FAECAL WASTE MANAGEMENT PRACTICES AND PERFORMANCE OF SANITATION SERVICE CHAIN IN MARSABIT TOWN, MARSABIT COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other institution.

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DECLARATION BY SUPERVISORS

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DEDICATION

I dedicate this thesis to my Dad Ali Mohamed and Mum Batula Jaro who gave unwavering support in the course of my project development as well as thesis writing.

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LIST OF ACRONYMS

BCT	Behavior Change Technique
CLTS	Community Led Total Sanitation
CLTSH	Community Led Total Sanitation and Hygiene
COD	Carbon Oxygen Demand
CSB	Community Sanitation Block
EED	Environmental Enteric Dysfunction
EU	European Union
FSM	Faecal Sludge Management
FWFC	Faecal Waste Flow Calculator
IBMWASH	Integrated Behavioral Model for Water, Sanitation, and Hygiene
IBNET	International Benchmarking Network
IRC	International Resource Centre
JMP	Joint Monitoring Programme
KDHS	Kenya Demographic and Health Survey
KNBS	Kenya National Bureau of Statistics
KPHS	Kenya Population and Housing Census
LMICs	Low- and middle-income countries
MAXQDA	Maxweber Qualitative Data Analysis
MDGs	Millennium Development Goals
NGO	Non-Governmental Organization
OD	Open Defecation
ODF	Open Defecation Free
OSS	On-site Sanitation Systems

PAS	Performance Assessment System
RANAS	Risks, Attitudes, Norms, Abilities, and Self-regulation
SBM	Swach Bharat Mission
SDGs	Sustainable Development Goals
SFD	Shit Flow Diagram
SHINE	Sanitation Hygiene Infant Nutrition Efficacy
SL	Shared Latrine
SSA	Sub-Saharan Africa
SSP	Sanitation Safety Planning
TSC	Total Sanitation Campaign
UNICEF	United Nations Children's Fund
USD	United States Dollar
USAID	United States Agency for International Development
VFA	Volatile Fatty Acids

OPERATIONAL DEFINITION OF TERMS

Community-led total sanitation	is an approach that focuses on igniting a change in sanitation behavior through community participation rather than constructing toilets
Open defecation free	is the termination of faecal-oral transmission where there is no visible faeces found in the environment, and every household as well as institutions use safe technology option for disposal of faeces
Sanitation	is the process of keeping places clean and healthy especially by providing sewerage system and a clean water supply

ABSTRACT

Safe faecal waste management can reduce transmission routes where pathogens in faecal particles pass from one person to the mouth of another. Globally, 780 million people lack access to safe water and approximately 2.5 billion people in the developing world have limited access to adequate sanitation, a situation that has led to increased mortality due to sanitation related illnesses. This research sought to explore the faecal waste management practices among households across sanitation service chain in Marsabit town, Marsabit County, Kenya. Descriptive cross-sectional study design adopting mixed method was used and the study targeted a sample size of 612 households sampled from nine (9) Zones. Data collection was done through observations and interviews. The SPSS tools were used for data analysis and generating tables. About 64.9% of Marsabit county population practice open defecation. Toilet position during defecation differed from person to person and was culture-dependent. Out of 612 respondents approximately 81% (n=495) respondents reported squatting during defecation as a common preferred toilet use. Sitting position was at 19% (n=117). Majority of the community were washers at 77.6% (n=475) and wipers at 22.4% (n=137). Approximately 70% (n=429) responded abandoning their latrine once they are full. Infant mortality has been observed in Marsabit county with increased mortality especially in children under five years of age, occurring daily. This could be attributed to lack of adequate sanitation leading to open defecation, poor hygiene as well as the low water table in the area

CHAPTER ONE: INTRODUCTION

1.0 Introduction

The chapter explores the background of the sanitation situation globally, regionally, and nationally and the sanitation challenges.

1.1 Background Information

Globally, 780 million people lack access to safe water and 2.5 billion people in the developing world live without access to adequate sanitation (Agingu *et al*., 2020). It is estimated up to 38 million Indians are affected by waterborne diseases annually and approximately 1.5 million children die of diarrhea and more than seventy working days are not recovered due to waterborne disease each year (UNICEF, 2019). Lack of adequate urban governance, economies that are growing in each country, population increase in urban community, lack of enough housing and degrading sanitation in slum areas of cities have created environment for waterborne diseases (Ayessa *et al*., 2016).

High rates of urban development and shift of focus to Sustainable Development Goals (SDGs) cover the period from 2015 to 2030 suggest that the challenge for sanitation in the future will be even greater. The urban population will rise to 6.7 billion by 2050 (United Nations Department for Economic and Social Affairs, 2018). Shit flow diagram (SFD) approach has had rapid uptake and is now accepted as a tool for focusing political will and technical effort on critical sanitation problems at city level. For example, based on this approach, the World Bank developed the Faecal Sludge Management (FSM) Diagnostics for Service Delivery in Urban Areas tools (Scott *et al*., 2019) and the International Resource Centre (IRC) developed a Faecal Waste Flow Calculator (IRC, 2018).

The monitoring and evaluating the target 6.2 of the Sustainable Development Goals have had tremendous experience as its indicator the proportion of the population with safely

managed sanitation. Although the definition of safe management used by the Joint Monitoring Programme for Water Supply, Sanitation and Hygiene (JMP) is not the same as those used to prepare an SFD (World Health Organization/United Nations Children Fund, 2017). The 2018 World Health Organization guidelines on health issues and sanitation-related problems have made use of the SFD methodology (World Health Organization [WHO], 2018).

Onsite sanitation systems, in developing countries, are sustainably resilient and potentially suitable for faecal management, since they adapt more to environmental and demographic changes and can permit the recovery of nutrients. Yet only about 18% of faecal sludge produced from these onsite amenities globally gets treated before disposal or end-use (Weststrate *et al*., 2019); this contributes to underground water pollution, agricultural produce contamination, and the spread of enteric diseases like helminths and diarrhoea. Sanitary collection, treatment and disposal, or reuse of faecal matter (FM) from onsite sanitation facilities like septic tanks and pit latrines remain a daunting task especially in low- and middle-income countries (Diener *et al*. 2011), and the sludge is directly discarded into nearby fields or water bodies.

A Shit Flow Diagram report by Naveen Kumar (2020) from Centre for Science and Environment in Barwar India based on sample household survey, KIIs and FGDs with relevant stakeholders showed that approximately 100% of population was dependent on the On-site Sanitation Systems (OSS). According to Ahilan (2020), as many as 47 per cent toilets were in just four districts of Poorva Medinipur, Birbhum, Bankura and Cooch Behar. Those made by communities of NGOs were more accessible (68%) than government-made funded ones (56%). Toilets were inaccessible because they were locked (60%), damaged with broken fittings (28%) or incomplete (6%).

Mihaylova (2019) explains that especially in North Macedonia and Albania, the water and sanitation supply was well below EU standards, but there was also a strong need for action in Romania. In the three countries, there is an increased deficit between rural and urban areas on infrastructure development and the improved living conditions. In rural areas, the supply of clean water and sanitation systems are not up to date and need to be improved (Hanjra *et al*., 2016). Families were often dependent on wells for their water supply, which was usually not adequately protected against anthropogenic pollution. Demmelbauer (2019) further discusses that information on water quality was not known or accessible to the public in rural areas.

Studies have shown that safe latrine pit emptying services is substantially lower than market prices, and household contributions only covered an estimated 47% of safe pit latrine emptying costs in rural Bangladesh (Evans *et al*., 2017). 40% of emptying costs in urban Rwanda (Murray *et al*., 2019), and 25–50% of emptying costs in urban Kenya (MacLeod *et al*., 2020).In Tanzania and Kenya, experimental trials found that less than five percent of rural households were willing to pay the market price for latrine slabs, though demand was much higher at discounted levels: approximately 90% of households in Kenya (Peletz 2019) while 60% in Tanzania (Haji 2017) were willing to pay some amount for latrine slabs.

Contaminants in pit latrines may migrate into surface water and ground water systems serving as drinking water sources and pose human health risks according to Gwenzi (2023). This results into contaminants' movement from pit latrines to groundwater. Health and social problems can arise from lack of emptying and maintenance of these facilities (Umer 2022). However, there are differences in pit latrine filling and decomposition rates, which are linked to variety of external factors such as number of latrine users, presence of household waste, latrine habits of users, anaerobic conditions,

soils that surround the pit latrine and the groundwater. This is important from a public health perspective given that the pits either need to be emptied after filling, or become unusable, leading to increase in open defecation. These risks potentially increase exposure to diarrhea and other pathogens. Understanding best how pit latrine microbiota might be linked to pit fill-up rates by determining how bacterial activity changed with the pit latrine depth and if these activities could be correlated with filling rates and environmental conditions in the pit is important (Farling *et al*., 2019). The study observed clear differences in bacterial communities across pit latrine sample depth and were able to correlate specific microbial taxa with environmental parameters and filling rates.

Pathogens have been observed to be consistently abundant across pit latrine depth, but these changes in the environmental conditions which may impact the overall microbial communities, and decomposition rates within different regions of the pit. The distribution of microorganisms within an individual pit latrine is an important factor Capone (2021). However, the distribution of microbial communities and source of microbes that is most responsible for decomposition or fill-up rates remain unknown. Therefore, it's necessary to understand how pit latrine microbiota might be linked to pit fill-up rates by determining how the microbiota changed with pit sample depth and if these could be correlated with filling rates and environmental conditions in the pit Ndoziya (2019). Also this study aimed at investigating the faecal waste management on service delivery along sanitation service chain in Marsabit town, Marsabit County, Kenya from collection, transportation, treatment and reuse or disposal of the generated faecal waste.

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and filling rates as microbial pit latrine research has primarily focused on assessing water contamination downstream.

1.2 Problem Statement

Majority of the urban population in Sub-Saharan Africa (SSA) use pit latrine as their primary means of excreta disposal. In informal settlements, household pit latrines are mainly shared by a large number of people resulting in high filling rates (Manga *et al*., 2022a).On-site sanitation systems often represent a significant contamination threat towards groundwater associated with faecal matter accumulations which can result in leaching of contaminants into the subsurface aquifer. Leachates in pits can lead to both microbiological and chemical contamination. In a pit latrine, the liquid fraction of waste that infiltrates into the soil is referred to as the hydraulic load. Since pit latrines are usually not sealed, higher hydraulic loads cause direct contamination of groundwater sources. Designs of most pit latrines allow the liquid waste to infiltrate into the soil (Chirwa *et al*., 2017).

About 50% of household in Marsabit County have no access to improved source of water for basic use and less than 30% have access to basic sanitation (Nutrition smart survey 2019). Marsabit town is not served by a public sewer line for effluent management. Sewage generated in 2017 was 3,464 cubic meters per day, and it's projected to become 4,379 cubic meters per day in 2027 (WHO 2018). There is no data collection, disposal and treatment strategies of faecal waste of Marsabit town along sanitation service chain. The research intends to evaluate faecal waste management practices in Marsabit town, Marsabit County, Kenya as informed by these challenges.

1.3 Significance of Study

The total annual capital costs of meeting SDG target 6.2 have been estimated at USD19.5 billion for achieving basic sanitation and USD49 billion for safe faecal waste

management (Hutton and Varughese, 2016). Given that 2.7 billion people worldwide currently use onsite sanitation systems, and since this is also the preferred system in many regions based on logistical reasons, costs or water scarcity, the challenge is extreme and solutions are needed (Hutton *et al*., 2016).The government of Kenya has limited approach to policy on onsite sanitation system for faecal sludge management. The government of Kenya will need to look into the most suitable approach between improved on-site sanitation systems for faecal sludge management and expansion of networked sewerage solutions to maximize service delivery at affordable costs which aims at meeting SDG target 6.2.

Shit flow diagram (SFD) is useful tool to inform urban sanitation by visualizing the status of urban sanitation services on the fate of excreta. The study will offer innovative ways to engage stakeholders from political leaders to sanitation experts and civic society organizations in coordinated dialogue about excreta management in Marsabit town. Marsabit County has no sanitation management system across the county. It lacks basic sanitation management system, with communities left to establish convenient sanitation disposal system. The finding is significant to policy makers, environmentalist and urban planners to bridge the gap that will reduce disease burden associated with poor sanitation associated with collection, disposal and faecal waste treatment strategies.

1.4 Research Questions

i. What are waste collection practices performances of sanitation service chain in Marsabit town, Marsabit County, Kenya?
ii. What are waste disposal practices and performance of sanitation service chain in Marsabit town, Marsabit County, Kenya?
iii. What is waste treatment strategies performance of sanitation service chain in Marsabit town, Marsabit County, Kenya?

1.5 General Objective

To investigate the faecal waste management on service delivery along sanitation service chain in Marsabit town, Marsabit county, Kenya.

1.5.1 Specific objectives

i. To examine waste collection practices performance of sanitation service chain in Marsabit town, Marsabit County, Kenya
ii. To examine disposal of waste and performance of sanitation service chain in Marsabit town, Marsabit county, Kenya
iii. To identify waste treatment strategies performance of sanitation service chain in Marsabit town, Marsabit County, Kenya

1.6 Limitations

The questionnaires were written in English, but not all respondents understood the language. The questions were translated for easier communication. Faecal matter is a topic some respondents shy away and did not want to talk about. However, the researcher explained to the respondents that the study on faeces was for academic use.

1.7 Delimitations

This study was delimited to households in Marsabit town, and focused on household heads. It examines the faecal waste collection, faecal waste treatment and faecal waste disposal practices.

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

Improving water and sanitation is part of the United Nations' which include the 2030 target for development of sustainable urban communities which aims at equitable sanitation, improved hygiene for people living in rural and urban areas, and the end of open defecation (WHO, 2017). A set of recent randomized trials has shown that interventions containing infrastructure, information and communication components can increase latrine ownership (Ben 2017). Some have also demonstrated health benefits from latrine adoption and reduced open defecation (Cameron *et al*., 2021). The World Bank (2013) estimates that globally, economic losses from lack of sanitation amount to US$ 260 billion annually. Hutton *et al*. (2007) estimate that each dollar spent on improved sanitation generates an economic benefit of about US$ 10.

Access to sanitation facilities also reduces the risk of rape or sexual assault for women and girls (Lennon, 2011) as those who are compelled to defecate in the open and after dark expose themselves to serious danger. Girls are particularly vulnerable and require adequate and separated sanitation facilities at schools that are appropriately designed for menstrual hygiene management. Adequate access keeps girls from dropping out of schools, and increases their attendance rates (Mahon & Fernandes, 2010). Safety and privacy are very strong motivators for women wanting a latrine. The safe and final disposal and/ or productive uses of faecal sludge remain a neglected area. It is estimated that 4 billion people lack access to safe sanitation when the safe and final disposal of faecal sludge is taken into account. Improved sanitation is linked to food security and energy production.

Opportunities exist in capturing and productively using human waste as a resource for nutrients, organic matter, energy and water. For instance, the value of human excreta from one single person in Niger equals US$ 9 annually: for a Nigerian household of nine, this is equivalent to approximately 90 kg of chemical fertilizer per year, an amount beyond the reach of many local, small-holder farmers (Linus, 2009).

Over time, in many different places and cultures, local farmers and entrepreneurs have recognized the value of human excreta and wastewater. Scott *et al*. (2004) estimate that approximately 700 million people in 50 countries eat food from crops irrigated with untreated or inadequately treated wastewater from sewage systems. They estimate that a total areal surface of at least 20 million hectares is irrigated with unsafe water. Finally, sanitation is everybody's business and in everyone's interest. Hence, it is the responsibility of governments to ensure public and environmental health for all: sanitation is in the public's interest from a preventative health, education, economic and human rights perspective.

The public sector therefore needs to assume a key role for the provision of sanitation services. For this role to materialize, political commitment to sanitation is needed at all levels. However, in many cases this commitment is insufficiently present.

2.1 Faecal Management Service Chain

Sustainable Development Goal (SDG) 6.2 draws the focus on safe human excreta management along the entire sanitation service chain, from waste generation and containment to disposal or reuse instead of only addressing access to sanitation facilities (UNICEF & WHO, 2020). Faecal management (FM) entails all activities for the adequate storage, collection, transport, treatment, and safe end use or disposal of faecal (Strande *et al*., 2014) within non-sewered sanitation systems such as pit latrines and septic tanks. There is an increasing acknowledgment at the international and national

level of the need for equitable sanitation services in urban areas and cities where rapid urbanization places pressure on service delivery.

Sanitation refers to the management of generated human excreta and wastewater through its safe containment, handling, and final disposal or reuse, thereby preventing the waste's disposal directly into the environment.

In many Sub-Saharan cities, onsite sanitation technologies such as pit latrines constitute the majority compared to sewer systems (AfWA, 2017). Globally, access to sanitation in urban areas is estimated at 65–100% with a negligible safe disposal of faecal matter posing a groundwater quality risk and water-borne diseases (Strande *et al*., 2014). There is a dire need for adequate faecal sludge management for onsite sanitation systems to safeguard human health and prevent environmental pollution (Rao *et al*., 2017).

Faecal waste management has the potential to improve health outcomes and provide livelihood opportunities for the populations. Unsafe faecal disposal brings health and environmental risks, disrupts drinking water supply treatment, and in turn undermines water security and sustainable growth. African economies have had high financial losses in addressing these environmental and public health threats documented to have undermined human welfare and national economic development aspirations (Mara *et al*., 2010).

Onsite sanitation systems and subsequent faecal waste management are key components of sanitation services to safeguard human health and prevent environmental pollution. Therefore, their inclusion in sanitation plans of urban areas of low and middle-income countries is valid (Rao *et al*., 2017). Onsite sanitation systems provide global sustainable solutions, especially in densely populated urban areas of low- and middle-income countries.

The effective management of faecal sludge should address the entire sanitation service chain and which comprises all activities of containment, collection, storage, conveyance, treatment, and end-use (Cross & Buckley, 2016; Gitonga *et al*., 2021; Okoth *et al*., 2017). Pearl *et al*. (2014) checked the quality of urban sanitation services in 12 Sub-Saharan Africa (SSA) Countries and the findings illustrated the importance of FSM models of service delivery that conform with the sanitation service chain. Similarly, a city service delivery assessment of faecal sludge management services recommended the need for a well-functioning service chain in Dhaka, Bangladesh (Ross *et al*., 2016).

In five cities in the Global South, onsite sanitation technologies inferred as "non-networked" serve low-income countries and discharged faecal sludge to the local area and irrigation channels (Scott *et al*., 2017). In Tamil Nadu India, onsite sanitation systems such as improved pit latrines and septic tanks serve 42% of the population (Devaraj *et al*., 2021). In Kenya's informal settlements, onsite sanitation systems are predominant, whereas in Kibera a slum 28% of households empty pit latrines manually, and 33% use mechanical means (Okoth *et al*., 2017). The faecal sludge from networked onsite technologies is taken to the transfer station in Mukuru and Kibera slums (Mallory *et al*., 2021). It appears the major onsite sanitation facilities such as pit latrines, and septic tanks serve low-income areas.

The need to find ways to manage faecal sludge and get human excreta out of the urban environment as well as the development of sustainable and globally relevant solutions for managing faecal into the future drive faecal waste management. The FWM sanitation service chain comprises a system of onsite containment of excreta, emptying and transportation of FS, treatment, and safe disposal or end use as resource recovery. Containment or Faecal capture is the starting point for management. The proper containment of faecal waste prevents feces from spreading into the environment,

reducing the risk of contamination and allowing for pre-and subsequent faecal waste treatment and facilitating collection, quantification, and transportation. Faecal can be removed by mechanical means or manually depending on the type of containment system, the local climate, access to the site, the type of equipment used by the service provider, and their expertise level (Strande *et al*. 2014). The user interface/containment and emptying/ collection, therefore, guarantee convenience, dignity, and quality of life and safeguard residents' health. Single pit systems are the most common systems in Kenya requiring a single-pit technology to collect and store excreta. Depending on the user interface, the system is used with or without flush water. The user interface (dry or pour flush toilet) is directly connected to the collection and storage/ treatment of single pit or single ventilated improved pit.

When the pit system is full, faecal waste is removed and transported for further treatment using either human-powered emptying and transportation or motorized emptying and transportation. The collected faecal is either transported to a wastewater treatment plant or discharged directly into the surrounding environment.

2.2 Policy and Practice in Faecal Sludge Management

Policies are important in regulating and controlling the faecal sludge management chain. A case study in Dhaka, Bangladesh reiterated that public policy on FSM services is in severe shortage, which has caused many challenges such as missing the FSM framework, and latrines discharging faecal sludge to drains (Ross *et al*., 2016). OneWASH National Program was incorporated into the Integrated Urban Sanitation and Hygiene Strategy in Ethiopia, which indicates that FSM is a priority.

As for Dar es Salaam where the majority of the onsite facilities are toilets, the municipal bylaws regulate the FS (Ross *et al*., 2016). However, in Kenya and Haiti, policies are unclear and fail to incentivize the use and sale of fertilizer (Moya *et al*., 2019). Similarly,

the urban sanitation situational analysis in Nairobi by Mansour *et al*. (2017), in Kenya, affirmed that sanitation policy frameworks are fragmented.

In Malawi, Nyirenda and Holm (2015) castigated that little has been done in formulating policy to inform the stakeholders charged with ensuring that the faecal sludge management service chain is provided. The legislative antagonism existed in the FSM services between the public health Act and National Environmental Act (Nyirenda & Holm, 2015; Strande *et al*., 2014).

However, Mansour *et al*. (2017) asserted that sanitation frameworks exist and with diverse service provisions models, but significant overlap and fragmentation of roles exist between the ministry of water and the ministry of health. The Kenya Environmental Sanitation and Hygiene Strategic Framework (KESSF) 2016-2020 formulated by the ministry of health envisage the roadmap for improved urban sanitation sustainability. However, Nanyonjo *et al*. (2020), study resonates faecal sludge management in Kenya is disregarded within the legislative and policy frameworks and is less likely to be operationalized in the plans of the government.

2.2.1 Measuring collection service delivery practices

The water, sanitation and hygiene sector (referred to as the WASH sector) is facing deep-seated challenges. While all people have a basic human right to safe water and hygienic sanitation1, the reality is—that at least two billion people are unable to maintain a safe separation between themselves and their own or other people's excreta (UNICEF/WHO, 2012). Despite decades of sector reforms and billions of dollars of investment, progress towards achieving universal access to basic WASH services has been frustratingly slow, particularly for sanitation, with dramatic impacts.

In their economic analysis, Hutton and Haller (2004) reported that the lack of adequate sanitation and hygiene results in 5.4 billion cases of diarrhea leading to 1.6 million

deaths, mainly among young children, each year. Sustained access to adequate sanitation has benefits other than those directly related to health.

WASHCost was a five-year action research Programme, led by International Resource Centre (IRC), running from 2008 to 2012 with partner organizations in Burkina Faso, Ghana, Andhra Pradesh (India) and Mozambique. WASHCost collected and analyzed cost and service level information for water, sanitation, and hygiene in rural and peri-urban areas, applying a life-cycle costs approach.

A life-cycle costs approach examines the complex relationships between expenditure, service delivery, poverty, effectiveness and sustainability. WASHCost's key sanitation-related findings were; Public expenditure on sector sanitation policy, planning, monitoring and staffing (indirect support) is not prioritized in the WASHCost research countries.

There were equity issues, especially in rural areas; WASHCost research suggests that it is unlikely that poor families can meet the costs of a basic and decent sanitation system. Technically advanced latrines cost more but do not necessarily deliver significantly better services. This may reflect an expenditure that is damaging service levels and sustainability. Improved traditional pit latrines are capable of delivering similar levels of service to more expensive latrines, and do not seem to require higher operating and maintenance expenditure.

In Burkina Faso, Mozambique and Ghana, higher levels of service are achieved in peri-urban/ small town areas in comparison to rural areas, due to improved environmental protection and reliability. This coincides with generally higher construction expenditure and recurrent costs. The need for improved sanitation in higher-density urban areas is apparently recognized by households. The research makes a strong case for policy makers to refocus their sanitation priorities. Planning for demand creation and latrine

construction is important. It is also critical to plan for higher expenditure on support and measures to promote latrine use and environmental protection, including systems for pit emptying and the safe disposal of faecal sludge.

A sanitation service focuses on the long-term provision of sanitation services for all and at scale, while meeting the following parameters; it provides access to sanitary latrines; it ensures continuous and hygienic use by all, throughout the year, for people in and around the household; it ensures that latrines are maintained, replaced, and emptied when full; and, faecal sludge is safely disposed of or used productively, to ensure that there are no negative impacts on the environment.

A sanitation services model describes the way in which sanitation services are provided. 'It defines the legal and institutional scope for delivering service, including commonly understood and accepted roles for the organizations involved' (IRC, 2012). The BRAC WASH Programme is an example of a large-scale sanitation system that encompasses key determinants in ensuring sustainability.

The BRAC WASH Programme seeks to create a lasting change in the lives of 55 million people living in rural Bangladesh by ensuring that all use a hygienic latrine, adopt safe hygienic behavior, and have access to safe drinking water. Providing girls in secondary schools with adequate access to sanitary facilities is also key to the Program's aims. Changes in practices (such as handwashing with soap, continued use and maintenance of latrines, using safe water sources or keeping water safe from source to mouth) take time to establish.

The key components of the BRAC WASH Programme that signify success are; 'Telling not selling' with a focus on seven key behaviors related to water, sanitation, and hygiene: It involves a combination of social mobilization and social marketing, and is characterized by frequent interpersonal communication through different channels.

Activities in communities are initiated through social mapping, establishment and orientation of the Village WASH Committee (VWC), and a series of cluster meetings with different groups.

Strengthening the supply chain: To ensure the availability of sanitation products such as rings and concrete slabs, at least one Rural Sanitation Mart (RSM) per union has been set up. Through capacity strengthening activities (trainings) and granting loans (credit), a total of 1,648 RSMs have been set up. Strengthening of enabling environment: The VWC plays a key role during Programme implementation and in monitoring progress in all communities. The enabling environment includes clearly-developed implementation strategies and guidelines and the implementation of a rigorous performance monitoring system.

Appropriate financial arrangements: Individual household latrines are financed through three channels: self-finance (nonpoor), soft loan (poor), and hardware subsidy for the hard-core (extremely) poor. Latrine construction in schools is jointly funded by the school (with support from parents) and BRAC WASH. Sanitation entrepreneurs receive a soft loan of Thaka 10,000.

The first phase focuses on providing easy access to sanitary household latrines and ensuring use by all. This is termed: “stepping onto the sanitation ladder”. This phase is the establishment phase in the sanitation service: it includes a process of establishing relationships between stakeholders, of constructing infrastructure, and of advocating and affirming hygiene behavior patterns.

The second phase seeks to ensure that services are reliable, and that faecal sludge is disposed of safely (or used productively) to protect the environment from further degradation: in other words, activities in phase 2 make sure that households stay on, and/ or progressively climb the sanitation ladder. Also referred to as the consolidation phase,

systems are set in place and households affirm their adherence to safe and acceptable sanitation practices. During this phase, specific attention is paid to operation and maintenance, replacement and improvement, and the safe and final disposal of faecal sludge or its productive uses thereof.

The sanitation service framework described in this paper accentuates the following significant gaps and weaknesses in current knowledge on non-sewered sanitation service delivery; Models and approaches for the delivery of non-sewered sanitation services that have emerged over the years are limited in their focus, and most of these models and approaches focus on the initial implementation phase.

Limited attention is given to ensure sustainability of, or the possibility to scale up the service provision. There are many gaps in existing and combined global knowledge, such as: the efficiency and effectiveness of different approaches for demand creation and behavioral change, low-cost sanitation technologies for areas with high groundwater tables or are flood prone, the safe disposal of faecal sludge at scale, and the sequencing and linking of different sanitation components.

2.2.2 Measuring treatment service delivery practices

Communities everywhere include households with diverse individual and collective ways of managing excreta. It has been estimated that over 3.1 billion people globally rely on household on-site sanitation facilities pit latrines, cesspits and diverse septic systems (UNICEF & WHO, 2019), and this population is anticipated to increase to 5 billion by 2030. The on-site systems function by containing excreta, either in a pit latrine which receives excreta with minimal water until it is filled, when its contents are emptied as faecal sludge or in some form of septic system which allows for the management of large amounts of wastewater without necessarily spilling directly into the local environment. In this paper the term “septic system” in quotation marks refers to any of a wide variety

of poorly designed and operated on-site sanitation systems which receives wastewater, stores septage, and discharges liquid effluent to the environment.

In contrast, the term septic system without quotation marks refers to a much narrower, and rarer, subset of well-designed and operated systems which meet common widely accepted engineering design criteria for septic systems to improve performance. The term pit refers to an on-site sanitation system which receives excreta or wastewater into a hole, and stores faecal sludge as the liquid fraction ex-filtrates into the surrounding soils.

In India, about 45% of the urban households about 600 million people (Plecher, 2020) are served by on-site sanitation systems –mainly "septic systems" (Rohilla *et al*., 2016b). In Urban Tamil Nadu, India, around 38% of households use "septic systems" for their sanitation needs, 27% are connected to sanitary sewers, and 35% use others (such as pit latrines (6.0%), shared facilities (9.9%), direct discharge pipes (1.2%), open defecation (16.5%), (IIPS and ICF, 2017).

This range of sanitation technologies and service chains poses practical and important questions for sanitation managers which is a greater public health priority in a given city: reduction of covert faecal sludge dumping from "septic systems" and pit latrines, or better wastewater treatment? Reduction of the immediate direct discharge of black-water to the environment or open defecation by a small fraction of the population, or better treatment or control of "septic system" effluent discharged by many? Such decisions should reflect the relative benefits, costs, reliability, and operation and maintenance requirements of different technologies, which all vary with local conditions (Georgia Department of Public Health, 2019).

In principle, a septic system consists of both a well-designed watertight chamber and fully-lined tank that receives domestic wastewater for basic treatment through sedimentation and anaerobic processes to reduce organics and total solids; and the

effluent receiver such as a drain field for further treatment and disposal of the tank effluent (Wang *et al*., 2021). However, the design, construction, operation, and maintenance of septic systems are not well understood by users, policy makers, and utility authorities especially in the global south. This confusion has resulted in a chaotic mixture of poorly designed and constructed tanks/on-site sanitation systems for management of excreta, with widely varying effluent quality and disposal practice, with little or no concern for public health (Strande, 2018).

The problem is complex because faecal sludge and effluent from on-site sanitation systems vary substantively, depending upon factors including type of containment, detention time, desludging practice, quality of construction, household usage, and operation of the system. Previous studies on the performance of on-site sanitation technologies especially septic systems focus on removal of physical-chemical pollutant indicators (e.g. pH, conductivity, total suspended solids, biochemical oxygen demand, algal nutrients, from liquid effluent or faecal sludge (Prasad *et al*., 2021).

However, studies of pathogen reduction in septic systems are few. Some studies demonstrate that the fully-lined tanks of the septic systems act as primary treatment units for solids removal from wastewater, reducing *E. coli* concentrations by 1–2 Log_{10} – mainly through sedimentation (Abbassi *et al*., 2018); however these studies do not account for the release of *E. coli* in emptied faecal sludge and/or liquid discharge. 30% of the sewage collected in Trichy returns to the environment unsafely before reaching the treatment plant according to Rohilla *et al*. (2016a).

The unsafe return per household connected to the sanitary sewer was therefore computed based on; the reported daily water usage per capita in Trichy, (135 L/day), (TNUSSP, 2017), the average household size; the assumption that 80% of water used returns as wastewater; and the assumption that 30% of sewage returns to the environment unsafely.

The computed volume was considered as the household average daily discharge as sewage overflow release (q_D) in litres/day to the environment.

Pathogens, including *E. coli,* are released from containment systems through periodic desludging as well as in liquid effluent or overflow. Release in this study refers to removal from the containment system either as release to the environment or release to the next stage of the sanitation management chain; the fate of emptied faecal sludge is often unclear, with widespread reports of clandestine dumping or use as agricultural fertilizer.

In 2018, China alone had six megacities and ten cities with populations ranging from 5 to 10 million. According to projections, by 2030, there will be 43 megacities, the majority of which will be in developing countries, with nearly half of the top 30 largest urban areas located in low- or lower-middle-income regions. Large and small cities also play a key role in global urbanization. Nearly half of the world's urban residents live in settlements with less than 500,000 people. Another 22 per cent of the global urban population live in cities of 1 to 5 million inhabitants.

In some regions, and Sub-Saharan Africa in particular, urban growth is occurring in smaller towns and cities with a population range of 100,000 to 500,000. Over the next decade, the majority of the world's urban population will continue to reside in small cities. Urban populations are particularly vulnerable to climate change because of their size and density. For instance, concrete and asphalt surfaces in urban areas reduce infiltration, resulting in fast surface run-off that can increase flash floods and landslides. These events can damage urban infrastructure, hinder access to basic services, and threaten livelihoods. As well as being heavily impacted, cities are a key contributor to climate change.

An estimated 70 per cent of global CO2 emissions come from urban areas, primarily from transportation and buildings (UCCRN, 2018). Wastewater management also contributes to greenhouse gas (GHG) emissions. There is a relative lack of data on global emissions linked to sanitation, with some estimates suggesting the contribution of onsite sanitation systems is circa 377 Mt CO2e/year, accounting for 4.7 per cent of the total anthropogenic CH4 emission, with India and China as major contributors, and excluding emissions from other sanitation systems (Cheng et.al, 2022).

A whole-systems analysis of greenhouse gas emissions from citywide sanitation in Kampala, Uganda, suggests sanitation may represent more than half of total city-level emissions (Johnson *et al*., 2022) greater understanding of the importance of waste and wastewater disposal. The principle followed at first was to assume "the solution of pollution is dilution" (Angelakais *et al.,* 2018). Prior to the invention of the modern sewerage systems with associated treatment plants, the approach to wastewater management consisted mainly in directing wastewater onto water bodies, with the view that small amounts of sewage discharged into flowing water initiates a self-purification process.

However, densely populated areas generate volumes of sewage such that dilution alone is ineffective to prevent pollution – and stench. In London, "the Great Stink" of August 1858, when the smell of untreated human waste discharged in the river Thames became untenable for members of Parliament and inhabitants, prompted the start of works for wastewater management in the city. This started with the construction of sewers.

The first contemporary method of treating wastewater emerged in the 19th century. After that wastewater treatment appeared necessary prior to disposal from sewers. Centralized sewage treatment plants started to be built from the 19th century, primarily in the United Kingdom and the United States. Instead of directly being discharged into a nearby water

body, sewage was first processed to remove pollutants using physical, biological and chemical processes.

2.2.3 Measuring disposal of service delivery practices

Lack of safe sanitation systems leads to infections and diseases such as diarrhea. Leading causes of disease and death in children under five years in middle and low-income countries are neglected tropical diseases such as soil-transmitted helminth infections, schistosomiasis, and trachoma that cause a significant burden globally; and vector-borne diseases such as West Nile Virus, lymphatic filariasis and Japanese Encephalitis through poor sanitation facilitating the spread of Culex mosquitos (WHO&UNICEF, 2017). One in three households in Ethiopia has no toilet facility, leading to open defecation in the bush or fields 39% in rural areas and 7% in urban areas.

As a result, diarrhea contributes to more than one in every ten child deaths in the country. The situation in Kombolcha town is not different. It has been observed that no field research or evaluation has been conducted on the entire faecal sludge management system in Kombolcha town. Moreover, there is a lack of published documentation on comprehensive assessments comprising containment, emptying, transport or conveyance, treatment, and reuse or disposal, based on actual practices. The only available estimations are from WHO and UNICEF at the country level (WHO & UNICEF, 2017).

The housing types of the town can be classified into government rental houses, townhouses (narrow homes that share walls and toilets with neighboring units), private homes and condominium housing (a building with a maximum of four floors having multi housing unites ranges from 8 to 10 per floor that has a single toilet per housing unit). Approximately 379 government rental houses are occupied by low-income households. The remaining housing stock consists of around 7722 private houses, 931

townhouses, and 1545 condominium housing units according to the Kombolcha Town administration in 2019.

As a result, research on faecal sludge management services is crucial for saving lives and safeguarding community health. This study aims to evaluate the management of faecal sludge along the sanitation service chain, identify any gaps in the management process, and isolate the key building blocks for taking action. At present, overflow and leakage of pits, illegal pit/ tank outlet connections to drainage canals, and water bodies are the main problems. These, together with other unsanitary circumstances such as open defecation, lead to extremely serious environmental and community health hazards.

To overcome the faecal management limitations in the study area, research on entire faecal sludge management gaps along the sanitation delivery chain from containment up to end disposal/reuse is of paramount importance. Thus, this research was conducted to map excreta flows from containment up to end disposal to show the management gaps at each stage of the service chain and to provide baseline data for future intervention planning.

Currently, there is no available data regarding the distribution of shared or private toilet facilities by housing type and by flush, VIP, and pit latrine technologies in Kombolcha town. The only existing data is from the 2007 Central Statistical Authority (CSA) housing unit census, which provides information on the types of toilet facilities for 15,261 households in the town. Of these households, 3,505 (23%) had no toilet facility, while 861 (5.6%), 1,760 (11.6%), and 9,129 (59.8%) had access to a flush toilet, VIP latrine, and pit latrine technology, respectively, which may or may not have been shared. Out of the 243 representative sample housing units, 69.1% were privately owned houses. The survey did not randomly select respondents within multiple housing units, but instead relied on landlords as the primary source of information regarding faecal sludge

management arrangements. In cases (11.9%) where landlords were unavailable, tenants were interviewed. Of the 243 sample housing units surveyed, 81% were occupied by tenants of rental room within the landlord's compound (a mix of tenants and landlords). The rest 19% of sample housing units were government-owned and occupied by tenants or townhouses. Among these, 46% were shared house owners or townhouses, referring to narrow homes that share walls and toilets with neighboring units.

The principal goal being, to keep human faecal waste contained throughout the sanitation chain. An impact assessment to capture potential externalities from implementation of business models for Faecal Sludge Management (FSM) should be considered for future study. Internalizing the significant social and environmental benefits of safe FSM for reuse into corporate accounting can, in addition, easily justify financial support and public policy instruments for the set-up and operations of enterprises in this sector. Applying a systems-strengthening approach to the sanitation chain means looking at the chain in its entirety and making sure that each link is present and secure. It is only by ensuring that each segment of the sanitation chain works well that we can manage faecal waste properly, reduce environmental harm and health risks and ensure safe sanitation services that last for all.

The environment would then be protected and resources saved (Semiyaga *et al*., 2015). After treatment, the treated waste often called effluent is either safely disposed of or reused. Disposal methods may include discharge into water bodies (following strict regulations), land application for agricultural purposes (with proper treatment to meet health and environmental standards), or safe disposal in landfills. Reuse options may involve using treated wastewater for irrigation, industrial processes, or non-potable water needs.

In addition, economic value of faecal sludge end-products could incentivize more appropriate and viable faecal sludge management (Zewde *et al*., 2021). It is questionable whether sanitation sector stakeholders in low-income countries could perform vermicomposting or Black Soldier Fly Larvae (BSFL) composting, given the fact that these are sensitive processes and require skilled daily operation and maintenance, unlike solar drying and co-composting (Tayler, 2018). Since sector stakeholders appear to lack knowledge on certain treatment options, vermicomposting and BSFL composting technologies would require significant investment in capacity development and training before being introduced (Rao *et al*., 2017).

2.3 Faecal Waste Management on Service Delivery

In unimproved onsite sanitation facilities, the raw and slurry mixture of accumulated human excreta is called faecal sludge (WHO, 2017), and in the under-developed world, the most common unimproved sanitation option for defecation (UNICEF, 2017). With the tendency of population in the countries increase in the following years, Troeger (2018) noted that there are demands for rapid solutions to zero out the percentage of people without essential sanitation services.

The latrine components include of pit opened in the ground to accumulate human excreta (Adukia *et al*., 2021). In these facilities, the faecal sludge variates from a fresh solid to partially degraded and stabilized residue, depending on factors such as residence time, pit depth, and volume (Luby *et al*., 2018). When filled, latrines require periodic emptying, which can lead to the direct dump into the environment and to groundwater contamination, especially when the majority of latrines are either full or overflowing (Humphrey, 2019).

Aliyu (2020) have focused on communities in microbes of the pit latrines. The microbe in communities within pit latrines are hugely understudied and knowledge gaps remain

with respect to spatially, in temporal form, and environmental driver of microbiota composition and activity. Beukes (2019) discovered Bacillus and Pseudomonas species were the dominant taxa in ventilated improved pit latrines from South Africa. While geographic and user population differences may explain some of these observed differences, ventilated improved pit latrine in South African latrine have significant oxygen intrusion, which would impact the latrine microbiome, in particular the anaerobic digestion is typically the primary degradation process.

It was evident in a study by Abilahi (2019) that there are significant variations in microbe composed in pit latrines in urban and rural area that local environmental conditions are major drivers of microbial community assembly. There is high possibility of ground water contamination as pits are usually unlined and possibility of surface water pollution as in many cases, faecal sludge is emptied into water courses with devastating effects on surface water (Tobias *et al*., 2017).

Majority of latrine installation cost comes from pit lining, pit excavation and the making of cover slabs (Duku *et al*., 2018). Only the substructure of the pour-flush toilet for instance was estimated in year 2018 by Duku *et al*., to cost between GHS 1569–1726 (US$ 382.25 – 431.5) and that of the VIP toilet was estimated to cost GHS 1482 - 1630 (US$ 370.5 – 407.5). A similar project conducted in Mauritania by Ulrich *et al*., (2015) revealed that the cost incurred for lining the pit of latrines accounts for about 62%−76% of the total cost of latrine installations.

Kulabako (2016) and Gibson (2019) carried out study in Tanzania which showed that pit latrine sample depth was determinant and significant for community living in microbe structure, and vary as observed in lack of similarity in diversity of beta family, and increased microbe families, at different depths within latrines. This contradict the work by Holm (2021) who noted pathogen detection was largely consistent across pit latrine

sampling depth. The qPCR was used for pathogen initial detection in that work, so the wider microbiota was not studied.

It is therefore not possible to determine whether or not the observed consistent pathogen detection also occurred in parallel with consistent overall microbiota composition in that study. Pit latrine configuration may have played a key role as Capone (2021) studied lined pit latrines and reported that approximately 25% of the latrines in the study were lined which may have minimized interactions with the surrounding environmental microbial communities. Louis (2022) answered the question of whether the microbe community structure influenced fill-up rate beyond that variation that is accounted for by the environmental variables. The analyzed data indicated that microbial contents was correlated.

The finding may be partly explained by the top layers of the pit latrine being continually enriched with these gut-associated microorganisms, hence heavily-used latrines that fill up more quickly could have a higher proportional abundance of faecal microbes. Lactobacillaceae were particularly strongly correlated with pit latrine fill-up rates. The species of Lactobacillus, Pediococcus, and Paralactobacillus family generated lactic acid as primary product for fermentation which showed significance in the role of pit latrine dynamic of microbe that lactic acid was key obstacle of the structure of microbe community and activity in anaerobic environments which include the mammalian gut (Walker, 2022).

Veillonellaceae family included lactic acid-utilizing species according to Sheridan (2022) which was negatively associated with pit fill-up rates, adding further evidence that lactic acid production and consumption might be important for pit latrine microbiota functionality. The sedi Incertae taxa was decreasingly inclined with the fill-up rate. Thus, further analysis into the profiles of these organisms, and their interactions within pit

latrines may help to unravel these factors. These bacteria are from the class Clostridia and are commonly found in the gut, but are poorly characterized and not well understood. The study showed evident sample depth gradient within pit latrines, with gut-derived microbes associated with the upper layers and environmental-associated microbes with the lower layers, thus demonstrating that spatial sampling is key for understanding the processes and microbial activity within pit latrines. The aim of study by Torondel (2019) aimed at correlating microbe composition and measured environmental variables with pit fill-up rates. Volatile solids (VS) were associated in increased form with correlation of fill-up rate. This was showed by decomposition which was lower than the rate at which new organic material was added to the ventilated improved pit latrine.

The decomposition of faecal matter through anaerobic digestion or decomposition could reduce VS and the fill-up rates increased. The study showed pH was increasingly correlated with fill-up rate because of increased in both fill-up rates and pH. The correlation with pH is to some extent expected, as a lower pH indicates an increased microbial degradation activity due to the release of volatile fatty acids (VFA) in anaerobic fermentation (Schuman *et al*., 2019).

The increase of activity in fermentation might resulted to reduction of the fill-up rate. There was significantly increased VFA levels which upgraded the correlation in the study with the fill-up rate. According to Water and Sanitation for the Urban Poor (2018), the construction of sanitation infrastructure, consisted of subsidized provision of pour-flush toilets to septic tank with a drain field shared by multiple households in compounds. Compounds with approximately 15– 20 people received a shared latrine (SL) and generally compounds with ≥21 people received a community sanitation block (CSB).

Compound residents were expected to contribute about 8–10% of the construction cost and compounds contributed on average $97 for a CSB and $64 for a SL per compound,

but operation and maintenance costs, including pit-emptying, were not subsidized. High-water table areas were excluded from receiving sanitation infrastructure to prevent water infiltration into the system sub-structure. Additionally, intervention systems were designed with the intention that future emptying would be performed hygienically with mechanized equipment every two years, and access by a vacuum truck was a site criterion for community sanitation blocks and ≤60 m from a truck-accessible road but was not considered for placement of the shared latrine (Water and Sanitation for the Urban Poor, 2018).

Drabble (2018) explains that the proportion of shared latrines to community sanitation blocks emptied in the previous year was the same in Maputo as their proportion overall, suggesting both filled at similar rates. Intervention sanitation facilities were built during 2015–2016 and interviews took place in 2018. As some control respondents moved into their compounds after the on-site sanitation system had been constructed, the study was unable to accurately determine the year that control systems were built for comparison. Additionally, intervention systems were not built in areas with high water tables; and most control compounds were in the same neighborhoods as intervention compounds, but water table level was not a factor in control compound selection (Knee *et al*., 2018). Between August 2017 and February 2018, 25% (28/112) of the truck visits to the WWTP by the intervention pit-emptiers originated in intervention neighborhoods, suggesting the companies served low-income residents in the project area and residents outside the project area. Similar work by WSUP (2018) in Bangladesh demonstrated that for subsidized emptying companies a 70/30 mix of high-income and commercial customers to customers in low-income neighborhoods provided sufficient profit to encourage participation.

Renouf (2018) reviewed data provided by the Maputo local municipality to assess the prevalence of emptying activities by the intervention equipped pit-emptiers. Between August 2017 and February 2018, the pit-emptiers accounted for 0.95% (112/11,831) of all truck visits to dispose of faecal sludge at the WWTP. Amongst trucks originating from intervention neighborhoods, the pit-emptiers accounted for 4.2% (28/667) of truck visits to the WWTP. To guarantee service to low-income neighborhoods, WSUP subsidized emptiers in Bangladesh can be fined if less than 30 percent of their customers do not live in low-income neighborhoods. Where the market cannot support the full cost of emptying, and enough high-income residents exist to provide a cross-subsidy. A similar approach may be used to provide hygienic emptying services in Maputo. A study by Miriam (2023) discussed latrine performance, the reduced solids could be enhanced by controlling the moisture content. The average moisture content in the higher levels pit latrines was 69% and in the laboratory the moisture content in the bottles was higher than 98.5%. This shows that water addition would need to be controlled to avoid simply filling the latrine with water.

Walter (2023) discusses that a further difference with respect to the in vitro tests was that the contents of the bottles were well mixed so there is no local accumulation of intermediates or end products. Latrine contents were not mixed at present and this could be a further factor to explore together with moisture content in future research. In a larger study of 29 latrines where only top and bottom layer samples were compared, values of 47.8% ± 13.6 and 58.8% ± 28.2 that the demand for oxygen and carbon removal were used for average potential removal and actual removal. These would be expected to be lower than the values when the change from stool to top layer was not included. There is a reasonably close comparison in the values given the variability present (Miriam *et al*., 2023).

A study by Portiolli (2021) explains that the concept of trash exclusion is not new as screens have been part of pump inlets in water and sludge removal systems. However, screens in the pit latrine context cannot be used due to the pieces of trash that block flow. Active trash exclusion, using the auger clearing head reported in this study, is an innovative approach that continuously clears the screen and allows continuous pumping regardless of configuration such as the portable vacuums or vacuum trucks. At the end of the faecal sludge emptying process, the trash is left behind in the pit. This represents a change to current practice and can be seen as a disadvantage, because most household customers expect their pits to be completely emptied of faecal sludge as well as trash. Pit latrines are designed for faecal sludge, and not for disposing of trash or household solid waste (Tsai, 2021).

The contract for pit emptying should be specifically for removal of faecal sludge, and removal of solid waste after the pit is emptied is a different task. Therefore, this is a shift from current practice in many communities that use pit latrines, and it would require changes in both household behaviour and infrastructure such as solid waste management in the communities. Rather than seeing this as a disadvantage, Tatte (2021) shows trash exclusion as a factor in enabling these changes to occur. For example, changes in behaviour such as not disposing of household waste in the pit may be incentivized by new business models that separate pit emptying from solid waste handling and require separate fees.

This would also lead to pressure for governments to support and provide solid waste management services and infrastructure. These new business models needed to be tested in real communities. An additional advantage of trash exclusion is that downstream processing from treatment, reuse, or disposal of faecal sludge is more efficient and cost effective. Separation of sludge from trash often occurs at the faecal sludge treatment

facility, if the sludge treatment process cannot handle trash e.g., anaerobic digestion. Thus, trash separation occurs anyway, with the cost borne by the faecal sludge facility. Although continuous refinement of both technology and business models are needed, Portiolli (2021) shows that trash exclusion has potential in making mechanized pit emptying feasible in pits with variable levels of trash.

By 2018, 82% of the latrines in Ethiopia were unimproved, failing to prevent direct contact with faeces, and only minor share of latrines approximately 7% for rural Ethiopia were safely managed sanitation facilities (UNICEF/WHO 2019). To increase rural latrine coverage, various methods have been used and generally aim to improve sanitation supply and demand (Venkataramanan *et al*., 2017) through different financing, market-based, or behavioral techniques. Financing methods typically operate through households or businesses by increasing affordability and broadly include subsidies, discounts, microfinance loans, and output-based aid, all of which reduce or defer the cost of constructing, operating, or maintaining a latrine (Willetts & Powell, 2016). Financing methods can also target certain demographics e.g., women, poor, disabled to increase equity (USAID 2019). Market-based methods typically operate through private businesses that sell or install latrines by developing the supply chain for sanitation technologies and broadly focus on traditional commercial business principles, including capacity building, profit maximization and market efficiency (UNICEF, 2020).

According to Kalina (2022), improper disposal of masks are public health risk and source of infection, especially at risk are children. The risk of discarded masks to adults was low, because adults know that masks are potentially hazardous and to avoid them. This fear was first targeted towards careless individuals who might discard a mask on the ground which may be picked up by a child. Ali (2022) in a study in Blantyre explains

that dumping was common and because children play freely throughout the community, they often play within dumping grounds and play with waste objects.

Respondents either burn waste or dispose them down their pit latrines. However, more than 90 percent of Blantyre respondents reported using pit latrine to dispose of their mask. Pit latrines were considered an ideal place to dispose of a mask, because once dropped down the pit, the mask would remain there, and hence nobody would come into contact with the discarded item. Others expressed concern about the safety of even burying contaminated masks for fear by respondents, and the pit latrine was considered the one reliable place to dispose waste, and it will not come back to threaten your health and that of your community.

Lam (2020) describes Chinese villages having been long known for their small bridges and flowing water, which means that Chinese villages are usually built near streams, where great rivers originated. During the field investigation of 3 villages in Jiangxi province, China, the study found that they were all located upstream of the river, and many pit latrines were scattered around the rural houses throughout the villages. Mamera (2020) describes a typical pit latrine in rural China which consists of 3 main parts: a shelter for creating a private space, a slab or floor with a small hole for villagers to defecate, and a cesspool for storing faeces and urine. There was usually a small window on the wall of cesspool for farmers to take the excreta as a natural fertilizer. To make it easier for farmers to get the excreta, some cesspools were built on the open next to the shelter.

As described in similar research studies by Hoek (2020) and Mapetere (2020), human urine and faeces as fertilizer could meet the needs of plants for potassium and phosphorus, and improve soil structure, and using human excreta as fertilizer is free, which leads to the villagers to use excreta as fertilizer. The study by Van (2020) surveyed

27 villages in Jiangxi and Hubei provinces by contacting the village committees through phone, email and WeChat, and found out that about 0%–60%; 31% on average of rural households used the excreta directly from the pit latrines as crop fertilizer in recent 3 years. According to the villagers, the excreta in the open cesspools may be washed by rainwater, or be carried by animal like dogs, cats, or field mouse, eventually polluting the local water. The villagers' domestic water is all diverted from the mountain stream by water pipes rather than groundwater.

A solution to mitigate all the impacts caused by faeces can be obtained by developing and optimizing devices and technologies that use thermochemical processes to destroy hazardous wastes, such as pyrolysis, combustion, and gasification (Prendergast *et al*., 2017). These processes consist of using the energy potential of faeces, expressed in its heating value, combining heat transfer and chemical reactions to produce energy and, consequently, eliminate pathogens (Levy *et al*., 2017).

The Performance Assessment System (PAS) developed in India for water supply and sanitation benchmarking and AQUASTAT (Food and Agriculture Organization, 2018), and the International Benchmarking Network (IBNET) (2018), all attempt to describe the current status of urban sanitation in large numbers of locations. Performance Assessment System is comprehensive and widely accepted in parts of India but AQUASTAT and IBNET have both largely failed to encompass systems outside of those provided by large scale utility service providers. Very little reliable data are to be found on overall performance of the mixed and somewhat chaotic sanitation systems, which predominate in rapidly growing low-income and middle-income towns with limited management capability or planning control. Sanitation Safety Planning (SSP) assesses risked and degraded health issues in sanitation (World Health Organization, 2016).

Considering the poor conditions of latrines, more people are choosing to practice open defecation instead of using sanitation facilities that do not attend minimum hygiene standards (Wodnik *et al*., 2017). The significance on the surrounded ecosystems, pit latrines were a source for greenhouse gases, emitting around 3 Tgy−1 of CH4 through anaerobic digestion of the waste's organic matter (George *et al*., 2016). According to WHO (2017), 2 billion people still lacked a basic sanitation service, and almost 700 million people defecated in the open.

The FeD-Latrine uses the thermochemical structure of smoldering combustion to impose the oxidation of pyrolysis gases of faeces (McAliley *et al*., 2017). Unsafe sanitation threatens the health and well-being of billions of people around the world (Ngure *et al*., 2013). The private pit latrine is the most basic solution in the effort to expand access to safe sanitation and to reduce exposure to pathogens and improve human health outcomes (Penakalapati *et al*., 2017).

Nevertheless, despite the efforts made in recent years to reach these goals, the use of unimproved sanitation facilities and the practice of open defecation are still responsible for generating around 69% of the total faecal matter produced in the world, primarily in low-income and middle-income countries (Guiteras *et al*., 2019). The consequences extend from social and economic problems to the spread of diseases caused by water contamination (Kayser *et al*., 2021).

Worldwide, around 500 Tgy−1 of faeces were produced by users of nonsewered facilities, representing 58%, and by practitioners of open defecation, accounting for 11% (Pongolani *et al*., 2018). Only a few countries are on track to eliminate open defecation in 2030, while in others, open defecation was actually increasing (Mbuya *et al*., 2016). There is an urge to mitigate the impact of these hazardous wastes on humble

communities to avoid inequalities and the marginalization of the most vulnerable (Orgle *et al*., 2018).

2.4 Faecal Waste Collection Practices along Sanitation Service Chain

A series of nationally legislated, locally implemented rural sanitation initiatives starting with the Central Rural Sanitation Program and culminating with the Swachh Bharat Mission have attempted to expand household latrine access and use (Jacob *et al*., 2019). The Total Sanitation Campaign (TSC) and the Swachh Bharat Mission (SBM), examined household sanitation behaviors in rural Orissa, India, and despite the benefits of safe sanitation and policy efforts designed to lower financial and informational barriers to uptake, many households have not adopted improved sanitation (Oindo *et al*., 2016). Peer effects may offer an explanation as the sanitation choices of one household can depend on behaviors among physical neighbors and other social contacts (Ellis *et al*., 2019).

Better performances were particularly obtained by lowering faeces moisture content to around 39 wt%, although burning few grams of faeces with a maximum moisture content of 65 wt% was also achieved (Meyer *et al*., 2020). The composition was based on socio-demographics which include sex, education and education (Pattanayak *et al*., 2020). Sombe (2016) showed that latrine construction and use was associated with the status of education in the household.

Nonrandomized studies also identified relationships between reduced open defecation and improvements in infant mortality, childhood diarrhea, and child nutritional outcomes (Spears *et al*., 2018). In addition to health benefits, latrine use affords convenience, safety, dignity, and social status positively impact educational outcomes (Routray *et al*., 2015).

Although consistent results were obtained in these previous works, they were still performed using a mixture of faeces and sand (Yount *et al*., 2017). Davis (2018) showed that smoldering combustion can be used as a heat source to drive energy-intensive processes, recovering heat either at a fluid-porous interface or out-of-bed, through walls. There is combination of both heat recovery mechanisms to develop the concept of a latrine-like device that destroys fresh human faeces in real defecation scenarios (Rawat *et al*., 2017). Stunting affects 24% of children who were younger than five years of age, mostly those from low- and middle-income countries (LMICs). Environmental enteric dysfunction (EED), an established risk factor for growth impairment through malabsorption, is almost universally found in places where water, sanitation, and hygiene (WASH) are optimal, and enteric pathogen carriage is high (Voigt *et al*., 2016).

Much of the evidence linking latrine promotion to improved sanitation focuses on reporting the size of short-term treatment effects rather than long-term impacts (Kim *et al*., 2017). While the literature focuses on latrine adoption, few studies evaluate sustained latrine use, even though the use of latrine is essential to achieve health benefits (Cairncross *et al*., 2016). The updated status report on the Sustainable Development Goals of 2017 acknowledged that this goal will not be reached (WHO, 2017). The global community has set itself the goal of providing access to safe sanitation facilities for all by 2030 of SDG 6. Approximately 2.3 billion people also lacked access to basic sanitation services, and another 892 million people practiced open defecation (UNICEF, 2017). The effectiveness and sustainability of public health and development interventions are crucial and understudied questions (Martin *et al*., 2018).

In Bangladeshi households where animals or chickens were inside the same room at night with children, there was a significant association to Environmental enteric dysfunction (EED) disease activity scores and stunting (Hussain *et al*., 2015). The lack of

knowledge should also impact intervention design, educating caregivers about potential negative impacts of exposure to animal and chicken faeces to themselves and their children (Boisson *et al*., 2016).

Additional work is needed, however, to assess the policy and social drivers of latrine uptake and use. Brooks (2016) focused on sanitation practices in the context of India, where rates of open defecation and unsafe sanitation have remained high, particularly in rural areas. As such, achieving universal latrine access has long been a policy priority in India.

2.5 Community-Led Total Sanitation

The effects may operate through related channels such as learning about costs, benefits, and social acceptability of different sanitation practices, the evolution and enforcement of social norms, and the fact that area-level sanitation contributes to individual health risks (Azage *et al*., 2020). To make clear the multi-levelled nature of the present research and sub-Saharan Africa (SSA) made gradual progress in water and sanitation access between 1990 and 2015, 71% of its population are without basic sanitation at the end of the Millennium Development Goals (MDG) period (USAID, 2018). the Integrated Behavioral Model for Water, Sanitation, and Hygiene interventions (IBMWASH) approach was found to be effective (Shrestha *et al*., 2017). The IBM-WASH, a theoretical model specially developed to understand water, sanitation, and hygiene interventions and behaviors, is widely accepted as providing an across-the-board methodology for analyzing and addressing multiple levels of influences (Sclar *et al*., 2017). To shed light on this pressing policy issue, Cheng (2020) estimated the role of peer effects in households' sanitation choices and examines how these peer effects interact with sanitation policy interventions in rural India.

In addition, although caretakers did express interest in potties, most cited affordability as a barrier to potty use for children similar to studies conducted in Bangladesh (Mahmud *et al*., 2018). In CLTS, social relations and cohesion among community members are key for collective actions and mutual support in latrine construction (Abrha *et al*., 2018). The physical context includes the natural and built environment. In Bangladesh, low-cost redesigned hoes proved to be a useful tool for removing child faeces from the household compound and lacked the same cost barrier as a potty, a consideration for future intervention design (Islam *et al*., 2018).

The psychosocial factors are embedded in contextual landscapes that may also influence latrine construction decisions. Psychosocial characteristics include social, physical, and personal factors (Rahman *et al*., 2018). The social context represents the cultural and social relations, policies and laws, economic conditions household's income, and the information environment including sanitation campaigns such as CLTS. Gnilo (2017) argue that the cost of household latrines is a significant constraint on latrine construction. Croker (2016) also stated that the policies and legislation on sanitation are least accessible to marginalized groups in ways that limit their ability to switch to latrine use.

It has also been suggested that, despite the impact of income on latrine construction, other contextual factors drive latrine construction decisions (Dickinson *et al*., 2015). The RANAS factors were used to examine the latrine construction behaviors of households that might have contributed to the construction of latrines. The perceived risk of diarrhea was significantly higher for households who constructed only pit and superstructure, while the ownership of a complete latrine as well as latrine use reduced the perceived risk (Mulat *et al*., 2017). The perceived risk of a practice has the potential to stimulate and shape households' behaviors.

Through these social processes, individuals exchange knowledge and ideas and adopt the healthy behaviors of one another while strengthening social cohesion and inclusion. In the study, Rayasam (2019) found that the construction of latrines by relatives has a snowball effect that motivates other community members of the same kin to construct. Diarrheal disease accounts for about 8.7% of under-five mortality worldwide, and inadequate water and sanitation have been associated with diarrhea. The risk factors represent a person's understanding of the health risk of open defecation, the person's perceived perception of his or her risk of contracting diarrhea, and his or her perception of the severity of diarrhea and its consequences (Hammer *et al*., 2016). In South America, Sharada (2019) noted that around 9 million Brazilian households did not have private sanitary facilities, and defecation occurred in cesspits, ditches, rivers, lakes, or sea. Degraded sanitation has overwhelmingly been approached as a health concern related to the consumption of water and food contaminated with faecal bacteria (Lucero *et al*., 2019).

For instance, whether the soil is loose or firm has to be considered when choosing the best fit design for latrine substructure so as to prevent latrine collapse (Roba *et al*., 2017). Sanitation approaches adopted by governmental and non-governmental organizations assessed the sanitation needs of households and provided either free or subsidized latrines (WHO, 2018). The result supports previous findings by Gertler (2015), which showed that latrine ownership among an individuals' family status is a significant influencer of an individual's latrine ownership.

To understand latrine completion and use decisions among households, Sinha (2017) used the Risks, Attitudes, Norms, Abilities, and Self-regulation (RANAS) model of behaviour change as a conceptual guide. The RANAS model underscores the importance of psychosocial factors in determining households' sanitation behaviors. Although

parents associated cleanliness with swept dirt compounds, they were not concerned with the social norm of children eating dirt and mouthing objects, an attitude also found in Zimbabwe (Dean *et al*., 2019).

Household sanitation practices are no different where these behaviors have social roots reflecting the influence of local social pressures (Guiteras *et al*., 2019). According to the Joint Monitoring Program (JMP 2016) on Water, Sanitation and Hygiene, approximately 844 million people lacked basic drinking water and 2.3 billion were without basic sanitation in 2015 with significant differences across regions.

However, Weitzman (2016) explains that little is known about the households that have not been able to complete the construction of their latrines during CLTS interventions in India. In addition, the existing literature has not examined how level of latrine completion is associated with defecation habits among households (Firth *et al*., 2020).

CLTS approaches open defecation as a collective health hazard, triggers communities for change, and inspires local innovation and mutual support for latrine construction and latrine use (Green *et al*., 2016). Although CLTS has significantly facilitated the process of stopping open defecation, the 72% latrine coverage threshold required for improved health has not yet been reached, and problems persist with the long-term sustainability of latrines (Dixon *et al*., 2015).

This includes the awareness expressed by a village, tribe, or religious leaders and other institutions (Gore *et al*., 2017). The ability factors take three forms which include confidence in a person's perceived ability to organize and execute latrine construction, confidence to continue latrine construction and ability in being able to deal with barriers that arise, and confidence in recovering from setbacks, to continue the construction and after disruptions (Bos *et al*., 2017). Self-regulation factors show a person's strategies for

constructing a latrine; his or her plans for overcoming potential barriers in the course of latrine construction; and monitoring to keep construction on track (Stocks *et al*., 2014).

However, WHO (2018) found out that despite the presence of well-meaning policy outlines, 892 million people practice open field defecation globally whereas, the number of people who utilize unimproved latrine facilities has surpassed 856 million. In both cases, the majority of those affected are the impoverished rural population found in the least developed countries. In the developing world, poor sanitation has become the key challenge for both the public health and economic systems (Farooq *et al*., 2020).

Zennaro (2019) reported that latrine coverage and ownership do not necessarily translate into latrine use. Even among households with latrines, open defecation is often still practiced. Caregivers were concerned about the smell of faeces on unwashed cloth or potties and the potential to attract flies within the compound; these concerns align with other studies where adults expressed disgust when faeces were visible.

The latrine interventions to result in meaningful improvements to public health, behaviors and technologies need to be adopted and sustained at scale over time, but evidence of sustained adoption of new practices in Ethiopia is mixed (Mekonnen *et al*., 2020).

2.6 Faecal Waste Disposal along Sanitation Service Chain

Although several recent studies have addressed the disposal of child faeces and related practices, they have not applied these findings for intervention design (Yu *et al*., 2020). Research on the faecal–oral pathway of children under two years has largely consisted of observational studies, but it has rarely combined observations with qualitative methods to understand why people may or may not practice behaviors that contribute to these pathways (Friedrich *et al*., 2018).

Hanna (2020) confirms that although there are generalizations of how to address potential pathways of faecal–oral transmission, and the study was to create an intervention that addresses multiple pathways while being locally acceptable and feasible. Exposure to faecal pathogens early in life results in both acute and chronic morbidity, and diarrheal diseases account for 446,000 deaths of children younger than 5 years annually (UNICEF 2018). Growth failure such as stunting, results from the interactions of chronic undernutrition with acute and repeated infection with faecal pathogens (Carter *et al*., 2020). Academics and policymakers have long recognized that they are key drivers of many technology adoption and behavior change decisions, from agricultural technology adoption to voting (Khalil *et al*., 2019).

The contextual dimension encompasses the character of the individual, setting, and environment that are outside of the scope of conventional health technology and behavior interventions. (Enyew *et al*., 2020). These psychosocial factors are used to develop theory-based and evidence-based behaviour change interventions (Alebel *et al*., 2018). Differences are observed between the psychosocial determinants of people who already show the new behaviour and those who do not yet show it. Psychosocial dimension describes social, behavioral, and psychosocial factors that bring about behavior alteration to intervention. The technological dimension explains behaviors and practices detailed to the WASH technology and also addresses the continued use and maintenance of latrines (WHO, 2019).

In Zimbabwe, Kassiri (2018) found out that young children who crawled or played on dirt floors or compounds were exposed to *Escherichia coli* through ingestion of soil and chicken faeces. In Bangladesh, children who ingested soil through daily activities were shown to have an elevated risk of stunting (Pickering *et al*., 2018). Studies have shown that children's faeces contain a higher enteric load than adults, and the potential for

household contamination is due to local disregard for child faeces (Sun *et al*., 2020). Cleaning children's faeces, washing children's clothes after defecation, and cleaning the compound may also be potential pathways of contamination with human pathogens, especially if caregivers are not washing their hands with soap after such activities (Yawson *et al*., 2018).

The determinants that show the greatest differences are those targeted in behaviour change campaigns (Clair *et al*., 2018). Some of the influences reflect basic public economics and households do not capture all the returns to sanitation investments because they improve public health, not just private health but improved sanitation will be undersupplied in an unregulated market. Yadav (2016) found that households that roofed their latrines are more likely to switch from open defecation. Households would more likely switch from open defecation to latrine use if latrines protect their privacy. The health and non-health benefits safe sanitation can provide, investments in private latrines like many other environmental health technologies continue to be inefficient (Pattanayak *et al*., 2018). Attitudes are a person's beliefs about the costs of money and time or effort and benefits such as good health, greater respect, personal safety of constructing a latrine and his or her positive feelings about owning a latrine (Higgins *et al*., 2018).

Achieving the Sustainable Development Goals (SDGs) is likely to be aided by better understanding of the factors associated with levels of latrine completion and consequent latrine use (Harter *et al*., 2018). The few rigorous scientific studies of CLTS's effectiveness have produced diverse and ambiguous findings (Pickering *et al*., 2015).

Similarly, a study by Fekadu (2017) on sanitation showed that privacy and safety are the major reasons for latrine construction and use among women. Other possible reasons related to latrine use among the study households include the cleanliness of the latrine

and its structural condition. However, having a latrine did not always translate into latrine use. USAID (2018) noted that about 4.9% of households at level-privacy still practice open defecation.

Although there were significant differences between household size, age, marital status or literacy rates among respondents across the levels of latrine completion, other research works have reported the influence of these factors on latrine construction and use (Bartram *et al*., 2017). Koo (2016) in a study examined factors associated with levels of latrine completion and use in CLTS intervention communities in Northern Ghana. Given the wide adoption of CLTS (Cavill *et al*., 2018), its effectiveness has still rarely been scientifically investigated. Odagiri (2017) showed that households with the highest incomes are the most likely to construct latrines. Household income affects the availability of resources for latrine construction. However, Ketema (2016) found that households with the highest incomes were at the lowest level of latrine construction.

However, Clasen (2017) explains that even though risk perception may evoke precautionary measures, it is not a determinant of preventive health behaviours. Existing literature on CLTS indicates that convenience, comfort, and health benefits are recurring reasons for latrine use (Hyun *et al*., 2019). The adoption of healthy behaviours is dependent upon the social process triggered by CLTS, social norms, social networks, and social capital. For example, one qualitative study conducted in Benin found prestige to be the main motivation for latrine construction, which had little to do with health risk (Kumie *et al*., 2017).

2.7 Faecal Waste Treatment Strategies along Sanitation Service Chain

Beyond the low-cost drying methods proposed in faecal sludge treatment systems, such as solar drying beds (Orgill *et al*., 2020), which are prolonged processes, the attempts to overcome the constraints of the faeces moisture content in thermochemical processes

were based on co-combusting faecal matter and carbonaceous fuels (Chileshe *et al*., 2018), or mixing faeces with dry inert materials to ensure sample homogeneity. Bench-scale incinerators and combustors had been proposed as thermal devices to burn faeces inbed, yet in need of pre-treatments for drying and pelletizing faeces (Reid *et al*., 2018). Hypotheses tested by comparing the effects of interventions undergoing works advised the necessity of improving the heat transfer process to destroy fresh faeces in continuous runs successfully (Wilson *et al*., 2020). In bench-scale smoldering reactors, the use of smoldering combustion for the destruction of hazardous wastes was applied to destroy surrogate faeces mixed with sand and Powell (2020) confirms that the concept was implemented to biosolids, and organic wastes.

The model identifies three dimensions of water, sanitation, and hygiene-related behavior contextual, psychosocial, technological at five separate societal, community, household, individual, and habitual levels (Cini *et al*., 2020).

This lack of knowledge could have long-term health impacts, as ingestion of chicken faeces and soil containing chicken faeces may be a major source of infection and be important in the study of environmental enteropathy (Gertler *et al*., 2015). Observations conducted in Kisumu, Kenya, to understand oral contact events for infants aged 3–9 months showed they were likely to mouth their own hands approximately 0.4 times per hour (Abodoo *et al*., 2016). If children were playing or sleeping in areas where chickens or animals are kept, their hands were likely to come in contact with animal faeces, and their hands were likely to end up in the mouth (Bagshaw *et al*., 2020). Of additional concern is that caregivers and a community health worker reported that children and chickens both slept in the kitchen (Friedrich *et al*., 2018).

Mothers and grandmothers in Zimbabwe were unconcerned with geophagy, believing that it could benefit the child (Chneider *et al*., 2020). In rural Kenya, (Dubey *et al*., 2018)

found out that geophagy may be a social norm, and 76% of children aged 10–18 years reported eating soil daily, a risk factor for soil-transmitted helminth infections. Although caregivers did not identify geophagy as a beneficial behavior, they did associate geophagy with soil transmitted helminth infections, showing an understanding of potential consequences. However, Hazen (2019) noted that caregivers were able to access deworming pills for children at health clinics or from community health workers. Dolgui (2019) found that people are less likely to use latrines when they are dirty and damaged. Latrines that have roof and protect user privacy were also found to be cleaner. These structural characteristics that influence latrine use could be used as examples against which constructed latrines could be measured in CLTS (Delea *et al*., 2018). The time cost of accessing deworming pills to correct the negative outcome soil-transmitted helminths was relatively low, whereas the time cost to constantly observe the child was high (Carnovale *et al*., 2019). Social norms were one of the most influential aspects in determining caregiver behavior and were challenges caregivers experienced related to physical opportunities such as time, affordability of materials, and access to water (Mosler, 2014).

Practices shifted depending on the caretaker; when older siblings were responsible, they were less likely to dispose off child faeces in latrines or ensure that the area children were playing in was safe or clean, as found in Cambodia (Singh, 2016). Practices did not shift over and community showed limited reactivity (Holcomb *et al*., 2019). Addressing social norms has been found to be critical to behavior change related to hygiene, and sanitation; although shifting social norms forms a significant challenge, it must be considered in intervention design (Majorin *et al*., 2016). Research by Lilje (2018) revealed that the determinants of optimal caregiver practices contributing to a clean

compound were reflected through combinations of the behavioral determinants' capability, opportunity, and motivation.

Haren (2020) noted opportunity challenges such as the physical environment, the lack of time to practice optimal behaviors, competing priorities for caregivers, and social norms of open defecation, children eating dirt, and sharing living space with poultry and animals. The factors influencing latrine construction and use are broadly classified into demographic and socio-economic factors, knowledge and attitudes, and social influence (Bensch, 2015). A behavior change intervention designed to address these challenges will require awareness of the opportunity challenges impacting caregiver motivation and the limitations of behavior change alone to overcome these challenges (Hills *et al*., 2020).

2.8 Theoretical Framework

The theories that support the research are introduced below. The theories include theory of waste treatment, theory of waste disposal, theory of change, theory of psychosocial development, functionalist theory.

2.8.1 Theory of waste treatment

Collective behaviour change is required to achieve an environment free of open defecation. Community-Led Total Sanitation (CLTS) is a participatory approach that evokes collective behaviour change in rural settings. Originally developed in Bangladesh in 2008 (Chambers *et al*., 2008), it has since been adopted globally (USAID, 2018).

The approach combines a range of activities that are implemented by local facilitators at a community level (Sokolov *et al*., 2016). This fact shows that open defecation is not only an individual health hazard. Individuals might change from open defecation to latrine usage, but as long as their neighbours continue defecating in the latrine, users remain threatened by faecal contamination of water bodies and food (Julian *et al*., 2016).

Pre-triggering, each community is visited, and information is gathered about the population and their readiness for behaviour change. Sanitation programs should include information and advice on various low-cost toilet designs and options. If communities wonder how to create and express their need for sustainable latrines, the facilitators of CLTSH should provide technical advice (Mosler *et al*., 2018). Lack of skill to construct safely managed latrine is another underlying factor for open defecation-free slippage, and usually, unskilled persons build a highly collapsible toilet (Aunger *et al*., 2019).

Freeman (2019) showed that among adults, sanitation interventions reach up to 26% reduction in diarrheal diseases, and evidence is presented that the effect is higher in communities with higher latrine coverages. The deaths of approximately 361,000 children under five could be prevented by safe sanitation (Medlicott *et al*., 2017). Triggering this information is used to adjust participatory behaviour change techniques (BCTs); and these techniques are then applied during a community event such as community mapping or a transect walk along which the community is confronted with faecal contamination (Shakya *et al*., 2015). The optimal outcome of this community meeting, also called the triggering event, is an increase in community members' awareness that they are eating their own faeces.

This realization should lead to a change in sanitation conditions by constructing latrines (Guiteras *et al*., 2015). During the post-triggering phase, facilitators support the community in achieving the status of an open defecation free community, by helping in the construction of latrines (Chilengi *et al*., 2019).

The original CLTS process works without any subsidies (Kar *et al*., 2003). The evaluation of Community-Led Total Sanitation and Hygiene effectiveness in African countries similarly stated that interventions designed to advise on upgrading and

improving sanitation facilities using local materials maintain open defecation-free status (Kaseva *et al*., 2020).

A study report by Kumar (2020) from villages of East Java showed a significant relationship between better quality triggering and sustained open defecation-free status. This finding is surprising considering previous studies that found highly significant RANAS-based intervention effects in various cultural settings and behavioural contexts for example, on collecting arsenic-free drinking water in Bangladesh (Inauen, 2014), hand-washing interventions in Burundi (Sonego *et al*., 2014), shared latrine cleaning in Uganda (Tumwebaze *et al*., 2015), and disinfecting drinking water in rural Chad (Mosler *et al*., 2018).

The Sanitation Hygiene Infant Nutrition Efficacy (SHINE) trial in Zimbabwe included a previously neglected pathway exposure within the household living compound; they found that although the intervention reduced behaviors geophagia and ingestion of chicken faeces, it did not result in the complete prevention of these activities (Bates *et al*., 2020). Early certification of ODF Early certification of ODF appeared in the analyzed documents.

Children in LMICs may be exposed to zoonotic and human pathogens through their immediate play environment within the household compound, typically a dirt-packed yard (Garn *et al*., 2017). As a result of open defecation, 1.8 billion people worldwide use drinking water that is contaminated with faecal bacteria (UNICEF, 2017). Zoonotic pathogens from animal stool, commonly found in shared human and animal environments, may be major contributors to the global burden of enteric disease (Belk *et al*., 2019).

A meta-analysis on the impact of sanitation campaigns showed that CLTS typically increases latrine coverage by 7% to 13% and can reach up to 29% (Garn *et al*., 2016).

Another recent review shows that most of the literature on CLTS is grey literature and that only 6% can be categorized as scientific studies (Venkataramanan *et al*., 2018).

Shu (2020) in a study investigated the intervention effect of a classic CLTS intervention on latrine construction. It was randomized controlled trial to examine the effects of population-tailored and data-driven behaviour change techniques in addition to classic CLTS, and investigated how CLTS promotes latrine construction by changes in psychosocial determinants.

The results showed once more that CLTS is powerful in evoking latrine construction, as reported by previous studies (Bongartz *et al*., 2016). The 63% latrine coverage in the intervention communities, compared to just 7.7% in control communities, is higher than in other CLTS interventions in Ghana 43%, (USAID, 2018) or to other sanitation campaigns 29%, (Garn 2016). It is comparable to CLTS outcomes in other countries, such as Mali (63%) or Malawi (98% (USAID, 2018).

Campaign activities based on the RANAS approach for systematic behaviour change according to Contzen (2016) tended to show increased latrine coverage but was not significant compared to CLTS alone. One reason that no additional effects were observed for the RANAS interventions is low intervention (Crocker *et al*., 2016). The implementation protocols of the implementing NGO indicate that shit flow diagram and intervention exposure, for example, only 42.5% of the interviewed sample received the sticker as sign for their commitment to construct a latrine, and a further 12.3% received the flag as a sign of their completed latrine (Pickering *et al*., 2015).

An evaluation report in Sierra Leone depicted that children who continued open defecation were students who went to school exactly at the same time as CLTSH triggering or who did not attend the CLTSH triggering event (USAID 2018). Another study conducted in Eritrea concluded that people who missed attending CLTSH

triggering moment could not stop open defecation (Crider *et al*., 2019); and villages with more community involvement also have a low open defecation-free slippage rate. CLTS was also able to make people feel more confident in constructing and maintaining their own household latrine, and this higher confidence helped them to actually complete this task (Alexander *et al*., 2017). This finding is in line with previous research on WASH behaviours for example, in the case of Burundi (Sonego *et al*., 2014). Research report by Kato (2017) also confirmed that the effective sanitation interventions involve women and religious groups. The involvement of these groups is a critical stage for open defecation-free sustainability. Poor and disadvantaged households are at a much higher risk of open defecation-free slippage (Morse *et al*., 2017).

The study by Bongartz (2016) showed that changes in people's mindsets are responsible for the intervention effects of CLTS on latrine construction. Following the hypothesis, positive changes in psychosocial determinants caused by participation in CLTS led to higher latrine coverage in the communities. CLTS made participants more aware of the latrine construction behaviour of their social environment and led to an increased perception that community leaders approve of latrine construction (Dooley *et al*., 2016). Participants in CLTS developed greater confidence that they would be able to construct, maintain, and repair their own household latrine; and they were more committed and more likely to form action plans detailing how, when, and with whose help to construct latrines (Harter *et al*., 2018). These changes were all positively related to a higher probability of constructing latrines (Venkataramanan *et al*., 2018).

CLTS also achieved its goal by strengthening peoples' commitment to latrine construction (Mosler *et al*., 2016). The role of commitment is important in hygienic behaviour and has been shown by previous research by Contzen (2015) who noted that

improved latrine facilities are excreta disposal facilities that can guarantee the hygienic separation of human excreta from human and insect contact.

2.8.2 Theory of waste disposal

According to Kosoe (2018), determinants are clustered in five factor blocks which include risk factors such as individuals' health knowledge, its perceived severity, and their vulnerability to it; attitude include feelings about the new behaviour and the perceived costs and benefits of performing it; norm include people's perceptions of others' behaviour and their perceived disapproval when an individual shows the new behaviour; the knowledge of how to perform the behaviour and confidence in starting a behaviour, continuously performing it, and recovering it after relapse; (Osumanu *et al*., 2018) and the self-regulation contains the individual's action plans for the behaviour, how he or she deals with barriers, self-monitoring e.g., action control and remembering the new behaviour and the commitment to performing the behaviour.

In a study by Guiteras (2015), respondents expressed a general feeling of pride in latrine ownership, although those at level-superstructure perceived latrines to be very expensive to construct. CLTS processes produce norms and social networks between members of the community and also with their external environment. The impact was high among poor people with limited free access to durable materials. Thus, latrine construction using short-lasting materials results in low-quality latrine and elevated open defecation-free slippage (Ayamga *et al*., 2017). Other factors leading to the slippage are the induction of CLTSH without sufficient planning and the lack of successful social mobilization methods. In many of the prior studies conducted in Ethiopia and other African nations having a larger family, an advanced education, and being male were associated with the increased adoption and utilization of latrines (UNDP, 2018).

Undernutrition and infection resulting in growth failure in early childhood have long-term impacts, including impaired motor and cognitive development, reduced schooling performance, and lower economic productivity in adulthood (Leshargie *et al*., 2018). Designing interventions that sufficiently reduce faecal pathogen exposure to impact growth and diarrhea has proved a challenge (Coffey *et al*., 2017).

The bioaerosols can be expelled from the air within the bowl of toilet depending on an upward velocity of air from flushing, and eventually be transmitted by air motion of indoor (Li *et al*., 2020). The unacceptable pressure on communities for early certification of ODF will contribute to slippage. Technology acceptability and changing behavior toward its utilization require a sufficient time of adoption.

Flight attendants were infected with norovirus during the flight from London to Philippines because they used the toilet in the plane (Widdowson *et al*., 2005). The toilet has been the main site of germ and virus transmission as well as inhaled infection illnesses, and it is therefore important to understand the process and the influencing factors of toilet bioaerosols generation (Hagos *et al*., 2018). Norm factors represent the perceived social pressure to construct a latrine. They describe a person's observation and awareness of others' behaviour, his or her perception as to which behaviors are typically practiced. Norm also describes a person's perception as to which behaviors are typically practiced approved or disapproved by relatives, friends, or neighbors (Baker *et al*., 2015).

The impact evaluations of WASH and nutrition interventions found mixed impact on diarrhea and no impact on stunting (Rout *et al*., 2017). Recent findings of the WASH Benefits trials in Bangladesh (Unicomb *et al*., 2015) and Kenya (Muganda *et al*., 2018) demonstrated that the interventions may not have been sufficiently intensive to block faecal transmission or that they were not the appropriate interventions to address all faecal pathways

Poor sanitation together with scarce water and hygiene services was to blame for 824,000 diarrheal deaths in low and middle-income countries, accounting for 58% of the total diarrheal deaths (Cumming *et al*., 2019). Of these deaths, nearly 361,000 over 1000 deaths per day occurred in children below the age of five (Nyieku *et al*., 2018). In 2015, the pooled global economic loss attributed to sanitation-related premature deaths, health care expenditure for treating sanitation correlated diseases, output lost due to illness, and time lost to access sanitation facilities was estimated to be 222.9 billion Dollars (Menon *et al*., 2017). Ethiopia succeeded greatly in the reduction of open defecation practices from 79% in 2000 to 28% in 2015 (George *et al*., 2016).

Nelson (2019) investigated how CLTS promotes latrine construction by examining which psychosocial mechanisms of the RANAS model explain its effectiveness. The RANAS approach was used to develop interventions based on the data gathered about the target population at the baseline survey (Mosler *et al*., 2016). The RANAS approach identifies the psychosocial determinants that increase latrine construction and then selects BCTs that target these determinants (Contzen, *et al*., 2016). Baseline data revealed that latrine construction was steered by determinants of the social and physical context, of the risk factor block, and of attitudes, norms, and self-regulation factor blocks (Oswald *et al*.,2016).

Childe (2018) sought to understand what determinants influence caregivers' practices of latrine use, safe child faeces disposal, and caregivers' perceptions of what a safe and clean environment are, and how they prioritized making that space for children. Spears (2016) detail the approach and findings of research to inform the development of a behavior change intervention to improve compound cleanliness in western Kenya. This review concludes that CLTS still lacks a systematic and detailed understanding of the mechanisms of behaviour change, which is common practice according to the National

Institutes of Health (NIH); the NIH instead recommends to investigate mechanisms of behaviour change strategies (Nielsen *et al*., 2017).

Blome (2018) in a study examined the effectiveness of CLTS and combines CLTS with data-driven and population-tailored interventions following the RANAS approach. CLTS in any combination motivates people to construct latrines and that the combination of CLTS plus RANAS-based interventions are effective in motivating latrine construction (Venkataramanan *et al*., 2018).

The RANAS model offers BCTs that are linked to corresponding psychosocial determinants (Wolf *et al*., 2019). Those techniques can be combined to create complex data-driven and population-tailored interventions. Campaigns planned following the RANAS model have demonstrated success in changing behaviour and evoking new and sustainable habits in various contexts of the WASH sector (Contzen *et al*., 2015).

In a study by Nopia (2018), compounds lacked nearby water access, so caregivers prioritized time and water, both examples of physical opportunity, limiting the number of times per day they would clean nappies and potties. Without latrines, caregivers were unable to safely dispose of child faeces as per the Kenyan government standards (Kerr *et al*., 2020).

2.8.3 Theory of change

In many WASH interventions, the theory of change, if fully articulated, is not typically based on research and behavioral theory; this is due to limited behavior change in the sector (Damtew *et al*., 2017). Abay (2018) conducted research using predefined behavior change theories which reflects the growing need to identify specific determinants to challenges and develop interventions addressing those determinants. Categorizing the determinants using a predefined change theory supports the development of a theory-informed intervention (George *et al*., 2019).

The theory of change is relevant to this study in initiating sanitation behaviour change and community empowerment that could promote sustained access to improved sanitation (Cheru *et al*., 2018), formulation and dissemination sanitation policy, strategy formulation and implementation for intended result in Marsabit town.

2.8.4 Theory of psychosocial development

The theory of psychosocial development was invented by the famous American psychologist Erik Erikson. According to Erikson, all people go through eight crises or conflicts in their development. Psychosocial adaptation achieved by a person at each stage of development can change their character at a later age, sometimes radically. For example, children who were deprived of love and warmth in childhood can become normal adults if they are given additional attention at later stages. However, the nature of psychosocial adaptation to conflicts plays an important role in developing a specific person. The resolution of these conflicts is cumulative, and the way a person adapts to life at each stage of development affects how they cope with the next conflict.

According to Erikson, human development is a process in distinct discontinuous stages, each characterized by a particular psychosocial crisis or challenge (Orenstein & Lewis, 2021).In the book Childhood and Society, Erikson (1963) divided a person's life into eight separate stages of psychosocial development of the "ego." These stages are the result of an epigenetically unfolded personality blueprint that is passed down genetically.

The epigenetic concept of development is based on the idea that each life cycle stage occurs at a specific time ("critical period") and that a full-fledged personality is formed only by successively passing through all stages in its development. In addition, each psychosocial stage is accompanied by a crisis – a turning point in an individual's life, which occurs due to reaching a certain level of psychological maturity and social requirements presented to the individual at this stage (Erikson, 1963). So, in simple

terms, Erikson's psychosocial development theory is a framework for understanding how individuals grow and develop throughout their life span, each stage of which is characterized by a particular psychosocial challenge or crisis.

The successful development of trust during the infancy stage can have a more positive outlook in adult life, can help develop self-esteem, and build healthy relations. Without the proper encouragement and development, a child can become highly distrustful due to unstable caregiving, negligence, mistreatment, separation issues, or even excessive protection (Erikson, 1963). The failure to develop trust during infancy can have significant consequences on a child's psychological and emotional development, leading to issues such as anxiety, depression, and even aggression. Parents' encouragement, support, and freedom to make choices are critical factors in helping children successfully transition through the autonomy vs shame and doubt stage (Lewis & Abell, 2017).

The successful development of autonomy in children helps them increase confidence, gain independence, and have better relationships with others at a small age and in adult life (Slee *et al*., 2012). A child can become less autonomous and develop feelings of shame and doubt if they are not allowed to make decisions on their own, have overly controlling parents, have stressful events, or even lack of support (Erikson, 1963). The inability to develop autonomy can lead to a child's lack of confidence and poor social skills or even create a negative self-image. A supportive environment, encouragement of independence, and support for creativity that enable a child to succeed at the initiative vs. guilt stage (Erikson, 1963).

When children develop initiative, they can increase their self-esteem, improve problem-solving skills, gain greater independence, better academic performance, and even improve physical health. Criticism and punishment, lack of opportunities and encouragement, overprotective parenting, fear of failure, and traumas are among the

factors that can cause children to fail at the initiative vs. guilt stage (Erikson, 1963). When parents fail to develop their child's initiative, the consequences can range from negative to serious. These include a lack of self-confidence and independence, poor academic performance, anxiety, and depression. Lack of a supportive environment, poor academic performance, bullying, and limited exposure to new activities can all be contributing factors for children not succeeding in the industry vs. inferiority stage (Erikson, 1963).

Failing to establish the capabilities and frame of mind required for success in the industry versus the inferiority stage can lead a child to experience serious issues, including decreased self-confidence, social troubles, and academic difficulties. Positive role models, encouragement to be an independent, safe and supportive environment, open communication, and freedom to express themselves have helped children to succeed at the identity vs role confusion stage (Erikson, 1963). The successful development of identity during the identity vs role confusion stage can help improve self-esteem, build stronger interpersonal relationships, improve physical health, increase creativity, and even improve academic performance. Lack of support, negative role models, traumas, social pressure, psychological issues that affect human brain and change behaviour which could contribute to an inability to successfully transition into adulthood (Erikson, 1963).

Without developing a robust sense of identity, one may experience a loss of direction and purpose in life, find it hard to build meaningful connections with others, or simply be unable to decide on the right career path. Establishing meaningful connections has a host of positive implications for one's emotional and physical well-being, personal growth, and overall life satisfaction. Intimacy paves the way to lead an enriched life. Lack of trust, difficulty communicating, social isolation, traumas, and some other personal issues

can hinder the development of intimacy in relationships (Erikson, 1963). If neglected, the intimacy vs isolation stage can result in loneliness and trouble forming meaningful relationships. Furthermore, it can lead to a fear of rejection and a detrimental effect on one's physical health.

The success of developing generativity can have positive consequences for both the individual and society as a whole – from creating fulfillment in life and improving health to making the world better. People's self-centeredness, lack of personal growth and meaningful relationships, fear of failure, and even lack of resources significantly impact their ability to develop generativity, thus, leading to stagnation (Erikson, 1963). The failure to develop generativity during the middle adulthood stage can lead to feelings of stagnation and a lack of fulfillment in life.

Such people may experience a sense of purposelessness and feel disconnected from the world around them. The success of developing integrity has several positive consequences for individuals, have create room for individuals to have feeling of accomplishment, increased self-awareness, better mental health, a greater sense of purpose, and enhanced relationships. Lack of meaningful relationships and accomplishment, illness or disability, isolation, mental health issues, and difficulty with self-awareness can all contribute to an individual's failure in the integrity vs despair stage (Erikson, 1963).

The consequences of failing to develop integrity during the later stages of life can result in feelings of despair, regret, and dissatisfaction, which can lead to a sense of hopelessness and a negative outlook on life. Erik Erikson (Homberger), born of an unknown Danish father and a Jewish mother, was subjected to taunts from his peers during his youth due to the juxtaposition of his Nordic appearance with a Jewish upbringing (Carley, 2015). As he roamed in search of purpose, Erik pursued a dream to

become an artist. But the onset of World War II forced Erikson and his wife to relocate multiple times until ultimately settling in Boston. During his travels, he changed his name to reflect the constant transformation of identity that he was experiencing himself – an idea that is ubiquitously found throughout all his theories on personal development.

Erikson had many anthropology associates, such as Ruth Benedict, Gregory Bateson, and Margaret Mead. Yet none impacted him as much as Sigmund Freud did with his ideas and theories. Taking inspiration from Freud's work, Erikson has expanded upon the latter's theories and crafted a unique set of his own (Carley, 2015). Whereas Sigmund Freud proposed five stages in human development that culminate in adolescence, Erik Erikson formulated eight foundational phases. Freud believed that a person's childhood is the fundamental cornerstone of their identity, while Erikson argued that personal development continues to progress and evolve over one's lifetime. This growth even can be seen in late adulthood.

Before his first publication of Childhood and Society, Erikson immersed himself amongst Native American tribes (Carley, 2015). There, he discovered dream quests – a hunt for boys reaching adulthood – and saw how their traditional identities were being dissolved by modern white practices. These observations also influenced Erikson's view of psychosocial development theory. He felt that the identity crisis and dissonance Native American boys experienced could be found in young people of all societies – a notion that is highly celebrated today.

2.8.5 Functionalist theory

Functionalists think of parts of society as organs of a body (Herbert Spencer). Each part of society performs a function that makes it work as a whole, just as a human body needs all the organs to perform their parts to make the body work (Emile Durkheim and Talcott Parsons). Herbert Spencer (1820-1903), one of the early proponents of functionalism was

a biologist by training. So, some of the earliest formulations of functionalism were expressed in the language of natural biology. George Peter Murdock (1949) was among the first to articulate clearly the functionalist perspective on the family. Talcott Parsons (1951) took the argument on the functionalist perspective of the family one step further.

Emile Durkehim's (1858-1917) doctoral dissertation, The Division of Labour in Society published in 1893, was considered a seminal text of structural functionalism. Durkheim attempted to reorient functionalist thought towards a more capitalist-industrialist way of thinking. This was in keeping with the rapid transition of traditional societies to industrial capitalist societies during his time. Functionalism was the predominant theoretical framework for sociological thinking till the 1960s, after which it began to retreat following critiques from various intellectual quarters such as feminism, postmodernism, post colonialism.

Applications of functionalism today tend to be a lot more nuanced and take into account the critiques offered by the various schools of thought. People have been satisfied with biological need for sex, ensuring procreation, development of the species, ensuring the transmission of social and cultural values to the young, making sure that the essential needs – food, shelter – of the members of the family are met. He argued that not only does the family perform all the functions mentioned by Murdock, the family is also a highly adaptive unit capable of modifying itself according to the demands of the society. The family thus mimics the functioning of an organism that adapts itself to change to continue being functional. As an example, Parsons gave the nuclear family in response to industrialization that served all the critical familial functions demanded of it.

Parsons argued that the pre-industrial extended family could not adapt to the new demands of mobility imposed upon the working populations. As workers, and consequently, families needed to be constantly on the move, the structure of the family

adapted itself to the new function required of it. However, in most parts of the world, elderly care is the responsibility of the family. In this, the family performs a critical function of taking care of the aged and the infirm. The functionalist perspective applied to schools examines the function performed by the school in contributing to society. Below are a few examples of how functionalism is applied to education. The school is thus an institution that helps a society function by producing individuals capable of sustained improvement of economy which is important for the survival of any society.

A child learns skills such as cooperation, coexistence, and conflict management within the school environment. In ethnically, racially, culturally, and linguistically diverse societies, children learn how to accept and be welcoming of differences, helping to create a more accommodating society. Children also learn how to obey rules and the consequences of transgressing rules that condition them into becoming law-abiding adults later on in life. For instance, the American sociologist Talcott Parsons believed that a school uses the hidden curriculum to instill values such as competition and individualism that are characteristic of American society, and essential to its continued progress. Parsons believed that it is in a school that children understand the meaning of a meritocracy where your achievements and your status are a function of the effort you put in; the notion of meritocracy being another cherished value in American society.

Durkheim based his views on a study of Australian Aboriginal tribes but we can experience this function of religion even today. For many people, their strongest sense of identity is often with their religion, rather than with other institutions such as the nation or linguistic community. For instance, religious nationalism is a vital force in many parts of the world such as South Asia, where the sense of belonging to the wider community fostered by religion overcomes linguistic, ethnic, and racial divides. For many people religion can act to improve mentally and emotionally overwhelming situations. For

others religion provides a way of dealing with trauma and provides answers to the deepest questions of human existence, such the meanings of life and death, that neither science, nor art can provide.

Bronislaw (1925) showed through his anthropological work that religion acts as a coping mechanism for individuals and society when faced with the essentially unpredictable nature of life. Some of the oldest legal codes in the world are to be found in religious texts and Law of Moses that is found in the Torah. Many countries in the Islamic world are governed by the Islamic Shari'a law. Beyond formal legal codes, religions also shape our ideas of morality. For instance several principles that we almost unconsciously imbibe in our everyday life, and which influence the definition of ideal human morality such as "love thy neighbor" or "do unto others as you would have others do unto you" are of Biblical origin.

Similarly, the practice of charity and helping the poor are institutionalized in the form of obligatory practice in many religions such as Sikhism. Talcott Parsons believed that this aspect of religion performed the critical function of maintaining social order. The mother and father form the leadership team. Within that team, traditionally the mother and father have also been seen as taking on gender roles granted to them by god. It is through the family relationship that father and mother take on a defined role, that the functioning nuclear family can produce future moral citizens.

The parents also take on the role of providers as with Murdock's 4 Functions of the Family model outlined earlier, the nuclear family unit is seen as essential in Christianity so that the children may be provided for. Here, we will often see the strengths of the mother and father both employed to create a well-rounded environment for children's growth. Within the family unit, the children also take on important social roles. They spend their formative years learning morality, respect, and discipline from the leadership

team (the parents). Functionalism is a theory that views the various structures and institutions within a society as not just performing useful functions, but also being interdependent on each other. In the examples cited above, the family, the school, and religion not just perform useful functions for society by themselves, but are also interdependent.

Functionalists view the school as an intermediary between the family and the society at large, thus being linked to, and dependent on both. Religion provides a sense of security and belonging much like a family, but at a higher level of organization, and it provides values and enables socialization just like a school. Almost all religions lay stress on the importance of family life, and provide mechanisms for the education of their adherents in their religious doctrines through religious schools. Thus, each structure, in interdependent, and performs a useful function in the smooth running of society.

However, even considering the high fixed carbon content of faeces (Brachi *et al*.,2016), which favors thermochemical processes, the water content of fresh faeces is definitely a constraint: the average moisture content of fresh faeces hovers around 75 wt%, is lower in moisture content as compared to the pit latrines' faecal sludge, 82 wt% (Winter 2016). The performance of a simple energy balance, the effective energies of faeces and faecal sludge combustion discounting the energy parcel required to remove the water content is below 1 MJ/kg (Jadhav, 2016). This result highlights the difficulty of using these wastes as combustible sources.

Research by McLean (2016) showed that the adoption and sustained use of latrines is largely rooted in the social norms and networks of communities and the rate of adoption of sanitation behaviors varies amongst households. Therefore, households' decision to construct and use a latrine may be influenced by the social norms of rural community (Jan 2016).

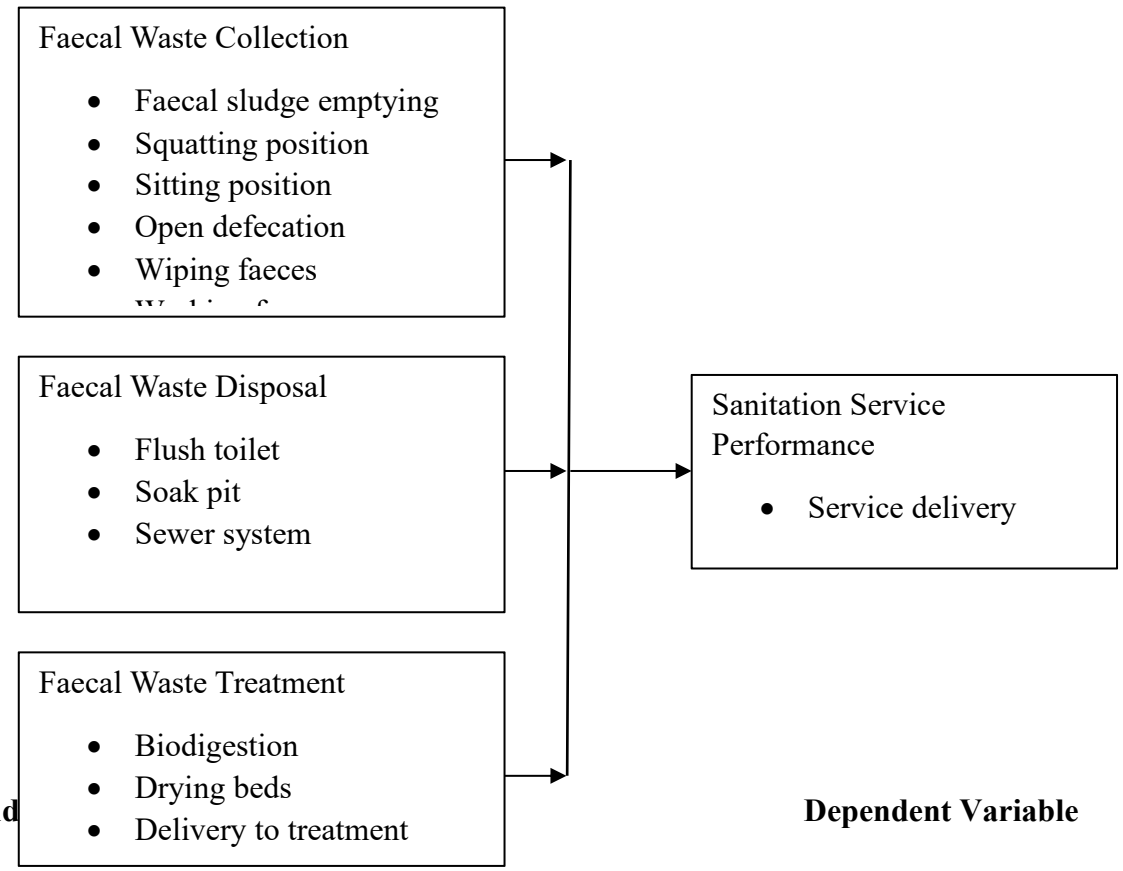
To compare the different communities, research on CLTS in has been carried out in low-income economy countries has been extensive, few studies examine why people change their behaviour from a psychosocial perspective. However, understanding the mechanisms underlying behaviour change interventions is needed to improve its effectiveness (Kihara, 2015).

2.9 Conceptual Framework

The independent variables are faecal waste collection practices, faecal waste disposal and faecal waste treatment strategies while the dependent variables are the sanitation service chain. Sanitation service chain is determinant on responsive and efficient faecal waste collection practices, faecal waste disposal, effective and sustainable faecal waste treatment strategies.

Figure 2. 1

Conceptual Framework



Source: Researcher 2023

CHAPTER THREE: RESEARCH METHODOLOGY

3.0 Introduction

This chapter presents the methodology including the study location, design, approach, population, sample size, eligibility criteria, data collection, piloting, data analysis, and ethical consideration.

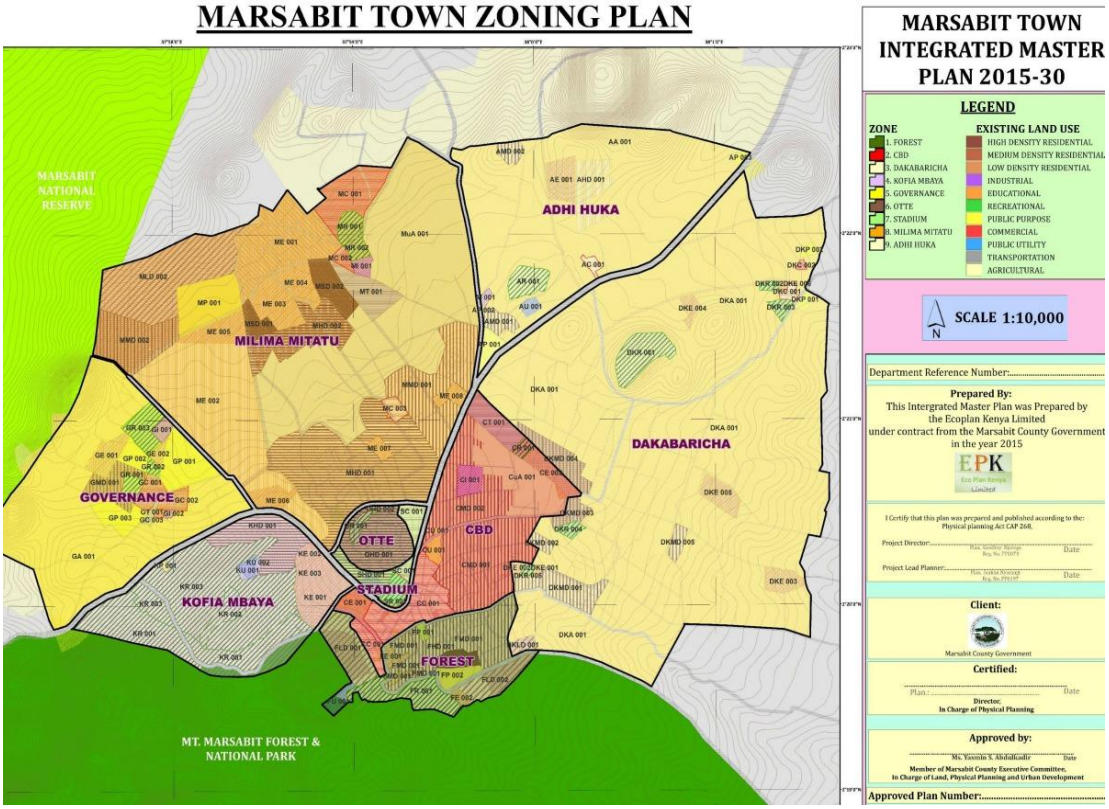
3.1 Study Location

The study was at Marsabit town, Marsabit Central ward of Saku Sub County. Saku Sub County Borders North Horr Sub County to the North and Laisamis Sub County to the South. Marsabit town is the administrative headquarters of Marsabit County. Marsabit town was used for the study because Marsabit municipality is yet to implement sewerage treatment plant and construction of sewerage system (WHO, 2017). Marsabit town lies in a water-scarce area where there are no permanent rivers. Marsabit Central ward has a population of 78,167, the number of households was 15,849 and household size of 4.9 (KNBS, 2019).

Residents rely on water supplied from outside of Marsabit town and increased sanitation risk. According to 2019 Kenya Population and Housing Census Report, there is a growing urban population and increase in commercial and residential buildings throughout the municipality. Because of these underlying factors and necessary understanding the movement and ultimate fate of faecal waste in Marsabit town along the sanitation service chain. The sample of 612 respondents was necessary to factor all the residents of large number of Marsabit Central Ward.

Figure 3.1:

Map of Marsabit Town



Source: Ecoplan Kenya Limited (2015)

3.2 Research Design

A cross sectional descriptive study design was employed for the study. Both qualitative and quantitative data were collected. The study majorly described the safely managed faecal waste and unsafely managed faecal waste in Marsabit town for the purpose of public health planning. Data was collected on individual characteristics by identifying the sources of water and types of toilets residents of Marsabit used for their daily activities. The study design aided the researcher to comprehensively understand the exposure risk factors to sanitation related illnesses that residents of Marsabit faced as they used their toilets.

3.3 Research Approach

Mixed method approach employing qualitative research methods and quantitative methods was used in this study to assess waste collection practices, waste disposal and feacal waste treatment strategies along sanitation service chain. The questionnaire included open ended and close ended questions where emerging questions were answered on sanitation. Observation method was used to observe the type of sanitation system in use. The population for the study is 612 from the identified 9 zones in Marsabit town. The data was summarized in a data summary sheet and presented inform of figures and tables.

3.4 Study Population

Study population included all households within Marsabit township. The study participants were household heads selected from the households of Marsabit town. According to KNBS census data (2019), Marsabit central ward has 15,849 households and population of 78,167, with average household size of 4.9 as shown in table 3.1.

Table 3. 1

Population and Households In Marsabit Central Ward

Ward	Households	Population	Average Household size
Marsabit Central	15,849	78,167	4.9

Source; KNBS Census data (2019)

3.5 Sample Size Determination and Sampling Technique

Cluster sampling was used to select the zones in Marsabit town. Cluster sampling divided the population of Marsabit town which consisted of 4,800 households. Sampling design of simple random was used to select the participants within the zones of Marsabit town and enabled each member of the population an equal chance of being selected.

Samples of household heads was derived by dividing population of a zone of Marsabit town by the total population of Marsabit town, and multiplying by the sample respondents.

Taro Yamane's formula was used:

$n = N / [1 + N (e)2]$ (1)

n = no. of samples.

N = total population.

e = error margin/margin of error/precision/level of accuracy eg. (0.01). According to KDHS (2019), the population of Marsabit town was projected at 16,000 residents.

Sampling size determination will be calculated as follows:

$n = N / [1 + N (e)2]$

n = 16000/1+(16000*0.01) *6.

Population sample (n) will be 612 respondents.

Quarterly sampling method was used which is non probabilistic method to allocate the sample to each zone. The zones of Marsabit town included Central Business District, Forest, Dakabaricha, Kofia Mbaya, Governance, Otte, Stadium, Milima Mitatu and Adhi Huka as shown in table 3.2.

Table 3. 2

Household Population per Zones of Marsabit Town

Zones of Marsabit town	**Sample per zone (n)**
Forest	69
Cental Business District	70
Dakabaricha	70
Kofia Mbaya	68
Governance	65

Otte	70
Stadium	65
Milima Mitatu	67
Adhi Huka	68
Total	612

Source: Researcher (2023)

3.6 Inclusion and Eligibility Criteria

3.6.1 Inclusion criteria

Household heads met the following criteria: were aged 18 years and above, gave consent to participate in the study by signing or appending thumb print for those who could not read or write and were residents of Marsabit town.

3.6.2 Eligibility criteria

Any household head who did not meet the inclusion criteria was excluded and did not participate in the study.

3.7 Data Collection Method

Questionnaires were administered to all the selected samples from the zones of Marsabit town was used in the study. The questionnaire had both close-ended and open-ended questions. The research investigator in collaboration with 4 research assistants collected data of the zones of Marsabit town. This was done with accuracy to minimize bias in data gathered and ensured that the data collected was representative of the general population of Marsabit town. Questionnaire was translated into local language for better understanding by respondents. The four sections of questionnaire included demographic information, faecal waste collection practices, faecal waste treatment methods, faecal waste disposal practices. Observation checklists was also administered at the households

during the interview. The researcher created checklist of interview schedules and collected data from household heads using in-depth interviews.

The four research assistants were trained on how to administer questionnaire to household heads. They were trained to build rapport with interviewees assuring them that participation in the interview was voluntary and they were free to decline participation. Household heads questionnaires were administered at their homes and when the participants gave consent for the interview and signed the consent form, the questionnaire was filled in by respondent. Research assistants handed over the completed questionnaire to the study investigator every week.

The researcher carried out secondary data which included e-journals, e-books, and Kenya Population and Housing Census Report of 2019.

3.7.1 Pretest

The research investigator ensured that the research instruments were suitable before the intended purpose during the field data collection. Piloting was carried out at Otte zone of Marsabit town using 15% of the sample size. Afterwards, errors were identified and corrected.

3.7.2 Validity of research instruments

According to Joppe (2000), validity determines whether the research measures that which it was intended to measure or how truthful the research results are. Validation involved collecting and analyzing the data to establish the accuracy of data collecting instrument and comparing the results after a repeated trial, and the research investigator ensured the validity of instruments by seeking opinions from three PhD holders who had in-depth knowledge on research instruments. The relevance of questionnaire was given and their feedback and recommendations were incorporated into final questionnaire to improve the validity of the contents in the research. The research investigator also

examined the data analyzed from pre-tested questionnaires before the actual field work and corrected the errors.

3.7.3 Reliability

Reliability is the degree to which a measurement instrument gives the same results each time that it is used, and the underlying variable being measured does not change (Kirk 1986). The measurement instrument used and what was being measured stays the same over time, the instrument will have high reliability. According to Miller (1986), the types of reliability relate to the degree to which a measurement remains the same, the stability of measurement over time, and the similarity of measurement within a given time period. Reliability described the extent the results were consistent over time and the representation of the study population was accurate. In order to establish the reliability of research instruments, the questionnaire was re-tested in randomly selected samples of Marsabit town and the data was analyzed and pretest was conducted after three weeks to determine the consistency of the results. The research investigator examined the clarity of the questionnaire and items found to be inadequate and unclear were changed to improve the quality of research instruments.

3.8 Pilot Study

Once the training of research assistants was carried out being familiar with data collection tools and procedures. The research investigator closely investigated collection of data exercise. A pilot study was carried out before the actual field work to identify and correct errors in the data collection tools.

3.9 Data Analysis

Qualitative was carried out using audio recording and duly-filled questionnaires. The recordings of respondent voice was transcribed into written texts and the data was compared with notes written by research assistants. Quantitative data collected at the

households was analyzed using the descriptive statistics in SPSS version 25. Descriptive data was presented in percentages, means, standard deviations, frequencies in tables and graphs.

3.10 Ethical Consideration

Permission to carry out research was authorized by Meru University Institutional Research and Ethics Review Committee (MIRERC), National Commission for Science, Technology and Innovation and letter of introduction from Meru University of Science and Technology. This ensured that collected data was used for its intended purpose and provided confidentiality of participants. Consent forms were signed by participants to ensure respondent was ready to participate in the study. Therefore, their participation was voluntary with no form of coercion. The collected hardcopy data was stored safely in locked cabinets while softcopy data was protected using private passwords in zipped folder to prevent access by unauthorized persons. Interview respondents' names were not included anywhere in the field notes, questionnaires, audio recordings and the final project report so as to hide the identity of participants.

CHAPTER FOUR: RESEARCH RESULTS

4.0 Introduction

This chapter details the results obtained from the collected data. The findings are presented in tables.

4.1 Response Rate

The research sought to explore the faecal waste management practices among institutions and households across sanitation service chain in Marsabit town, Marsabit County. This section captures the findings on the faecal waste management practices. This chapter discussed the response rate from questionnaire, respondent's demographics, and findings on the faecal waste management practices**.**

Response rate is the number of properly filled questionnaires expressed as percentage of the total number of respondents (Mugenda, 2013). The study targeted a sample size of 612 household heads. Response Rate is determined as follows;

Response rate = properly filled questionnaires X 100% Total number of respondents

The targeted 612 household's properly filled questionnaires giving a response rate of 100%. This was comparable to Fincham (2008) who recommended rate of at least 80% and Kothari (2010) recommended rate of above 50%. These rates are therefore adequate representation for generalization of the target population. Central Business district, Dakabaracha and Otte had equal frequency and percentage in response rate at 70 and 11.44% respectively. The least response rate was from Governance and Stadium area. This could as result of urban mobility in search of livelihood (Table 4.1).

Table 4. 1

Household Frequency per Zones of Marsabit Town

Zone	Frequency (n)	Percent (%)
Forest	69	11.27
Central Business District	70	11.44
Dakabaricha	70	11.44
Kofia Mbaya	68	11.11
Governance	65	10.62
Otte	70	11.44
Stadium	65	10.62
Mlima Mitatu	67	10.95
Adhi Huka	68	11.11
Total	612	100.00

Source: Researcher (2023)

4.2 Descriptive Statistics

The results of the socio-demographic information of the respondents are represented in form of frequency tables and pie chart. It shows the summary of the descriptive statistics in form of the frequency distribution. The data is grouped into age, education level, gender and the size of the household.

4.2.1 Age of the household head

The highest number of 251 (n=612) were aged between 30 and 39 years. This contributed to the largest percentage of the sample size of 41.01%. The household heads within the age bracket below 29 years were 13.40% of the total sample size while those aged between 40 and 49 years old were 28.27%. The age group aged group between 60

and 69 years had correspondents of 1.80% of the sample size. The age group with the least respondents at 0.98% were the people of 70 years and above (Table 4.2).

Table 4. 2

Age of the Household Head

Classification	Frequency (n=612)	Percent (%)
Below 29	82	13.40
30 – 39	251	41.01
40 – 49	173	28.27
50 – 59	89	14.54
60 – 69	11	1.80
Above 70	6	0.98
Total	612	100.00

Source: Researcher (2023)

4.2.2 Gender of the household head

Out of the total sample size 54.58% (n=334) were male while 45.42% (n=278) were female. The findings indicate that the male gender had the higher response compared to the female gender as detailed in Table 4.3. The male gender upholds the traditional norm of head of the households in this community.

Table 4. 3

Gender of the Household Head

Classification	Frequency (n=612)	Percent (%)
Male	334	54.58
Female	278	45.42
Total	612	100.00

Source: Researcher (2023)

4.2.3 Level of education of the household head

Study results showed that 14.38% (n=88) of the household heads had tertiary level of education, 55.23% (n=338) had secondary education, 18.30% (n=112) had primary education while 12.09% (n=74) had no formal education (table 4.4). This shows that most of the respondents in the town were holding secondary education certificate and they were able to understand the questionnaire. Least numbers were recorded amongst individuals without any formal education as detailed in table 4.4 below.

Table 4. 4

Level of Education of the Household Head

Classification	Frequency (n=612)	Percent (%)
Tertiary	88	14.38
Secondary	338	55.23
Primary	112	18.30
No education	74	12.09
Total	612	100.00

Source: Researcher (2023)

4.2.4 Size of the household

The distribution 6.70% (n=41) of the households had less than three people, 53.43% (n=327) had three to five members, 30.72% (n=188) had six to nine members, 9.15% (n=56) had more than nine members (Table 4.5). The household with classification between 3-5 members had highest frequency 327 (53.43%) with the least being below 3 classification at frequency 419 (6.7%).

Table 4. 5

Size of the Household

Classification	Frequency (n)	Percent (%)
<3	41	6.70
3 – 5	327	53.43
6 – 9	188	30.72
>9	56	9.15
Total	612	100.00

Source: Researcher (2023)

4.2.5 Distribution by religion

Approximately 17.0% (n=104) of the respondents were Christians and 76.14% (n=466) were Muslims. There were 5.07% (n=31) of traditional religion and 1.47% (n=9) of participants did not belong to any religion. There were 0.16% (n=1) Hindus and also Jews at 0.16% (n=1) (table 4.6). These findings showed that Islam was the predominant religion in the study area who were anal washers. Anal washing practices could be a challenge due to water scarcity.

Table 4. 6

Respondents' Distribution by Religion

Classification	Frequency (n)	Percent (%)
Christians	104	17.00
Muslims	466	76.14
Traditions	31	5.07
No religion	9	1.47
Hindus	1	0.16
Jews	1	0.16
Total	612	100.00

Source: Researcher (2023)

4.2.6 Distribution by occupation

The residents of Marsabit town were 4.41% (n=27) livestock herders, 18.30% (n=112) of participants were salaried, 20.92% (n=128) were farmers, 14.05% (n=86) were engaged in casual labour, 25.09% (n=156) were unemployed, and 16.83% (n=103) were entrepreneurs (table 4.7). Community in this town are ago-pastoralist and also depend on annual salary for their livelihood.

Table 4. 7

Distribution by Occupation

Classification	Frequency (n=612)	Percent (%)
Livestock herding	27	4.41
Salaried	112	18.30
Farming	128	20.92

Casual labor	86	14.05
Trader/entrepreneur	103	16.83
Unemployed	156	25.49
Total	612	100.00

Source: Researcher (2023)

4.2.7 Source of water

Sixteen percent (n=99) of participants used tanker trucks as source of water, 5.72% (n=35) used rain water, 33.17% (n=203) used unprotected wells, 1.31% (n=8) used boreholes, 32.19% (n=197) used public water taps or water kiosks, 8.82% (n=54) used surface water, and 2.61% (n=16) used water piped into household. The highest frequency of the residents used unprotected well 33.17%(n=203), followed by public water taps/water kiosks at 32.19(n=197). Borehole, rain water and surface water were at 1.31% (n=8),5.72(n=35) and 8.82%(n=54). Only 2.61% (n=16) of the residents reported having water piped into households (table 4.8).

Table 4. 8

Water Sources used by Household

Classification	**Frequency (n=612)**	**Percent (%)**
Tanker trucks	99	16.18
Rain water	35	5.72
Unprotected wells	203	33.17
Boreholes	8	1.31
Public water taps/water kiosks	197	32.19
Water piped into household	16	2.61
Surface water	54	8.82
Total	612	100.00

Source: Researcher (2023)

4.3 Examination of Waste Collection Practices along Sanitation Service Chain

From the survey out of the 612 Marsabit town respondents interviewed, 18.79% (n=115) of participants used flush to pit latrine, 24.02% (n=147) used ventilated improved pit latrine, 31.86% (n=195) pit latrine containing slab, 14.87% (n=91) used open pit, 1.47% (n=9) used composting toilet, 5.72% (n=35) used hanging toilet, and 3.27% (n=20) of participants had no toilet facility (table 4.11). Pit latrine with slab constitute highest classification of waste disposal 31.86%(n=195) followed by Ventilated improved pit latrine at 24.02%(n=147). Open defecation is still practiced by these urban dwellers with 3.27%(n=20) reporting no toilet facility. The least mode of waste disposal was composting toilet at 1.47%(n=9) as indicated in table 4.9 below.

Table 4. 9

Type of Sanitation Facility

Classification	Frequency (n=612)	Percent (%)
Flush to pit latrine	115	18.79
Ventilated improved pit latrine	147	24.02
Pit latrine containing slab	195	31.86
Pit	91	14.87
Composting toilet	9	1.47
No toilet facility	20	3.27
Hanging toilet	35	5.72
Total	612	100.00

Source: Researcher (2023)

4.3.1 Safely and unsafely managed faecal waste

From the survey only 8% of faecal waste were safely managed, and 92% of faecal waste were unsafely managed, with high possibility in contaminating environment and water body during raining seasons through water run -off as indicated in table 4.10 below.

Table 4. 10

Safely and Unsafely Managed Faecal Waste

Classification	Frequency (n=612)	Percent (%)
Safely managed faecal waste	48	8.00
Unsafely managed faecal waste	564	92.00
Total	**612**	**100.00**

Source: Researcher (2023)

4.3.2 Faecal collection practices

The faecal waste collection practices include flush to pit latrine, ventilated improved pit latrine, pit latrine with slab, composting toilet, no toilet facility, hanging toilet and open pit.

A total of eight (8) zones were interviewed with 612 respondents on faecal collection practices and 115 respondents reported using flush to pit latrine. Central Business District had highest at 31.3% (n=36). The least respondents were Milimitatu zone at 3.48% (n=4) (Table 4.11).

Table 4. 11

Flush to Pit Latrine Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	16	13.91
Central Business District	36	31.30
Dakabaricha	11	9.60
Kofia Mbaya	9	7.82
Governance	13	11.30
Otte	9	7.82
Stadium	12	10.43
Mlima Mitatu	4	3.48
Adhi Huka	5	4.34
Total	**115**	**100.00**

Source: Researcher (2023)

Ventilated improved pit latrine is common practice in these zones with Dakabaricha, Kofia mbaya and Otte taking the lead at 12.5%(n=18) (table 4.12).

Table 4. 12

Ventilated Improved Pit Latrine Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	15	10.20
Central Business District	14	9.52
Dakabaricha	18	12.25
Kofia Mbaya	18	12.25
Governance	15	10.20
Otte	18	12.25
Stadium	16	10.88
Mlima Mitatu	17	11.57
Adhi Huka	16	10.88
Total	147	100.00

Source: Researcher (2023)

Pit latrine with slab is common at the zone of stadium at 15.9% (n=31). Pit latrine collection practice is prevalent in the zone of Governance at 16.48 (n=15) (table 4.13).

Table 4. 13

Pit Latrine with Slab Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	22	11.28
Central Business District	14	7.17
Dakabaricha	21	10.80
Kofia Mbaya	20	10.26
Governance	18	9.22

Otte	27	13.85
Stadium	31	15.90
Mlima Mitatu	18	9.22
Adhi Huka	24	12.30
Total	**195**	**100.00**

Source: *Researcher (2023)*

Composting toilet is practiced at Forest and Kofia mbaya zones and least at stadium and central business District at 0% (n=0) (table 4.14).

Table 4. 14

Composting Toilet Practices per Zone

Zone	**Frequency (n=612)**	**Percent (%)**
Forest	2	22.22
Central Business District	0	0.00
Dakabaricha	1	11.11
Kofia Mbaya	2	22.22
Governance	1	11.11
Otte	1	11.11
Stadium	0	0.00
Mlima Mitatu	1	11.12
Adhi Huka	1	11.11
Total	**9**	**100.00**

Source: Researcher (2023)

Four (4) zone out of 8 zones respondents reported not having toilets at 15% (n=3) thus practicing open defecation and hanging toilets practiced commonly approximately at 14% (n=5) and 11% (n=4) as detailed in table 4.15, 4.16 and 4.17 below.

Table 4. 15

Toilet Facility Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	3	15.00
Central Business District	1	5.00
Dakabaricha	3	15.00
Kofia Mbaya	2	10.00
Governance	2	10.00
Otte	2	10.00
Stadium	1	5.00
Mlima Mitatu	3	15.00
Adhi Huka	3	15.00
Total	**20**	**100.00**

Source: Researcher (2023)

Table 4. 16

Hanging Toilet Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	3	8.57
Central Business District	1	2.90
Dakabaricha	5	14.30
Kofia Mbaya	5	14.28
Governance	3	8.54
Otte	5	14.26
Stadium	4	11.43

Mlima Mitatu	4	11.43
Adhi Huka	5	14.29
Total	35	100.00

Source: Researcher (2023)

Table 4. 17

Open Pit Practices per Zone

Zone	Frequency (n=612)	Percent (%)
Forest	7	7.70
Central Business District	4	4.40
Dakabaricha	10	11.00
Kofia Mbaya	13	14.25
Governance	15	16.48
Otte	11	12.09
Stadium	12	13.19
Mlima Mitatu	11	12.09
Adhi Huka	8	8.80
Total	91	100.00

Source: Researcher (2023)

4.3.3 User preference in toilets use

Toilet position during defecation differs from person to person and its culture -dependent. Out of 612 respondents 495 reported squatting as the preferred position during defecation. Approximately 80.88% (n=495) respondents reported squatting during defecation as a common preferred toilet use. Sitting position remain at 19.12% (n=117). The community were washers at 77.6% (n=475) and wipers at 22.4% (n=137) as detailed in table 4.18.

Table 4. 18

User Preference in Toilets Use

Classification	Frequency (n=612)	Percent (%)
Sitting	117	19.12
Squatting	495	80.88
Total	**612**	**100.00**
Washing	475	77.61
Wiping	137	22.39
Total	612	100.00

Source: Researcher (2023)

4.4 Examination of Disposal of Waste along Sanitation Service Chain

Flush toilet connected to soak pit is at 10.29% (n=63), latrine discharged to open drain is at 6.7% (n=41). Approximately 70.1% (n=429) responded abandoning their latrine once they are full. Open defecation was reported to be practiced among this community of Marsabit town at 3.27%(n=20). There is 0% sewerage connection from Flush toilet connected to sewer system (table 4.19).

Table 4. 19

Faecal Waste Disposal Practices

Classification	Frequency (n=612)	Percent (%)
Latrine discharges to sewer	0	0.00
Latrine discharges to soak pit	4	0.65
Latrine discharges to open drain	41	6.70
Latrine abandoned when full	429	70.10
Latrine discharges to open ground	3	0.49

Flush toilet connected to one pit	11	1.80
Flush toilet connected to two pits	39	6.37
Flush toilet connected to septic tank	2	0.33
Flush toilet connected to soak pit	63	10.29
Flush toilet connected to sewer system	0	0.00
Open defecation	20	3.27
Total	612	100.00

Source: Researcher (2023)

4.5 Set Down Waste Treatment Strategies along Sanitation Service Chain

The identified zones reported highest at 90.52% (n=554) with no treatment technology to remove faecal waste, followed by bio digestion at 5.07% (n=31) while the least was by suction at 4.41% (n=27) as detailed in table 4.22t. Marsabit town is yet to embrace sewerage waste treatment strategies along sanitation service chain. This could be due to scarcity of water system to maintain and drain waste disposal.

Table 4. 20

Waste Treatment Strategies

Classification	**Frequency (n=612)**	**Percent (%)**
Toilet removes faecal waste by drying beds	27	4.41
Toilet removes faecal waste by biodigestion	31	5.07
No treatment technology to remove faecal waste	554	90.52
Total	612	100.00

Source: Researcher (2023)

4.6 Correlation Analysis

Correlation analysis is a statistical method used to evaluate the strength and direction of the relationship between two or more variables. The significant concepts include correlation coefficient (r) which measures the degree of linear relationship between two variables. The value ranges from -1 to +1 where +1 represents perfect positive correlation, 0 shows no linear correlation, and -1 represents perfect negative correlation.

The types of correlation include positive correlation where both variables move in the same direction, and negative correlation shows that one variable increases while the other decreases. Zero correlation shows that there is no predictable relationship.

Correlation coefficients include Pearson's r which measures linear relationships between continuous variables, Spearman's ρ (rho) measures monotonic relationships using ranked data, and Kendall's τ (tau) is a rank-based measure which is less sensitive to outliers than Spearman.

The table 4.21 below shows the correlation analysis across the zones between hanging and composting toilets.

Table 4. 21

Correlation Coefficient for Hanging and Composting Toilets

Zone	**x (Hanging toilet) (%)**	**y (Composting toilet) (%)**	$x - \bar{x}$	$y - \bar{y}$	$(x - \bar{x})(y - \bar{y})$	$(x - \bar{x})^2$	$(y - \bar{y})^2$
Forest	8.57	22.22	-2.541	11.22	-28.52	6.46	125.86
Cbd	2.90	0.00	-8.211	-11.00	90.32	67.42	121.00
Dakabaricha	14.30	11.11	3.189	0.11	0.35	10.17	0.01

Kofia mbaya	14.28	22.22	3.169	11.22	35.55	10.04	125.86
Governance	8.54	11.11	-2.571	0.11	-0.28	6.61	0.01
Otte	14.26	11.11	3.149	0.11	0.35	9.91	0.01
Stadium	11.43	0.00	0.319	-11.00	-3.51	0.10	121.00
Mlima tatu	11.43	11.12	0.319	0.12	0.04	0.10	0.01
Adhi huka	14.29	11.11	3.179	0.11	0.35	10.11	0.01

Source: Researcher (2023)

Using Pearson's correlation formula, r is 0.39 which is a weak positive correlation between hanging and composting toilets across the zones.

CHAPTER FIVE: DISCUSSION

5.0 Introduction

This section deals with the discussion of the findings of the study presented in chapter four on faecal waste management practices among institutions and households across sanitation service chain in Marsabit town, Marsabit County. This section captures the findings on the faecal waste management practices. The findings of the study have insights into the options and technologies for waste collection, treatment and disposal and gap between policy and practice in faecal sludge management chain.

5.1 Examination of Waste Collection Practices along Sanitation Service Chain

Out of total 612 Marsabit town respondents 18.79% (n=115) of participants used flushed to pit latrine, 24.02% (n=147) used ventilated and improved pit latrine, Pit latrine which contain slab was the preferred method of waste collection at 31.86% (n=195), 14.87% (n=91) used open pit, 1.47% (n=9) used composting toilet, 5.72% (n=35) used hanging toilet, and 3.27% (n=20) of participants had no toilet facility. Pit latrine with slab constitute highest classification of waste disposal 31.86% (n=195) followed by Ventilated improved pit latrine at 24.02% (n=147).

Study results showed that open defecation is still practiced by these urban dwellers with 3.27% (n=20) reporting no toilet facility, a result that corresponds to an earlier report by Terefe (2020). The findings from the study showed that majority of the residents in Marsabit town uses pit latrine with slab as waste collection and disposal(31.86%)(table 4.11).The sanitation needs of most peri-urban residents in the country are met by pit latrines (both traditional and improved pit latrines). For example, pit latrine constitutes approximately 75% of household sanitation systems in peri-urban areas of Kisumu City (Owako and Renouf 2018).

The pit latrines provide varying degrees of safety, hygiene, and privacy; however, they have been reported to be rudimental, poorly constructed, and sometimes very shallow with increasing risk of surface and groundwater contamination and associated environmental and health risks. The pit latrines also have a fast-filling rate as they are mostly communal. This is the case in informal settlements such as Kibera slums, Nairobi County. A survey in Kibera slum showed that pit latrines are built next to houses and are hardly 15 meters deep. When it rains, the pit latrines fill up and overflow into the Nairobi River (Karanja, 2008).

A similar survey carried out by UNICEF (2017) in Bangladesh in low-income settings found that 92.7% of households rely on onsite containment facilities such as pit latrines. UNICEF's (2019) survey confirms the same that the population in low and middle-income settings with latrines or toilets is estimated at 99% (UNICEF, 2019). Nonetheless, shared sanitation facilities are deemed appropriate sanitation provision options in high population settlements in the country. The availability of space and funds for constructing new toilet determine whether a full pit latrine will be emptied or abandoned. Key challenge of pit latrine usage is the filling up, emptying and replacement of pit latrines is costly due to the manpower needed. Emptying and disposal of pit latrines is hazardous to human health. Pit latrines fill-up rate is difficult to determine from individual households AccTilley (2019) and Nyenje (2016). Fill-up rate is related to latrine size and architecture, the drainage rate in the pit, the number of users, decomposition rates, and whether other wastes such as household garbage have also been added to the pit latrine.

Interestingly, the use of composting toilets was reported by only 1.47% of the respondents. This finding suggests limited adoption of this technology, and which is linked to factors such as lack of awareness, cultural preferences, or infrastructure

constraints (Mansour *et al.,* 2017). The finding concurs with Bhagwan *et al.*, (2019) and Russel *et al.*(2019a) who found that affordability plays also crucial role in determining the quality and availability of faecal sludge management technologies. Mehta *et al.* (2019) emphasized the importance of promoting sustainable sanitation technologies like composting toilets for faecal sludge management, as they offer potential benefits such as resource recovery and reduced environmental impact. Residents of Marsabit town are cosmopolitan with different social economic status and religious background.

Furthermore, study findings showed that collection practice along sanitation service chain was indirectly and directly influenced by economic status of the community for safe management and disposal which agrees with earlier report by Sun (2021). The safe collection, transport and disposal of waste is important but underappreciated links in the sanitation system. Waste management is a major challenge that is not limited to poor infrastructure and technologies, inadequate financing, lack of public awareness on good sanitation practices and inadequate legal and regulatory framework. (UN-HABITAT, 2013).

However, a total of nine (9) zones were interviewed with 612 respondents on faecal collection practices and 115 respondents reported using flush to pit latrine. Central Business District had highest at 31.3% (n=36) due to urbanization and its occupants being of middle income. The least respondents were Milima mitatu zone at 3.48% (n=4 using flush to pit latrine due to their low economic status, being far from CBD and scarcity of water supply. Pit latrine with slab was common at the zone of stadium at 15.9% (n=31). Four (4) zone out of 8 zones respondents reported not having toilets at 15% (n=3) thus practicing open defecation and hanging toilets practiced commonly approximately at 14% (n=5) and 11% (n=4) respectively. This scenario corresponds with a study done in Ghana where approximately 85% of households relied on communal

latrines and open defecation, with most of the study population depending on shared toilet facilities.

Additionally, most toilet rooms were found unclean, because users do not take up the duty to clean up and therefore pose a high risk of accumulation of sanitary waste into faecal sludge (Kosoe 2019). A study done in Nigeria found out in many cases the method of waste collection adopted and equipment used were faced with many challenges and with no investment presently made on improving the existing development plan to initiate a modern waste collection system (Olukanni, 2016).

Marsabit town occupy an area where 66% of the faecal sludge are neither contained and nor treated as detailed in figure 3.1. According to study findings, there was significant relationship between containment of faecal sludge, faecal sludge treatment and scarcity of water. A study conducted in informal settlements of Kampala, Uganda, found that three key factors for improving service provision were truck capacity, fuel costs and travel distance (Murungi, 2014).

However, toilet position during defecation differed from person to person and it was culture-dependent. Approximately 80.88% (n=495) respondents reported squatting during defecation as a common preferred toilet use. Sitting position remain at 19.12% (n=117). The community were washers at 77.6% (n=475) who were mostly from the members that embraced Muslim religion and wipers at 22.4% (n=137(table 4.20).

The choice of a toilet like user interface technology depends on water supply, habits, and preferences of users such as squatting or sitting, wiping or washing, special needs of user groups, local materials availability, and compatibility with the subsequent collection, storage, treatment or transport technologies. The toilets are categorized into dry and water-based technologies based on water requirements for their operation.

Dry technologies operate without water and include dry toilets, urine-diverting dry toilets, and urinal. Meanwhile, water-based technologies such as pour flush toilets, cistern flush toilets, and urine diverting flush toilets require a constant supply of water to operate properly. Further, a study in Morocco where most community members practiced Islamic religion were washers amd there was water scarcity. This constituted a real burden on the health of population and were prone to water-borne illnesses (Chahlaoui, 2019), which to agrees with reported findings for Marsabit township.

5.2 Examination of Disposal of Waste along Sanitation Service Chain

Safe waste disposal along sanitation service chain is significate to environment and wellbeing of the residents of Marsabit town. According to study findings, Flush toilet connected to soak pit was at 10.29% (n=63), latrine discharged to open drain was at 6.7% (n=41). Approximately 70% (n=429) responded abandoning their latrine once they are full. Open defecation was reported to be practiced among this community of Marsabit town at 3.27% (n=20)(table 4.21). The Poor design of treatment plants, pit latrines, and lack of sanitation facilities are the root causes of the increase of microbes in the environment. The inadequate sanitation facility has resulted in people resorting to open defecation. This has increased threats to health as groundwater is contaminated which leads to high concentrations of E. coli in the environment (Hajam *et al*., 2023) .

Treated faecal sludge effluent is mostly disposed into water bodies. Such is the case for Ruai and Kipevu sewerage plant where treated effluent flows into the Nairobi River and the Indian Ocean, respectively. This practice has a negative ecological impact on aquatic ecosystems, such as the destruction of coral in the ocean. Another option used in Kenya is to allow treated effluent to percolate into the ground. Such is the case at Gakoromone treatment works in Meru Town, Meru County, where treated effluent is allowed to percolate into the ground in a soak-away area planted with eucalyptus trees. However, in

case of failure in the treatment process, this treatment method possesses groundwater contamination risks. Wastewater treatment works with drying beds such as in Nakuru Town, Nakuru County, and recycles treated faecal waste into compost fertilizer for landscaping, as well as into briquettes for use as fuel instead of wood charcoal (Eppinga, 2019).

Surprisingly, there was 0% sewerage connection from Flush toilet connected to sewer system. Marsabit town is yet to embrace safe waste disposal. A study conducted in Bangladesh (Abul, 2020) and in Peru (Krauss, 2021) contradicts this study finding whereby majority of slum residents were connected to sewer network and waterborne illnesses increased while this study proposed a better sanitation can be achieved when sewer system is implemented in Marsabit town.

Latrine abandonment when its full was the highest at 70% (table 4.21) as most of the area has a high water table that limits digging very deep pit latrines. The latrines often fill up leaving residents with very small pieces of land with no area for digging pits (Nakagiri *et al*., 2015). This again informs the need for provision of an alternative faecal waste management system within this community. Inadequate faecal waste treatment not only contributes to environmental pollution but also increases the possibility of microbial transmission across multiple channels, raising serious public health problems (Nakagiri *et al*., 2015, 2016). Addressing the issues of faecal sludge management necessitates comprehensive approaches that include improved sanitation infrastructure, effective treatment technologies, and community involvement efforts targeted at encouraging proper sanitation and minimizing faecal contamination pathways.

5.3 Identified Waste Treatment Strategies along Sanitation Service Chain

Among the identified zones, 90.52% (n=554) had no treatment technology to remove faecal waste, followed by bio digestion at 5.07% (n=31) while the least was by drying

beds at 4.41% (n=27) (table 4.22). Marsabit town is yet to embrace sewerage waste treatment strategies along sanitation service chain. This could be due to scarcity of water system to maintain and drain waste disposal as this explains why the residents prefer pit latrines where when they are filled up, they are abandoned and dig new ones or discharge it into open drains. The County of Marsabit, located in a hot and arid northern region of Kenya, is one of the most underdeveloped regions in the country, where water and energy are precious resources. Water is a scarce resource, mainly sourced from boreholes, although many households harvest rainwater in the rainy season. There are no sewer or solid waste collection systems in urban areas, although the county is planning to set up a controlled landfill to dispose of the garbage. (Government of the Marsabit County, 2016)

Ideally, the collected faecal sludge is supposed to be transported to centralized treatment facilities (designed for sewer wastewater treatment) but its disposed off in an unsanitary way into the surrounding environment (Taweesan *et al*. 2017). Poor disposal of Faecal is exacerbated by increased urbanization that exceeds infrastructure growth coupled with poor urban planning. However, the majority of the OSS in Kenya slums directly discharges faecal matter into nearby low-lying areas or drains.

Overflow of containment and odor nuisance are some of the reasons for containment emptying (Peletz *et al*., 2020) as only 8% of waste is safely managed from the study. Considering the millions of pit latrines and septic tanks filling up, the continued negligence of safe and final disposal of faecal sludge is an area of concern that needs to be addressed urgently. However, most current approaches focus on improving access to and use of sanitation latrines and hardly address the emptying of pits and tanks. Access to transport and treatment services for onsite sanitation is generally poor. Shit flow diagrams (SFDs) produced for Kisumu City and Nakuru Town indicate that over 65% of

excreta produced ends up in the environment untreated, due to inefficient transport and treatment services (Mansour *et al*., 2017).

CHAPTER SIX: CONCLUSION, RECOMMENDATIONS AND PUBLICATION

6.1 Introduction

Marsabit town did not have an existing sewer line or a treatment plant hence the residents, out of the 612 Marsabit town respondents interviewed, 18.79% (n=115) of participants used flush to pit latrine, 24.02% (n=147) used ventilated improved pit latrine, 31.86% (n=195) used pit latrine with slab, 14.87% (n=91) used open pit, 1.47% (n=9) used composting toilet, 5.72% (n=35) used hanging toilet, and 3.27% (n=20) of participants had no toilet facility. Approximately 8% of faecal waste were safely managed, and 92% of faecal waste were unsafely managed, with high possibility in contaminating environment and water bodies during raining seasons through water run - off.

6.2 Conclusion

Waste collection practice along sanitation service chain was indirectly and directly influenced by economic status of the community for safe management and disposal. These community practice pit latrine with slab as the main form of waste collection at 31% (n=195). The community additionally practice rotational waste disposal method, where approximately 70% (n=429) respondents abandoned their latrine once they were full. Open defecation is still practiced by these urban dwellers of Marsabit township with 3.27% (n=20) reporting no toilet facility.

The identified zones reported highest at 90.5% (n=554) with no treatment technology to remove faecal waste, Marsabit town is yet to embrace sewerage waste treatment strategies along sanitation service chain. This could be due to scarcity of water system to maintain and drain waste disposal. This data and highlighted challenges in this study will provide guidance to county stakeholders in providing framework for planning and legislation in effective and sustainable faecal waste management along service chain in

Marsabit town. Additionally, findings enabled research investigator to examine the safely managed faecal waste and unsafely managed faecal waste.

6.3 Recommendations

Improved social economic status of the community through economic growth and wealth creation will improve effective waste collection practices along service chain. The community and zonal regions of Marsabit town need to embrace safe waste disposal through community engagement and identifying the viable long-lasting solution to waste disposal. Faecal waste treatment strategies such as adapting bio digester and modern sewerage treatment plants are recommended for the upcoming urban town of Marsabit. Additionally, the study recommends further future studies in order to find out and evaluate sustainability of sewerage system once adopted by the municipality of Marsabit town.

6.4 Publication

Ali, M., Shano M. & Kagendo D. (2025). Faecal waste management practices and performance along sanitation service chain in Marsabit town, Marsabit county, Kenya. *International journal of current science. 15*(3), 103-105. https://rjpn.org/ijcspub/papers/IJCSP25C1118.pdf

REFERENCES

Adane, M., Mengistie, B., Kloos, H., Medhin, G., & Mulat, W. (2017). Sanitation facilities, hygienic conditions, and prevalence of acute diarrhea among under-five children in slums of Addis Ababa, Ethiopia: Baseline survey of a longitudinal study. *PLoS ONE, 12*(8).

Adukia, A., Alsan, M., Babiarz, K., Goldhaber-Fiebert, J. D., & Prince, L. (2021). Religion and sanitation practices. *The World Bank Economic Review*, *35*(2), 287-302.

Aldrighetti, R., Zennaro, I., Finco, S., & Battini, D. (2019). Healthcare supply chain simulation with disruption considerations: a case study from Northern Italy. *Global Journal of Flexible Systems Management,20*, 81–102.

Appiah–Effah, E., Duku, G. A., Dwumfour–Asare, B., Manu, I., & Nyarko, K. B. (2020). Toilet chemical additives and their effect on faecal sludge characteristics. *Heliyon*, *6*(9).

Armah, F. A., Ekumah, B., Yawson, D. O., Odoi, J. O., Afitiri, A. R., & Nyieku, F. E. (2018). Access to improved water and sanitation in sub-Saharan Africa in a quarter century. *Heliyon*, *4*(11).

Azage M, Motbainor A, Nigatu D. (2020). Exploring geographical variations and inequalities in access to improved water and sanitation in Ethiopia: mapping and spatial analysis. *Heliyon. 6*(4).

Bagshaw, E., & Powell, D. (2020). Supermarkets stockpile, toilet paper production runs 24 hours. *The Sydney Morning Herald*, *3*.

Bancalari, A., & Martinez, S. (2018). Exposure to sewage from on-site sanitation and child health: a spatial analysis of linkages and externalities in peri-urban Bolivia. *Journal of Water, Sanitation and Hygiene for Development*, *8*(1), 90-99.

Belachew, A. B., Abrha, M. B., Gebrezgi, Z. A., & Tekle, D. Y. (2018). Availability and utilization of sanitation facilities in Enderta district, Tigray, Ethiopia. *Journal of preventive medicine and hygiene*, *59*(3), E219.

Beukes, L. S. (2019). *Pit latrines in peri-urban South African community: a hygiene challenge and a health risk owing to current desludging practices and biofilm-forming, multi-drug resistant bacteria* (Doctoral dissertation). University of KwaZulu-Natal, Douban, South Africa.

Bhatt, N., Budhathoki, S. S., Lucero-Prisno, D. E. I., Shrestha, G., Bhattachan, M., Thapa, J., ... & Pokharel, P. K. (2019). What motivates open defecation? A qualitative study from a rural setting in Nepal. *PloS one*, *14*(7), e0219246.

Budhathoki, S. S., Shrestha, G., Bhattachan, M., Singh, S. B., Jha, N., & Pokharel, P. K. (2017). Latrine coverage and its utilisation in a rural village of Eastern Nepal: a community-based cross-sectional study. *BMC research notes*, *10*, 1-7.

Burt, Z., Sklar, R., & Murray, A. (2019). Costs and willingness to pay for pit latrine emptying services in Kigali, Rwanda. *International Journal of Environmental Research and Public Health*, *16*(23), 4738.

Cameron, L., Santos, P., Thomas, M., & Albert, J. (2021). Sanitation, financial incentives and health spillovers: a cluster randomised trial. *Journal of Health Economics*, *77*, 102456.

Capone, D., Buxton, H., Cumming, O., Dreibelbis, R., Knee, J., Nalá, R., ... & Brown, J. (2020). Impact of an intervention to improve pit latrine emptying practices in low income urban neighborhoods of Maputo, Mozambique. *International journal of hygiene and environmental health*, *226*, 113480.

Capone, D., Chigwechokha, P., de Los Reyes III, F. L., Holm, R. H., Risk, B. B., Tilley, E., & Brown, J. (2021). Impact of sampling depth on pathogen detection in pit latrines. *PLoS neglected tropical diseases*, *15*(3), e0009176.

Caruso, B. A., Clasen, T. F., Hadley, C., Yount, K. M., Haardörfer, R., Rout, M., ... & Cooper, H. L. (2017). Understanding and defining sanitation insecurity: women's gendered experiences of urination, defecation and menstruation in rural Odisha, India. *BMJ global health*, *2*(4), e000414.

Caruso, B. A., Sclar, G. D., Routray, P., Majorin, F., Nagel, C., & Clasen, T. (2019). A cluster-randomized multi-level intervention to increase latrine use and safe disposal of child feces in rural Odisha, India: the Sundara Grama research protocol. *BMC Public Health*, *19*, 1-9.

Chanie, T., Gedefaw, M., & Ketema, K. (2016). Latrine utilization and associated factors in rural community of Aneded district, North West Ethiopia, 2014. *J Community Med Health Educ*, *6*(478), 1-12.

Cheng, S., Li, Z., Uddin, S. M. N., Mang, H. P., Zhou, X., Zhang, J., ... & Zhang, L. (2018). Toilet revolution in China. *Journal of environmental management*, *216*, 347-356.

Chirwa, C. F., Hall, R. P., Krometis, L. A. H., Vance, E. A., Edwards, A., Guan, T., & Holm, R. H. (2017). Pit latrine faecal sludge resistance using a dynamic cone penetrometer in low income areas in Mzuzu City, Malawi. *International journal of environmental research and public health*, *14*(2), 87.

Clair, R. P., Rastogi, R., Lee, S., Clawson, R. A., Blatchley III, E. R., & Erdmann, C. (2019). A dialectical and dialogical approach to health policies and programs: the case of open defecation in India. *Health Communication*, *34*(11), 1231-1241.

Coffey, D., Spears, D., & Vyas, S. (2017). Switching to sanitation: understanding latrine adoption in a representative panel of rural Indian households. *Social Science & Medicine*, *188*, 41-50.

County Government of Marsabit (2016). Environmental and Social Baseline Survey. Marsabit.

Crocker, J., Abodoo, E., Asamani, D., Domapielle, W., Gyapong, B., & Bartram, J. (2016). Impact evaluation of training natural leaders during a community-led total sanitation intervention: a cluster-randomized field trial in Ghana. *Environmental science & technology*, *50*(16), 8867-8875.

Crocker, J., Saywell, D., & Bartram, J. (2017). Sustainability of community-led total sanitation outcomes: Evidence from Ethiopia and Ghana. *International journal of hygiene and environmental health*, *220*(3), 551-557.

Cronin, A. A., Gnilo, M. E., Odagiri, M., & Wijesekera, S. (2017). Equity implications for sanitation from recent health and nutrition evidence. *International Journal for Equity in Health*, *16*, 1-6.

Davis, E., Cumming, O., Aseyo, R. E., Muganda, D. N., Baker, K. K., Mumma, J., & Dreibelbis, R. (2018). Oral contact events and caregiver hand hygiene: implications for faecal-oral exposure to enteric pathogens among infants 3–9 months living in informal, peri-urban communities in Kisumu, Kenya. *International journal of environmental research and public health*, *15*(2), 192.

Dehghani, R., & Kassiri, H. (2020). A brief review on the possible role of houseflies and cockroaches in the mechanical transmission of coronavirus disease 2019 (COVID-19). *Archives of Clinical Infectious Diseases*, *15*(COVID-19).

Devaraj, R., Raman, R. K., Wankhade, K., Narayan, D., Ramasamy, N., & Malladi, T. (2021). Planning faecal sludge management systems: challenges observed in a small town in southern India. *Journal of Environmental Management*, *281*, 111811.

Dickinson, K. L., Patil, S. R., Pattanayak, S. K., Poulos, C., & Yang, J. H. (2015). Nature's call: impacts of sanitation choices in Orissa, India. *Economic Development and Cultural Change*, *64*(1), 1-29.

Ellis, A., McClintic, E. E., Awino, E. O., Caruso, B. A., Arriola, K. R., Ventura, S. G., ... & Freeman, M. C. (2020). Practices and perspectives on latrine use, child feces disposal, and clean play environments in western Kenya. *The American journal of tropical medicine and hygiene*, *102*(5), 1094.

Eppinga, R. (2019). How Nakuru (Kenya) managed to create value out of shit. https://snv.org/update/how-nakurukenya-managed-create-value-out-shit

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

Fathi, S., Hajizadeh, Y., Nikaeen, M., & Gorbani, M. (2017). Assessment of microbial aerosol emissions in an urban wastewater treatment plant operated with activated sludge process. *Aerobiologia*, *33*, 507-515.

Freeman, M. C., Majorin, F., Boisson, S., Routray, P., Torondel, B., & Clasen, T. (2016). The impact of a rural sanitation programme on safe disposal of child faeces: a cluster randomised trial in Odisha, India. *Transactions of the Royal Society of Tropical Medicine and Hygiene*, *110*(7), 386-392.

Friedrich, M. N., Kappler, A., & Mosler, H. J. (2018). Enhancing handwashing frequency and technique of primary caregivers in Harare, Zimbabwe: a cluster-randomized

controlled trial using behavioral and microbial outcomes. *Social science & medicine*, *196*, 66-76.

Furlong, C., Gibson, W. T., Oak, A., Thakar, G., Kodgire, M., & Patankar, R. (2016). Technical and user evaluation of a novel worm-based, on-site sanitation system in rural India. *Waterlines*, 148-162.

Garn, J. V., Sclar, G. D., Freeman, M. C., Penakalapati, G., Alexander, K. T., Brooks, P., ... & Clasen, T. F. (2017). The impact of sanitation interventions on latrine coverage and latrine use: A systematic review and meta-analysis. *International journal of hygiene and environmental health*, *220*(2), 329-340.

George, C. M., Oldja, L., Biswas, S., Perin, J., Sack, R. B., Ahmed, S., ... & Faruque, A. G. (2016). Unsafe child feces disposal is associated with environmental enteropathy and impaired growth. *The Journal of pediatrics*, *176*, 43-49.

Gertler, P., Shah, M., Alzua, M. L., Cameron, L., Martinez, S., & Patil, S. (2015). *How does health promotion work? Evidence from the dirty business of eliminating open defecation* (No. w20997). National Bureau of Economic Research.

Gitonga, F. K., Kanyepi, T., & Tanyanyiwa, V. I. (2021). faecal Sludge Management for Sustainable Cities: Glimpses from Kenya. In *Clean Water and Sanitation* (pp. 1-13). Cham: Springer International Publishing.

Greenland, K., Dixon, R., Khan, S. A., Gunawardena, K., Kihara, J. H., Smith, J. L., ... & Kumar, S. (2015). The epidemiology of soil-transmitted helminths in Bihar State, India. *PLoS neglected tropical diseases*, *9*(5), e0003790.

Guiteras, R., Levinsohn, J., & Mobarak, A. M. (2015). Encouraging sanitation investment in the developing world: A cluster-randomized trial. *Science*, *348*(6237), 903-906.

Gwenzi, W., Marumure, J., Makuvara, Z., Simbanegavi, T. T., Njomou-Ngounou, E. L., Nya, E. L., ... & Rzymski, P. (2023). The pit latrine paradox in low-income settings: A sanitation technology of choice or a pollution hotspot? *Science of the Total Environment*, *879*, 163179.

Hammer, J., & Spears, D. (2016). Village sanitation and child health: Effects and external validity in a randomized field experiment in rural India. *Journal of health economics*, *48*, 135-148.

Harter, M., Inauen, J., & Mosler, H. J. (2020). How does Community-Led Total Sanitation (CLTS) promote latrine construction, and can it be improved? A cluster-randomized controlled trial in Ghana. *Social science & medicine*, *245*, 112705.

Harter, M., Mosch, S., & Mosler, H. J. (2018). How does Community-Led Total Sanitation (CLTS) affect latrine ownership? A quantitative case study from Mozambique. *BMC public health*, *18*, 1-10.

Headey, D., Nguyen, P., Kim, S., Rawat, R., Ruel, M., & Menon, P. (2017). Is exposure to animal feces harmful to child nutrition and health outcomes? A multicountry observational analysis. *The American journal of tropical medicine and hygiene*, *96*(4), 961.

Huda, T. M. N., Schmidt, W. P., Pickering, A. J., Mahmud, Z. H., Islam, M. S., Rahman, M. S., ... & Biran, A. (2018). A cross sectional study of the association between sanitation type and faecal contamination of the household environment in rural Bangladesh. *The American journal of tropical medicine and hygiene*, *98*(4), 967.

Hussain, F., Clasen, T., Akter, S., Bawel, V., Luby, S. P., Leontsini, E., ... & Winch, P. J. (2017). Advantages and limitations for users of double pit pour-flush latrines: a qualitative study in rural Bangladesh. *BMC public health*, *17*, 1-9.

Hutton, G., & Chase, C. (2016). The knowledge base for achieving the sustainable development goal targets on water supply, sanitation and hygiene. *International journal of environmental research and public health*, *13*(6), 536.

Hyun, C., Burt, Z., Crider, Y., Nelson, K. L., Prasad, C. S., Rayasam, S. D., ... & Ray, I. (2019). Sanitation for low-income regions: a cross-disciplinary review. *Annual Review of Environment and Resources*, *44*, 287-318.

Ijaz, U. Z., Gundogdu, O., Keating, C., Eekert, M. V., Gibson, W., Parkhill, J., ... & Walker, A. W. (2022). Analysis of pit latrine microbiota reveals depth-related variation in composition, and key parameters and taxa associated with latrine fill-up rate. *Frontiers in microbiology*, *13*, 960747.

Jacob Arriola, K. R., Ellis, A., Webb-Girard, A., Ogutu, E. A., McClintic, E., Caruso, B., & Freeman, M. C. (2020). Designing integrated interventions to improve nutrition and WASH behaviors in Kenya. *Pilot and feasibility studies*, *6*, 1-16.

Jadhav, A., Weitzman, A., & Smith-Greenaway, E. (2016). Household sanitation facilities and women's risk of non-partner sexual violence in India. *BMC public health*, *16*, 1-10.

Janmohamed, A., Karakochuk, C. D., McLean, J., & Green, T. J. (2016). Improved sanitation facilities are associated with higher body mass index and higher hemoglobin concentration among rural Cambodian women in the first trimester of pregnancy. *The American Journal of Tropical Medicine and Hygiene*, *95*(5), 1211.

Kalina, M., Kwangulero, J., Ali, F., & Tilley, E. (2022). "You need to dispose of them somewhere safe": Covid-19, masks, and the pit latrine in Malawi and South Africa. *Plos one*, *17*(2), e0262741.

Karanja, J. M. (2008). Sanitation and hygiene in Kibera Slums, Nairobi: women´ s concerns and nurses promotional tools.

Kayser, G. L., Rao, N., Jose, R., & Raj, A. (2019). Water, sanitation and hygiene: measuring gender equality and empowerment. *Bulletin of the World Health Organization*, *97*(6), 438.

Khalil, U., Mookerjee, S., & Tierney, R. (2019). Social interactions in voting behavior: Evidence from India. *Journal of Economic Behavior & Organization*, *163*, 158-171.

Kirk, C. P., & Rifkin, L. S. (2020). I'll trade you diamonds for toilet paper: Consumer reacting, coping and adapting behaviors in the COVID-19 pandemic. *Journal of business research*, *117*, 124-131.

Knee, J., Sumner, T., Adriano, Z., Berendes, D., de Bruijn, E., Schmidt, W. P., ... & Brown, J. (2018). Risk factors for childhood enteric infection in urban Maputo, Mozambique: A cross-sectional study. *PLoS neglected tropical diseases*, *12*(11), e0006956.

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of chiropractic medicine*, *15*(2), 155-163.

Kosoe, E. A., & Osumanu, I. K. (2018). Entertaining risks to health: the state of human faecal matter managemnt in Wa, Ghana. *Ghana Journal of Development Studies*, *15*(1), 151-172.

Lam, K. L., Zlatanović, L., & van Der Hoek, J. P. (2020). Life cycle assessment of nutrient recycling from wastewater: A critical review. *Water research*, *173*, 115519.

Leshargie, C. T., Alebel, A., Negesse, A., Mengistu, G., Wondemagegn, A. T., Mulugeta, H., ... & Kibret, G. D. (2018). Household latrine utilization and its association with educational status of household heads in Ethiopia: a systematic review and meta-analysis. *BMC public health*, *18*, 1-12.

Louis, P., Duncan, S. H., Sheridan, P. O., Walker, A. W., & Flint, H. J. (2022). Microbial lactate utilisation and the stability of the gut microbiome. *Gut Microbiome*, *3*, e3.

Luby, S. P., Rahman, M., Arnold, B. F., Unicomb, L., Ashraf, S., Winch, P. J., ... & Colford, J. M. (2018). Effects of water quality, sanitation, handwashing, and nutritional interventions on diarrhoea and child growth in rural Bangladesh: a cluster randomised controlled trial. *The Lancet Global Health*, *6*(3), e302-e315.

Mallory, A., Mdee, A., Agol, D., Hyde-Smith, L., Kiogora, D., Riungu, J., & Parker, A. (2022). The potential for scaling up container-based sanitation in informal settlements in Kenya. *Journal of International Development*, *34*(7), 1347-1361.

Mamera, M., van Tol, J. J., Aghoghovwia, M. P., & Mapetere, G. T. (2020). Community faecal management strategies and perceptions on sludge use in agriculture. *International Journal of Environmental Research and Public Health*, *17*(11), 4128.

Manga, M., Evans, B. E., Ngasala, T. M., & Camargo-Valero, M. A. (2022). Recycling of faecal sludge: nitrogen, carbon and organic matter transformation during co-composting of faecal sludge with different bulking agents. *International Journal of Environmental Research and Public Health*, *19*(17), 10592.

Mansour, G., Islam, W., & Akhtaruzzaman, M. (2017). Situation analysis of the urban sanitation sector in Bangladesh. *WSUP-Water & Sanitation for the Urban Poor, London, UK*.

Mara, D., Lane, J., Scott, B., & Trouba, D. (2010). Sanitation and health. *PLoS medicine*, *7*(11), e1000363.

Mbuya, M. N., & Humphrey, J. H. (2016). Preventing environmental enteric dysfunction through improved water, sanitation and hygiene: an opportunity for stunting reduction in developing countries. *Maternal & child nutrition*, *12*, 106-120.

Miller-Petrie, M. K., Voigt, L., McLennan, L., Cairncross, S., & Jenkins, M. W. (2016). Infant and young child feces management and enabling products for their hygienic collection, transport, and disposal in Cambodia. *The American journal of tropical medicine and hygiene*, *94*(2), 456.

Nakagiri, A., Niwagaba, C. B., Nyenje, P. M., Kulabako, R. N., Tumuhairwe, J. B., & Kansiime, F. (2015). Are pit latrines in urban areas of Sub-Saharan Africa performing? A review of usage, filling, insects and odour nuisances. *BMC public health*, *16*, 1-16.

Ndoziya, A. T., Hoko, Z., & Gumindoga, W. (2019). Assessment of the impact of pit latrines on groundwater contamination in Hopley Settlement, Harare, Zimbabwe. *Journal of Water, Sanitation and Hygiene for Development*, *9*(3), 464-476.

Ngure, F. M., Humphrey, J. H., Mbuya, M. N., Majo, F., Mutasa, K., Govha, M., ... & Stoltzfus, R. J. (2013). Formative research on hygiene behaviors and geophagy among infants and young children and implications of exposure to faecal bacteria. *The American journal of tropical medicine and hygiene*, *89*(4), 709.

Okoth, S. O., Ronoh, A., & Mbalo, D. (2017). Scaling up feacal sludge management in Kenya's urban areas. *FSM Innovation: Overview and Analysis. Bill and Melinda Gates Foundation, Seattle, USA*, 59-69.

Orgill-Meyer, J., & Pattanayak, S. K. (2020). Improved sanitation increases long-term cognitive test scores. *World Development*, *132*, 104975.

Osumanu, I. K., & Atia, S. A. (2017). Collaboration and partnership in forest conservation: the role of communities in the management of the Gbele Reserve in North-Western Ghana. *Ghana Journal of Geography*, *9*(2), 91-124.

Owako, E., & Renouf, R. (2018). Strengthening the enabling environment for urban sanitation: public-private collaboration in Kisumu, Kenya.

Pattanayak, S. K., Pakhtigian, E. L., & Litzow, E. L. (2018). Through the looking glass: Environmental health economics in low and middle income countries. In *Handbook of Environmental Economics* (Vol. 4, pp. 143-191). Elsevier.

Peal, A., Evans, B., Blackett, I., Hawkins, P., & Heymans, C. (2014). faecal sludge management (FSM): analytical tools for assessing FSM in cities. *Journal of Water, Sanitation and Hygiene for Development*, *4*(3), 371-383.

Peletz, R., Feng, A., MacLeod, C., Vernon, D., Wang, T., Kones, J., ... & Khush, R. (2020). Expanding safe faecal sludge management in Kisumu, Kenya: an experimental comparison of latrine pit-emptying services. *Journal of Water, Sanitation and Hygiene for Development*, *10*(4), 744-755.

Penakalapati, G., Swarthout, J., Delahoy, M. J., McAliley, L., Wodnik, B., Levy, K., & Freeman, M. C. (2017). Exposure to animal feces and human health: a systematic review and proposed research priorities. *Environmental science & technology*, *51*(20), 11537-11552.

Pickering, A. J., Djebbari, H., Lopez, C., Coulibaly, M., & Alzua, M. L. (2015). Effect of a community-led sanitation intervention on child diarrhoea and child growth in rural Mali: a cluster-randomised controlled trial. *The Lancet Global Health*, *3*(11), e701-e711.

Portiolli, G. F., Rogers, T. W., Beckwith, W., Tsai, J., Wilson, N., & de los Reyes, F. L. (2021). Development of trash exclusion for mechanized pit latrine emptying. *Environmental Science: Water Research & Technology*, *7*(10), 1714-1722.

Prendergast, A. J. (2017). The sanitation hygiene infant nutrition efficacy (SHINE) trial: what's next. *Baltimore: American Society of Tropical Medicine and Hygiene*.

Prendergast, A. J., Chasekwa, B., Evans, C., Mutasa, K., Mbuya, M. N., Stoltzfus, R. J., ... & Humphrey, J. H. (2019). Independent and combined effects of improved water, sanitation, and hygiene, and improved complementary feeding, on stunting and anaemia among HIV-exposed children in rural Zimbabwe: a cluster-randomised controlled trial. *The Lancet Child & Adolescent Health*, *3*(2), 77-90.

Rao, K. C., Otoo, M., Drechsel, P., & Hanjra, M. A. (2017). Resource recovery and reuse as an incentive for a more viable sanitation service chain. *Water Alternatives*, *10*(2), 493.

Ravenscroft, P., Mahmud, Z. H., Islam, M. S., Hossain, A. K. M. Z., Zahid, A., Saha, G. C., ... & Islam, M. S. (2017). The public health significance of latrines discharging to groundwater used for drinking. *Water research*, *124*, 192-201.

Reese, H., Routray, P., Torondel, B., Sclar, G., Delea, M. G., Sinharoy, S. S., ... & Clasen, T. (2017). Design and rationale of a matched cohort study to assess the effectiveness of a combined household-level piped water and sanitation intervention in rural Odisha, India. *BMJ open*, *7*(3), e012719.

Reid, B., Orgle, J., Roy, K., Pongolani, C., Chileshe, M., & Stoltzfus, R. (2018). Characterizing potential risks of faecal–oral microbial transmission for infants and young children in rural Zambia. *The American Journal of Tropical Medicine and Hygiene*, *98*(3), 816.

Renouf, R. & Drabble, S. (2018). Incentivising the Private Sector to Target Low-Income Customers. *Water & Sanitation for the Urban Poor* (Perspective piece).

Reymond, P., Chandragiri, R., & Ulrich, L. (2020). Governance arrangements for the scaling up of small-scale wastewater treatment and reuse systems–lessons from India. *Frontiers in Environmental Science*, *8*, 72.

Ross, I., Scott, R., Blackett, I. C., & Hawkins, P. M. (2016). faecal sludge management: diagnostics for service delivery in urban areas-summary report.

Russel, K. C., Hughes, K., Roach, M., Auerbach, D., Foote, A., Kramer, S., & Briceño, R. (2019). Taking container-based sanitation to scale: opportunities and challenges. *Frontiers in Environmental Science*, *7*, 190.

Scott, R. E., Ross, I., & Smith, M. D. (2017). Diagnostic and decision-support tools for effective faecal sludge management (FSM) services.

Sinha, A. (2017). *Assessing latrine use in low-income countries: A field study in rural India* (Doctoral dissertation, London School of Hygiene & Tropical Medicine).

Siva Kumar, P., & Anbanandam, R. (2020). Theory building on supply chain resilience: A SAP–LAP analysis. *Global Journal of Flexible Systems Management*, *21*(2), 113-133.

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

Strunz, E. C., Addiss, D. G., Stocks, M. E., Ogden, S., Utzinger, J., & Freeman, M. C. (2014). Water, sanitation, hygiene, and soil-transmitted helminth infection: a systematic review and meta-analysis. *PLoS medicine*, *11*(3), e1001620.

Tafere, Y., Abate, B. A., Enyew, H. D., & Mekonnen, A. B. (2020). Diarrheal diseases in under-five children and associated factors among Farta district rural community, Amhara regional state, north central Ethiopia: a comparative cross-sectional study. *Journal of Environmental and Public Health*, *2020*.

Taweesan, A., Koottatep, T., & Dongo, K. (2017). Factors influencing the performance of faecal sludge management services: Case study in Thailand municipalities. *Environment, Development and Sustainability*, *19*, 125-140.

Tessema, R. A. (2017). Assessment of the implementation of community-led total sanitation, hygiene, and associated factors in Diretiyara district, Eastern Ethiopia. *PLoS ONE, 12(*4).

Troeger, C., Khalil, I. A., Rao, P. C., Cao, S., Blacker, B. F., Ahmed, T., ... & Reiner, R. C. (2018). Rotavirus vaccination and the global burden of rotavirus diarrhea among children younger than 5 years. *JAMA pediatrics*, *172*(10), 958-965.

Tulu, L., Kumie, A., Hawas, S. B., Demissie, H. F., & Segni, M. T. (2017). Latrine utilization and associated factors among kebeles implementing and non implementing urban community led total sanitation and hygiene in Hawassa town, Ethiopia. *African Journal of Environmental Science and Technology*, *11*(3), 151-162.

UNDP.(2018). National Human Development Report: Planning the Opportunities for a Youthful Population, United Nations Development Programme.

UNICEF. (2017). Progress on drinking water, sanitation and hygiene.

USAID (2019). An Examination of CLTS's Contributions toward Universal Sanitation. USAID Setty, K., Jiménez, A., Willetts, J., Leifels, M., & Bartram, J. (2020). Global water, sanitation and hygiene research priorities and learning challenges under Sustainable Development Goal 6. *Development Policy Review*, *38*(1), 64-84.

USAID. (2018). An Examination of CLTS’s Contributions Toward Universal Sanitation.

Usman, M., Farooq, M., & Hanna, K. (2020). Existence of SARS-CoV-2 in Wastewater: Implications for Its Environmental Transmission in Developing Communities. *Environmental Science and Technology*, *54*(13), 7758-7759.

Usman, U. F., & Aliyu, B. (2020). Impact of pit latrine on groundwater quality in some communities of Nguru Town, Nguru Local Government Area, Yobe State, Nigeria. *East Afr. Schol. Multidiscipl. Bull*, *3*, 218-225.

van Eekert, M. H., Gibson, W. T., Torondel, B., Abilahi, F., Liseki, B., Schuman, E., ... & Ensink, J. H. (2019). Anaerobic digestion is the dominant pathway for pit latrine decomposition and is limited by intrinsic factors. *Water Science and Technology*, *79*(12), 2242-2250.

van Eekert, M. H., Gibson, W. T., Torondel, B., Abilahi, F., Liseki, B., Schuman, E., ... & Ensink, J. H. (2019). Anaerobic digestion is the dominant pathway for pit latrine decomposition and is limited by intrinsic factors. *Water Science and Technology*, *79*(12), 2242-2250.

Venkataramanan, V., Crocker, J., Karon, A., & Bartram, J. (2018). Community-led total sanitation: a mixed-methods systematic review of evidence and its quality. *Environmental health perspectives*, *126*(2), 026001.

Vyas, S., & Spears, D. (2018). Sanitation and religion in South Asia: what accounts for differences across countries?. *The journal of development studies*, *54*(11), 2119-2135.

Wang, L., Li, M., Yu, S., Chen, X., Li, Z., Zhang, Y., ... & Seinfeld, J. H. (2020). Unexpected rise of ozone in urban and rural areas, and sulfur dioxide in rural areas during the coronavirus city lockdown in Hangzhou, China: implications for air quality. *Environmental Chemistry Letters*, *18*, 1713-1723.WHO (2018). Guidelines on sanitation and health. Geneva

WHO (2017). World Health Data Platform - Population practising open defecation

Widdowson, M. A., Glass, R., Monroe, S., Beard, R. S., Bateman, J. W., Lurie, P., & Johnson, C. (2005). Probable transmission of norovirus on an airplane. *Jama*, *293*(15), 1855-1860.

Winter, S. C., & Barchi, F. (2016). Access to sanitation and violence against women: evidence from Demographic Health Survey (DHS) data in Kenya. *International journal of environmental health research*, *26*(3), 291-305.

Wodnik, B. K., Freeman, M. C., Ellis, A. S., Awino Ogutu, E., Webb Girard, A., & Caruso, B. A. (2018). Development and application of novel caregiver hygiene behavior measures relating to food preparation, handwashing, and play environments in rural Kenya. *International journal of environmental research and public health*, *15*(9), 1994.

Wolf, J., Hunter, P. R., Freeman, M. C., Cumming, O., Clasen, T., Bartram, J., ... & Prüss-Ustün, A. (2018). Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Tropical medicine & international health*, *23*(5), 508-525.

World Health Organization. (2018). *Guidelines on sanitation and health*. World Health Organization.

World Health Organization. (2019). *Progress on household drinking water, sanitation and hygiene 2000-2017: special focus on inequalities*. World Health Organization.

World Health Organization. (2020). World health statistics 2020.

Xiao, F., Sun, J., Xu, Y., Li, F., Huang, X., Li, H., ... & Zhao, J. (2020). Infectious SARS-CoV-2 in feces of patient with severe COVID-19. *Emerging infectious diseases*, *26*(8), 1920.

Yadav, D. K., & Barve, A. (2016). Modeling post-disaster challenges of humanitarian supply chains: A TISM approach. *Global Journal of Flexible Systems Management*, *17*, 321-340.

Yishay, A. B., Fraker, A., Guiteras, R., Palloni, G., Shah, N. B., Shirrell, S., & Wang, P. (2017). Microcredit and willingness to pay for environmental quality: Evidence from a randomized-controlled trial of finance for sanitation in rural Cambodia. *Journal of Environmental Economics and Management*, *86*, 121-140.

APPENDICES

Appendix A: Publication

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Faecal Waste Management Practices And Performance Along Sanitation Service Chain In Marsabit Town, Marsabit County, Kenya

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Dr. Dorothy Kagendo

Abstract

Safe faecal waste management can reduce transmission routes where pathogens in faecal particles pass from one person to the mouth of another. Globally, 780 million people lack access to safe water and approximately 2.5 billion people in the developing world have limited access to adequate sanitation, a situation that has led to increased mortality due to sanitation related illnesses. This research sought to explore the faecal waste management practices among households across sanitation service chain in Marsabit town, Marsabit County, Kenya. Descriptive cross-sectional study design adopting mixed method was used and the study targeted a sample size of 612 households sampled from nine (9) Zones. Data collection was done through observations and interviews. The SPSS tools were used for data analysis and generating tables. About 64.9% of Marsabit county population practice open defecation. Toilet position during defecation differed from person to person and was culture-dependent. Out of 612 respondents approximately 81% (n=495) respondents reported squatting during defecation as a common preferred toilet use. Sitting position was at 19% (n=117). Majority of the community were washers at 77.6% (n=475) and wipers at 22.4% (n=137). Approximately 70% (n=429) responded abandoning their latrine once they are full. Infant mortality has been observed in Marsabit county with increased mortality especially in children under five years of age, occurring daily. This could be attributed to lack of adequate sanitation leading to open defecation, poor hygiene as well as the low water table in the area.

Appendix B:Informed Consent Form

Dear Sir/Madam,

My name is Mohamed Ali, a student from Meru University of Science and Technology. I am here today to conduct a survey on sanitation in Marsabit town. This survey will investigate faecal waste management in Marsabit town. Your household has been randomly selected for this survey. I would like to ask you questions on how you contain, empty, transport, treat and dispose faecal waste in your household. Your participation is voluntary and the information you will be providing us will be confidential. The information that you will provide us is important to the policy makers to improve the sanitation and hygiene condition of Marsabit town. The interview will take approximately 25 minutes. Are you willing to participate in the interview? Yes.../No...

Signature of Participant: …… Date: ……

Appendix C:Research permit

MUST INSTITUTIONAL RESEARCH & ETHICS REVIEW COMMITTEE
(MIRERC)

TO: Mohammed Ali
FROM: Chairman MIRERC
REF: MU/1/39/28 Vol.2 (138)
SUBJECT: MIRERC clearance and approval of Research
DATE: 10th May 2023

I hereby forward Ethical clearance and approval of your research proposal '*Fecal Waste Management' for* implementation: Note that the implementation of the project should strictly adhere to and follow expected attributes of Justice, Respect, Beneficence and Non-maleficence to the study subjects.

The committee expects to be informed on the progress of the project from time to time and any amendments that may be instituted or incorporated into the proposal during its implementation to be pointed out.

The committee also expects this research project implementer(s) will not at any time risk the study subjects/data in terms of unfair disclosure of information that may come to their knowledge by way of this project or subject the study subjects/data to any bias or consequences whatsoever if or not a study subject withdraws from the project or access to data is denied.

The committee and study subjects will expect to be considered favorably for any benefits that arise from this study. The university would be grateful to act as repository for the data that your project will generate.

The MIRERC committee therefore accords the clearance and approval for this project to be implemented by the investigator(s) during the period specified by the project.

Thank you.

Yours Sincerely,

Dr. Fr. Elias Kinoti
For: Chairman, MIRERC

MUST is ISO 9001:2015 and ISO/IEC 27001:2013 CERTIFIED

Appendix D:Faecal waste collection

	Not At All 1	**Low Extent 2**	**Moderate Extent 3**	**Great Extent 4**	**Very Great Extent 5**
Faecal sludge not contained and not emptied					
Squatting position during defecation instead of sitting on toilet when defecating					
Prone to open defecation when pit latrine is full					
Wiping faeces instead of washing with water when defecating					

Appendix E:Faecal waste disposal

	Not at All 1	**Low Extent** 2	**Moderate Extent 3**	**Great Extent 4**	**Very Great Extent 5**
Flush toilet connected is connected to soak pit					
Flush toilet is connected to sewer system					
Pit latrine is abandoned once they become full					
Pit latrine is discharged to open drain					

Appendix F:Mean and Standard Deviation

	Forest	CBD	Dakabaricha	Kofia Mbaya	Governance	Otte	Stadium	Mlima Mitatu	Adhi Huka
count	7.000000	7.000000	7.000000	7.000000	7.000000	7.000000	7.000000	7.000000	7.000000
mean	9.714286	10.000000	9.857143	9.857143	9.571429	10.428571	10.857143	8.285714	8.857143
std	7.910210	12.948616	7.537209	7.380799	7.253899	9.342682	10.776960	7.016986	8.234654
min	2.000000	0.000000	1.000000	2.000000	1.000000	1.000000	0.000000	1.000000	1.000000
25%	3.000000	1.000000	4.000000	3.500000	2.500000	3.500000	2.500000	3.500000	4.000000
50%	7.000000	4.000000	10.000000	9.000000	13.000000	9.000000	12.000000	4.000000	5.000000
75%	15.500000	14.000000	14.500000	15.500000	15.000000	14.500000	14.000000	14.000000	12.000000
max	22.000000	36.000000	21.000000	20.000000	18.000000	27.000000	31.000000	18.000000	24.000000

Appendix G:Programming codes

In [7]:
```
x = [14.5, 24.5, 44.5, 54.5,64.5,84.5]
y = [82,251, 173,89,11,6]

import statistics
statistics.mean(y)
```

Out[7]:
```
102
```

In [8]:
```
statistics.stdev(y)
```

Out[8]:
```
95.1924366743493
```

In [9]:
```
from numpy import cov
covariance = cov(x, y)
print(covariance)
```

```
[[  666.66666667 -1634.        ]
 [-1634.          9061.6       ]]
```

In [10]:
```
from scipy.stats import pearsonr
corr, _ = pearsonr(x, y)
print('Pearsons correlation: %.3f' % corr)
```

```
Pearsons correlation: -0.665
```

In [11]:
```
from scipy.stats import spearmanr
corr, _ = spearmanr(x, y)
print('Spearmans correlation: %.3f' % corr)
```

```
Spearmans correlation: -0.657
```

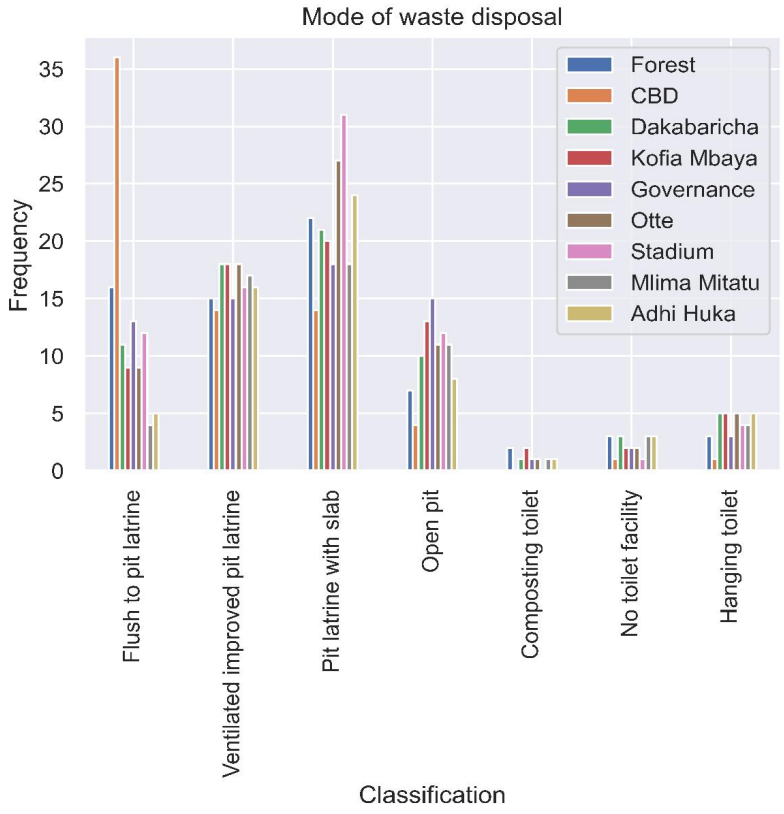
In [12]:
```
import numpy as np
from sklearn.linear_model import LinearRegression

x = np.array([14.5, 24.5, 44.5, 54.5,64.5,84.5]).reshape((-1, 1))
y = np.array([82,251, 173,89,11,6])

model = LinearRegression().fit(x, y)
r_sq = model.score(x, y)
print(f"coefficient of determination: {r_sq}")
print(f"intercept: {model.intercept_}")
print(f"slope: {model.coef_}")
```

```
coefficient of determination: 0.4419676436832348
intercept: 219.23950000000002
slope: [-2.451]
```

Appendix H:Mode of Waste Disposal



Appendix I:Plagiarism Report

DrillBit

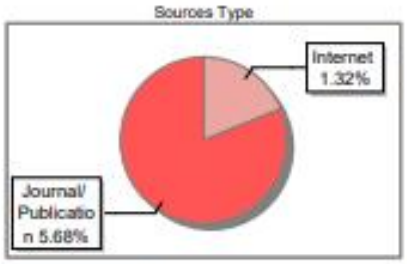
The Report is Generated by DrillBit Plagiarism Detection Software

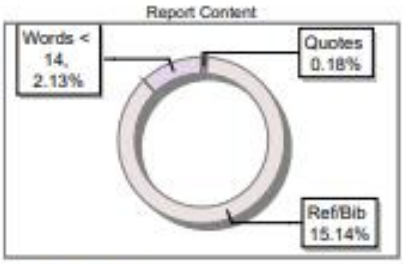
Submission Information

Author Name	MOHAMED ALI
Title	FAECAL WASTE MANAGEMENT PRACTICES AND PERFORMANCE OF SANITATION SERVICE CHAIN IN MARSABIT TOWN, MARSABIT COUNTY, KENYA.
Paper/Submission ID	2207579
Submitted by	mmusungu@must.ac.ke
Submission Date	2024-08-06 12:25:19
Total Pages, Total Words	127, 30038
Document type	Thesis

Result Information

Similarity 7 %





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