pit latrines offer the cheapest option for disposal of human excreta in areas not served by sewerage connections. However, pit latrines have failed to offer sustainable sanitation services because of faster fill up rates resulting in overflows, abandonment hence spread of diseases and environmental pollution associated with disposal of their faecal sludge. Although a number of researches on pit latrine design in Kenya have been documented, there is limited research on the user management, vault content characteristics and how they affect faecal sludge accumulation rates. There is need to investigate and document user management practices and characterize faecal sludge in pit latrines to generate information for management and promote sustainable services from pit latrines. This information will be important to pit latrine users, policy makers. It will further promote environmental sanitation and sustainability of pit latrine use.

1.3 Study Objectives

1.3.1 General Objective

To investigate and document the association of operational management, properties and sustainability of pit latrines serving low income peri-urban settlements

1.3.2 Specific Objectives

1. To evaluate the designs, user activities and management practices of pit latrines

2. To determine pit latrine fill-up rates in relation to management practices
3. To compare the physicochemical properties of faecal sludge at varying depths
4. To determine degradation extent of pit content at different depths of pit latrines

1.4 Research questions

1. Are there significant differences in the design, user activities and management practices of the pit latrines?
2. Is there a significant relationship between fill up rates and management practices of the pit latrines?
3. What are the characteristics of faecal sludge at varying depths of the pit latrines?
4. Are there significant differences in degradation levels of pit latrine contents at different depths?

1.5 Justification

Improperly functioning and unsustainable pit latrines attract animals, vermin, and rodents that spread germs triggering disease outbreaks. Inefficient pit latrines create a nuisance of intolerable odour and site. Poor excreta disposal is linked to numerous communicable, non-communicable, intestinal and helminthic infections. Although there have been major improvements in the provision of water with the MDG target to halve the proportion of people without improved water by the year 2015 being met in 2010, the MDG target to halve the proportion of people with unimproved sanitation by the year 2015 was not met (WHO & UNICEF, 2015). This highlights the fact that sanitation remains a major global issue demanding a global response. Developing countries are the most affected when it comes to sanitation with many people staying without safe and adequate methods to dispose human excreta (Nansubuga *et al.*, 2016). The constitution of Kenya has enumerated supply of water and basic sanitation as a bill of right thus signifying the importance attached to its provision. In addition, Kenya's premium development agenda, Vision 2030 has provision for sanitation as one of its goals.

Quick filling up of pit latrines pose environmental health challenges and heavy economic burden because of emptying or putting up new facilities. Determining pit latrine fill up rates, content decomposition and related management practices provide information to the users and authorities regarding unit performance thus offering information and knowledge for efficient management and sustainable use of on-site sanitation provision.

1.6 Scope of the Study

This study was part of a wider study on scientific understanding of pit latrine content characteristics. It was carried out in Nakuru and Njoro Sub-Counties with sampling units taken from households in low-income settlements. The survey targeted pit latrines user management and information was obtained by administering a questionnaire to each property owner or the senior most household member by residence time per facility. Fill up monitoring was from the squatting hole to the sludge level within the vault. Sludge analysis included laboratory analysis of physicochemical parameters (Total Solids, Volatile Solids, Moisture Content, Chemical Oxygen Demand, Biological Oxygen Demand, Ammonia, Total Phosphorous and Total Nitrogen) at different depths. The management practices were documented to infer how they influence pit latrine fill up rate, content characteristics, while degradation against pit depth was inferred from the physicochemical properties of the sludge. The study focussed mainly on user management operations that affect the content inside the pit latrine vault. Therefore, the objective of the work was to understand processes inside the vault and characteristics of materials within the vault.

1.7 Assumptions and limitations of the Study

Assumptions of the study;

- The factors with the potential of affecting faecal content characteristics like age and health of users were not considered and assumed uniform across the study area
- Environmental conditions and movement of ground water that have an influence on the drainage and ground moisture were not factored in and were assumed as constant for all the samples.

Limitations of the study;

- Documenting the specific user activities and management practices was challenging because of tenancy changes and unavailable property owners in some cases. This was managed by interviewing property owners or tenants who have stayed and used the facility for the longest duration.
- Determining the exact volume of pit vaults posed difficulties in the estimation of the fill up rates. This was controlled through physical measurements of unoccupied vault dimensions for estimations.

- Decommissioning of a fraction of the units and emptying of some facilities during the study period lead to a reduction of the study sample, as they could not be monitored to the end of the study. However, the retained numbers were sufficient and satisfactorily provided the objective requirements for fill up monitoring.

1.8 Operational Definitions

Biodegradation; Decomposition of faecal matter inferred by the reduction of organic content

Faecal Sludge- raw or partially digested slurry or solid resulting from storage of human excreta in a pit latrine

Improved sanitation facility; Facility hygienically separating excreta from human contact. Have the following characteristics; non-shared, connected to piped sewer, flush or pour, connection to septic systems, pit latrine with slab, composting toilet and ventilated improved pit latrines

On site sanitation; Sanitation approach dealing with the human excreta at the point of its disposal majorly offering point of release storage

Pit Latrine; Place or building, usually out of the house for deposition, retention, and sometimes decomposition of human excreta.

Pit Latrine Fill-up; Rise in pit sludge level as documented from the squatting hole

Sanitation- conditions affecting health, especially dealing with dirt and infection with specificity to disposal of faecal matter and refuse from households

User management activities; All the pit latrine user related practices applied in the process of operating the unit, including routine usage, cleaning services, anal cleansing materials, performance enhancers and post fill up maintenance practices

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

Pit latrines are the most commonly used sanitation facility in many developing countries, where they serve about 1.77 billion people (Graham and Polizzotto, 2013). The technology involves digging deep pits, deposition of excreta and it storage in it or decomposition within a single unit. This is different from what is viewed as an ideal excreta disposal model which involves four stages of management; collection of excreta, transportation to a suitable location of disposal, storage or treatment, reusing or returning excreta to the environment (Torondel, 2010). Pit latrines offer excreta disposal to populations with no connection to sewerage in Kenya especially in rural areas and peri-urban settlements that lack sewerage connections. When these pit latrine facilities fail to serve the users in an efficient and sustainable way, they pose health risks, become an economic constraint, and pose environmental health hazards.

2.2 Problems Associated with Pit Latrines

The challenges with on-site sanitation facilities like pit latrines are normally linked to user behaviours and design faults. Some of the challenges include nature of the soil structures where it is built, closeness to water tables, terrain, and potential of bottom or walls leaching into the environment. Globally, basic sanitation has a massive impact on health and development of the population (Belen, 2008). Urban dwellers in Kenya use inexpensive pit latrines and also draw water from the nearby boreholes risking contamination of the water sources. Sanitation standards in these areas are low as there is little distance between pit latrines, points of water collection and residential places. Studies by Wambui *et al.* (2007) reported the presence of thermo tolerant coliform in water of Langas slum, Eldoret. The source of the faecal contamination is reported as the pit latrines with close proximity to the water sources.

2.2.1 Ground Water Pollution

Risks of ground water pollutions by seepages of faecal materials are high when on-site sanitation facilities are used. These may be enhanced even more by pit latrine flooding, leaching from pit walls and vault floor. Faecal sludge seepage have negative effects on ground water sources, especially when combined with surface runoff and rain water. Water polluted by faecal

matter presents a disease-breeding habitat and promotes the transmission of infections (Chaggu, 2004; Winblad and Simpson-Herbert, 2004). The water table of pit vault locations is significant as high water levels may lead to pollution of ground and surface sources, hence the need for pit lining (Chaggu, 2004). For the safety of the ground water resources, pit depths should not be close to the water table.

2.2.2 Fast Fill Up and Pit Emptying

The management practices like addition of performance enhancers, water ingression, and waste disposal in the pit latrines that is practised by some of the users cause low biodegradation of pit contents hence accelerating fill up rates of the vaults (Buckley et al., 2008). Rapid fill up rates lead to frequent emptying. The exercise is expensive and a potential health hazard in the disposal of faecal products. The filling up of the units has association with the blocking of soil pores on the bottom of the units reducing soil permeability. Moreover, ingress water from sides contributes to content volumes (Chaggu, 2004).

2.2.3 Design and Construction Faults

Environmental conditions, geological characteristics of the sites, and socioeconomic status play a significant role in the design of pit latrines. The superstructure, slab, and walls need to be firm to prevent collapsing of the structure. The vent pipe should have flow marsh and a pedestal with the shutter working well control flies population and odour respectively (Mara, 1984). Proper construction and management of improved and non-improved pit latrines should ensure protection of the environment and human health through breaking disease cycles (Buckley *et al.*, 2008). However, design and construction faults are common due to the absence of knowledge on appropriate designs within developing countries. Therefore, technology and financial limitations contribute significantly to pit latrine problems.

2.3 Pit Latrine Management Practices

2.3.1 User Practices

User practices play a fundamental role in the process within a pit latrine and its efficiency (Grimason *et al*, 2000). Efficient management and related hygiene practices increase health, safety and reduce related occupational risks (Mara, 2008; Tumwebaze *et al.*, 2013). The

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activities of users like waste disposal determine content decomposition; fill up, ease of emptying and maintenance of an onsite sanitation facility (Buckley *et al.*, 2008; Nwaneri, 2009).

The users are at the centre of the latrine functioning and sanitation provision (Dale, 1979). Therefore, sanitation developments and implementations require factoring the social, economic, education, awareness, age and technical issues affecting appropriate use of the pit latrines. Excreta handling practices are extremely difficult to modify, as they are part of the basic community practice and socio-cultural norms (Chaggu *et al.*, 2002). Some common user practices such as addition of water into the vault as reported by Nwaneri (2009), which has no substantiated benefits, and dumping of wastes within the vault, caused by lack of alternative modes of handling household refuse only contribute to faster fill up rates of vaults

2.3.2 Use of Disinfectants and Non-Biodegradable Materials

Apart from human excreta, other materials, including detergents, grey water, and commercial chemical additives may be added into pit latrines either intentionally or accidentally. The efficiency of the pit additives on improving organic matter biodegradation has not been scientifically verified (Nwaneri, 2009). However, beliefs and anecdotal information associate products like ash and battery acid with enhanced pit performance. Buckley *et al.*, 2008 carried out field trials on twelve commercial pit additives that showed that the chemicals had no detectable correlation with placebo and additives.

Some additives may interfere with the biological community within the pit latrine such as the microbes, which are important in the organic matter breakdown. However, some of these materials are bactericidal hence would reduce populations of beneficial biota. Information on functioning of commercial decomposition enhancers has not had comprehensive documentations globally. Cleaning detergents and components of grey water have an immediate and a residual effect on the biological community within the pit latrine. The chemicals in these materials are persistent in the environment with a possibility of leaching into ground water hence likely to cause environmental pollution (Buckley *et al.*, 2008). Therefore, the practice should be discouraged.

2.3.3 Household Wastes Disposal

Waste disposal in the pit latrine vault vary with households. In areas with limited space and absence of waste collection programs, pit latrines offer alternative points for disposal. Studies report the use of pit latrines as points of disposing wastewater and household solid wastes (Buckley, 2008). A study in EThekwini municipality documented that a majority of households have solid wastes dumped into their pit latrines (Nwaneri, 2009). Similar findings have been reported in developing countries and this maybe is because municipalities have inefficient programs for waste handling. In Blantyre, an urban set up with about 0.5 million residents, only 2 waste vans serve the population (Palamuleni, 2002). Similar findings of inefficient waste handling were documented in Eldoret, Kenya where waste handling facilities are almost absent with significantly low organised programs for collection of household level refuge (Henry *et al.*, 2006).

Wastes dumped into pit latrines vary in form and state. In some areas, wastewater is the highest constituent and other areas solid wastes represent the largest proportion. Water disposal into vaults affect biota balance through reduced aeration hence have negative impacts on content biodegradation while solid materials increase the organic load, hence negating biodegradation but enhancing pit fill up rates (Taljaard *et al.*, 2003; Buckley *et al.*; 2008). In regards to content management and emptying practices, non-biodegradable components are associated with vacuum tank blockages hence posing technical barriers to the emptying procedures.

2.4 Pit latrine Fill-up

2.4.1 Factors Affecting Pit Content Accumulation

Sludge accumulation within the pit and ultimate vault fill up is associated with quantity of materials entering the vault, degradation rates of contents plus movement of water into and out of the pit (Buckley *et al.*, 2008) and the number of users (Still, 2002; Buckley *et al.*, 2008). Moreover, individual faeces volume contributions depend on age, diet, health, locality and many other factors. Unit design, geophysical properties, and content biodegradation also have significant contributions to the fill up rates of these units (Mara, 1984).

Globally, large populations use pit latrines without adequate planning of post fill up thus management making the users to face sanitation disasters on fill-up. For example, the Department of Water Affairs (DWA), South Africa reported that in 2003, about one million

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Ventilated Improved Pit latrines (VIP) were in use by South Africans with 85% being over 5 years old hence nearing fill ups (DWA, 2003). This suggest that pits fill up faster than expected, requiring planning, budget, program and trained personnel on ways of handling full pit latrines. Property owners and authorities need to develop capacity for dealing with the units at the post fill up time. Understanding the variables affecting fill ups will enable accurate fill up predictions to be made. In addition, property owners and authorities would be able to manipulate the variables hence obtaining better services from the facilities (DWA, 2003).

2.4.2 Pit Latrine Fill-up Determinants

a. Number of Users, Anal Cleansing Materials, and Solid Waste

In terms of individual contributions to pit fill ups, an adult produces 0.12 to 0.40 litres of faeces and 0.6 to 1.5 litres of urine per day. The annual average is about 110 litres of faeces and 440 litres of urine per person giving an individual's total contribution of 550 litres of excreta per year (Buckley *et al.*, 2008). While elevated moisture content may encourage anaerobic digestion, high amounts of water, such as from flushing, disposal, or ground drainage significantly, encourage fill ups.

Faecal decomposition within the pit latrine results into reduction in the sludge volume thus lowering the fill up rate. The decomposition process is influenced by seasonal shifts in temperature, humidity, and ground water, which affect the physical and biochemical properties of the sludge (Nordin, 2006). .

Types of anal cleansing materials used also contribute to the fill up rates of pit latrines. These materials vary with culture, social status, and religion. Within the Asian and Islamic communities, washing is preferred to wiping. Anal washing would add water into the vault thereby increasing moisture content of the sludge whereas wiping may encourage organic loading of sludge and may affect the biodegradability of the pit content. Most communities of the world use anal wiping by tissue papers or other types of materials such as plant leaves, grasses, rocks, polythene bags, one's own hands and maize cobs (Mara, 1984; Cotton, 1995; Peasey, 2000; Sam-Wobo, et al., 2005;Vivas, *et al.*, 2010). Due to economic constraints and limited access, tissue paper use is low (Still, 2002). .

In the absence of waste handling and collection services, pit latrines occasionally act as units for household waste and grey water disposal. These wastes vary in terms of volume and biodegradability. Solid waste disposal has greater significance in lowering the life of pit latrines. Fill up models indicate that pit fill up time can be extended by 15 to 25 years if all solid wastes are excluded from the vault (Broukaert *et al.*, 2012). Pits of about 1.5 m^3 can serve average family size of 5.5 people for five years on the assumption of no decomposition. From an economic point of view, understanding the fill up rates would assist in programs of relocations and emptying.

b. Ownership and user education

Low-income urban settlements have pit latrines belonging to individuals, but used by the public or a large number of tenants. However, the peri-urban settlements and rural communities in Africa have the individual family model (Cotton *et al*, 1995; WHO/ UNICEF, 2006). Basic sanitation services are part of the free equity given to tenants hence the sense of ownership is low especially in urban set ups. The lack of a sense of ownership by the users leads to unwillingness to keep such systems in proper conditions.

Providing sanitation facilities to communities without related training and awareness on its proper use is a major cause of failure on the sustainability of these systems. Understanding of the infrastructure and its maintenance would provide a great avenue for better use of the facilities (DWA, 2003). Health and hygiene programs are part of sanitation provision hence authorities should factor them in the sanitation provision chain (Still and Foxon, 2012).

c. Geological and Climatic characteristics

Soil types, water table, and ground slope would affect the content accumulation. Impermeable or shallow soil would limit drainage and encourage digging shallow pits; hence encourage faster fill ups (Pearson, 2002). Where vault lining is required, there would be need to allow percolation of liquid component into the surrounding soil. Extensions of pits into the water table would lead to intrusion of water into the vault hence faster fill up. Moreover, flooding of the pit latrines presents a sanitation hazard. Such cases also lead to pollution of ground water with pathogens and nutrients (Still, 2002).

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d. **Biological Activity in the Pit**

The biological community in the pit such as maggots, fungal organisms, roaches, and bacteria play a significant role in facilitating sludge biodegradation (Kele, 2005). The microbial community decompose the sludge through aerobic and anaerobic processes. Other factors like temperature, pH, and moisture content that affects the activities of this biota contribute to the determination of content accumulation (Still, 2002). Biological community operate at varying pH and environmental conditions hence maintaining favourable conditions would encourage there activity enhancing degradation rates.

2.5 Vault Properties and Processes

2.5.1 Characteristics of pit contents

The contents of the pit latrines form a biological environment. Introduction of foreign materials into the pits would affect the biological processes taking place in these pits (Buckley *et al.*, 2008). Studies indicate that content properties differ within and between pits thus explaining the differences in pit performances (Bakare *et al.*, 2012). Various substrates in the diet determine the level of fermentation occurring due to differences of metabolic routes of products in the faeces. Therefore, the age and health status of pit latrine users will determine the substrate in their faeces, affecting degradation of their sludge (Torondel, 2010).

Processes within the pit latrine include; transfer of water into and out of the pit, accumulation of the faecal sludge in the pit, pathogen die offs and biological transformations (Buckley *et al.*, 2008). Any extraneous factors like waste disposal into the vault, environmental disruptions, and management practices affect the balance of the four processes (Leitao *et al.*, 2006; Broukaert *et al.*, 2013). Studies in Durban, South Africa reported that net addition of other materials like waste affects decomposition and accumulation of materials in the vault. The types of anal cleansing materials determine the rate of degradation, some degrade faster and others slowly influencing pit content accumulation (Torondel, 2010). This is because some are low degrading and others have high organic contents.

Properly decomposing pit contents have minimal problems of flies and strong stench compared to rudimentary sanitation units (Franceys *et al.*, 1992; Cotton *et al.*, 1995; Bester and Austin, 2000). However, pit contents do not have similar properties. Bakare *et al.* (2012)

reported that, based on household habits and environmental conditions, pit latrines have varying organic content, non-biodegradable content, and microbial population. The presence of flies and maggots around the latrine are reported to have an association with missing or poorly fitted back plates, pedestals, vent pipes, pedestal lids, or doors (Nwaneri, 2009).

2.5.2 Physical Processes

The basic physical process occurring in the pit latrine is accumulation of organic and inorganic wastes (Buckley *et al.*, 2008) through the addition of faecal matter, cleaning materials and other components into the pit. There are also, transfers of water into and out of the pit intermittently or regularly. Anecdotal information suggests environmental and geological factors as having direct impact on all the physical processes occurring within the pit latrine (Buckley *et al.*, 2008). In cases where the dumped households are non-biodegradable, they enhance the rate of fill up and reduce the efficiency of the pit latrines. In addition, users' activities and practices like the type of anal cleansing materials determine the fill up rates.

Changes in environmental factors associated with seasonality like temperature and humidity affect the physical properties of faecal matter deposited in the pit latrines. Changes in moisture and temperature affect the physical properties of faeces within the pit latrine (Ottoson *et al.*, 2008). Moisture content affects solids through dilution. The temperature changes are associated with contraction and expansion of the pit contents hence has a affecting volume variations. Hydraulic transport of materials within the pit is affected by hydro-geological, topographical characteristics of the area and pit wall sealing (Buckley *et al*, 2008).

2.6 Biodegradation of Pit Content

2.6.1 Decomposition Processes within the Pit Vault

Decomposition of sludge is driven by aerobic and anaerobic digestion of biological community. In the upper layers including the top layers, aerobic processes may be possible. In the un-aerated deeper components of the pit latrines, the major processes are anaerobic in nature. The movement of moisture and air into and out of the pit latrine will determine the extent of biological degradation (Buckley *et al.*, 2008).

The degradation processes in the pit latrines are also determined by the amount and extent of the non-biodegradable materials in the pit latrines. According to Buckley *et al.* (2008), theoretically processes of content within the vault are as follows:

- All the readily biodegradable materials originating from faeces undergo aerobic degradation aided by naturally existing microorganisms within a short duration after arriving at the surface of the pit.

- A significant portion of the remaining biodegradable materials undergo aerobic degradation before covering by new pit contents

- Most of the remaining materials that are biodegradable including the organic residues from dead cells of microorganisms and from the original faeces undergo slow conversion to soluble products.
- Materials within the buried layers and materials remaining at the bottom of the latrine after previous degradation and as residues from all the processes are majorly non-biodegradable contents in nature.

Anaerobic digestion of pit latrine content especially at the surface could get accelerated through the addition of water. This process would increase the rate of production of gases like Ammonia by between 0.006 to 0.02 ml/g of the solid/day per 1% increase of moisture content above the base line content of 76%. Materials buried in the deeper layers of the latrine exhibit low production of gases associated with low biological activities. They have low degradation because depths act as residence of materials that have undergone almost complete degradation (Buckley *et al.*, 2008). As the pit latrine content approaches fill up, the materials at the bottom layers become stable with no significant degradation process occurring any more.

The duration that the faecal content stays within the pit latrines, act as sanitisation period. The longer the matter has resided in the pit, the more the pathogens are deactivated. They cannot stay alive over a long duration because the decomposition process is accompanied by changes in temperature, pH and moisture (Franceys *et al.*, 1992). Managing composted wastes by changing temperature and moisture accompanied with extended storage durations have been confirmed as effective ways of reducing pathogen numbers and lowering their survival (Nicholson *et al.*, 2005).

2.6.2 Sludge Properties and Impact on Biodegradability

Bacterial degradation of content can lead to production of liquids and gases (methane, carbon dioxide, and ammonia) which can then exit the pit resulting in reduction of the remaining volumes (Foxon *et al.*, 2009). The microorganisms involved in the processes have numerous environmental conditions requirements like ranges of temperature, pH and nutrients (Fricke *et al.*, 2007).

The net decomposition of the content depends on the composition of the additional materials in the pit latrine (Zavala *et al.*, 2005; Nwaneri, 2009). Studies indicate that 80% of faecal matters are biodegradable with 20% being inert materials. The content undergoing aerobic digestion has 73% of original matter converted to CO_2; while in anaerobic state, 79% of the matter is converted to methane. This is supported by literature reports which show that wet pit latrines in which anaerobic process predominate because of occlusion of air by water, accumulate more slowly than dry pit latrines. The location of sourcing the faecal sludge can contribute the significant variations in the characteristics as shown in table 1.

Table 1: Characteristics of Faecal Sludge

Parameter	Lopez *et al.* 2002	Brouckaert and Foxon, 2008	Nwaneri, 2009	Still and Foxon, 2012	Appiah-Effah and Nyark, 2014
Total Solids	18.2%	20%	22%		663.7mg/L
Volatile Solids	84.4%		13.8mg/L	76%	77%
COD	145 mg/g	220 mg/g	100 mg/g	445 mg/g	8599.8 mg/L
BOD	-				0.027 mg/g
Ammonia Nitrogen	34 mg/g	100 mg/g	-		2568mg/L
Total Nitrogen	60 mg/g	-	-		4083 mg/L
Moisture content				60%	

Source; Almeida *et al.*, 1999, Lopez et *al*, 2002, Brouckaert and Foxon, 2008, Nwaneri, 2009, Still and Foxon, 2012 and Appiah-Effah and Nyark, 2014

2.6.3 Organic Load of Sludge and Biodegradation

The organic loads of pit latrines are measured in chemical oxygen demands (COD) and volatile solids (VS) contents (Magagna, 2006; Buckley *et al.*, 2008). High COD and VS concentrations indicate that the sludge has undergone low degradation. Biological processes require micronutrients in the form of Nitrogen, Phosphorous, Sulphur and ion for

microorganisms' growth. Other micronutrient requirements are in small amounts (Henze *et al.*, 2001). Nitrogen is essential in the formation of new biomass during anaerobic processes. These nutrients are generated from the biodegradation of organic matter in the faecal sludge from which they are released. Imbalance and unavailability of nutrients can influence anaerobic processes within the pit latrine hence lowering sludge biodegradation (Schanbacher *et al.*, 2005).

Some substances are inhibitory to the biodegradation process and may lower organic content conversion based on the type of microorganisms involved in the biodegradation process. Such inhibitory components include Volatile Fatty Acids (VFA) and Ammonia (Anderson et al., 2003). VFA are significant metabolites and intermediates in biological processes. Their presence within the sludge is indicative of bacterial activity. Ammonia is released during the anaerobic mineralization of organic nitrogen compounds within the sludge. Increase in pH is associated with ammonium production. However, ammonification provides buffering of anaerobic reactions. An optimal pH of 6.4 and 7.2 is recommended for anaerobic digestion hence ammonia and ammonium balance help maintain the pH (Fricke *et al.*, 2007).

2.7 Environmental Factors Associated With Performance of Pit Latrines

Proper functioning pit latrines are characterized by the presence of vent pipes that allow wind to flow above the vent pipe and into the superstructure thereby encouraging aeration. It provides a pathway for attracting and trapping flies and mosquitoes (Curtis and Hawkins, 1982). Environmental conditions play an important role in biological processes. Moreover, temperature has significance on the performance of pit latrines and pit vaults with near optimal temperatures have better degradation associated with enhanced microbial activity (Ryan and Mara, 1983). Scientific evidence from Lusaka, Zambia show better anaerobic conditions in the summer when temperatures are high characterizing better degradation compared to the winter conditions (Morais, 1966).

Temperatures conditions in a pit latrine unit vary depending on the time of the day. Seasons also influence these temperature variations. Temperature conditions influence biodegradation processes in pit latrines through their influence on the microbial processes that breakdown the organic matter in the faecal materials (Morgan and Mara, 1982). Other factors influencing the biodegradation process is the moisture content in the faecal matter in the pits. The moisture content is influenced by the weather pattern and the ground water seepage into the pit.

2.8 Hazards of Pit Latrine Use

2.8.1 Environmental Sanitation Concerns

From a health and safety perspective, *Ascaris lumbricoides* is considered an indicator organism and their inactivation from faecal matter indicate inactivation of all other faecal parasites (Jimenez, 2007). Their presence in the pit contents indicates harmful or disease causing organisms, including bacteria, viruses and parasites that have a negative impact on human health and safety of environmental resources (The British Columbia Ground Water Association, 2007). The accumulation of faecal matter in one position over a long duration encourages leaching of contaminants hence pollution of the ground water and soil. Studies in Marondera district, Zimbabwe found out that a pit latrine microbiologically impact on the quality of groundwater for up to a distance of 25 m laterally (Dzwairo *et al.*, 2006). Poor functioning pit latrines can be the source of water related diseases especially in areas where water is sourced from boreholes or wells (Eisenburg *et al.*, 2001). In developing countries, most areas use boreholes and wells especially in peri-urban areas for domestic water hence when the sanitation facilities fail to function properly then they pose sanitation risks to the populations (Lawrence and MacDonald, 2001). Shallow water tables increase the potential of pollution from such pit latrines.

Sanitation facilities are important since they significantly contribute to the reduction in burden of diseases within populations (Montgomery and Elimelech, 2007). The health risks of poorly performing sanitation facilities vary. Some risks are due to back flush of latrine content exposing users to pathogens when the vault is full, whereas watery pit latrines provide breeding grounds for flies that are major disease vectors. Shared sanitation facilities have been reported to have more health risks compared to single-family units. A study in the Nile Delta Hamlet reported high socio-demographic and environmental risk factors for children between 1-5 years of age in settlements with wide scale sharing of facilities (Courtright *et al.*, 1991).

If the sanitation facilities are not functioning optimally it may cause an increase in the incidence and prevalence of infectious diseases because of the presence of pathogenic microorganisms in the environment. Most of the diseases causing pathogens are transmitted through faecal contamination of food or drinking water (Lawrence and MacDonald, 2001). The transmission of these pathogens occurs through various routes, including flies, water, food, and poor personal hygiene like hand washing. Therefore, for efficient reduction in the burden of diseases, mechanisms need to be put in place for handling the disposal of excreta.

2.8.2 Occupational Hazard of Pit Latrines

Owners of pit latrines often have challenges in dealing with them once they fill up (Templeton and Mansoor, 2011). The technology is always implemented without consideration of their decommissioning when they are full or emptying them through engineering provision of the facility. Where the pits are not lined, they become a health hazard to users and emptying personnel as the vault walls may collapse. Failure to make firm walling of the pit may lead to pit collapse due to pressure differences caused by the vacuum sucker and reduction in pit contents (Thye *et al.*, 2011). The lining can be done using stone, bricks, or concrete (Mara, 1984).

Hygienic and safe handling of pit latrine sludge is necessary during emptying for human and environmental health safety. Open disposal of the faecal sludge on land may contaminate water and other food substances thereby causing a public health nuisance (Pedley and Howard, 1997). During pit latrines emptying, the handlers are exposed to pathogens in the faecal matter; hence need to use personal protective gear. In her study of pit latrine emptying practices in eThekwini, South Africa, Nwaneri (2009) found helminthic eggs on the clothes of the workers emptying these facilities. This suggests lack of proper and safe handling practices by these people. Faecal matter is associated with the following pathogens; viruses, bacteria, protozoa and helminth parasites, mainly *Ascaris lumbricoides* (Schonning and Stenstron, 2004; Buckley *et al.*, 2008). *A. lumbricoides* form the largest common nematode to human with a simple life cycle hence making it a serious health threat during the use of pit latrines. Emptying and overflow of the poorly functioning pit latrines offer a rich avenue for these highly infectious and robust *Ascaris* to infect users.

2.9 National Sanitation Policies and Stakeholder Interventions

The Ministry of Health (MoH), the National Environment Management Authority (NEMA) and Local authorities have regulations on locations of pit latrines. However, there is minimal information on the actual user management practices to achieve efficiency and users' safety. Directorates of planning in most town councils have regulations for locations of pit latrines but constraints of land space availability push residents to use fragile locations, hence posing ecological hazards (Mutisya and Yarime, 2011).

Kenya is a developing country with under developed basic infrastructure, especially sanitation, access to water and drainage. Alternative excreta disposal approaches offer services that reduce cases of open defecation and related health risks of improper human waste disposal

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(Mutisya and Yarime, 2011). The mandate of the Ministry of Health includes the coordination of issues related to sanitation (MoH, 2016). It coordinates with other sectors including Ministry of Education to ensure proper sanitation in both the school and other environments. The country presently uses a legal framework of the Water Act of 2002 to achieve most of the targets of improving water supply and basic sanitation to its people. To enhance sanitation provision, the Ministry has taken the following steps: Involvement of non-governmental entities in management of water and sanitation, decentralizing sanitation management to lowest organs of Counties and Sub-counties and separation of management of water and sanitation services from provision of the resources

In addition to these guiding legal framework for improvement of the Kenyan sanitation provision, the government of Kenya in June (2007), formulated a guide for the implementation of the Water Act. It is referred to as the National Water Services Strategy of 2007 to 2015. The strategy had the goals of realizing the goals of MDG declaration and Vision 2030 of the Kenyan government. The vision 2030 is the Government's development blueprint and focuses on access to safe and affordable water and basic sanitation by responsive institutions within standards and regulations. In addition to these policy issues, the government has put in place programs for the pro poor implementation of basic sanitation and water supply (Hakijamii, 2002). The Ministry of Public Health and other stakeholders have also massively trained communities on aspects of community lead total sanitation (CLTS) with an aim of minimization and elimination open defaecation (OD). Plan Kenya has CLTS trained personnel that have had a massive impact on training and improvement of sanitation in the country since its formation in May 2008. It is in partnership with the Ministry of Health, Aga Khan Foundation, UNICEF, NETWAS, NGOS, and CBOS aiming to train people at all levels across the country on sanitation and hygiene with CLTS approach (Makutsa *et al.*,2001). In 2008, the government of Kenya also initiated the Pan Africa CLTS programme with an aim of reducing infant mortality and morbidity. In addition, it aimed at empowering rural and peri-urban communities in Kenya to improve their sanitation and hygiene practices. The initiatives of the government have brought knowledge and improvements in sanitation (Otieno, 2010). However, they experience barriers in form of slow uptake, doubt and sceptics, allowance culture, weak monitoring and evaluation reporting, and inadequate support and monitoring.

2.10 Conceptual framework

The conceptual framework (Fig. 1) illustrates the relationship of variables determining pit latrine sludge accumulation and content biodegradation. Processes in the pit latrine involve biochemical transformations and physical changes. The biological processes involve decomposition of organic pit contents by community of microorganisms. The physical process includes the introduction of new materials into the vault and transportation of dissolved materials in the pit latrine. Whereas the chemical status of the pit latrine acts as buffering for reactions within the facility as it affects the rate of accumulations.

The independent variables include user practices, structural design, pit latrine size, depth, period of use and geology. These factors determine the performance of the pit latrines as they influence content characteristics and degradation of the sludge. The user activities and management practices are a significant factor affecting decomposition, content accumulation, and sanitation of the facility. The intervening factors in the study included the age of users, diet, ownership, awareness, policies, and regulations. Age of users and diet may influence the quantity of faeces produced and its biodegradability. Whereas ownership and awareness determine the management practices plus value attached to the facility. Awareness, education, policies and regulations play a significant role in the structural design, locating of pit latrines, facility conditions, operational management and hygiene standards of sanitation facilities.

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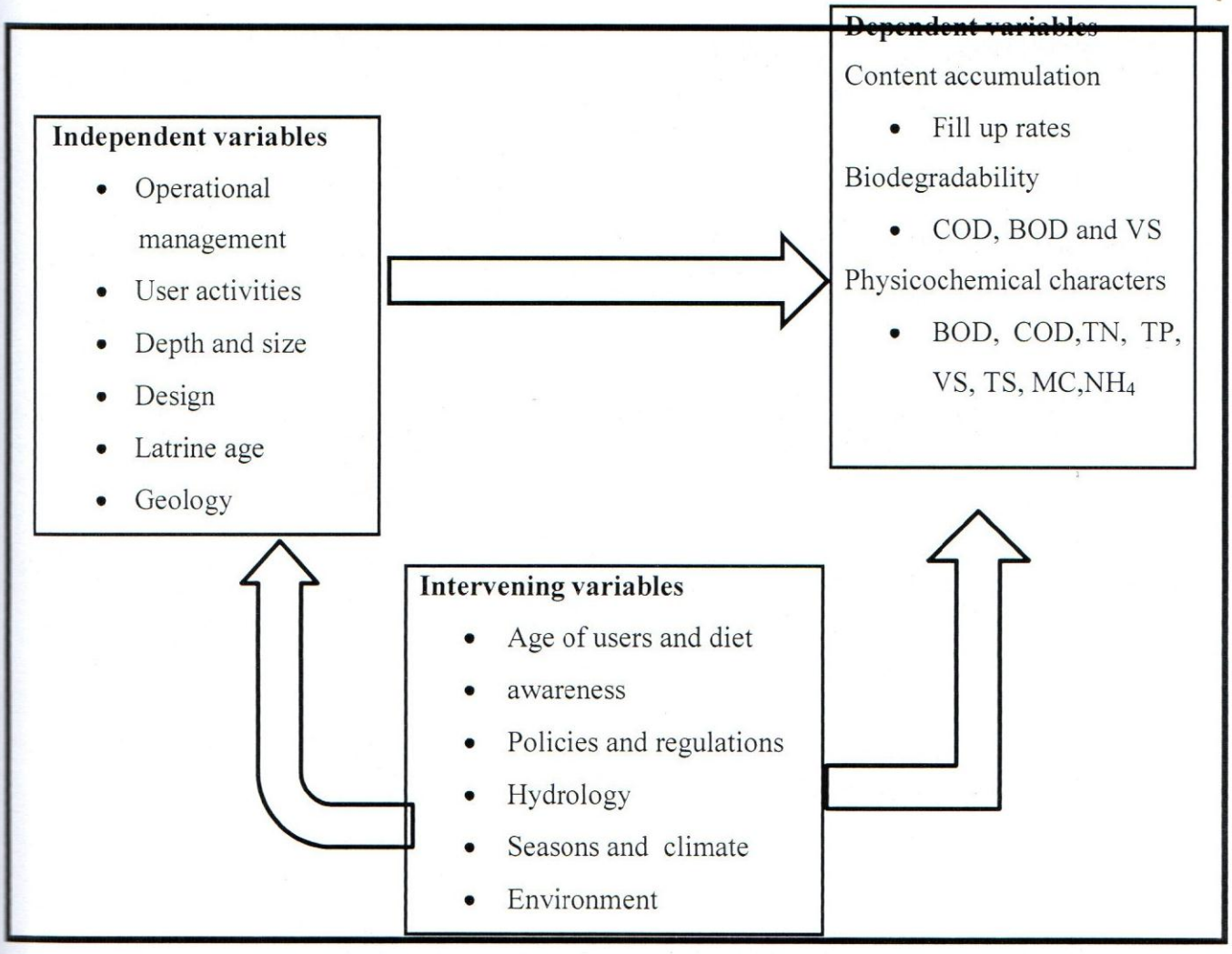


Figure 1: Framework of Variable Relationship

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Description of the study area

The study focused on five areas of Nakuru County, Nakuru and Njoro Sub-counties. Three of these areas were located within the peri-urban low-income settlements of Nakuru Sub-county at Kaptembwo, Free Area and Hilton while the other two were located in Njoro Sub-county at Jewathu and Njokerio (Figure 2). Nakuru town is one of the fastest growing urban centres in Kenya. The town is the fourth largest urban centre in Kenya with a population of about 307,990 inhabitants (GoK, 2010). The study areas within the town are located at an altitude of between 1810- 1950m and experience a bimodal mild climate. Temperatures range between 17-25^{0}C, while the average annual rainfall is 1000 mm. The economic activities of the inhabitants are majorly in the informal sector with irregular sources of livelihood.

In Njoro Sub-county, high population is made up of students and workers in the neighbouring agricultural farms, institutions and industries that characterize the settlements. The two study areas have a total population of 57,429 inhabitants (GoK, 2010). They lie at an altitude between 2157- 2286 m. The region experience mild bimodal climate and rainfall range between 760 -1270 mm annually. Poverty level is high as the main commercial activity in the area is casual labour and subsistence farming (GoK, 2010). Availability of water and proper sanitation are major problems to the local authorities because the settlements have no connection to water and sewerage lines. Pit latrines are the main sanitation facility used for excreta disposal.

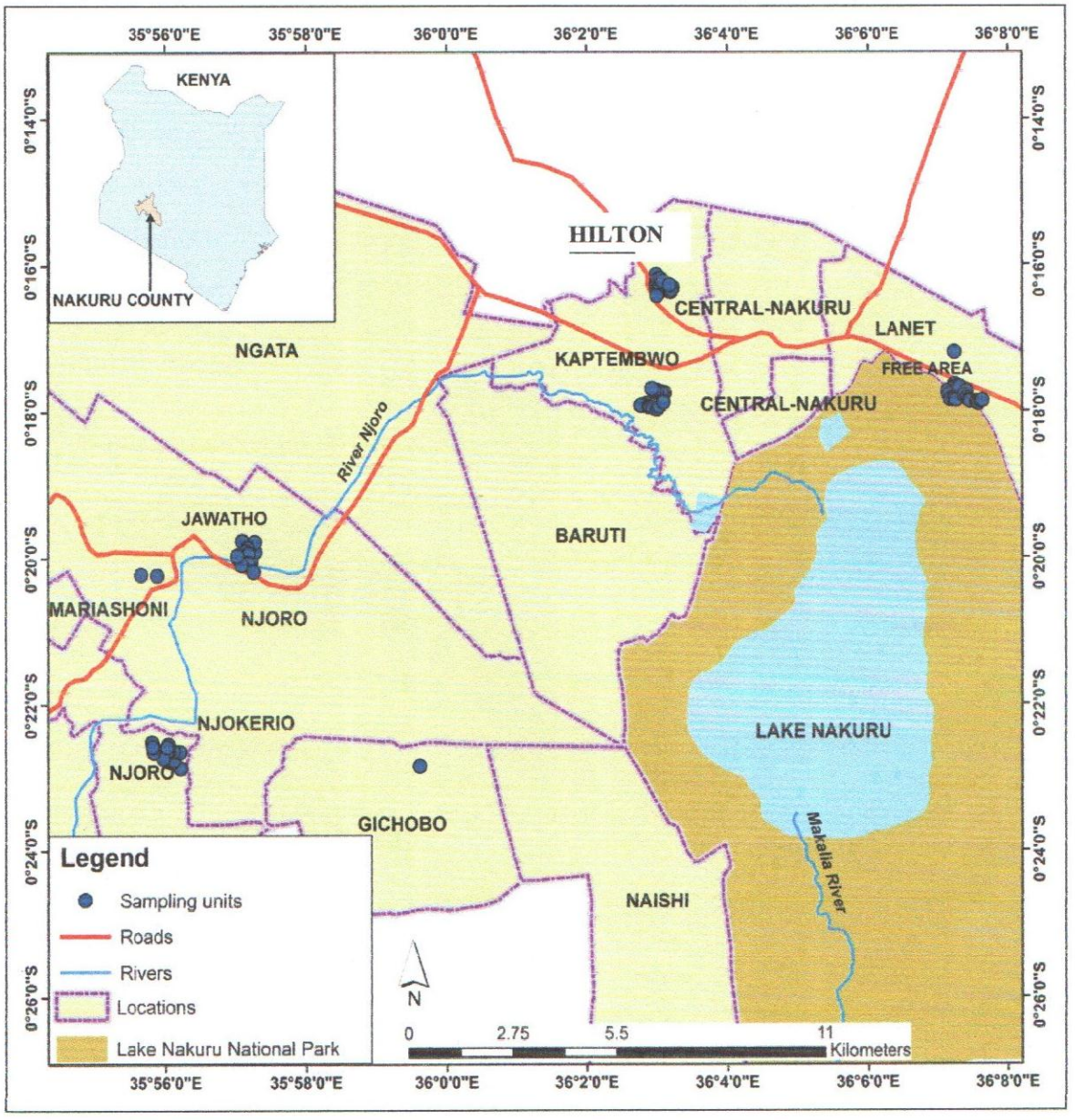


Figure 2: Study area showing the locations where the sampled pit latrines are located

(Source: Survey of Kenya Topographical maps, scale 1:50,000, using ILRI boundary Shape files: GIS ArcGIS 10.2)

3.2 Study Design

The study entailed a combination of various study designs that included a cross sectional design, longitudinal design, and laboratory analysis. The cross sectional design was used to provide a snapshot of the population at a given time and to obtain information on unit designs,

management and user behaviours from the purposively sampled pit latrine users. The information was obtained using a questionnaire and provided insight of design and management practices. The longitudinal study approach was used to monitor pit latrine fill up rates for a period of 10 months. The approach was applicable as it enables monitoring long-term effects of unit use on changes in vault volumes. Thereafter, laboratory analyses of the pit contents were done for the selected physicochemical parameters. Standard operating procedures for waste and wastewater analysis were used to establish the content properties.

3.3 Sampling design

3.3.1 Sample size determination

The sample size was determined using the formula developed by (Chow *et al.*, 2007).

Sample size (n); $$n = \left[\frac{Z_{\alpha/2}\sigma}{E}\right]^2$$

Where:

The $Z_{\alpha/2}$ is the critical value,

The positive z value that is at the vertical boundary of the area of $\alpha/2$ in the right tail of the standard normal distribution

σ is the population standard deviation

n, is the sample size

Fixing the margin of error as 1.32 and the estimated population variance from the sample household as 6.95 then the sample size is given by;

$$n = \left(\frac{1.96 \times 6.95}{1.32}\right)^2$$

$$= 106.49$$

This was then approximated to 110 household samples.

3.3.2 Sampling Procedure

For this study, 20 households with pit latrines that satisfy the study inclusion criteria were selected each from Hilton, Jewathu and Njokerio, while 25 households were selected from Free

Area and Kaptembwa each due to their larger areas and populations. The pit latrines included in the study were selected purposively based on the following criteria:

- Dry pit content; pit latrines without connection to water sources
- Pit latrines serving more than one household daily
- Level of pit contents; pit latrines with contents not more than 1m from the drop hole level

Ten pit latrines were not monitored to the end of the study because of logistical constraints. Therefore, 100 pit latrines formed the study sample with Njokerio having 16 pit latrines, Hilton and Jewathu each having 18 pit latrines, Free Area, and Kaptembwa each having 24 pit latrines.

3.3.3 Data and Sample Collection

Data collection

The pit latrine fill-up rates were documented using a digital laser range finder (Bosch PLR 25, Bosch GmbH-Germany) with a level fixed to previously determined points within the latrine (Plate 1). The distance from the squat hole and the surface of the sludge were documented for 10 months on bi-monthly sampling. Information on user activities was obtained using questionnaires and an observation schedule focussing on user activities and management practices (Appendix 1). One questionnaire was administered to one user of the pit latrine (property owner or longest user) to document user management activities.

Sample collection

Sludge samples from the pit latrines for laboratory analysis were collected between April and June 2015. Sample collection was at the surface, 1m, 2m and 3m layers of the pit latrine. The sampling distance was to show the differences in stabilization of the content with surface layers expected to be fresh material hence less degraded and lower depths having older and therefore more degraded materials. Sampling of the pit latrine contents were carried out alongside bi-monthly fill up monitoring. Samples of about 500 ml were collected from each layer using modified faecal sludge samplers and held in plastic containers (Plate 2). The samples were carried in a cool box to the laboratory and where the samples were stored at 4^0C until analysis. Analysis for BOD and NH_4 were done within 12 hours after sampling whereas the analysis for other parameters was done within 24 hours of sampling. The key parameters analysed are stated in the table 2;



Plate 1: Survey of users and bi-monthly fill up measurement of pit latrines

Table 2: Analysed physicochemical parameters and their rationale

Parameter(s)	Rationale
TN & TP	Indicator of nutrient load of the sludge
Ammonia	Influences/indicates microbial activity
COD & BOD	Measures organic material present and reveals changes with depth
TS & MS	Measures dry matter present and moisture content. Expect to correlate with latrine content bulk
VS	Quantifies organic vs inorganic matter present in the overall total solids

The average results of physicochemical parameters were calculated per gram dry weight to allow for comparison of the faecal sludge characteristics in moisture free conditions.

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3.3.5 Safety Precaution

The fieldwork (fill up monitoring and sampling) and laboratory analysis was done while wearing personal protective clothes and equipment (Plate 1 and 2). Instant hand sanitizers and disinfectants were available for body, benches, and sanitization of all appliances. Samples were disposed according to the national regulatory guidelines on disposal of sludge and wastewater (EMCA, 1999). After handling the samples, hands and benches were washed with soap and disinfected.

3.3.6 Ethical considerations

Ethical approval was obtained from Egerton University ethics committee. In addition, written informed consent was obtained from study respondents prior to administration of the questionnaire as it formed the introductory part of the survey tool (Appendix 1).

3.4 Sample Analysis Procedures

Sample analysis was done in accordance with the standard methods of analysing wastewater according to APHA 1998 and 2005. Samples were homogenised to make representative sample, then a stock solution of 0.05g/ml was prepared and used for analysis at the Egerton University Biological Sciences Laboratory. Standard laboratory reagents and apparatus were used to determine the selected physicochemical parameters of the faecal sludge samples. Samples for analyses of NH_4, TN and TP were filtered using GF/C glass fibre filters (Whatman, UK) with 0.45µm pore diameter. Table 3 shows the summary of sample analysis procedures and the full procedure is in Appendix 5.

Table 3: Sample Analysis Procedures

Parameter	Analysis method	Instrument/procedure	Source
NH_4	Calorimetric	Spectrophotometry	APHA 1998
VS	Gravimetric method	Muffle furnace, Desiccators & Fine Balance	APHA 1998
MC	Gravimetric method	Oven Drier, Desiccators & Fine Balance	APHA 1998
TS	Gravimetric method	Oven Drier Desiccators & Fine Balance	APHA 1998
BOD	Oxygen reduction	Standard method BOD_5	APHA 2005
COD	Closed reflux	Spectrophotometry	APHA 2005
TN	Calorimetric	Spectrophotometry	APHA 2005
TP	Calorimetric	Spectrophotometry	APHA 2005

3.5 Statistical Analysis

The concentrations of the analysed parameters were obtained using standard calibration curves of absorbance versus concentrations. The data analysis was carried out using Minitab and SPSS. Prior to analysis, the collected data were subjected to normality tests using the Kolmogorov - Sminorv test. All the statistical analyses for each of the objectives are reported in table 4.

Table 4: Summary of Data Analysis Techniques

Research question	Variables	Data analysis
What are the differences in design, user activities, and management practices of the pit latrines?	Structural design User activities Management practices	Descriptive statistics
Is there a significant relationship between fill up rates and management practices of the pit latrines?	Height variation Volume changes User activities	Descriptive statistics ANOVA Fisher's Exact Test
What are the characteristics of faecal sludge at varying depths of the pit latrines?	BOD,COD,NH_4 TN,TP, VS, TS & MC	Descriptive statistics ANOVA Fisher's Exact Test
Are there significant differences in degradation of pit latrine contents at different depths?	COD & VS of TS	Descriptive statistics ANOVA Fischer's Exact Test Pearson's Correlations

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Demographic Characteristics of the Respondents

The majority of the respondents were aged between 51-60 years, constituting 27% with those aged between 30-40 years representing 10% of the sampled population. Respondents aged below 20 years represented 12%, 21-30 and 41-50 years were both 15%, with 21% being above 60 years old.

Education levels of the sampled populations, those with upper primary (primary) education as the highest formal education were the highest proportion at 29% (Figure 3). Lower primary education represents 1 to 4 years of formal education and upper primary represents 5 to 8 years of formal education and secondary education represent post primary education of 4 years (Figure 3).

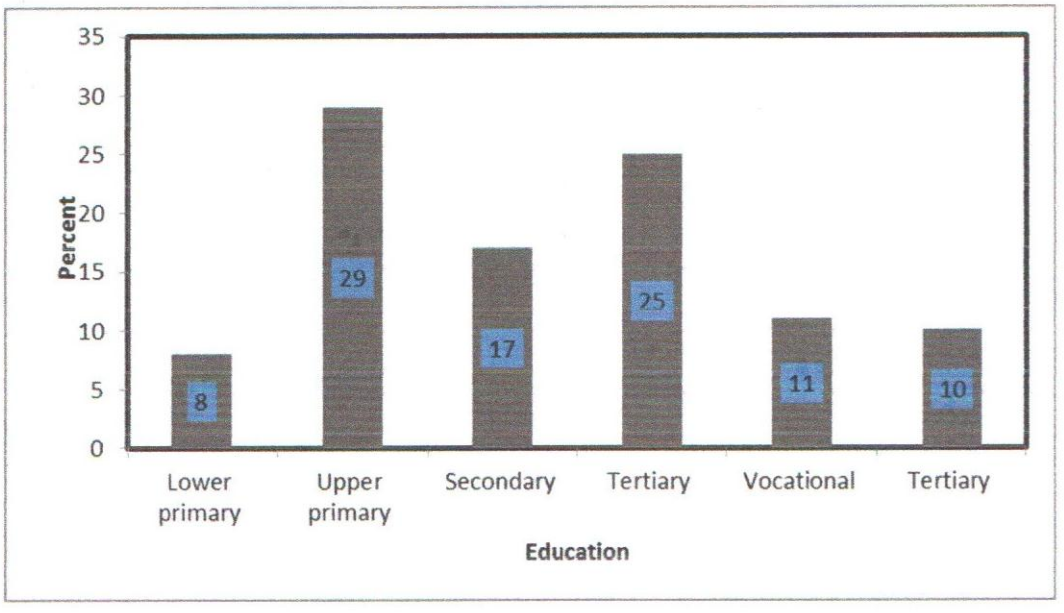


Figure 3: Education levels of the study respondents

Income levels were relatively low with a greater proportion of the population having monthly earnings that ranged between KES. 7001 and KES.9000. The lowest earners reported less than Kshs.1000 per month (Table 5). Fifty-seven percent of the inhabitants were unemployed. The low levels of income are characteristics of the inhabitants of these peri-urban settlements. The reported low levels of education and unemployment contribute to poverty.

Table 5: Distribution of the monthly income levels of the study respondents

Income (KSH)	Number of respondents	Percentage
<1000	5	5
1001-3000	21	21
3001-5000	15	15
5001-7000	9	9
7001-9000	33	33
9000+	17	17
TOTAL	100	100

Majority (48%) of the respondents were aged 51 years and above because the survey was targeting individuals who had used the selected pit latrines for the longest duration. In addition, the history of the facility from the dates of construction to present day management and use was integral to the study, hence the justification for surveying mostly individuals who had used the facility for the longest duration. The approach ensured that the provided information on use and history of the unit covered most of the latrine operations since its earliest stages. The income levels were relatively low, as most of the residents did not have employment. Individual income can inform poverty levels. In 2005, approximately 17 million Kenyans, representing 47% of the national population were living in poverty. The food costs per individual in urban areas were estimated as KSH. 2,913 (KIPPRA, 2013). Majority of the inhabitants having primary level of education is associated with low paying jobs, hence contributing to higher poverty levels observed in these settlements.

4. 2 Evaluation of unit design, user activities and management practices of pit latrines

4.2.1 Duration of the pit latrine use

The duration of pit latrines use varied across the study areas with some having been used for over 26 years without any major maintenance services or emptying. However, the mean duration of use was 15 years. Four of the study areas had some pit latrines that had been used for the longest period (over 26 years) without getting full. The majority of the units (25%) have been used for 11 to 15 years (Table 6) and are still in use.

Table 6: Number of years of unit use in various study sites

Location	Duration of use (years)						Total
	<5 years	6-10 years	11-15 years	16-20 years	21-25 years	>26 years	
Hilton	1	1	4	2	4	6	18
Free Area	4	5	1	5	4	5	24
Kaptembwa	0	10	13	1	0	0	24
Jewathu	0	1	3	6	4	4	18
Njokerio	0	6	4	4	0	2	16
Total (%)	5	23	25	18	12	17	100

The case of Hilton, which has lower fill up compared to the other regions, could be attributed to the rocky bedrock and anecdotal information that the area falls along a fault line of the Kenyan Rift Valley hence assumed seepage into the ground. However, the case of Njokerio, Free Area and Jewadhu could be attributed to few users and relatively reported deep pit vaults.

In the study areas, disposal of solid waste and waste water in the pit latrines are common. Moreover, the designs do not factor in the number of users and post fill up management, as owners have no plans for the duration of use plus the associated post fill up management programs. Fill up models indicate that pit fill up time can be extended by 15 to 25 years if all solid wastes are excluded from the vault (Broukaert *et al.*, 2012). Pits of about 1.5 m can serve average family size of 5.5 people for five years on the assumption of no decomposition (Buckley *et al.*, 2008). However, no studied units have any plans on the duration of use. From an economic and environmental sustainability perspective, understanding the fill up rates would assist in programs of relocations and emptying of the facility. .

4.2.2 Number of Families and Individuals sharing a Pit Latrine per Day

All the investigated pit latrines were shared by more than 1 family. The highest proportion (47%) of pit latrines were shared by families ranging between 6 and 15 families, 31% of the pit latrines were shared by less than 5 families, 2% of the pit latrines were shared by families ranging between 35 and 45 members. Moreover, families ranging between 26 and 35 and above 46 represented 1% respectively of the number of pit latrine users. Daily facility users ranged from 4 to 56 people with a mean of 23 individuals. The number of individual users showed great variation with the largest proportion of units (24%) being shared by more than 46 individuals per day (Figure 4).

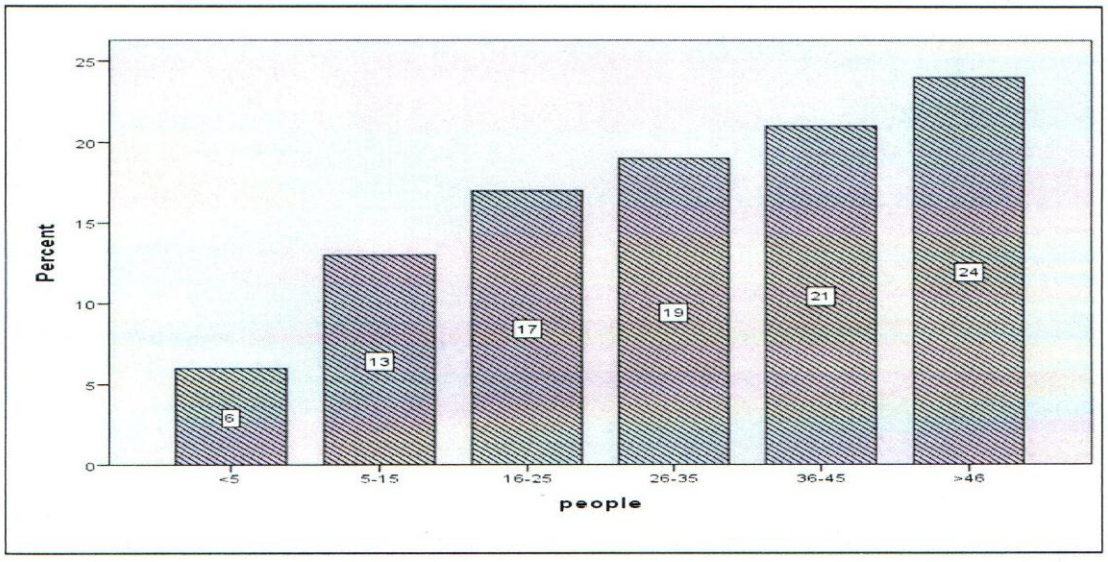


Figure 4: Number of individuals sharing a unit per day

In most facilities, the number of individuals sharing a unit was relatively high. Individuals sharing a facility are higher compared to those reported in Kampala that averaged 10 people in the peri-urban centres (Tumwine *et al.*, 2003). However, the reported number of individuals sharing a facility is lower compared to those documented in Kibera, Kenya where the average number of users is 150 people per unit (Gulis *et al.,* 2004). Sharing a unit has profound implications on the dignity of users and has association with open defecations encouraged by long ques during peak periods of facility use (early morning and night). No sampled units met the WHO standards on improved sanitation facility. According to the WHO classification of sanitation ladder, units shared by more than two families are classified as unimproved (WHO/ UNICEF, 2013). The competitive access to the facility would encourage open defecation and lower hygiene standards. From an occupational health perspective, this forms an important sanitation determinant that can cause debilitating and dehumanising misery that would promote the spread of diseases and environmental pollution (WHO, 2013). The United Nations report on Progress in Drinking Water and Sanitation updated in 2012 indicate that improved sanitation is still lagging behind in sub Saharan Africa and the burden falls majorly on women and girls (WHO/UNICEF, 2015). These findings concur with the report of a study in Kampala showing that the informal settlements populations far exceed the sanitation infrastructure capacity leading to deterioration of the urban environment (Matagi, 2002). The large numbers of daily users poses

significant pressure on basic hygiene maintenance and are associated with faster fill up rates. The findings confirm that communal sanitation alternatives for slums are a viable option in low-income settlements (Katukiza *et al.*, 2010; Schouten and Mathenge, 2010).

4.2.3 Structural Design of Units

From the design, the number of doors per unit represented the number of partitioning. The majority of the pit latrines (31%) had 2 doors with 2 compartments (Table 7).

Table 7: Number of doors per pit latrine at different localities

	DOOR(S)						
Study area	1	2	3	4	5	6	7
Hilton	3	5	7	3	-	-	-
Free Area	8	11	4	-	-	1	-
Kaptembwa	3	3	13	3	1	1	-
Jewathu	6	6	3	2	-	-	1
Njokerio	5	6	3	2	-	-	-
Total (%)	25	31	30	10	1	2	1

More than one door per facility would provide separate compartments for use by different gender, ages, or families. In addition, it would reduce congestion and use pressure during peak hours. Separate compartments within a single pit latrine allow delegation to families and individuals. Users and property owners can then have an ease in organizing and delegating management operations like cleaning of the facility and maintaining hygienic conditions.

Single compartment designs for sharing by more than one family not only present a problem of use pressure, but also limit basic hygiene maintenance. Such facilities significantly negate privacy and dignity of users. Building of single compartment units could be attributed to limited space and economic constraints (Kimani-Murage and Ngindu, 2007). However, housing pressure associated with large populations within these areas prioritise settlements without factoring basic sanitation provisions. Almost all the pit latrines size designs do not factor number of users hence emptying cycle is a major management challenge that is missing in the plans.

The slab and floors of the facilities affect hygiene and sanitation maintenance. Significantly, large proportions of the facilities had the slabs made from concrete 78% (Table 8).

Existence of pit latrines with floors made of earth present traditional pit latrines posing health risks to the users. Such facilities have poor aeration, high fly populations and unhygienic floors.

Table 8: Distributions of the type of flooring materials as a percentage

Location	Timber	Concrete	Earth
Hilton	6.2	21.8	-
Free Area	12.5	26.9	20
Kaptembwa	12.5	28.2	-
Jewathu	50.0	11.5	20
Njokerio	18.8	11.5	60

The floor types have significant association with activities of basic hygiene programs. They also contribute to flies harbouring and bad smell associated with spilled excreta. Studies have reported the lack of concrete slabs as significantly associated with the presence of helminthic eggs (Baker and Ensink, 2012). Units without regular cleaning programs have flies infestations, bad odours and slabs characterised with faecal droppings. Such features are similar to reports on use of pit latrines in Blantyre, Malawi (Grimason *et al.*, 2000).

All the units had roof made of iron sheet. The walls had varying materials as the component of making the superstructure with the largest proportion being concrete at 53%. Units within Nakuru Sub-county had most of the superstructure made from concrete (Table 9).

Table 9: Materials used to make the walls of the structures

Location	Stones	Concrete	Iron sheet	Timber	Earth
Hilton	-	16	1	1	
Free Area	1	12	7	3	1
Kaptembwa	1	16	3	3	1
Jewathu	1	5	1	11	
Njokerio	1	4	1	9	1
Total (%)	4	53	13	27	3

It was notable that the facilities significantly had no structural components associated with improved pit latrines. None of the studied units had vent pipes, provisions for emptying and pit squat-hole covers. Generally, unit designs do not follow specific construction standards. They do not factor social, cultural, organizational, behavioural and gender aspects of sanitation facilities hence are destined to fail in the provision of the intended service (Al-Sa'ed and Mubarak, 2006; Mara *et al.*, 2010; Isunju *et al.*, 2011; Kaminsky and Javernick-Will, 2013).

The wall and roof materials determine the durability of the structure, ventilation, and interior temperatures that have significant impact on the performance of the facility. The case in Kenya is contrary to countries in Africa with minimum standard for a sanitation facility; South Africa (VIP latrine), Malawi (Blair VIP latrine) and Botswana (Double Vaulted VIP latrine). Kenya has no programmes and infrastructure designs on acceptable basic pit latrine standards (SRFA/WRC, 2015). The country has embraced VIP as the common pit design applicable according to the recommendations of Mara (1984). However, there is limited awareness and information by the government and limited policy support. Owners' socio economic status widely determines the design of the facilities, a fact that resonates with other findings in the urban settlements of the developing countries (Luthi *et al.*, 2010; Mara *et al.*, 2010).

4.2.4 Management of pit latrine

Pit latrine performance enhancers use in the studied units was relatively low. Sixteen percent of the facilities have previously used compounds for enhancing pit performance. Water addition was reported as the main management method of content level reduction by 55 % of the facility owners adding purposeful water and 45% randomly adding water into the vault. Moreover, 57% of the units dispose grey water into the vaults, as they do not have alternative points of grey water disposal. The sources of water poured into the vault varied with locations with wastewater disposal being the most common practice (Table 10).

Table 10: Sources of water added into the pit latrines

Location	Cleaning water	Anal cleaning water	Bathroom water	Purposeful addition	Disposal point
Hilton	13		1	2	2
Free Area	10			1	13
Kaptembwa	12	1	1	3	7
Jewathu	7			1	10
Njokerio	8				8
Total (%)	50	1	2	7	40

Disposal of water into the pit latrines is associated with lack of structures designed for grey water disposal such as soak pits. Units within Nakuru sub-county presented more cases of wastewater disposal into the vault compared to those in Njoro sub-county. However, in Njoro most users dispose the water into the environment around the compound. The management

activities like addition of water are carried out in the ignorance of householders, they do not have positive outcome on pit latrine content management. This study reported that water dozed with detergents or disinfectants are the common added component to encourage pit content reduction, reduce odour, control of fly population or random addition. Similar practices were reported in South Africa (Bhagwan, *et al.*, 2008; Foxon *et al.*, 2009). However, there are no documented results of the benefits of the processes. To the contrary, such practices increase dilution of sludge, occlusion of air, reduce biological activities, and lead to pollution of ground water. The area does not have wide scale use of commercial pit performance enhancing products. Some products (Bio-digester plus) have previously been used for performance enhancement, but results have remained speculative. Similar findings of non-substantiated outcomes of pit latrine performance enhancers use have been reported in other studies (Buckley, *et al.*, 2008; Nwaneri, 2009; Still and Foxon, 2012).

4.2.5 Fill up and emptying of the pit latrines

Twenty-four percent of the pit latrines have previously filled up (n=100). 20.8 % of the filled up facilities were decommissioned on fill up, 58.3 % of the units have been abandoned, and 20.8 % (n=24) have been emptied.

The structural design of the units does not factor in post fill up management, as they do not have emptying provisions. When the units eventually fill up, owners and users are presented with the dilemma of the subsequent options of management. Apart from Hilton where the majority (83%) of its facilities were accessible for emptying when the units fill up, all the other four-study locations have most of the structures in areas that are not accessible to emptying machinery. Design failure to factor post fill up management is a major challenge observed in many developing countries as also reported in EThekwini Municipality and Kampala (Katukiza *et al.*, 2010; Still and Foxon, 2012).

The cost-benefit of emptying pit latrine contents is higher than the construction of a new pit latrine (Lewis *et al.*, 1982; Chaggu, 2004; Thye *et al.*, 2011). Abandoning or decommissioning of these facilities is the predominant practice. The facilities were designed without post fill up management plans, as they have no emptying provision while a large proportion of these structures are located in inaccessible areas within the compound where

emptying vacuum tankers can not reach. Similar findings were reported in Kibera (WUP, 2003). Vacuum tankers are one of the safest modes of pit latrine content emptying, but due to the inaccessibility of these pit latrines, manual emptying technologies are the most common emptying technology used in most of the Sub Saharan Africa countries (WUP, 2003; Schouten and Mathenge, 2010).

However, manual emptying pose numerous occupational health risks to the workers. The absence of emptying provision results in the destruction of the squatting slab and digging out the sludge with tools like spades, shovels, and buckets (Eales, 2005). The technology is discouraged because of the pathogenic and undesirable nature of the work and the problems of final disposal of the sludge (Parkinson and Quader, 2008).

4.2.6 Waste Disposal and Anal Cleaning Materials

Disposal of wastes into the vault and on the slab showed that 61% of the pit latrines contained other solid wastes apart from the faecal sludge (Plate 3). Kaptembwa showed the highest cases of solids thrown into the vault at 17%. Hilton had 16%, Free Area had 14%, Njokerio 8%, and Jewadhu showed the lowest proportion at 6%.

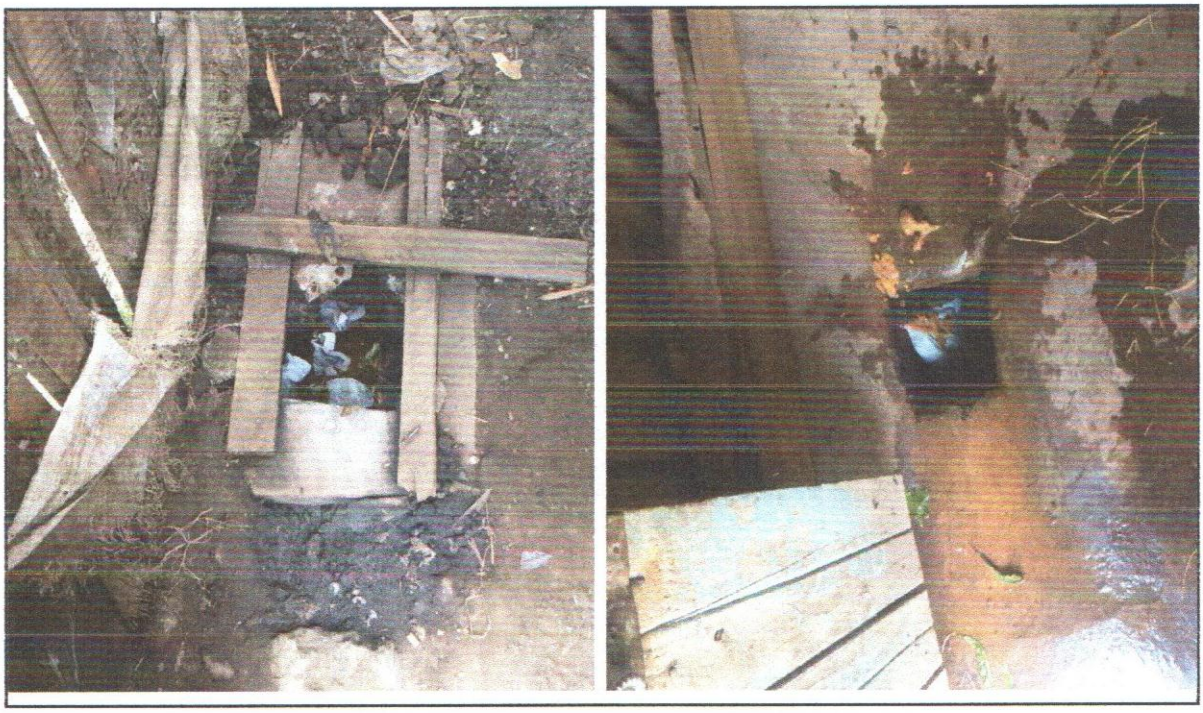


Plate 3: Solid waste disposal into the pit

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Solid wastes found inside the pit latrine included; polythene, papers, cardboard, diapers, clothes, plant leaves, plastic and glass bottles. Waste disposal into the vaults were recorded as either purposeful or random. Purposeful disposal are the scenario where the users intentionally use the pit latrine as the disposal point. However, random disposal is a scenario in which wastes are disposed into the pit latrine arbitrarily without preplanning. Materials such as sanitary pads and diapers are purposefully disposed into the vaults whereas regular household wastes like papers and food remains are randomly disposed into the vaults.

Most of the residents use wiping mode of anal cleaning and drop these cleansing materials into the pit. Tissue paper was reported as the most used anal cleansing material (46.1 %) while use of water for anal cleansing was the lowest at 2% (Figure 5).

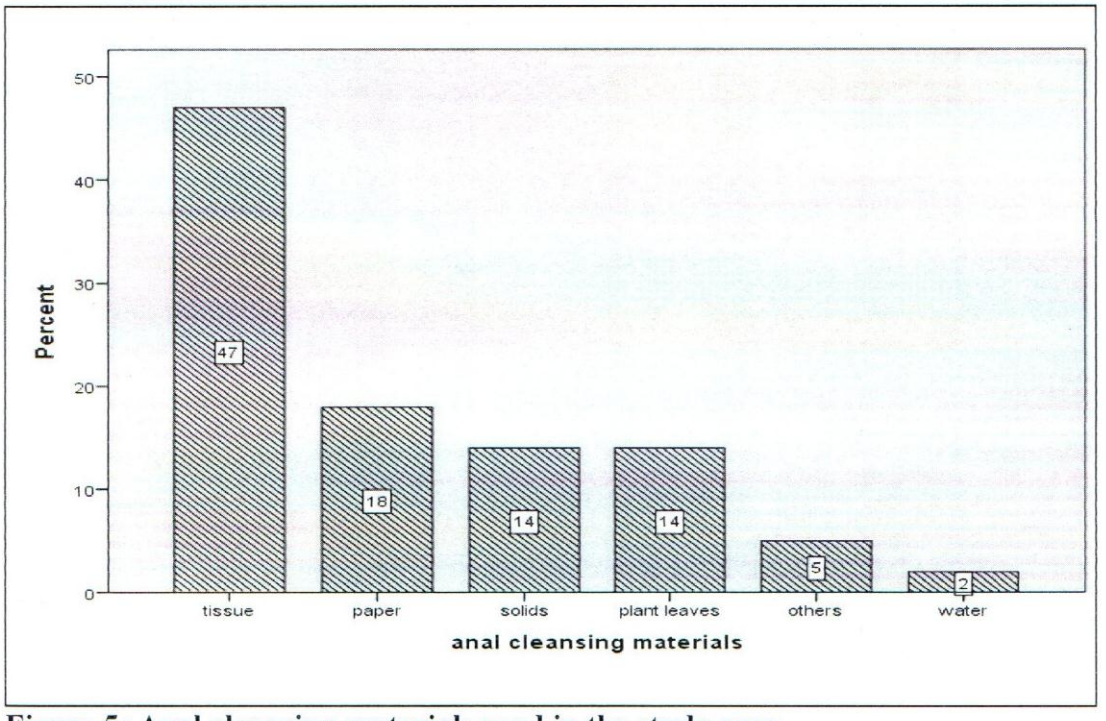


Figure 5: Anal cleansing materials used in the study area

(Tissue-tissue papers, solids include; stones, maize cobs etc.)

The type of anal cleansing materials used by a household is influenced by the socio-economic status and religious status of the members of the householder. Provision of anal cleansing materials within the pit latrines to the users is lacking in most of the facilities. Similar findings indicating significantly low emphasis and large ignorance on the significance of anal cleansing materials in the WASH provision have been reported in previous studies in Kenya

(McMahon *et al.*, 2011; Greene *et al.*, 2012; Alexander et al., 2013; Caruso *et al.*, 2014). Lack of anal cleansing materials affects personal hygiene and has a strong association with faecal contamination of hands and disease spread (McMahon *et al.*, 2011).

The high urbanization rates in the low-income settlements leads to heterogeneous and increased generation of wastes (Buenrostro and Bocco, 2003). Solid and liquid waste handling is relatively ineffective because the local authorities do not provide the services, but have contracted refuse collections to private handlers within their areas of jurisdiction. However, for sites outside such areas there are no organised solid wastes handling programs. The contracted solid waste handlers charge for this service that many residents are not willing to pay for due to poverty. In addition, grey water disposal facilities are not provided for in most residential settlements hence end up being discarded in the environment with a large proportion poured into the pit latrines. Water disposal affects sludge moisture content and gaseous balance, thereby interfering with aerobic and anaerobic degradation of faecal sludge in the pits (Nwaneri, 2009). Pit latrines and the environment form part of the alternative point of waste disposal in these areas. Inefficient waste handling within low income urban settlements has been reported in many regions of the world, including Kolkata, Blantyre and EThekwini Municipality (Palamuleni, 2002; Hazra and Goel, 2009; Still and Foxon, 2012).

The solid wastes and anal cleansing materials increase organic loading that affect decomposition of the sludge since some of these materials are non-biodegradable hence just accumulate within the pit and speed up the pit fill up rates and pose problems during pit emptying (Buckley *et al.*, 2008). Therefore, waste handling and type of anal cleansing material form an important component of pit latrine content accumulation.

4.2.6 Pit Latrine Hygiene Maintenance Services

The main hygiene maintenance program reported was the cleaning of the slab. Sixty-four percent of the units have regular cleaning programs, whereas 36% do not have regular cleaning programs. Cleaning programs varied with the largest proportion of hygiene services offered by families at 51% and the least proportion offered by workers at 2% (Figure 6). Some respondents reported their lack of knowledge of the cleaning programs of their facilities whereas for some units, the cleaning was based on occasional goodwill of the households using the facility.

Householders attribute the low provision of regular cleaning programs by the users to low levels of awareness and poor organization. Maintenance of sanitation facility does not form part of the core management program by the facility providers and property owners. The willingness to pay for the services by users may present constraints to such programs. In addition, the documented low income of the households shows that households may not be able to afford the costs of cleaning services (Table 5). Facility users have to organize for programs of handling hygiene practices. The process faces organizational and management technicalities.

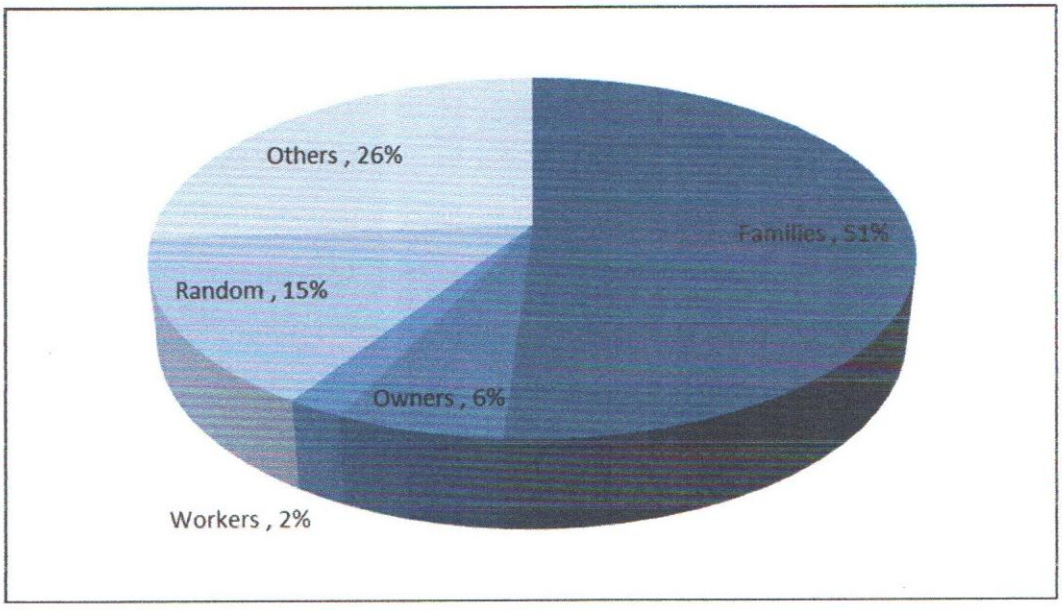


Figure 6: Responsibility for maintaining daily cleaning of the facility

4.2.7 Lack of Awareness on Importance of Sanitation Provision

The household survey showed that 45% of the residents have not had any awareness on maintenance of clean sanitation facilities. Awareness creation varied and the government was cited as the most common awareness provider at 21% (Table 11). The main hygiene maintenance activity reported was the cleaning of the slab. Sixty-four percent of the respondents have regular unit cleaning schedules, whereas 36% lack regular cleaning programs. Provision of pit latrine hygiene maintenance and cleaning services varied. The largest proportion of hygiene services are offered by families at 51% and the least proportion offered by workers at 2%. Owners (6%), random cleaning (15%) and voluntary cleaning (26%), provided the other cleaning service provisions.

Table 11: Providers of Sanitation Awareness

Provider(s)	Proportion (%)
Local government	21
Public health officials	15
CBOs/NGOs	8
Individuals/Residents	1
Property owners	9
Volunteers	1
No awareness	45
Total	100

Sanitation awareness is relatively low in the study region with 45% of the population having not received any basic sanitation awareness. The study areas within the municipality have had awareness from public health officials and NGOs/CBOs. However, the less urbanised areas have not received sanitation awareness. To achieve maximum performance of sanitation facilities, there is a need of linking hardware (structural design and technology) and software (hygiene practices, policy, and education) components (Waddington, *et al.*, 2009; Mosler, 2012).

However, in this case there is limited provision of the necessary information, yet education and awareness are important in the primary health provision. Knowledge and awareness should be provided to the design and construction personnel on most appropriate facilities and to users on management and operations of the facilities. Awareness would provide informed decision hence better services and enhanced facility performance. Householders attribute the low provision of regular cleaning programs to reported low levels of awareness and poor organization. Maintenance of sanitation facility does not form part of the core management program by the facility providers and property owners. The tenants may not be willing or may not afford cleaning services compensation. The willingness to pay for the services by users may present constraints to such sanitation hygiene maintenance services (Simiyu, 2015). In addition, the documented low income of the households shows that households may not be able to afford the costs of the services. Facility users have to organize for programs of handling hygiene practices.

4.3 Fill up Rates of Pit Latrines

4. 3.1 Temporal Fill up across the units

Sludge volume changes in the different pit latrines investigated during the study period ranged from -0.98 to 10.32 m^3. The mean volume change was 0.87 ± 0.19 m^3, the volume changes varied within, and across the study locations with Kaptembwa having highest fill up rates and Njokerio documenting the lowest rates (Table 12). Accumulation of the sludge varied and some units documented a decrease in sludge content (Appendix 3). Jewathu and Njokerio had units that documented reduction in volume shown by the negative volume changes (Table 12).

Table 12: Pit latrine fill up (M^3) measured between Dec 2014 and Sep 2015

Site	N	Mean ± SE	St Dev	Min	Max
Hilton	13	0.78± 0.25^{B}	0.91	0.12	3.01
Free Area	16	0.59±0.12^{B}	0.50	0.01	1.49
Kaptembwa	19	2.16± 0.62 ^{A}	2.71	0.06	10.32
Jewathu	12	0.24±0.18 ^{B}	0.59	-0.76	1.54
Njokerio	14	0.01± 0.17 ^{B}	0.64	-0.98	1.37

Means that do not share a letter are significantly different (Fisher Exact Test)

Cross evaluation of the fill up rates among individual pit latrines showed statistically significant volume changes across all the study units (One way ANOVA, F (4,365) =2. 61, p=0. 04). Comparison of the average volume changes of the pit latrines in the locations showed significant difference between pit latrines in Kaptembwa and those in all the other locations (Fisher's Exact Test, Table 12). Kaptembwa showed the highest amount of solid waste (70.83%) and grey water (50%) disposal into the pit latrines and this explain the high fill up documented in the area. The variations in user management practices as documented by the disposal justify the variations in the fill up of pit latrine within and between the study locations.

4.3.2 Individual Contributions to latrine fill ups annually

Individual contributions per year varied between study units and across the study areas. The largest mean and lowest mean were recorded in Kaptembwa and Jewathu respectively (Table 14). The accumulated contribution per person ranged from as low as 11.69 to 135.51 litres per person per year, with the mean and standard error being 41.82 ± 4.26 litres per person per year respectively. A fraction of the units (10.8%) showed reduction in content volumes and were not included in the general fill up computation (Appendix 2 & 3). The negative documentations were considered as out-liers. Noticeable is the high individual contributions reported in Kaptembwa (Table 14). This could be explained by two factors; variations in anal cleansing materials and disposal of waste into the pit latrines. Solid waste and grey water disposed into the units contributed to the relatively higher accumulation rates of pit contents.

Table 13: Data on annual sludge materials contribution per person (Litres)

Site	Mean ± SE	St Dev.	Min	Max
Free Area	34.87±8.47	26.78	11.69	100.96
Hilton	34.10±6.98	20.94	16.62	75.39
Jewathu	31.30±8.15	19.96	14.70	59.51
Kaptembwa	51.0±10.3	41.1	14.8	147.2
Njokerio	47.26±7.84	24.79	21.93	101.36

The mean rate of sludge accumulations of 41.84 litres per person annually and mean unit fill up rate of 870 litres annually was generally moderate. At this rate, a pit latrine of 2.5m^3 would serve 5 people for 12 years. The fill up rates findings are within the range reported by WHO in the 1950s indicating a mean annual fill up rates of 40 litres in dry pits and 60 litres in wet pits characterised by solid materials and other waste disposals (Wagner and Lanoix, 1958). However, they are lower than the data from Brazil that documented an average of 90 litres per person per year where solid materials are used for anal cleansing. To the contrary, studies by Norris, 2000 in South Africa reported relatively lower accumulation rates of 24 litres per person per year.

The significant variations in the annual fill up rates of the units in the study area can be attributed to the differences in the user practices and management activities as presented in

section 4.1. User practices account for the characteristics and make up of faeces that determine biodegradation of the faecal sludge (Buckley *et al.*, 2008). The varying diets, health status, geographical locations, and socioeconomic incomes might have also contributed to the variations. In addition, solid and liquid wastes have a potential of suppressing content biodegradation and encouraging vault content accumulation. The varying management practices and number of users among households as reported in the survey justify the differences in the fill up rates and performance of the pit latrines. The variations in the fill up rates of pit latrines across study areas are consistent with previous documentations reported in South Africa by Still (2012).

4.3 Spatial Physicochemical characteristics of Faecal Sludge

The mean concentrations of nutrients in the faecal sludge at various depths together with other physic-chemical parameters are presented in appendix 4. Concentrations of the parameters reduce with increase in depth indicating increasing stability and degradation of the sludge. Table 15 below shows the mean concentration and ranges of all parameters analysed in all the sampled 35 units. Figure 7 is the illustration of differences in average concentration of each parameter per study location.

Table 14: Summary of Faecal Sludge analysed characterization

Parameter		Surface	1m depth	2m depth	3m depth
TN (mg/g)	M	136.3±28.4	100.7±10.3	92.27±6.84	94.77±5.97
	R	12.0,206.4	6.7,211.9	8.63,207.90	1.28, 164.11
TP(mg/g)	M	286.2±56.2	266.2±53.7	212.1±66.8	26.91±3.81
	R	7.9, 990.2	5.9, 993.5	7.0, 992.0	12.37, 40.95
NH_4(mg/g)	M	63.16±7.11	59.82±6.78	68.60±7.65	54.04±8.47
	R	0.53, 163.53	0.90, 154.59	1.20, 131.88	28.20, 90.84
TS (mg/g)	M	199.8±30.2	155.6±18.7	143.0±71.1	101.8±20.5
	R	28.7, 890.0	40.0 , 745.0	20.0, 625.0	20.0, 635.0
VS (%TS)	M	68.56±7.60	60.17±4.63	55.86±4.16	50.58±4.60
	R	40.05, 97.50	21.80, 99.11	7.06, 99.60	3.80, 99.37
Moisture (%)	M	74.02±2.81	74.74±3.11	82.08±2.77	78.80±2.20
	R	16.00, 92.16	17.68, 99.52	32.00, 97.12	68.00, 84.00
COD (mg/g)	M	182.6±11.4	148.24±9.90	126.1± 16.3	83.4±27.5
	R	23.2, 451.3	28.4, 384.84	12.1, 317.8	28.9, 216.8
BOD (mg/g)	M	29.53±1.63	22.91±1.51	13.98±2.06	2.07±0.473
	R	0.13, 39.11	0.93, 38.76	0.15, 39.01	1.01, 4.790

Data represented as Mean ± SE, minimum and maximum and n=140, M; Mean, R; range

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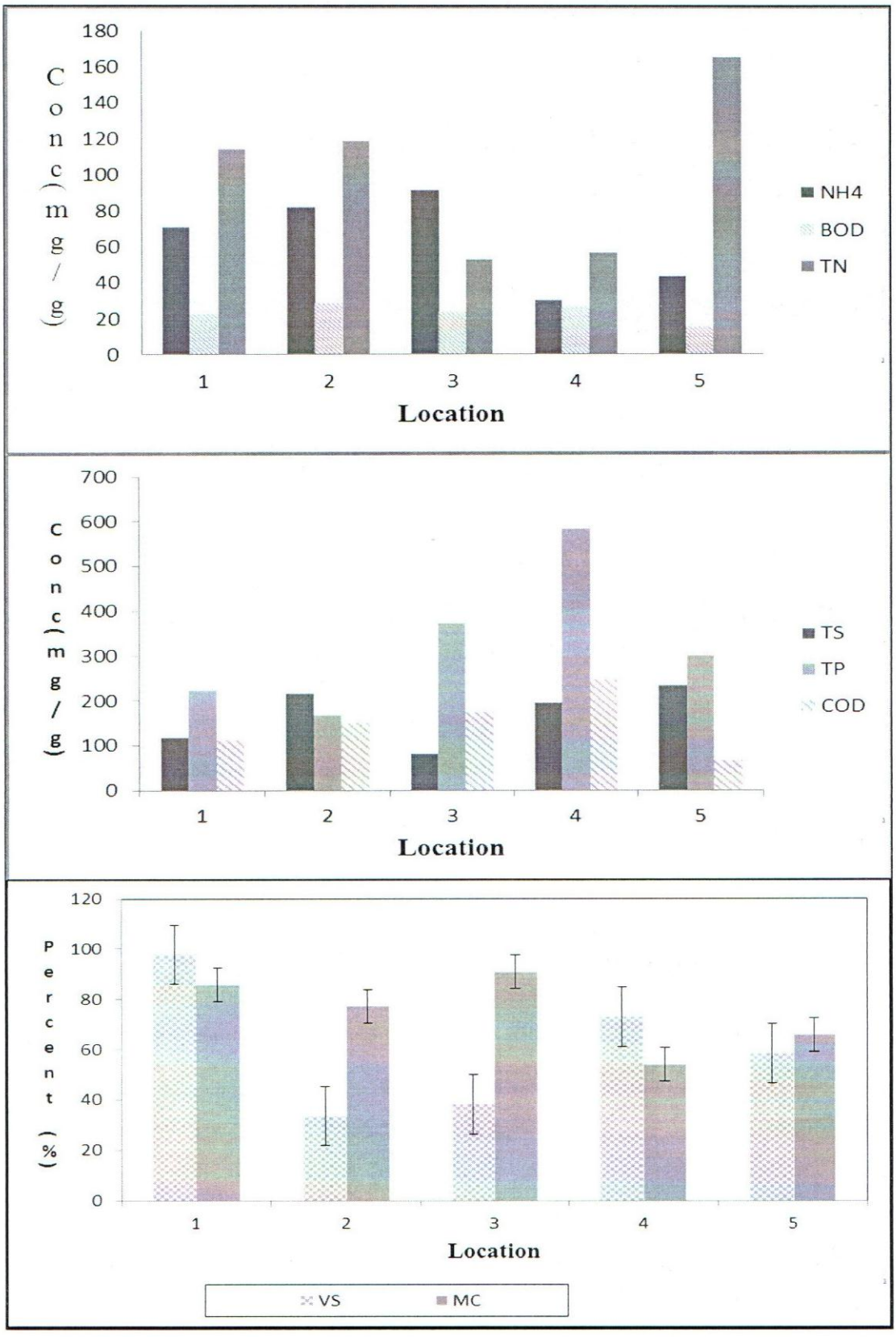


Figure 7: Average concentrations of parameters from the study locations

(Locations: 1-Hilton, 2-Free Area, 3-Kaptembwa, 4-Jewadhu, and 5-Njokerio)

Error bars indicate a 95% confidence interval of the mean

4.3.1 Nutrient concentration

a) Total Phosphorus (TP)

The TP concentration had a range of 5.87 to 987.64 mg/g with a mean concentration of 248.62±31.93 mg/g. Higher TP concentrations in the surface layer was observed with a trend of reduction in concentration as the depth increased. This was attributed to the disposal of waste water laced with detergents into the vaults. However, there was no significant difference in the concentrations with depth (One-Way Anova, F=0. 46, p=0. 711). The absence of significant difference in concentration with depth could be attributed to low breakdown of organic content rich in TP by microorganisms within the sludge and the dilution of the pit latrine content hence mixing of upper layers with lower layers. Variation in the concentrations of TP between the pit latrines was statistically significant (One-Way Anova, F=317. 34, p=0. 00). The variations observed are because of differences in disposal of wastewater by families.

The TP concentrations registered in this study were relatively high and it could be attributed to detergents used in unit washing and disposal of grey water into the pit latrines. Similar findings were reported in the study of public pit latrines in Kumasi (Awuah, *et al*, 2014). The high concentrations confirm the results of the survey indicating wastewater disposal into the pit latrine and regular cleaning using detergents. Higher concentrations of TP were noted for the latrines in Njoro sub-county than those in Nakuru sub-county. This could be attributed to more regular cleaning programs in Njoro Sub-county compared to those in the Nakuru sub-country as was reported in the survey section. High TP content in the sludge sourced from detergents may affect decomposition because they have a negative impact on microbial activities with some of these detergents being biocide hence inhibiting microbial functions (Block *et al*., 2001, Kawasaki *et al*., 2002). In addition, Phosphorous immobilizes other chemicals like Zinc and Copper that are essential for microbial life, making the reported concentrations a cause of concern to the beneficial microorganisms for faecal sludge degradation (Chang *et al*., 1983). Therefore, disposal of the pit latrine content into the environment and aquatic bodies would increase eutrophication and affect plant growth. Disposal into the environment must be discouraged hence there is need for proper treatment of the sludge prior to release into the environment.

b) Total Nitrogen (TN)

Total nitrogen concentration ranged from 1.28 to 210.66 mg/g with a mean of 97.46 ± 4.27 mg/g. The sludge concentrations at the sites in the Njoro sub - county were higher (Figure 7). The high concentration observed suggests lower rates of oxidation and degradation. The decrease in concentration with depth could be because of the higher mineralization of organic nitrogen over time. The concentrations of TN were statistically different among the pit latrines (F=71. 4, p=0. 00), whereas there were no statistically significant differences in concentrations with depth (F=1. 83, p=0. 144) in each pit latrine.

Differences in TN concentration could be attributed to variations in oxidation among the pit latrines which are affected by differences in management practices and biochemical properties of faeces deposited (Awuah, *et al*, 2014). This study showed that average concentrations of TN reduced with depth that could be because of degradation and oxidation over time. Surface concentrations were higher and this could be because of fresh faecal materials deposited in the vaults and pollution load from wastewater disposal and household detergents.

c) Ammonia (NH_4)

Ammonia concentration ranged from 0.53 to 163.53 mg/g. The mean concentration was 62.57±3.93 mg/g. Ammonia concentration was highest for the units in Kaptembwa (Figure 7). The concentration of NH_4 was statistically significant between units and with depth respectively (F=27. 46, p=0. 00, F=0. 31, p=0. 03). The differences in Ammonia concentration with depth and among the pit latrines are an indication of differences in organic nitrogen breakdown. Higher concentrations of Ammonia at the surface indicate higher microbial activity associated with sludge degradation. The lower layers have a reduction explaining stabilization of the sludge, increased volatilization and reduction of microbial breakdown.

Ammonia concentration is affected by ammonification of organic nitrogen by bacteria. The rate of Ammonia production is proportional to the rate of organic nitrogen removal hence higher concentrations show higher microbial activity and sludge breakdown (Fujishima *et al.*, 2000). The reduction of the concentration with depth indicates reduction in organic nitrogen proportions associated with more degraded content (Liu, 2003).

Total nitrogen and Total phosphorus concentrations were higher than those reported in literature, but Ammonia concentrations were within the reported range (Gaillard, 2002; Lopez *et al.*, 2002). High concentration of the TN and NH_4 could be because of ammonification and mineralization of organic Nitrogen in faecal sludge. The relatively high nutrient concentration in faecal sludge supports its regular application as manure in farms (Awuah, *et al*, 2014). However, within the study area, there is limited or no use of pit latrine sludge of composting. The material is discarded as wastes. Similar findings on non-reuse of pit latrine sludge were reported by previous studies in Africa (Angelakis, 2009; Chaggu *et al.*, 2002, Strande *et al.*, 2014). However, there are a number of reported beneficial uses of the faecal sludge in agriculture (Koottatep et *al.*, 2001, Keraita *et al.*, 2003, Scott *et al.*, 2004; Cofie *et al.*, 2005). The high nutrient concentration should encourage use in agricultural production.

4.3.2 Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD)

The average BOD concentrations ranged from 0.13 to 38.98 mg/g with a mean of 22.27±1.11 mg/g. The concentrations of BOD were statistically different between units and with depth respectively (One-Way ANOVA, F=18. 13, p=0. 00, F=22. 11, p=0. 00). The significant differences among pit latrines and within pit latrines with depth indicate variations in the degradation of the organic matter in the faecal sludge across and within individual units. Reductions of BOD with depth indicate increasing stability of the sludge hence reduction in microbial degradation. Units in Kaptembwa showed highest average BOD concentrations, indicating high organic load of the sludge. This may be attributed to organic waste disposal into the pit latrine or occlusion of air within the pit latrine because of addition of wastewater.

Chemical Oxygen Demand concentrations ranged from 12.06 to 451.35 mg/g with a mean of 152.48±7.02 mg/g. The concentration of COD was statistically different with location of the latrines and depth respectively (F=27. 87, p=0. 00, F=5. 59, p=0. 001). This shows that unit's total organic loads vary with depth and individual pit latrines. This could be attributed to the various user practices and variations of total organic content in individual faeces. The variations confirm the differences in fill up of the units reported in section 4.2, hence explaining the observed significant differences. The reductions with depth as reported in Appendix 3, indicate increasing stability and reduction of the total organic content of the sludge with depth.

Biochecmical Oxygen Demand concentrations were relatively high in Njoro sub-county pit latrines compared to those in Nakuru sub-county. This could be associated with higher content oxidation by natural microorganisms. The survey documented low grey water disposal into units in Njoro sub-county, hence low dilution of the content when compared to those in Nakuru Sub County. The low dilution would enable aeration and reduce oxygen occlusion encouraging microbial diversity plus related biodegradation hence the high BOD. Studies in Appeadu and Ougodogou also reported higher BOD concentration in the rural areas compared to the peri-urban area that was attributed to oxidation of organic wastes by naturally occurring microorganisms (Bassan, *et al.*, 2013; Appiah-Effah and Nyark, 2014).

This study reported low COD concentrations three times less than the results presented by Still and Foxon, 2012 (450 mg/g) for sites in EThekwini, South Africa. The relatively low COD concentrations can be attributed to longer residence times on average of 11 to 15 years documented in the pit latrines sampled compared to resident period of only 5 years as documented in the case of the South African context (Still and Foxon, 2012). In addition, the units in this study were sampled up to a depth of 3m whereas the South African context they were sampled up to the depth of 1.5m and this could lead to higher degradation associated with the longer residence period. Further, lower COD concentrations are due to low concentrations of biologically resistant organic matter (Sawyer and McCarty, 1978). Some of the units had higher concentrations of COD that is associated with waste disposal of resistant organic matter into the units (Bassan, *et al.*, 2013). High BOD concentration correlates with high oxygen required by microorganisms to decompose the sludge. In addition, it means that the disposal of the pit contents into the environment, especially in aquatic ecosystems would lead to high organic loading.

4.3.3 Total Solids (TS) and Volatile Solids (VS)

Total solids concentrations ranged from 20 to 890 mg/g with a mean of 165.13±14.44 mg/g (Table 14). The concentrations of TS were significantly different between the latrines and depth respectively ($F=3.77$, $p=0.006$ & $F=2.77$, $p=0.044$). It was observed that solids and other wastes get into the pit holes, hence could contribute to higher TS concentrations. Moreover, differences with depth are because with increasing depth contents become more stabilized.

Volatile solids portion of the TS ranged from 3.80 to 99.6 % with a mean of 55.55±2.52%. The VS portion of the sludge was significantly different between units (One-way Anova, F=48. 84, p=0. 00), but not significantly different with depth (One-way Anova, F=1. 22, p=0. 306). Volatile solids portion of the sludge of the pit latrines had large ranges. The large volatile solids ranges shows large variation in pit latrines contents organic loading. High VS concentration indicate low degradation that is associated with higher fill up, whereas some units have a low organic content showing highly degraded content hence lower fill up rates (Nwaneri, 2009). The variations could be attributed to differences in user management activities, diets, and health.

The high TS concentrations are an indication that sludge from pit latrines have high contaminant load. This necessitates a longer storage period for breakdown. It indicates that units need more settling or resident time to allow for degradation (Buckley *et al.*, 2008, Appiah-Effah and Nyark, 2014). The VS percentages of the sludge are similar to those reported by Nwaneri, 2009 but lower than the concentrations documented by Gillard (2002) and Lopez *et al.*, (2002). High VS values show that the sludge has high organic matter that lead to oxygen depletion hence need for further treatment before disposal into the environment. The findings present the need for treatment of the sludge prior to disposal (Straus *et al.*, 2007). Treatment options should be based on sludge characteristics factoring local parameter properties.

4.3.4 Moisture content (MC)

The moisture content of the sludge ranged from 16 to 99.52 percentages with a mean value of 76.26±1.16 percentage. The moisture content was statistically different between the units (F= 27.72, p=0. 00), but not significantly different with depth (F=1. 25, p=0. 295). The significant differences in MC proportions across the study between pit latrines could be attributed to differences in user management activities and differences in diets determining the moisture content of individual faeces. Differences in weather conditions and geological characteristics of the soils where the sanitation facilities are located may influence the drainage and intrusions of ground water into the pit latrines hence affect the moisture content.

The observed high moisture content in many of the facilities studied is because some unit users dispose wastewater into the vaults. Other sources may include water from cleaning and surface runoff flow into the vaults. Some units have a high volume of added water; hence, the content

dilution from higher depths to lower depths and this could contribute to the absence of significant differences with depth.

The moisture content has a significant role in aiding degradation. However, high water contents lead to dilution and occlusion of air. These significantly reduce aerobic and anaerobic degradation plus microorganism populations that are beneficial to sludge breakdown (Ottoson *et al.*, 2008). Anaerobic digestion of pit latrines could get acceleration through 1% increase of moisture content above the base line content of 76%. This process would increase the rate of production of gases by between 0.006 to 0.02 ml/g of the solid / day (Buckley *et al.*, 2008). The mean moisture content was within the ranges reported in the literature, but there are extreme cases as concentrations range from 16% to 99.52%. The high dilutions are associated with wastewater disposal into the units and ground water inflows into the pit holes. Therefore, the moisture content of some of the units would have negative impacts on the degradation of the sludge. To achieve optimum content properties, moisture content must be kept within a favourable range.

4.4 Inference of the Degradation of the Pit Content

Chemical Oxygen Demand (COD) measures total organic content and Volatile Solids (VS) quantify organic matter present in the sludge. COD and VS concentration variation was used to infer the degradation level at varying depths of the pit latrine faecal sludge. Higher concentration of COD and VS are indicators of a lower stability of the sludge showing lower degradation associated with higher fill up rates.

The mean concentration of COD and VS in the five study sites are presented in Figure 8. Generally, there is a reduction in COD and VS concentrations with increase in depth. The mean concentration of COD was significantly different with depth as explained in section 4.3.2. The analysis reported in appendix 4 and table 15 documented that COD concentration is highest at the surface and lower at the 3 meters with a decrease from 182.6 mg/g to 83.4 mg/g. This result represents 54.34 % concentration reduction from the surface to 3 meters depth of the pit latrines. This reduction shows the degradation of the total organic content of the sludge by over 50%. However, the VS concentration reduction from the surface to 3 meters depth was documented as from 68.56% to 50.58% showing a 26.22% reduction (Table 15). However, there were no significant differences in concentration with depth as documented in section 4.3.3. The VS

reduction is lower, indicating lower organic matter degradation by the microbial population in the sludge. The lower microbial activity leads to higher accumulation of the latrine content; hence, higher rates of pit latrine fill up. This could be accounted for by higher moisture content leading to occlusion of air, hence lower aeration leading to lower aerobic and anaerobic degradation. In addition, waste disposal into the vaults may have biocide effects interfering with microbial diversity hence lower populations leading to lower degradation.

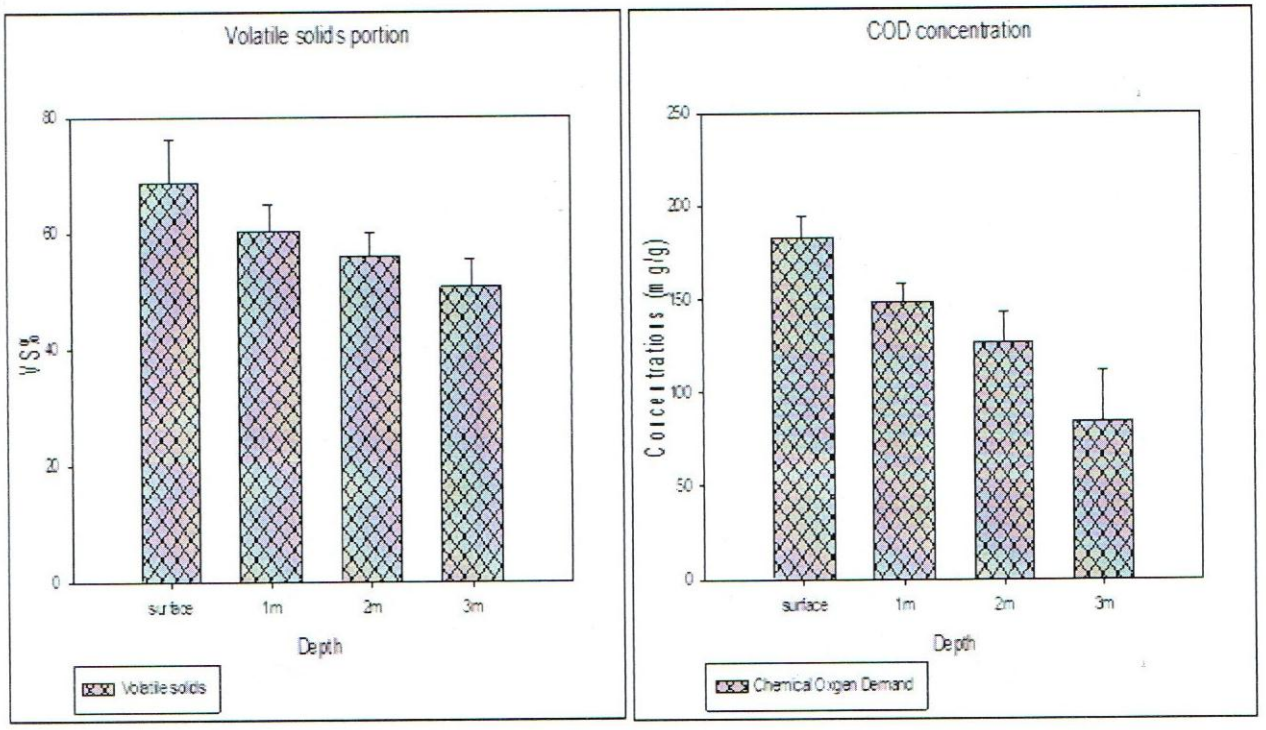


Figure 8: Cumulative COD and VS at different depths

Error bars indicate a 95% confidence interval of the mean

The results showed a general reduction trend of total organic content and organic matter with depth (Figure 8 and table 15). There is a negative correlation between the pit depth with COD and VS respectively (-0.326 & -0.159). In addition, the analysis of variance (4.2.2) shows that the surface layer had significantly higher total organic content than the lower depths (3 meters). The significant reduction with depth indicate increased sludge stabilization with depth, hence lower layers are more degraded.

The association between the physicochemical parameters and the indicators of degradation are documented in table 16. COD had a negative correlation with all the parameters

except BOD. However, COD has a statistically significant correlation with BOD, TN, VS, and NH_4 (Table 16) which shows that the concentration of the variables (BOD, TN, VS & NH_4) has a relationship with the total organic content of the sludge. VS has a weak positive correlation with TN and TS and a significant correlation with TP and NH_4 (Pearson's correlation, $p<0.05$). Increasing or reducing NH_4 and TP concentration in the sludge would affect the organic content levels. The BOD: COD ratio was determined as 1:6 and 1:4 for Nakuru and Njoro sub-county respectively, with a mean of 1:7 for all the studied pit latrines (Table 15, Appendix 4 and section 4.3.2). High BOD: COD ratio greater than 3 show low degradation of the sludge indicating that faecal sludge of units in Nakuru Sub County are less stable.

Table 15: Correlation between the parameters

	COD	BOD	VS	TP	TN	NH	TS
COD	1.00						
BOD	0.57*	1.00					
VS	-0.17*	-0.26*	1.00				
TP	-0.02	0.29*	-0.42*	1.00			
TN	-0.52*	-0.24*	0.02	0.31*	1.00		
NH_4	-0.25*	0.08	-0.26*	0.22*	0.07	1.00	
TS	-0.04	-0.02	0.10	0.03	-0.03	-0.19*	1.00
MC	-0.14	0.14	-0.13	0.09	0.09	0.52*	-0.34*

*shows correlation is significant at $p< 0.05$ level (Pearson correlation)

COD: BOD ratio was greater than 3 indicating low sludge stabilization. Moreover, large ratios could be because of the addition of other organic materials into the pit latrines. Individual unit COD and VS variations with depth showed significant average reduction of the concentrations from the surface to lower layers, whereas others had relatively low reductions in concentrations. High COD and VS concentration reductions indicate high degradation of the content. Nwaneri, (2009) reported similar findings of variations in loading and reductions with depth in EThekwini municipality, South Africa. The differences in biodegradation levels of studied pit latrines could be attributed to variations in the other documented physicochemical parameters as shown in the correlation analysis (Table 16). Other contributing factors may be factors inhibiting microbial activity, management practices, and environmental conditions. Moreover, the organic load changes with depth could be explained by the differences in moisture content, availability of nutrients, carbon content, and temperature (Nordin, 2006).

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This study expected differences in biodegradation in units and locations and these expectations were met. The cumulative evidence of the content properties, show stabilization with depth, differences of stabilization between units and variations between locations. This confirms related findings of variations of pit latrine properties reported in previous studies by Buckley *et al.*, (2008), Bakare et al., (2009) and Nwaneri, (2009) in South Africa and Appiah-Effah and Nyarko, (2014) in Ghana.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

1. The unit design, user activities and management practices during use period and post fill up operations gave the following information;

    a. Unit designs are rudimentary having no features of improved pit latrine structures in form of ventilation pipes, emptying provision and standard slabs. These factors affect efficiency during use and post fill up operations.

    b. The majority of the units (47%) are shared by 6 to 15 families per day and have an average 23 daily users. This leads to use pressure, faster fill up rates, reduced privacy, and encourage open defecation and lower dignity of the users.

    c. Disposal of solid wastes and use of slow degrading anal cleansing materials is a common practice contributing to faster fill-up rates.

    d. The main providers of cleaning services are families at 51%. Addition of water dosed with disinfectants and detergents (55%) forms the main management of the pit contents with the anecdotal role of reducing odour, lowering the content and killing flies. The additions affect microbial activities leading to negative contributions to biological degradation of the content. Households should minimize disposal of water into the vaults as it brings imbalance of moisture content of the sludge.

    e. Sanitation awareness is low among the facility users with 45% of them having not received any form of advice on purposes of these facilities. Most of the awareness provision (21%) is from the local authorities, mainly during public health inspections.

2. The mean pit latrines volume change was 0.87 ± 0.19 m^3 and mean individual contribution 41.84 litres per year. Variation in fill up within and across study areas are because of differences in user management practices across households. Higher fill up rates were documented in areas where user management activities associated with waste disposal into the pit latrihe are higher.

3. The physicochemical characteristics of the sludge had variations within a study area and across the locations. However, only the concentration of NH_4, COD, BOD and TS had significant differences with depth at $p<0.05$. Concentration of the parameters reduced in concentration with depth with the highest concentration at surface depth.
4. Indicators of pit content degradation (COD & VS) reduced from surface to 3m depth by 59.9% and 20.51% respectively. This study suggested that faecal sludge undergo stabilization with depth.

5.2 Recommendations

1. Property owners and construction artisans need to understand applicable and standard pit latrine designs in peri-urban settlements. There is need for further research and development in technologies applicable during use and after fill up in low-income peri-urban settlements.
2. Shared sanitation play a significant role in the sanitation service provision in the areas. Property owners, local communities and authorities need to embrace such facilities however, there is a fundamental requirement to develop efficient operational management practices like hygiene maintenance and regulating the number of people sharing the unit within manageable populations.
3. Proper and sustained awareness creation is necessary to ensure pit latrines are used well.
4. Post fill up management should form part of the pit latrines management strategy so that units are designed to serve precise number of individuals within a certain period. Such planning would factor post fill up management operations.
5. There is a need to document user activities and fill up of pit latrines from the construction stage to evaluate all variables affecting variations in fill up rates.

6. Faecal sludge physicochemical properties are high hence there is need for appropriate co-treatment prior to release into the environment as a control measure of environmental pollution

Recommendations for Further Research

1. Research on other variables e.g. microbial diversity, helminthic distribution, substrate concentrations, and environmental parameters are necessary to relate with physicochemical parameters to provide conclusive information on variations in content degradation at different depths and between pit latrines.
2. Full pit latrine content should not be handled as waste but there is need to document their potential use as organic matter in agriculture as they are rich in nutrients. Studies are necessary to understand health risks of faecal sludge, treatment options and handling procedures.

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APPENDICES

Appendix 1: Questionnaire and Respondent Consent Form

Questionnaire

RESPONDENTS CONSENT FORM

Good morning / afternoon,

My name is Fredrick Gudda and I am a Masters Student from Egerton University, Kenya. I am carrying out Research with Sanitation Research Fund for Africa (SRFA). We plan to study sanitation in Nakuru and Njoro Sub County. The study has interest in pit latrines serving many users, wants to find out user activities of the pit latrines, fill up, and factors influencing their functioning. The team has the aim of finding out the user activities associated with performance and maintenance of pit latrines in the area. The questionnaire will take about 15 minutes to complete. Eventually, we hope that this research will help us to develop new sanitation solutions that will improve the sanitation situation for people in the area, the country and globally.

Signature .....Date .....

Sanitation question per latrine

Date	GPS location:
1.Study area:	Latrine ID:
2. How old are you? (years)	1. <20 2. 21-30 3. 31-40 4. 41-50 5. 51-60 6. >61
3. What is your highest level of education?	1. No formal education 2. Lower primary 3. Primary 4. Secondary 5. Tertiary 6. Vocational training
4. What is the average family monthly income? (Kshs.)	.....
5. Is the latrine private or shared by more than one family	1. Private 2. Shared
6. If used by more than one family, how many families use the latrines?	1) <5 2) 5-15 3) 15-25 4) 25-35 5) 35-45 6) >45
7. How many people use the latrine on a daily basis?	1) <5 2) 5-15 3) 15-25 4) 25-35 5) 35-45 6) >45
8. How old is the latrine?	1. Less than 1 year 2. 1-3 years 3. 4-6 years 4. 7-9 years 5. 10-12 years 6. 13-15 years

	7. 16-19 years 8. >20 years
9. Has it ever filled up	1. YES 2. NO
10. If yes, what was done to the filled up pit latrine?	1.Emptied 2.Allowed to decompose 3.Abandoned 4.Decommisioned 5. Others .....
11. Are there any problems experienced when using the pit latrine?	1. YES 2. NO
12. If yes, what are the problems and how do you rank them?(Rank from 1-8. 1 being the most serious problem and 8 being the least serious)	1) Rapid fill up ( ) 2) Bad odours ( ) 3) Collapse of pit walls ( ) 4) Splashing of contents ( ) 5) Flies and insects ( ) 6) Waste dumping ( ) 7) Seepage into the environment ( ) 8) Others.....
13. Is the pit wall lined?	1. YES 2. NO
14. If lined, what is the pit wall lined with?	1. Masonry 2. cement 3. Plaster 4. concrete 5. Other_____
15. What is used for anal cleansing? (Rank from 1-7. 1 being the most used and 7 being the least used)	1) Water ( ) 2) Tissue paper ( ) 3) Newspapers ( ) 4) Plant leaves ( ) 5) Exercise book papers ( ) 6) Carton ( ) 7) Other: _____
16. Is there addition of water into the pit latrine.	1. YES 2. NO
17. If yes, what is the source of the addition?	1) Cleaning water 2) Anal cleaning water 3) Bathroom water 4) Rain water 5) Purposeful additions 6) Others.....
18. What is the purpose of the added water into the pit latrine?	1. Reduce odour 2. Increase biodegradation 3. Disposal point 4. Lower accumulation

	5. Others.....
19. Are there any compounds in the added water?	1. YES 2. NO
20. If yes, what are the compounds?	1. Detergents 2. Commercial additives 3. Limes and salts 4. Battery contents 5. Others .....
21. What are the perceived roles of the compounds mixed into the water?	1. Reduce malodour 2. Increase biodegradation 3. Kill flies 4. Others.....
22. Are there materials thrown into the pit latrine?	1. YES 2. NO
23. If yes, what kind of materials ?	1) Food remains 2) Grey water 3) Diapers 4) Sanitary pads 5) Clothes 6) Agricultural wastes 7) Others: _____
24. Does the Family use something to make the pit latrine perform better?	1. YES 2. NO
25. If Yes, what is the addition?	1) Wood ash 2) Lime 3) Soil 4) Detergents 5) Battery contents 6) Commercial products (list)..... 7) Other:_____
26. What has been the result?	1. Reduction of pit content volume 2. Reduction in smell 3. Reduction in flies population 4. No observable changes 5. Others .....
27. Are there sanitation programs for hygiene maintenance?	1. YES 2. NO
28. If yes, who is responsible for the sanitation maintenance?	1. Families/family 2. Owner 3. Municipality 4. Workers 5. Random cleaning

	6. Other.....
29. Has there been sanitation awareness in the area?	1. YES 2. NO
30. If yes, who provides awareness?	1. Local government 2. Public health officers 3. CBOs/NGOs 4. Individuals/ Residents 5. Property owners 6. Volunteers 7. Others.....

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OBSERVATION SCHEDULE

1. How many doors does the pit latrine have?	.....
2. What is the floor of the pit latrine made of?	1. Timber 2. Bricks 3. Concrete 4. Stone blocks 5. Earth 6. Tiles
3. What is the pit latrine walls made of?	1. Stones 2. Concrete 3. Iron sheet 4. Plastic sheet 5. Cement plaster 6. Timber 7. Earth
4. Does the structure have a roof?	1. YES 2. NO
5. If yes, what is the roof made of?	1. Iron sheet 2. Grasses 3. Polythene paper 4. Concrete roof 5. Asbestos 6. Roofing tiles 7. Others .....
6. Is there water around for hand washing after pit latrine use?	1. YES 2. NO
7. If yes, where is the water placed?	1. At the entrance 2. Inside the pit latrine 3. Next to the main house 4. Watering point in the compound 5. Others .....
8. Is there waste disposal site in or around the compound?	1. YES 2. NO
9. If no, are there indications of waste dumping into the pit latrine?	1.YES 2.NO
10. What are the observed wastes within the pit latrine?	1. Clothes 2. Food remains 3. Polythene 4. Farm

	remains 5. Plant leaves 6. Papers 7. Diapers 8. Sanitary pads 9. Others .....
11.Is the pit latrine designed with dislodging allowance at the floor or back	*1. YES* *2. NO*
12. Is the facility accessible by vehicles or dislodging equipment?	*1. YES* *2. NO*

THANK YOU

Appendix 2 : Individual pit latrine Fill up rates

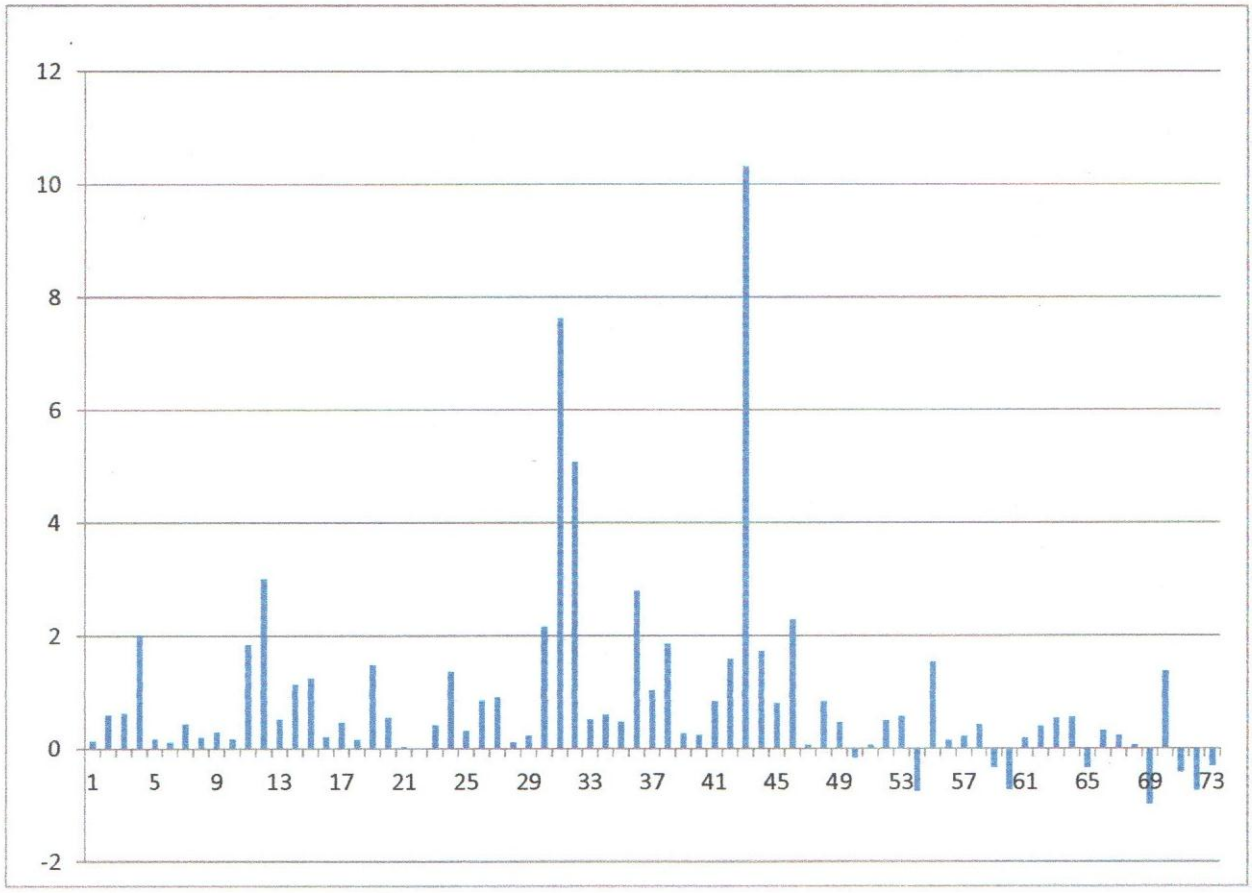
UNIT NO	UNIT ID	Duration (days)	Vol change (L)	% Vol change	(l/p/d)
1	H01	296	130.530512	18.13135985	0.013781
2	H02	296	604.871145	55.20102106	0.045411
3	H09	296	623.666406	27.50325098	0.055447
4	H10	296	2012.057763	21.61498996	0.205985
5	H11	296	179.27336	5.464480874	0.046589
6	H12	296	116.206464	1.730005672	0.021811
7	H14	296	444.835128	19.85590167	0.06831
8	H15	296	207.355833	15.36618754	0.021891
9	H19	296	297.5827653	11.75386883	0.047874
10	H20	296	177.0456	0.865051903	0.013292
11	H22	296	1852.96384	16.20178042	0.109825
12	H23	296	3004.171625	9.730012714	0.161099
13	H24	296	522.707328	7.244288948	0.098106
14	F03	302	1135.883016	52.33751425	0.098979
15	F06	302	1249.644078	5.139500734	0.27586
16	F07	302	212.371488	4.293655357	0.031964
17	F09	302	465.495504	5.848137085	0.036699
18	F11	302	168.7439628	8.053977273	0.016932
19	F12	302	1488.586667	35.90019745	0.129713
20	F14	302	551.59803	18.93502499	0.035125

21	F15	302	35.92140067	1.043338684	0.007434
22	F16	302	14.149324	1.147991016	0.003347
23	F17	302	417.937692	16.84743312	0.040703
24	F19	302	1366.38346	24.77014602	0.107725
25	F20	302	317.93828	6.609914872	0.026994
26	F21	302	855.285504	24.87582781	0.088502
27	F22	302	909.3369133	13.43371715	0.107537
28	F23	302	114.30432	5.538461538	0.014018
29	F25	302	229.248162	8.530805687	0.017653
30	K01	298	2157.38964	12.51738526	0.402198
31	KO2	298	7624.995083	57.32764552	0.91383
32	K03	298	5080.902903	37.83655369	0.347959
33	K04	298	513.7979167	9.243572596	0.057472
34	k05	298	601.450784	22.39130435	0.049227
35	KO6	298	475.871858	8.809055118	0.076042
36	K07	298	2801.841606	49.17500676	0.276534
37	K10	298	1034.726499	33.41239253	0.112008
38	K12	298	1856.842311	30.06675567	0.2077
39	K13	298	265.812888	12.70666037	0.040545
40	K16	298	237.264544	17.69273433	0.049762
41	K18	298	838.9605867	15.90853209	0.0599
42	K20	298	1589.250663	19.41787374	0.073056
43	k21	298	10316.7297	56.89220628	0.665767

44	K22	298	1732.702968	22.8097869	0.153012
45	k28	298	798.356225	21.00638978	0.10304
46	K29	298	2292.493168	32.00737116	0.142462
47	K30	298	64.21319167	27.5297619	0.005986
48	K31	298	835.3160853	9.613796899	0.080088
49	J01	298	464.781204	10.13289037	0.04874
50	J02	298	-163.17925	-6.772673734	-0.01521
51	J04	298	64.34143	11.59311892	0.008996
52	J05	298	490.3762087	9.288379531	0.060947
53	J11	298	574.5924	7.306380906	0.04017
54	J12	298	-758.8859227	-59.51690821	-0.05659
55	J15	298	1540.23263	31.00651346	0.147673
56	J21	298	154.3565973	15.33008418	0.014799
57	J22	298	221.0175	1.63839182	0.052976
58	J23	298	423.5613367	14.13959085	0.029611
59	J24	298	-334.345536	-1.270395569	-0.0748
60	NO1	295	-728.9756453	-6.69528893	-0.14536
61	N02	295	186.221655	3.700711054	0.026302
62	N03	295	402.478648	4.828150573	0.113695
63	N04	295	537.343527	25.89716122	0.107147
64	N05	295	548.630292	7.084019769	0.15498
65	N06	295	-339.802995	-4.766536965	-0.06399
66	N07	295	313.052244	10.56581986	0.08163

67	N08	295	229.80034	4.352126607	0.059922
68	N14	295	66.425508	0.637732507	0.007506
69	N17	295	-980.3511	-22.07485465	-0.27694
70	N18	295	1370.977621	9.040658396	0.108079
71	N19	295	-419.101232	-25.94113621	-0.07103
72	N20	295	-746.919549	-35.31580241	-0.21099
73	N21	295	-315.4125385	-7.148752211	-0.10692

Appendix 3: Pit Latrine Fill Up Patterns



Y axis- change in volume in m^3 and X axis- studied pit latrine IDs

Appendix 4: Physicochemical parameters

Variable	depth	Mean	SE	Minimum	Maximum
HILTON					
TN	1	129.23	2.48	117.56	136.68
	2	102.98	7.11	80.77	124.58
	3	107.72	7.97	79.38	124.97
TP	1	26.23	1.64	16.66	30.43
	2	18.40	2.04	9.54	23.98
	3	22.49	1.18	20.04	26.25
NH	1	47.93	6.20	22.61	78.73
	2	82.0	18.8	5.9	154.6
	3	85.6	13.4	50.7	124.4
COD	1	131.68	9.97	84.76	167.45
	2	104.67	9.63	62.92	140.26
	3	92.87	8.01	66.17	112.09
BOD	1	31.28	3.79	11.69	38.08
	2	24.63	3.98	7.33	37.56
	3	8.559	0.751	4.881	9.900
VS	1	97.627	0.610	94.524	99.367
	2	97.831	0.680	93.333	99.595
	3	97.721	0.660	95.522	99.107
MC	1	88.230	0.971	83.720	91.760
	2	82.82	2.88	68.04	90.28
	3	86.39	1.08	82.56	89.28
TS	1	98.08	8.09	68.67	135.67
	2	143.2	24.0	81.0	266.3
	3	113.44	9.01	89.33	145.33
FREE AREA					
TN	1	117.14	6.24	87.51	147.29
	2	124.0	12.1	57.3	207.9
	3	109.37	8.10	83.69	126.60
TP	1	945.41	9.20	875.07	990.22
	2	886.9	36.0	572.8	993.5
	3	927.0	28.9	836.9	992.0
NH	1	95.5	14.0	27.5	163.0
	2	73.9	13.1	10.2	146.7
	3	67.4	11.4	44.4	105.8
COD	1	163.2	12.2	65.9	226.8
	2	139.92	7.79	87.76	202.29
	3	149.2	20.1	106.2	214.0
BOD	1	34.41	1.21	23.64	39.11
	2	25.00	2.43	11.96	38.76
	3	24.91	4.37	14.11	39.01
VS	1	34.31	7.08	12.05	89.95
	2	33.51	5.84	7.06	97.96
	3	32.01	4.00	21.80	45.12
MC	1	77.23	3.99	42.56	92.16
	2	73.28	6.48	17.68	87.48
	3	86.113	0.461	84.840	87.640
TS	1	196.9	33.3	65.3	478.7
	2	279.1	98.9	104.3	1452.7
	3	115.72	3.85	103.00	126.33
KAPTEMBWA					
TN	1	56.3	10.7	1.3	122.9
	2	51.47	4.93	25.96	76.45
	3	56.5	11.7	6.7	99.0
	4	12.924	0.910	12.014	13.834
TP	1	33.84	2.25	7.89	43.46
	2	21.91	3.77	5.87	48.86
	3	13.37	1.76	6.96	19.73

	4	36.19	4.76	31.43	40.95
NH	1	94.1	11.4	38.4	163.5
	2	83.0	10.1	40.3	143.5
	3	107.1	10.2	61.9	131.9
	4	56.781	0.0186	56.763	56.800
COD	1	214.84	4.74	182.88	238.79
	2	157.5	22.5	28.4	295.6
	3	119.7	36.3	12.1	290.3
	4	208.62	8.19	200.42	216.81
BOD	1	36.403	0.736	28.022	38.414
	2	22.78	3.35	6.42	38.55
	3	9.09	1.86	2.71	18.57
	4	4.130	0.660	3.471	4.790
VS	1	23.24	2.81	3.80	43.36
	2	42.55	6.06	12.90	97.67
	3	55.80	5.73	40.30	87.06
	4	40.195	0.147	40.049	40.342
MC	1	87.751	0.831	83.120	91.400
	2	92.51	1.24	81.84	99.52
	3	94.48	1.03	89.48	97.12
	4	83.580	0.0600	83.520	83.640
TS	1	102.07	6.93	71.67	140.67
	2	76.0	13.0	28.7	193.7
	3	46.04	8.57	24.00	87.67
	4	136.83	0.500	136.33	137.33
JEWADHU					
TN	1	64.08	4.66	30.93	82.62
	2	54.41	6.58	8.63	76.50
	3	40.6	13.9	11.6	64.6
TP	1	78.22	7.57	43.87	115.23
	2	76.76	6.63	47.85	122.39
	3	91.8	14.9	65.0	119.0
NH	1	3.084	0.565	0.528	6.367
	2	3.016	0.796	0.895	8.666
	3	2.629	0.623	1.205	3.754
COD	1	269.4	34.3	73.8	451.3
	2	210.7	28.0	127.6	384.8
	3	274.3	22.6	228.5	317.8
BOD	1	24.11	3.98	0.13	35.34
	2	27.61	1.11	22.06	34.24
	3	29.90	2.12	25.84	34.29
VS	1	80.29	5.16	40.00	93.75
	2	70.49	8.29	8.33	94.12
	3	60.63	7.67	50.00	83.33
MC	1	54.40	4.51	36.00	80.00
	2	54.00	5.82	32.00	80.00
	3	53.0	11.1	32.0	76.0
TS	1	126.0	47.0	40.0	540.0
	2	404	127	60	1000
	3	77.50	6.29	60.00	90.00
NJOKERIO					
TN	1	137.5	14.9	84.4	164.1
	2	162.1	12.4	134.0	203.9
	3	184.3	13.5	138.3	211.9
	4	177.4	12.3	130.9	206.4
TP	1	30.18	7.91	9.56	53.38
	2	34.46	6.62	13.75	49.73
	3	31.83	8.32	11.51	58.82
	4	23.81	4.23	12.37	37.87
NH	1	35.82	8.36	12.01	62.50
	2	38.05	9.30	18.47	75.09
	3	45.54	7.30	22.13	66.64

	4	53.1	11.5	28.2	90.8
COD	1	75.4	25.0	23.2	176.1
	2	100.1	19.1	40.3	149.6
	3	46.08	7.29	13.26	62.98
	4	41.61	3.54	28.90	53.73
BOD	1	8.78	4.35	0.49	22.62
	2	8.20	3.41	0.93	18.89
	3	4.39	2.56	0.15	12.75
	4	1.382	0.107	1.008	1.637
VS	1	40.13	7.83	25.00	75.00
	2	58.70	6.07	39.06	80.00
	3	56.31	8.42	33.33	94.59
	4	78.02	6.03	62.50	97.50
MC	1	48.3	11.2	16.0	80.4
	2	60.5	11.1	24.0	82.8
	3	76.61	1.61	72.04	84.00
	4	77.20	2.64	68.00	84.00
TS	1	310.0	94.6	100.0	745.0
	2	317.5	92.8	90.0	625.0
	3	167	101	20	635
	4	145.0	97.1	20.0	625.0

Appendix 5: Laboratory analysis procedures

Collected samples in the field will be stored in sterile sample containers and will be labelled with the latrine ID, date and sampling depth. Sample containers will be stored on ice and transported to the laboratory for further processing.

Physico-chemical analysis

Mix the whole field sample well to make a homogenous representative sample.

Fill 1 Falcon tube for total solids/VSS analysis (weight approx 30g and place at 4°C for analysis within 1 week)

Fill 1 Falcon tube for Ammonia and COD analysis (prepare suspension of approx 1g/20 ml of double distilled H_2O)

Add sulphuric acid until pH2. Keep this and the rest at 4°C (1 week-28 days)

Fill 1 Falcon tube for VFA (1 g/20ml of double distilled H_2O) (keep at 4°C for 24h max)

Fill 1 Falcon tube and store at -80°C (back-up material)

Physical/(bio)chemistry

Balance, refrigerator (4-8 C)

Spectrophotometer

Heat block

Oven (103/550C)

Desicator

Homogeniser

Total solids and Volatile solids

Total solids is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total solids include total suspended solids (proportion of solids retained by a filter) and total dissolved solids, the proportion that passes through the filter.

"Fixed solids" is the term applied to the residue of total suspended, or dissolved solids after heating to dryness for a specified time at a specified temperature. The weight loss on ignition is called "volatile solids". (Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter).

Material

Evaporating dishes: dishes of 100 ml of capacity made of one of the following materials: porcelain (90 mm diam), high-silica glass.

Muffle furnace for operation at 500 ± 50°C.

Steam bath

Desiccator,

Drying oven, for operation at 103 to 105°C.

Analytical balance, capable of weighting 0.1 mg

Magnetic stirrer

Filter paper (filtering devices?)

Total Solids Protocol

Preparation of the evaporating dishes:

Prewash the aluminium or ceramic dish.

Place the dish in a 103-105°C oven to dry for 1h.

Cool the dishes thoroughly in a desiccator before use. Prepared dishes should be stored in a desiccators.

Sample analysis:

Weigh the dish (at room temperature) on an analytical balance. Use crucible tongs or wear lint free cotton gloves to transfer the dish from the desiccators to the balance pan. (don't do this with bare fingers).

Record the weight of the dish (B).

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Thoroughly mix the sample to be analysed (around 30g; exclude large, floating particles or submerged agglomerates of non-homogeneous materials from the sample if it is determined that their inclusion is not desired in the final result). Carefully measure the mass of sample transferred to the dish.

Place the dish in the oven to dry for one to two hours at 103°C. Depending of the mass of the sample and the amount of water on it.

When the sample is dry, cool sample in a desiccators to balance temperature, and weigh.

Return the dish to the drying oven for another 30 min. Cool, desiccate, reweigh until the change in the weight of the residue remains within 40% or less than 0.5mg from one weighing to the next

Record the final weigh.

Calculations:

Total solids(%)= (A-B)/(C-B) x100%

A=weigh of dish + dry sample (g)

B=weigh of dish (g)

C=weigh of dish +wet sample (g)

Volatile Total Solids Protocol

Preparation of the evaporating dishes:

Prewash the aluminium or ceramic dish.

Place the dish in a 103-105°C oven to dry. Move the dry dishes into a 550°C muffle furnace for 15 min.

Remove the dishes from the muffle furnace and place on a heat resistant surface. The surface temperature of the dish must be greater that 103°C when placed into the desiccators.

Cool the dishes thoroughly in a desiccator before use. Prepared dishes should be stored in a desiccator.

Sample analysis:

Place the dish and residue produced by %TS analysis in a muffle furnace at a temperature of 550°C for 15 to 30 min. The process is not complete until the heat has removed any carbon or soot deposit (black glaze) on the dishes.

Remove dish with ash from muffle furnace, cooling partially, then place in a desiccators until cooled.

Weigh cooled dish and ash on an analytical balance and record weight. Be careful when opening the desiccators. The cooled air (gas) inside the desiccators will have created a vacuum, sudden opening of the desiccators may cause the loss of some of the ash or fixed solids from the dish.

Repeat ignition, cooling and weighing until a constant weight is obtained or until weight loss is less than 4% of the previous weight.

Record the final ashed weight on the benchsheet and calculate the % volatile total solids.

Calculations:

Volatile Total Solids (%)=(A-C)/(A-B)X100

A=weigh of dish +dry sample (g)

B=weigh of dish (g)

C=weigh of dish+ sample after ashing or ignition (g)

Fixed solids (%)=(C-B)/(A-B)x100

Ash= Ash content given in %

Total Phosphorus (TP)

Total phosphorus can be determined by first digesting and reducing the forms of phosphorus present in the water into the free ortho-phosphate form (SRP) using persulphate digestion. After the digestion, the total reduced forms into the SRP formed is analysed using the same procedure as for the soluble reactive phosphorus. A standard calibration curve for total phosphorus should be made in which the standard solutions undergo the persulphate digestion procedure followed with the soluble reactive phosphorus test procedure.

Reagents:

Potassium persulphate K2S2O8

4 g of K2S2O8 is dissolved in 100 ml of distilled water by sonification for about half an hour.

To 25 ml of the sample, 1 ml of the still warm K2S2O8 solution is added. The bottles are weighed without the lids and their weight noted. The lids are put back but not closed tightly after which they are autoclaved for 90 minutes at about 120°C and 1.2 atm. After cooling, the bottles are re-weighed and the evaporated water replaced by addition of distilled water.

25 ml of the sample is used for the determination of total phosphorus and for this the steps used for the soluble reactive phosphorus should be used (see SRP determination).

Soluble Reactive Phosphorus (SRP)

Soluble reactive phosphorus (SRP) may be determined using the **ascorbic acid method** (APHA, 1995) on the filtered samples. All the glassware to be used must be acid-washed with 10% H2SO4 at least one day before the commencement of the exercise and rinsed with distilled water.

Standard calibration curve

Standard solution for the calibration of the standard curve is made by dissolving 5.623 g of potassium hydrogen phosphate (K2HPO4) pre-dried salt in the oven for 24 hrs at approximately 70°C in 1 litre of distilled water to make a stock solution with a concentration of 1g of PO4-P l-1. From this stock solution, 10 ml is diluted upto 1 litre using distilled water to give an intermediate solution with a concentration of 10 mg l-1. The intermediate solution is further diluted in a ratio of 1:20 (25 ml in 500 ml-distilled water) to give a working solution with a concentration of 500 µg l-1. The standard series is prepared by taking the following respective volumes of the working solution and diluting to 25 ml with distilled water as shown on the table below. Triplicate samples should be taken for each concentration.

Reagents:

A) Ammonium molybdate solution.

15 g (NH**4**)6MO7O**24** x 4 H**2**O) is dissolved in 500 ml distilled water

B) Sulphuric acid.

140 ml concentrated sulphuric acid is diluted up to 1000 ml with distilled water

C) Ascorbic acid.

2.7 g ascorbic acid is dissolved in 50 ml distilled water. This should always be **freshly prepared** since the acid is unstable and must be used **immediately before 24 hrs**.

D) Potassium-Antimonyltartrate-Solution:

0.34 g K-Antimonyltartrate is dissolved in 250 ml distilled water

The four reagents are mixed in the respective ratios: A:B:C:D = 2:5:2:1, where the order of mixing is very critical. The resulting solution is added to the sample in a ratio of 1:10, e.g. 2.5 ml reagent added to 25 ml of the sample. The prepared sample's absorbance is measured after 15 minutes of adding reagents to the samples at a wavelength of **885 nm** with distilled water as a reference. Where the samples are highly turbid, a natural reference sample for turbidity correction can be made by using 25 ml of the sample in which only reagents A and B are mixed in the same ratio and added to the sample, and its absorbance measured.

To 25 mls of the filtered sample (where necessary, the sample may be diluted) 2.5 mls of the mixed reagents is described above in the determination of SRP.

Ammonium-nitrogen (NH4-N)

Except under very alkaline conditions (pH>9) most of the (NH3) in freshwater exist in the ionic form (NH4+). Ammonium is an important source of nitrogen for bacteria, algae and larger plants in lakes and streams and because concentrations are very low, the content of the water samples can change quickly and markedly. Thus, the filtered samples should be analyzed as soon as possible or within 24 hours after collection.

Principle

Ammonium-nitrogen is determined according to the hypochlorite method using nitroprusside as a catalyst. Ammonium reacts with phenol and hypochlorite under alkaline conditions to form lime green colour. The colour development is proportional to the concentration of ammonium within a given range (0-1000µg *NH4-N* /l).

Standard calibration curve

This is made by using NH4Cl solids with a molecular weight of 53.492 g in which the nitrogen proportion of NH4–N is 1:14 of the weight. 0.955 g NH4Cl is dissolved in a 250 ml volumetric flask to prepare 250 ml of this solution, giving a stock solution with a concentration of 1g NH4-N l-1. 10 ml of this stock solution is diluted further to 1 litre with distilled water, giving an intermediate solution with a concentration of 10 mg l-1. From this solution, a working solution is made with a concentration of 250 µg l-1 by taking 25 ml of the intermediate solution and diluting it up to 1 litre. The working volume for calibration curve used is 25 ml. Different concentrations of this standard working solution can be made to determine the calibration curve by taking the following respective volumes of the working solution and diluting to 25 ml with distilled water as given in the table below.

Triplicate samples for each of the concentrations should be used to determine the calibration curve.

Reagents

A) Sodium salicylate solution: 130 g of sodium salicylate and 130 g of tri-sodium–dihydrate is mixed in 800 ml of distilled water. 0.97 g of sodium nitroprusside is then added to this solution. The solution is filled up to 1000 ml using distilled water. This solution has a bench life of two months.

B) Hypochlorid solution: 0.2g of sodium dichloroisocynurate which should always be freshly prepared is added and mixed with 100 ml of NaOH solution. The NaOH solution, made by dissolving 32 g NaOH in 1000 ml distilled water can be prepared early and has a bench life of two months.

Procedure

To 25 ml of the sample, 2.5 ml of reagent A is added, followed immediately by the addition of 2.5 ml of reagent B. The sample is then placed in a water bath at a temperature of 25 °C in the dark for 90 minutes. Absorbance is then determined at a wavelength of 655 nm.

Total Nitrogen

Digestion of water samples with the persulphate method (Koroleff, 1983)

Principle

The persulphate method determines total nitrogen by oxidation of all nitrogenous compounds to nitrate. The organic content in the water samples should not be too high. Should ammonia, nitrate and nitrite be determined individually, "organic nitrogen" can be obtained by the difference. The procedure gives good results for total nitrogen, composed of organic nitrogen (including some aromatic nitrogen-containing compounds), ammonia, nitrate and nitrite.

Molecular nitrogen is not determined and recovery of some industrial nitrogen-containing compounds is low.

Alkaline oxidation with persulphate at 100 – 110 °C converts organic and inorganic nitrogen to nitrate. Total nitrogen is determined by analysing the nitrate in the digestate.

The persulphate method is not effective in wastes with high organic loadings, dilute such samples and re-analyse until results from two dilutions agree.

Sampling and Preservation

Samples may not be preserved with acid! Preserve samples by cooling.

Apparatus

Hot plate, autoclave or microwave;

Spectrophotometer for use at 220 nm and 275 nm with 1-cm quartz cuvettes.

Reagents

(a) Dissolve 15 g NaOH in 1000 mL distilled water.

(b) Dissolve 5.0 g K2S2O8, potassium peroxodisulphate, in 80 mL of solution a). This will take some time. Add 3.0 g H3BO3 (boric acid). Raise the temp slightly to promote dissolution. Fill up to 100 mL with solution a), use a volumetric flask. pH=12. This solution is stable for 1 week.

(c) Glycine, the digestion check standard Dissolve 1.072 g glycine in 1000 mL distilled water. 1 mL = 200 µg N/L. This stock solution can be stored for 1 month at 4 °C.

(d) Nitrate standard solution; 1 mL = 10.0 µg NO3-N/L.

Stock NO3-N solution: Dissolve 0.722 g potassium nitrate, KNO3 (dried at 105°C for 24 h) in water and dilute to 1000 mL. Add 2 mL of chloroform (CHCl3). 1 mL = 100 µg NO3-N/L. This solution is stable for at least 6 months at 4 °C.

Standard NO3-N solution: Dilute 100 mL stock to 1000 mL. Add 2 mL of CHCl3. 1 mL = 10 µg NO3-N/L. This solution is stable for 6 months at 4 °C.

(e) 1 M HCl: Dilute 82.5 ml of 37% conc. HCL in 1 L distilled water. (Note: Prepare enough for analysis only to avoid wastage).

Standard calibration curve

1. Transfer 0; 5.00; 10.00; 15.00; 20.00 and 25.00 mL standard nitrate solution in 100 mL erlenmeyer flasks. The amount of N is in the range of 0-250 µg N/L. Fix a paper with a description of the sample/standard around the neck of the Erlenmeyer flask, use a pencil to write down the information on the label.

2. Add 5.0 mL solution b) and bring all volumes to about 30 mL with distilled water.

3. Cover each Erlenmeyer flask with a cotton plug and aluminium foil and mix the contents carefully.

4. Put the flasks in the autoclave/oven and destruct for 1 hour at 110 °C.

5. Cool the flasks and transfer the contents to 50.0 mL volumetric flasks and mix

6. Dilute 0; 5.00; 10.00; 15.00; 20.00 and 25.00 mL standard NO3-N to 50 mL with distilled water in volumetric flasks. Add 1 mL of reagent e) and mix.

7. Measure the absorbance at 220 and 275 nm against distilled water.

8. Subtract two times the absorbance reading at 275 nm from the reading at 220 nm to obtain absorbance due to NO3-N.

9. Plot the absorbance (y-axis) against mg NO3-N/50mL (x-axis) and determine the calibration equation and R2-square value of this line.

Sample analysis

1. Proceed as mentioned under standard calibration procedure (1 to 8) above for samples.

2. Calculate TN (as mg NO3-N/L) as follows:

Remarks:

(i) If absorbance at 275 nm is more than 10% of the absorbance at 220 nm, do not use this method.

(ii) The calibration graph is linear up to 500 µg NO3–N/50 mL (=10 mg NO3–N/L).

Biological Oxygen Demand (BOD)

Introduction

The Biological Oxygen Demand (BOD) is a parameter for the respiratory activity of micro-organisms during the biochemical degradation of organic compounds in a water sample. Biological oxidation of nitrogenous compounds may be halted by addition of a chemical inhibitor which reduces or stops the activity of the nitrifying organisms. The BOD is specified as O2 in mg/l which is consumed in a certain period of time. BOD measured without inhibition is generally referred to as BOD3 BOD5 or BOD7 for 3, 5 or 7 day incubation period respectively. The measurement of BOD is carried out in so called "dark flasks", which prevent the incidence of light to inhibit primary production by phytoplankton which generate oxygen in the process.

Principle

The method applied involves filling an airtight bottle of a precise specified volume to overflowing with a sample and incubating at a specified temperature usually, 20 oC for 3, 5 or 7 days. Dissolved oxygen (DO) is measured before and after incubation and the BOD is measured as a difference of the initial and final DO.

Sampling and storage

Analysis should be done as soon as possible. Before setup, sample temperatures of 20°C should be obtained.

Material and solutions needed

1. Winkler flasks (BOD bottles; 250 – 300 ml)

2. Aluminium foil (to wrap Winkler flasks) or dark chamber to keep bottles

3. Alarm clock

4. Winkler reagent for the determination of O2

5. Oxygen probe (with propeller or stirrer) if Winkler's Method is not used

Measurement

Fill water flasks (bottles) carefully with the water samples avoiding air bubbles and re-aeration. To achieve assured information, prepare three dark flasks per sampling site. Measure the O2-start-concentration and the temperature. Wrap "dark flasks" with tin foil; store all flasks at a temperature of 20°C. Note the time at incubation. Measure oxygen content and temperature after 3, 5 or 7 days according to the desired BODx.

The oxygen measurement can be carried out in two ways:

1. Winkler's method 2. O2 electrode method

Beside determination of the end value after x days, it is possible to access the shape of the BOD curve indicating the quality of available biodegradable carbon. For that purpose, oxygen determination should be carried out twice a day. Applying Winkler titration one flask has to be fixed for each measurement; using the O2 electrode, flasks can be closed again (after filling up should it be necessary) and stored at 20°C until the next measurement.

Calculation

BOD [mg/l] = (D1-D2)/P

D1= oxygen start concentration in mg/l

D2= oxygen end concentration in mg/l

P= decimal volumetric fraction used

If T <> 20°C; results should be recalculated to 20°C

Dilution of samples

Most surface waters have BOD greater than the *in-situ* oxygen concentration measured at any one time. In such samples dissolved oxygen is depleted completely after a given storage period as required for the determination of BOD. Such samples need to be diluted to achieve a reasonable OE (oxygen end concentration in mg/l) after storage. To achieve that dilution water will be required. There are standard methods for the preparation of dilution water. However, it is usually difficult to obtain dilution water that is representative of the actual chemical and/or microbiological composition of the water being investigated. To overcome this difficulty, it is advisable to use natural unpolluted/slightly polluted water of low BOD (<2mg/L BOD5) as dilution water. In that case no special preparations are required other than obtaining the water. Where such waters cannot be obtained, dilution water must be prepared following standard procedures.

Calculation

BOD [mg/l] = [(OE - OS) x F] - D

OE = Oxygen end concentration in mg/L OS = Oxygen start concentration in mg/L

F = Dilution factor = Vol. of BOD bottle/Vol. of sample water

D = BOD of dilution water in mg/L

Chemical Oxygen Demand (COD)

1. Closed Reflux Colorimetric Method (APHA, 2004)

Overview

The Chemical Oxygen Demand determines the amount of oxygen required for chemical oxidation of organic matter using a strong chemical oxidant, such as potassium dichromate under reflux conditions. The test is widely used to determine the same types of pollution aspects as the BOD. The limitation of the test lies in its inability to differentiate between the biologically oxidizable and biologically inert material.

COD determination has an advantage over BOD test in that the results can be obtained in less than 5 hours whereas BOD determination requires 5 days. Further the test is relatively easy and precise. Also there are not many interferences as in case of BOD. Volatile organic compounds are more completely oxidized in the closed system because of longer contact with the oxidant.

Principle

Most types of organic matter are oxidised by a boiling mixture of chromic and sulphuric acids. A sample is refluxed in strongly acid solution with a known excess of potassium dichromate (K2Cr2O7). The amount of dichromate consumed is proportional (1:7) to the oxygen required to oxidize the oxidizable organic matter. Usually a sample of 50 ml volume is used; however when other volume are used, keep ratios of reagent weights, volumes and strengths constant. The standard 2-h reflux time may be reduced if it has been shown that a shorter period yields the same results.

Method validation

Chlorides, nitrites, and iron are the main interfering radicals, inadvertently increasing COD, whereas straight-chain aliphatic compounds, aromatic hydrocarbons and fatty acids do not, or partly show up in the COD value.

Remedies

The interference by chlorides can be eliminated by addition of mercuric sulphate (HgSO4) to the sample prior to addition of other reagents. About 480 mg of HgSO4 is adequate to complex 20 mg Cl- ions in the form of poorly ionized mercuric chloride (HgCl2).

Nitrite exerts a COD of 1.1 mg/mg N. 120 mg of sulphamic acid is added to the Potassium dichromate, K2Cr2O7 solution in order to prevent the NO2 interference. When 20 ml sample and 10 ml dichromate is taken, this can take care of concentrations up to 6 mg /L NO2–N.

Silver sulphate is added to concentrated sulphuric acid H2SO4 (22 g/4 kg acid) as catalyst. This accelerates the oxidation of straight chain aliphatic compounds and aromatics compounds too.

For complete and better oxidation of organic matter it is necessary to see that the final concentration of H2SO4 concentration is at least 50%.

Sampling and Preservation

Samples should preferably be collected in glass bottles or clear plastic bottles. If samples are not analysed within 2 hours, preserve by reducing the pH to □ 2 using concentrated sulphuric acid. Samples should be well mixed before taking aliquots for reflux.

Reagents

Digestion solution

□ Distilled water

□ Potassium dichromate (K2Cr2O7) – primary standard grade

□ Concentrated sulphuric acid

□ Mercuric sulphate (HgSO4)

Add to about 500 ml distilled water, 10.216 g K2Cr2O7, primary standard grade, previously dried at 103 □C for 2 h, 167 ml conc. H2SO4 and 33.3 g HgSO4. Dissolve, cool to room temperature, and dilute to 1000 ml.

Hazards

Concentrated sulphuric acid is very corrosive. Gloves, laboratory overcoat must be put on. Use of gas mask / face shield is encouraged to avoid inhalation of fumes. Mercuric sulphate is poisonous. Use fume cupboard for preparation of the digestion solution.

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Equipment and Apparatus

a. Digestion vessels

Preferably use borosilicate culture tubes, 16- x 100-mm, 20- x 150-mm, or 25- x 150-mm, with TFE-lined screw caps. Alternatively, use borosilicate ampules, 10-ml capacity, 19-to 20- mm diam.

b. *Heating block*: Cast aluminium, 45 to 50 mm deep, with holes sized for close fit of culture tubes or ampules.

c. *Block heater or oven*, to operate at 150 □ 2 °C.

Note: Severe damage of most culture tube closures from oven digestion introduces a potential source of contamination and increases the probability of leakage. Use an over for culture-tube digestion only when it has been determined that 2 h exposure at 150 °C will not damage the caps.

d. *Ampule sealer*: Use only a mechanical sealer to insure strong, consistent seals.

e. *Spectrophotometer*, DR/2000, DR/2010

f. Spectrophotometer cuvettes

Procedure

Before use of each inspect culture-tube caps for breaks in the TFE (tetrafluoroethylene) liner. Select culture tube size for the degree of sensitivity desired. Use the 25- x 150-mm tube for samples with low COD content because a larger volume sample can be treated.

a. Treatment of samples:

Measure suitable volume of sample and reagents into tube or ampule as indicated in Table 5330-1. Prepare, digest and cool samples, blank, and one or more standards as directed in Section 52220C.4.

b. Measurement of dichromate reduction:

Invert cooled samples, blank, and standards several times and allow solids to settle before measuring absorbance. Dislodge solids that adhere to container wall by gentle tapping and settling. Insert unopened tube or ampule through access door into light path of spectrophotometer set at 600 mm. Read absorbance and compare to calibration curve. Use optically matched culture tubes or ampules for greater sensitivity, discard scratched or blemished glassware.

c. Preparation of calibration curve: Prepare at least five standards from potassium hydrogen phthalate solution with COD equivalents from 20 to 900 □g O2/L. Make up to volume with distilled water, use same reagent volumes, tube, or ampule size, and digestion procedure as for samples. Prepare calibration curve for each new lot of tubes or ampules or when standards prepared in 4a differ by –5% from calibration curve.

Calculation

COD as mg O2/L = mg O2 in final volume x 1000

ml sample

Results are expressed in mg/L COD as O2

Analytical Quality Control (AQC)

Use Potassium Hydrogen Phthalate as standard substance or do as for BOD. Both depend upon the COD value. For samples having a COD higher than 400 mg/L, precision up to 2 % is expected from good analyst. As the COD value goes on decreasing, the precision also becomes poorer and poorer.

The precision of the low COD samples may be improved by a method where diluted reagents are used. The accuracy of this method is till now not very clear. For most organic compounds the oxidation is 95 % to 100 % of the theoretical value.

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