

GUIDELINES FOR FAECAL SLUDGE COLLECTION, DISPOSAL AND VALORISATION

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Guidelines for Faecal Sludge Collection, Disposal and Valorisation

Final Report to the Water Research Commission

by

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EXECUTIVE SUMMARY

The constitution of South Africa (SA) has provided the right to water and sanitation as a fundamental right to all the citizens of the country. The Water Services Act 108 of 1997 was passed by Parliament to give effect to this right. The goal of this Act is to ensure that everyone has access to basic water and sanitation services. The act recognises that the right of access to basic water supply and to basic sanitation services is necessary to ensure sufficient water and an environment that is not harmful to the health or well-being of people and animals. In addition to that, the government has provided regulations that govern the supply and management of water and sanitation services.

South Africa is a water scarce country and a portion of the population, mainly in the peri-urban areas and rural areas, relies on the use of on-site sanitation facilities, as flush water toilets cannot be the reality for all. The faecal sludge (FS) accumulates in these on-site sanitation facilities over the years, there is a need for it to be safely emptied / collected, treated, used for resource recovery and / or safely disposed. The government has provided legislation that governs the safe collection, treatment and reuse of the FS and/or excreta.

Even though the legislation to collect, treat and reuse/dispose faecal sludges and/ or excreta in South Africa exists, there are currently no guidelines that regulatory authorities, managers, entrepreneurs and practitioners responsible for faecal sludge management (FSM) can easily understand and incorporate as part of their service provision operations. In many cases, the management of FS is deduced from the guidelines for wastewater sludge; however, the physico-chemical properties of FS (such as chemical oxygen demand, total solids, moisture content, etc.) differ considerably from those of wastewater sludge and therefore the management options for wastewater sludge are not always applicable to FS. These guidelines for FS collection and subsequent disposal or valorisation were developed through a wide spread review of the currently existing sanitation related literature documents together with the current existing regulations and policies that govern the water and sanitation sector in South Africa to ensure an effective, compelling and distinct regulatory provision incorporating all aspects of the sanitation service chain i.e. containment, collection, transport, treatment and end-use/safe disposal. These guidelines aim to provide guidance to: (i) local authorities, manager, practioners, and legislators involed in FSM; (ii) technology innovators and entrepreneurs involved in the design and development of sanitation facilities; and (iii) local sanitation workers or “emptiers” and households to provide and / or accept a good practice concerning collection, transportation and disposal of the FS.

EDITOR'S NOTE

Effective Faecal Sludge Management (FSM) is a cornerstone of sustainable sanitation, particularly in a country like South Africa, where a significant proportion of the population relies on Non-Sewered Sanitation (NSS) systems. Without proper FSM, communities face severe public health risks, environmental degradation, and challenges in achieving national and global sanitation targets. FSM is essential to ensuring safe collection, transport, treatment, and disposal or reuse of faecal sludge, thereby preventing waterborne diseases and safeguarding water resources..

Despite the existence of the Water Research Commission's (WRC's) Wastewater Sludge Management guidelines, FSM is not adequately addressed within them. Wastewater sludge is generated in centralised treatment plants, whereas faecal sludge originates from NSS systems such as pit latrines, septic tanks, and urine-diverting dry toilets. A significant body of research-based evidence by the WRC and partners has shown that the characteristics, handling, and treatment requirements of faecal sludge differ significantly locally and abroad, necessitating a dedicated management guideline. The absence of clear FSM guidelines has resulted in fragmented and inconsistent practices, or sometimes not at all, particularly in informal settlements and rural areas.

The development of this guideline aligns with South Africa's National FSM Strategy and the National Sanitation Implementation Plan (NSIP). The National FSM Strategy provides a structured approach to FSM service delivery, emphasising innovation, regulatory oversight, and capacity building. Meanwhile, the NSIP integrates FSM within broader sanitation planning, ensuring that investments and interventions in sanitation infrastructure and services are inclusive and sustainable. Together, these documents support the country's commitment to achieving universal access to safely managed sanitation, in line with the Sustainable Development Goals (SDGs) and the National Development Plan (NDP).

By formalising FSM practices through clear guidelines, South Africa can bridge the gap between policy and implementation, ensuring that all communities – regardless of their sanitation system – benefit from safe, dignified, and sustainable sanitation services.

It is important to note that this guideline presents case studies of selected disposal or reuse options. FSM solutions, particularly in the realms of treatment and reuse, remain in the early stages of development and have not reached significant scale in South Africa, especially when faecal sludge is the main sludge source. To advance FSM, future efforts must prioritise the development of sustainable and cost-effective efficient solutions and explore safe reuse options, such as resource recovery.

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ACRONYMS & ABBREVIATIONS

ANSI	American National Standards Institute
BMGF	Bill & Melinda Gates Foundation
BSF	Black Soldier Fly
BSFL	Black Soldier Fly Larvae
CIBD	Construction Industry Development Board
COD	Chemical Oxygen Demand
CSDA	City Service Delivery Assessment
DFFE	Department of Forestry, Fisheries and the Environment
DEA	Department of Environmental Affairs
DHS	Department of Human Settlements
DWA	Department of Water Affairs
DWS	Department of Water & Sanitation
EAWAG	Swiss Federal Institute of Aquatic Science and Technology (German acronym for Eidgenössische Anstalt für Wasserversorgung, Abwasserreinigung und Gewässerschutz)
EC	Eastern Cape
EWS	eThekweni Water and Sanitation
FS	Faecal Sludge
FSM	Faecal Sludge Management
GP	Gauteng Province
HTC	Hydrothermal Carbonisation
ISO	International Standards Organisation
KZN	KwaZulu Natal
LaDePa	Latrine Dehydration Pasteurisation
LOFLOS	Low flush On-site sanitation
LP	Limpopo Province
MAPET	Manual Pit Emptying Technology
MC	Moisture Content
MDG	Millennium Development Goals
MFMA	Municipal Finance Management Act
MP	Mpumalanga
MWIR	Medium-Wave Infrared
NEMWA	National Environmental Management: Waste
NC	Northern Cape
NSIP	National Sanitation Integrated Plan
NSS	Non-Sewered Sanitation
NSSS	Non-Sewered Sanitation System
NW	North West
N/A	Not Applicable
n/d	No Date
O&M	Operation & Maintenance
PID	Partners in Development

PPE	Personal Protective Equipment
PRG	Pollution Research Group
PSS	Particle Separation Solutions
ROM	Return on Manpower
RSA	Republic of South Africa
SA	South Africa
SAICE	South African Institution of Civil Engineering
SANS	South African National Standard
SANDEC	Department of Sanitation, Water and Solid Waste for Development
SASTEP	South African Sanitation Technology Evaluation Programme
SCO	Supercritical Oxidation
SFD	Shit Flow Diagram
Stats SA	Statistics South Africa
SDG	Sustainable Development Goal
SSWM	Sustainable Sanitation and. Water Management
SuSanA	Sustainable Sanitation Alliance
TS	Total Solids
UDDT	Urine Dehydration Dry Toilet
UKZN	University of KwaZulu-Natal
UN	United Nations
UNICEF	United Nations Childrens Fund
UPL	Unimproved Pit Latrine
US EPA	U.S. Environmental Protection Agency
WC	Western Cape
WEDC	Water Engineering and Development Centre
WHO	World Health Organisation
WIN-SA	Water Information Network South Africa
WSA	Water Service Authorities
WWTP	Wastewater Treatment plant
VIP	Ventilated Improved Pit

GLOSSARY

Terms	Definition
Containment	Refers to the type of toilet, pedestal, pan, or urinal that the user comes into contact with; it is the way users access the sanitation system.
Collection and Storage/Treatment	Technologies for on-site collection, storage, and sometimes (pre-) treatment of the products generated at the user interface.
Conveyance	Transport of products from one functional group to another.
End-use and/or disposal	Refers to the methods through which products are returned to the environment, either as useful resources or reduced-risk materials.
Desludging	The process of removing the accumulated sludge from a storage or treatment facility.
Excreta	Consists of urine and faeces that are not mixed with any flushwater.
Faeces	Refers to (semi-solid) excrement that is not mixed with urine or water.
Faecal sludge	Mixture of solids and liquids, containing mostly excreta and water, in combination with sand, grit, metals, trash and/or various chemical compounds; it comes from on-site sanitation technologies, i.e. it has not been transported through a sewer. The English UK spelling of this definition has been used throughout this document (in contrast to the USA spelling “fecal”).
Log Reduction	Organism removal efficiencies; 1 log unit = 90 %, 2 log units = 99 %, 3 log units = 99.9 %, etc.
Improved sanitation	Flush toilets connected to a public sewerage system or a septic tank, or a pit toilet with a ventilation pipe.
Off-site sanitation	A sanitation system in which excreta and wastewater are collected and conveyed away from the plot where they are generated. An offsite sanitation system relies on a sewer technology.
On-site sanitation	A sanitation system in which excreta and wastewater are collected and stored or treated on the plot where they are generated.
Operation and Maintenance (O & M)	Routine or periodic tasks required to keep a process or system functioning according to performance requirements and to prevent delays, repairs or downtime.
Pathogen	An organism or other agent that causes disease.
Personal Protective Equipment (PPE)	Protective clothing, including boots, masks, gloves, aprons, etc. or other garments or equipment designed to protect the wearer's body from injury or infection from sanitation products.
Sanitation	The means of safely collecting and hygienically disposing of excreta and liquid wastes for the protection of public health and the preservation of the quality of public water bodies and, more generally, of the environment.
Sanitation technologies	Specific infrastructure, methods, or services designed to collect, contain, transform and treat products, or to transport products to another functional group.
Sanitation system	A multi-step process in which sanitation products such as human excreta and wastewater are managed from the point of generation to the point of use or ultimate disposal.
Urine	Liquid produced by the body to rid itself of nitrogen in the form of urea and other waste products.
Washer	A person who prefers to use water to cleanse after defecating, rather than wipe with dry material
Wiper	Someone who prefers to use dry material (e.g., toilet paper or newspapers) to cleanse after defecating, rather than wash with water

STRUCTURE OF THIS GUIDELINE

These guidelines are divided into 7 Sections:

PART 1: Introduction	Gives an overview of sanitation status and use of different sanitation facilities in South Africa and further gives the development of these guidelines and the motivation therefor.
PART 2: Faecal Sludge Management	Gives an overview of the faecal sludge, the constituents, and the characteristics. It gives further insight into faecal sludge management (FSM), the sanitation value chain, including the on-site sanitation facilities, emptying and the FSM toolbox.
PART 3: Policy Aspects	Gives an overview of the current international policies and national policies, i.e, South African regulatory, legislative and best practice the faecal sludge collection, utilisation and subsequent disposal in SA.
PART 4: On-site Sanitation facilities	Describes the currently available and used on-site sanitation technologies, giving details on the benefits and constraints of each type of on-site sanitation facility and the important considerations for deciding on a certain type of on-site sanitation facility.
PART 5: Guidelines for faecal sludge collection	Offers best practice for faecal sludge collection, for both manual and mechanical / motorised faecal sludge collection. Including the personal protective equipment (ii) tools to use for safe collection – manual and mechanical (iii), collection methods for each on-site sanitation facility (iv) transportation facilities: outlining the expected condition of each transportation. It also focuses on the safe handling of the solid waste recovered during pit emptying. This section also focuses on the current practices of trash removal and classification of the types of trash found in on-site sanitation facilities. It further gives an overview of protocols for the safe handling of trash on-site and off-site.
PART 6: Guidelines for FS treatment	Focuses on (i) understanding the quality of the faecal sludge; (ii) the treatment methods and technologies of faecal sludge, such as composting, combustion; (iii) the valuable products that can be produced by the treatment of faecal sludge, faeces and urine, which include guidelines for the possible applications such as energy sources and other useful products.
PART 7: Guidelines for FS re-use/disposal	Entails the best practices/ approaches or faecal sludge disposal. These guidelines will minimise unregulated disposal of waste, taking into consideration human health, safety and other environmental life forms.

OUTLINE

This project, funded by the South African Water Research Commission (WRC), aims to develop accessible guidelines for the collection, utilisation and subsequent disposal or valorisation of on-site sanitation faecal sludge (FS). The guidelines are aimed at regulatory authorities, managers, and practitioners responsible for faecal sludge management (FSM), to be incorporated as part of their service provision operations. Specific objectives are to: (i) provide guidance to local communities and households on best practice of safe handling the FS; (ii) promote health by advocating efficient sanitation systems and practices; (iii) assist local authorities, managers, practitioners and entrepreneurs involved in FS, from the collection (i.e., emptying and transportation) of FS; treatment (treatment plants and technologies); end-use (the application of FS in different activities) to safe disposal of FS; and (iv) minimise the risks of exposure to waterborne diseases and improve management of waste. This project complements the Department of Water and Sanitation's (DWS) National Faecal Sludge Management Strategy 2023:

<https://www.dws.gov.za/Documents/PRINTERS%20FINAL%20=%20FSM%20Strategy%202023.pdf>.

When viewed together, they provide a well-rounded perspective, bridging gaps in FSM and reinforcing key insights that enhance the overall narrative.

PURPOSE OF THESE GUIDELINES

The purpose of these guidelines is to:

- Provide guidance for FS collection and subsequent disposal or valorisation that complements the current wastewater sludge disposal guidelines.
- Provide technical guidance and best practices for the management of FS and encourage the implementation of beneficial use of sludge.
- Provide advances in FS collection and valorisation technologies aligned with international best practice for FS.
- Provide safe handling practices for local communities and households.

WHO SHOULD USE THESE GUIDELINES?

- **Local authorities, managers, and practitioners** involved in FS management – to inform policy and decision-making in FSM.
- **Legislators** – to assess compliance pertaining to FS collection and disposal sites.
- **Technology innovators and entrepreneurs** – to design and develop faecal sludge collection (emptying and transportation) devices and treatment technologies that would protect the receiving environment.
- **Local pit emptiers** – to implement acceptable good practice concerning the collection, transportation and disposal of the FS.

- **Researchers and educators** – to build capacity, create awareness and to inform best practices throughout the sanitation chain.
- **Households and local communities** – to understand the protocol that needs to be followed when the on-site sanitation facilities are full at homes, community churches, community hall, etc.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

Safe sanitation is critical for good health and plays a major role in disease prevention and improving and preserving mental and social well-being (WHO, 2018). Diarrhoea disease is the third leading cause of disease in children under 5 years, which could be avoided through safe water and adequate hygiene and sanitation (WHO, 2023). (Hutton, 2013). Research suggests that up to 88% of diarrhoea-related deaths could be prevented through improved sanitation measures (WHO, 2023). Proper sanitation and hygiene interventions are essential in reducing the burden of diarrhoeal diseases by preventing the transmission of pathogens (WHO, 2018).

To achieve equitable sanitation for all and improve public health through sanitation measures, behaviour change across various stakeholders is necessary. This includes changes in the delivery and management of sanitation services, as well as at the individual, household, and community levels. Behavioural changes may involve: (i) discontinuing open defaecation and adopting safe sanitation facilities, (ii) practising handwashing with soap, (iii) constructing and using permanent on-site facilities that allow for easy emptying, (iv) ensuring regular desludging of on-site sanitation systems, (v) safely handling faecal sludge (FS), and (vi) building non-emptiable pit latrines, which are covered when full and replaced with new facilities (WHO, 2018).

Safe sanitation systems require the involvement of multiple stakeholders, though national and local governments bear the primary responsibility for delivering, maintaining, regulating, and monitoring these systems. In South Africa, the government is addressing the sanitation backlog outside the sewer network, with on-site systems like Ventilated Improved Pit (VIP) latrines being widely used as a form of improved sanitation. However, these systems face challenges, notably the accumulation of faecal sludge over time. On-site sanitation systems need to be emptied regularly, and since FS is classified as hazardous waste, it requires careful handling. Additionally, there are concerns about groundwater contamination from these systems (Still and Foxon, 2012). South Africa currently faces issues with full on-site sanitation systems and, in some cases, unlawful FS disposal. These guidelines offer best practices for faecal sludge conveyance, including both manual and mechanical emptying, transportation, safe handling, treatment options, and ways to derive valuable products for reuse or safe disposal.

1.2 CURRENT STATUS OF SANITATION IN SOUTH AFRICA

Statistics of South Africa (Stats SA, 2020) has reported that almost two-thirds of South African households have access to flush toilets (i.e, toilets connected to the sewer or septic tank), while 83,2% has access to improved sanitation (which may be access to a flush toilet or VIP latrine). **Figure 1.1** illustrates the percentage of households by type of toilet facilities.

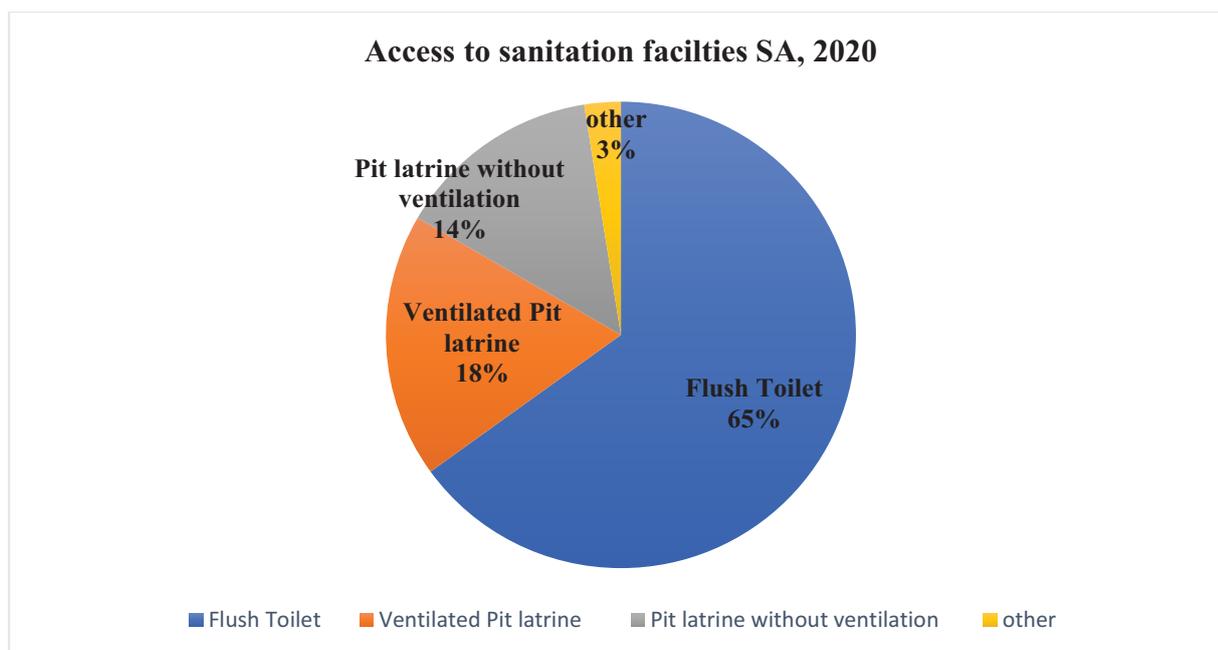


Figure 1-1: Percentage of households by type of toilet facilities (Stats SA, 2020)

There has been an improvement in the households that have access to improved sanitation per province from 2002 to 2020. The majority of households in Western Cape (WC) (93,9%) and Gauteng Province (GP) (90,5%) had access to improved sanitation, while access was most limited in Limpopo (LP) (58,7%) and Mpumalanga (MP) (64,4%) provinces. Eastern Cape (EC) recorded an improvement of 59,3 % of access to sanitation from 2002 to 2020. The national percentage of households that have access to improved sanitation in 2020 has been recorded to be 83,2%. **Figure 1.2** illustrates the percentage of households that have access to improved sanitation per province, 2002–2020 (Stats SA, 2020).

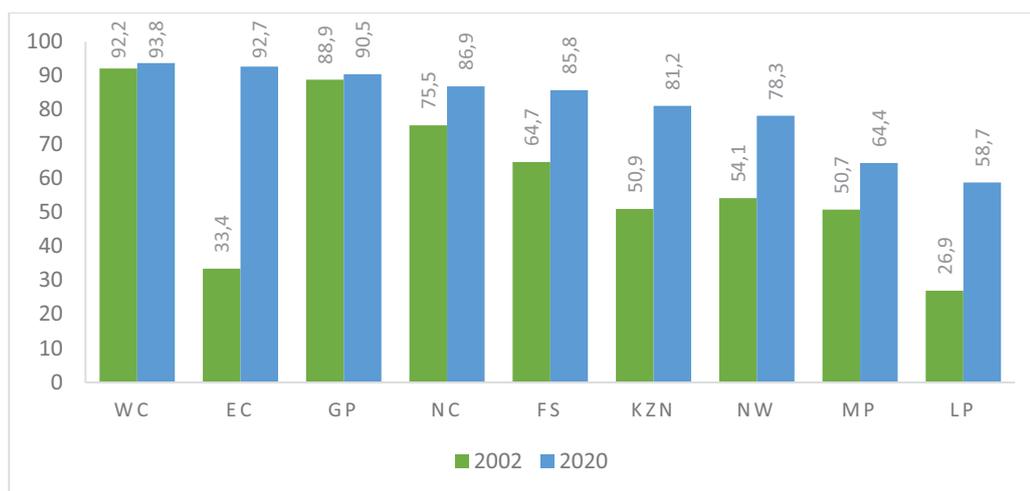


Figure 1-2: Percentage of households that have access to improved sanitation per province, 2002–2020 (Stats SA, 2020)

In 2020, 61,4% of households indicated that members of their household washed their hands with soap after having used the toilet, while 33,3% of households indicated that the members of their households only rinsed their hands with water. About 4,2% of households indicated that their members clean their hands with sanitiser or wet wipes, while 1,1% indicated that they do not clean their hands after toilet use. **Figure 1.3** indicates the percentage of households by access to hand washing facilities for each province in 2020. The provinces such as WC, GP, Free State, and NC have high access to hand washing facilities, while LP has limited access to hand washing facilities. Inadequate sanitation and access to clean water have been persistent issues in some areas of South Africa, leading to outbreaks of waterborne diseases. Diseases like cholera and waterborne gastroenteritis can spread when sanitation facilities are lacking, and water sources are contaminated (WHO, 2019). Improper sanitation practices, such as the incorrect disposal of waste, can lead to environmental contamination. This pollution negatively affects ecosystems, water quality, and public health. For instance, improper waste disposal can result in air and water pollution, land degradation, and the emission of hazardous substances, all of which contribute to climate change and pose significant health risks (WHO, 2018).

1.3 DEFICIENCIES IN THE FAECAL SLUDGE MANAGEMENT (FSM) SYSTEM IN SOUTH AFRICA

FSM in South Africa grapples with significant deficiencies, posing a formidable challenge to the nation's sanitation infrastructure and public health objectives. Despite considerable strides in various sectors, the shortcomings in handling FS have emerged as a critical issue, reflecting gaps in infrastructure, resources, and awareness.

One of the primary issues is the inadequate infrastructure for safe disposal and treatment of FS. Many regions lack proper sanitation facilities, leading to the indiscriminate dumping of untreated waste into water bodies, causing water pollution and endangering aquatic ecosystems. Additionally, there is a shortage of skilled personnel and resources for efficient FSM, resulting in delayed or insufficient responses to the growing sanitation needs. Furthermore, the lack of awareness and education about proper sanitation practices among the population exacerbates the problem, contributing to the perpetuation of unsafe waste disposal methods. The deficiencies in FSM not only pose immediate health risks but also hinder the overall progress towards achieving sustainable and inclusive sanitation goals in South Africa.

1.4 MOTIVATION FOR DEVELOPING GUIDELINES FOR THE COLLECTION, UTILISATION AND DISPOSAL OF FAECAL SLUDGE

The development of these guidelines is important and necessary as:

- (i) There is a general lack of knowledge of how to safely collect and dispose of FS from on-site sanitation systems.
- (ii) Options for FS disposal are inferred from the Wastewater Sludge Disposal Guidelines, whereas scientific evidence produced from the WRC and globally has shown faecal sludges to differ

significantly in physical-chemical properties from wastewater sludges. The management options for wastewater sludges are therefore not always applicable for faecal sludges.

- (iii) The current Wastewater Sludge Guidelines do not provide guidance on detritus removal from on-site sanitation systems, which have been shown to contribute significantly to the volume and mass of faecal sludges (Snyman, 2010; Harrison and Wilson, 2012). Further, this project began prior to the establishment of a national strategy, which was later formalised as the National Faecal Sludge Management Strategy 2023 (DWS, 2023). Despite this timeline, the documents are well aligned and complement each other, providing a cohesive framework for effective FSM.
- (iv) There has over the last two decades been significant scientific advances in FS collection and valorisation technologies. These guidelines will include the advances in the sanitation sector and be aligned with international best practices for faecal sludges.

1.5 DEVELOPMENT PROCESS

These guidelines for collection, disposal, and valorisation of FS from on-site sanitation systems are a result of a widespread review of the existing sanitation-related literature documents to ensure an effective, compelling and distinct regulatory provisions consisting of all aspects of the sanitation service chain, i.e, containment, emptying, transportation, treatment and end-use/safe disposal.

The WASH R&D Centre within the School of Chemical Engineering at the University of KwaZulu-Natal (UKZN) has been actively working in the research sector of water and sanitation for around 50 years. The WASH R&D Centre has acquired expertise in the areas of FS characterisation and other projects relating to faeces and urine and in general working with on-site sanitation facilities. The WASH R&D Centre has a long track record of work related to the characterisation and quantification of FS from different on-site sanitation facilities, community engagement and partnering with important actors in the on-site sanitation scene, such as the Water Research Commission (WRC) and Bill & Melinda Gates Foundation (BMGF). It is from that experience that these guidelines will be developed to contribute towards sustainable development solutions and ensure sustainable FSM.

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CHAPTER 2: INTRODUCTION TO FAECAL SLUDGE MANAGEMENT (FSM)

2.1 FAECAL SLUDGE

Faecal sludge (FS) is the human waste and trash that is stored in on-site sanitation systems such as pit latrines and septic tanks. It is deemed as an unpleasant material that contains pathogens and has the potential to generate odour and cause surface water and groundwater pollution (Tilley et al., 2014). The FS that is removed from septic tanks is called septage. Faecal sludge consists of all fluid, semi-solid and solid substances of pits and vaults gathering in on-site sanitation systems, specifically unsewered public and private latrines, water privies and septic tanks. These fluids are typically more amassed in suspended and disintegrated solids than wastewater (Tilley et al., 2014). The main inputs to the FS are (i) excreta, (ii) anal cleansing material, (iii) flush water and grey water, (iv) solid waste and (v) chemicals (Strande et al., 2014; Tilley et al., 2014; Velkushanova et al., 2021). When FS is poorly managed, it can cause waterborne diseases and water contamination. Inadequate sanitation is linked to the transmission of waterborne diseases such as cholera and dysentery, intestinal worm infections and other diseases such as polio (WHO, 2023).

FS varies greatly between different locations and types of on-site sanitation systems. The moisture content (MC) or total solids (TS) content of FS can range from dilute and watery material to slurries that can be pumped, to thick sludges that can only be emptied manually (Velkushanova et al., 2021). The various ranges of FS can influence which methods of emptying, analysis, treatment and subsequent valorisation or disposal. Based on TS concentration, there are four categories of FS (Velkushanova et al., 2021), and the constituents of each category differ from one to the other. **Figure 2.1** illustrates different types of FS:

- **Liquid FS: TS < 5 %**

This type of FS is a runny liquid having the consistency of water or domestic wastewater and the ability to be pumped. These are normally collected from leach pits, septic tanks, and ‘wet’ pit latrines.

- **Slurry FS: TS 5 – 15 %**

This type of FS is thicker than liquid but still runny, with a consistency ranging from watery to wet mud, pumpable in the lower range but too runny to shovel. This type can also be collected from septic tanks and leach pits.

- **Semi-solid FS: TS 15 – 25 %**

This type of FS is slightly thicker; it cannot be pumped and needs to be collected using a spade. These types are collected from on-site containments such as pit latrines, composting toilets, and leach pits, as well as dewatering treatment technologies.

- **Solid FS: TS > 25%**

In this type of FS, the majority of water has been removed. This type of FS can be collected from dry toilet systems and dewatering treatment systems.



(a) Liquid FS in the drying bed



(b) Slurry FS



(c) semi-solid sludge



(d) Solid sludge

Figure 2-1: Different types of FS (Source: Wash R&D Centre)

2.2 COMPONENTS OF FAECAL SLUDGE

2.2.1 Excreta

Human excreta consist of two main components: urine and faeces. Urine is composed of approximately 95% water by weight, with the remaining 5% consisting of inorganic salts and other organic compounds (Rose et al., 2015). The volume of urine excreted by an individual each day is primarily influenced by dietary intake and environmental factors such as temperature and humidity (Rose et al., 2015; Harder et al., 2019). On average, a healthy adult produces between 0.6 and 2.6 L of urine per day. Human urine contains essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) in a ratio of 11:1:2, making it a potential fertiliser (Okem et al., 2013). Recovering these nutrients as fertiliser can reduce the environmental impact associated with industrial fertilisers (Rose et al., 2015a; Grunbaum, 2010).

Human faeces, on the other hand, contain water, protein, undigested fats, polysaccharides, bacterial biomass, ash, and fibre (Somarin, 2020). The major elements in faeces by wet weight include oxygen (O) at 74%, hydrogen (H) at 10%, carbon (C) at 5%, and nitrogen (N) at 0.7%, with the hydrogen and oxygen coming from the water content (Rose et al., 2015). Faeces also contain a high carbon content (Rose et al., 2015a; Harder et

al., 2019). Of the nutrients consumed, approximately 10-20% of nitrogen, 20-50% of phosphorus, and 10-20% of potassium are excreted through faeces (Schouw et al., 2002; Jönsson et al., 2005; Vinnerås et al., 2006).

2.2.2 Cleansing Material

Global toilet habits can be divided into ‘wipers’ or ‘washers’. The washers are a group of people who use water for anal cleansing and wipers use toilet paper or other material for anal cleansing (Mara and Evans, 2011). In SA, most people are ‘wipers’ and the most common cleansing material is toilet paper. In areas where toilet paper can not be afforded, newspaper or book pages are alternatively used. These items do not decompose easily and therefore increase the filling rate of the pit (Still and Foxon, 2012). **Figure 2.2** demonstrates a modern toilet currently used in other parts of the world that accommodates both a washer and a wiper.



Figure 2-2: Demonstration of a current system, accommodating both a washer and a wiper (Source: WASH R&D Centre)

2.2.3 Chemicals

One of the main issues with on-site sanitation facilities, especially pit latrines, is that they become full over time, and safe, hygienic emptying services are often unavailable. For a standard pit latrine in South Africa, Foxon et al. (2011) made the following estimation: the annual waste contribution per person includes approximately 110 litres of faeces ($0.3 \text{ L/day} \times 365 \text{ days/year}$) and 440 litres of urine ($1.2 \text{ L/day} \times 365 \text{ days/year}$), resulting in a total volume of 550 litres per person per year. The rate at which the latrine fills is influenced by both the volume of waste added and the rate of degradation. Based on pit observations and the data estimates, it is estimated that pit latrines fill up at around 40 litres per capita per annum in South Africa (Foxon et al., 2011; Foxon and Still, 2012).

To address sludge accumulation and reduce emptying cycles, commercially available chemical additives entered the market on the premise that the sludge layer in the pit could be degraded. In a study in 2015, the scientific validity of the degradation claims was yet to be established in South Africa (Bakare et al., 2015).

Chemical additives are believed to enhance processes like FS decomposition and dehydration, resulting in reduced sludge volume and a decrease in pathogenic load (Cassini et al., 2006; Magri et al., 2013).

Additionally, household disposal of detergents into pit latrines presents environmental and health risks. Detergents, which contain chemicals like surfactants and fragrances, can contaminate groundwater and soil upon disposal. Their presence in pit latrines can disrupt the natural microbial balance, potentially hindering waste breakdown and the overall functionality of the system. Raising awareness about proper waste disposal and encouraging the use of eco-friendly alternatives to conventional detergents is crucial for mitigating these risks.

2.2.4 Solid Waste

In communities where solid waste collection is not provided by the municipality, the pit latrine is often used for solid waste disposal (Still and Foxon, 2012). Often in pits there are disposable nappies, chemicals, broken glass or sharp metal, textiles, feminine products, lightweight plastics, paper, plastics, stones, wood, hair extensions and material that cannot be burned easily, including vegetable and fruit peels (Still and Foxon 2012; Zuma et al., 2015). The amount and content of household rubbish in pits vary from household to household (Zuma et al., 2015). The solid waste found in pits shortens the life span of a pit and negatively affects the treatment process for FS (Still and Foxon, 2012). It is estimated that pit life could be extended from 15 years to over 20 years in South Africa through the elimination of detritus dumping into Ventilated Improved Pit (VIP) latrines (Brouckaert et al., 2013). **Figure 2.3** demonstrates the type of trash found in pit latrines.



(a) The use of the pit latrine for general household solid waste disposal shortens pit life and makes pit emptying by vacuum tanker almost impossible (Source: Still and Foxon, 2012)



(b) Rubbish removed from a pit during the course of the eThekweni pit emptying programme (after the rest of the contents had been washed through into the sewer) (Source: Still and Foxon, 2012)

Figure 2-3: Illustrating the use of a pit latrine for a general household, and (b) the solid waste removed from a pit emptying process

In 2020, Stats SA recorded regular refuse removal for almost 62,7% of households. Almost one-third (28,8%), however, used their own refuse dumps in the absence of services, while 5,6 % households relied on communal refuse dump and 2,4 % households dumped or left their own refuse anywhere (Stats SA, 2020).

The data indicates that a significant portion of households (28.8%) resort to using their own refuse dumps in the absence of formal services. This might include households with various types of sanitation facilities, including VIP toilets. If these households lack proper waste disposal facilities or services, residents might resort to creating their own refuse dumps, which could include the dumping of solid waste in the VIP toilets.

Figure 2.4 illustrates the percentage of households by type of refuse removal services (Stats SA, 2020).

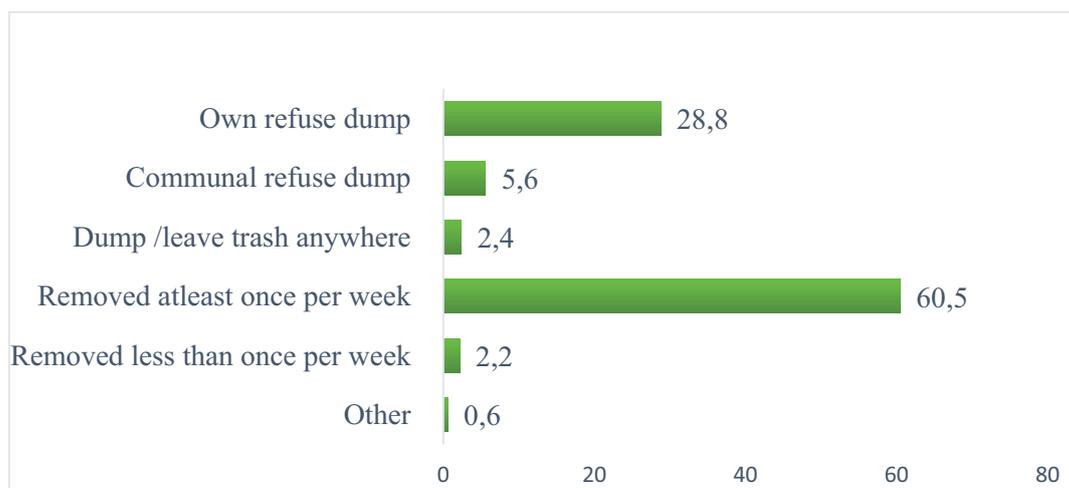


Figure 2-4: Percentage of households by type of refuse removal services (Stats SA, 2020)

2.3 HAZARDOUS COMPONENTS IN FAECAL SLUDGE

FS may contain a number of harmful components, including (Louton et al., 2018):

- Infectious organisms: bacteria, viruses, protozoa and helminths (intestinal worms);
- By-products of organisms in sludge; e.g bacteria, viruses, parasites and nutrients;
- Gases produced during decomposition of sludge; such as methane and hydrogen sulphide;
- Toxic or dangerous materials disposed of in the pit, including household cleaning chemicals and pharmaceuticals.

2.3.1 Bacteria

The type and number of organisms detected in sludge will differ from one family or community to the next. As some bacteria die and break down, they release toxic substances (endotoxins), which can present a risk during degradation. Toxic inorganic compounds formed during the breakdown of faecal matter may also be found in sludge. While VIP latrines provide for some ventilation, which lessens the risk of dangerous gases accumulating from microbial metabolisms, like methane, hydrogen sulphide, and carbon dioxide, they can become trapped in pits with insufficient ventilation (Louton et al., 2018). Pathogenic bacteria can cause symptoms such as diarrhoea, fever, cramps, and occasionally vomiting, headache, weakness, or loss of appetite

(Cleveland Clinic, 2023). **Table 2.1** below illustrates the type of pathogenic bacteria that may be found in FS and symptoms or diseases associated with these bacteria (Louton et al., 2018). In addition to their presence, it has been noted that antibiotic-resistant strains of bacteria exist in faecal sludges in South Africa (Beaukes et al., 2017; Beaukes and Schmidt, 2018; Beaukes et al., 2023). This poses a serious risk to public health, as infections caused by multidrug-resistant strains of bacteria can possibly spread and are harder to treat, thus leading to possible prolonged illness and increased mortality.

Table 2.1: Examples of bacteria found in faecal sludge which may pose a health threat (Source: Louton et al., 2018)

Organisms	Disease and Typical Symptoms
<i>Salmonella spp.</i>	Salmonellosis, Gastroenteritis, Typhoid fever
<i>Leptospira spp.</i>	Leptospirosis, headache, muscle pain, lack of appetite, jaundice, aseptic meningitis, harm to the nervous, renal and respiratory systems.
<i>Shigella spp.</i>	Shigellosis, diarrhoea, bacillary dysentery
<i>Vibrio cholerae</i>	Cholera
<i>Legionella pneumophila</i>	Pneumonia, Pontiac fever
<i>Escherichia coli</i>	Gastroenteritis, urinary tract infections, bacteraemia, haemolytic uraemic syndrome
<i>Campylobacter spp.</i>	Gastroenteritis
<i>Helicobacter pylori</i>	Gastric cancer
<i>Yersinia spp.</i>	Acute gastroenteritis
<i>Vibrio cholerae</i>	Cholera

2.3.2 Viruses

Viruses, typically ranging from 20 to 30 nanometers in size, can persist in water for extended periods and require a low infective dose to cause illness (Epstein, 1998; WHO, 2011). Rotaviruses, enteroviruses and noroviruses are the most common viruses that infect people (WHO, 2011). Rotavirus is a leading cause of acute diarrhoea, responsible for nearly 40% of all diarrhoea-related hospital admissions in children under five worldwide (UNICEF/WHO, 2009). **Table 2.2** illustrates the type of pathogenic viruses that may threaten a human life and symptoms or diseases associated with these viruses (Louton et al., 2018).

Table 2.2: Examples of viruses found in faecal sludge which may pose a health threat (Source: Louton et al., 2018)

Organism	Disease and typical symptoms
Enteroviruses (67 types)- Rotaviruses, Parvoviruses, reoviruses, Astrovirus, Calicivirus, Norwalk Agent	Gastroenteritis (24-hour flu)
Reovirus	Respiratory infections and gastroenteritis
Hepatitis A	Infectious hepatitis, liver damage, tiredness, abdominal pain, nausea, jaundice, diarrhoea, loss of appetite
Hepatitis B	Serum hepatitis (liver cancer, cirrhosis)
Coxsackiviruses	Aseptic meningitis, pneumonia, hepatitis and fever
Adenoviruses (31 types), Reoviruses, Coronavirus	Respiratory disease
Echovirusese	Meningitis, paralysis and encephalitis fever
Polioviruses	Poliomyelitis

2.3.3 Helminths

Helminth eggs are the infectious agents that normally lead to helminthiasis. Helminth eggs infect humans through: (i) the ingestion of food crops polluted with wastewater sludge or excreta; (ii) direct contact with polluted sludge or faecal material, and (iii) the ingestion of polluted meat or fish (Jiménez-Cisnero, 2006). Helminth eggs found in wastewater, sludge or excreta are not always infectious; however, for them to be infectious, larval development needs to transpire. The larval development occurs at almost 10 days of incubation at a certain temperature and moisture.

Helminthiasis are common diseases in areas where there is limited access to safe drinking water and poor sanitation conditions (Jiménez-Cisnero, 2006; WHO, 2003). Though mortality levels are low, the ascariasis helminthiasis disease is widespread in continents such as Africa, Latin America and is affecting children below the age of 15 years. Helminths have a hazardous effect on the host that operates as a mechanical, chemical and biotic agent; therefore damage the intestinal wall, erythrocytes, muscle tissue and internal organs (lungs, liver, kidneys, and brain) of the host (Jaromin-Gleń *et al.*, 2017). The presence of parasitic helminth eggs in wastewater and sludge has been considered a restriction for the re-use of wastewater and sludge in agricultural activities by the World Health Organisation (WHO). The WHO has therefore recommended a threshold value of less or equal to one egg per litre (≤ 1) (WHO 2006; Jimenez-Cisneros, 2006), to mitigate health risk associated with wastewater and sludge reuse. **Table 2.3** illustrates the type of pathogenic helminth that may threaten a human life and symptoms or diseases associated with these helminths.

Table 2.3: Examples of helminths found in faecal sludge which may pose a health threat (Source: Louton et al., 2018)

Organism	Disease and typical symptoms
<i>Ascaris Lumbricoides</i>	Coughing or difficulty in breathing, intestinal pain, and constipation
<i>Trichuris trichiura</i> (whipworm)	Digestive disturbances
<i>Strongyloides stercoralis</i>	Anaemia, rashes, gastrointestinal symptoms
<i>Enterobius vermicularis</i> (pinworm)	Anal itching
<i>Fasciola hepatica</i> (liver fluke)	Fever, malaise, enlarged liver, abdominal pain
<i>Schistosoma haematobium</i>	Schistosomiasis
<i>Taenia</i> spp. (including <i>Taenia solium</i> , <i>Taenia saginata</i>)	Schistosomiasis
<i>Schistosoma mansoni</i>	Nervous
<i>Hymenolepis nana</i>	
<i>Dipylidium caninum</i>	Loss of appetite, indigestion

Due to the variable nature of faecal sludges and their inherent differences between soil and wastewater, specific helminth ova detection methods have been developed by the University of KwaZulu-Natal (UKZN) (Naidoo and Archer, 2022).

2.3.4 Hazardous Inorganic Materials in Faecal Sludge

FS contains various inorganic substances, including essential nutrients like nitrogen, phosphorus, and potassium, which are present as inorganic salts. These elements are crucial for plant growth and can be recovered and reused as fertilisers (Rose et al., 2015a; Jönsson et al., 2005). The sludge also contains other inorganic compounds, such as calcium, magnesium, and sulphur, which result from human metabolic processes and contribute to the chemical composition of the waste (Schouw et al., 2002). While these inorganics can be beneficial in certain applications, they can also present environmental hazards when improperly managed. For example, high concentrations of heavy metals like cadmium, lead, and arsenic, which may be present in faecal sludge due to human exposure through food, water, or industrial sources, pose serious health risks. These metals can contaminate soil and groundwater, potentially leading to toxic effects on plants, animals, and humans (Jönsson et al., 2005; Vinnerås et al., 2006). An excess of nutrients, such as phosphorus and nitrogen, can cause eutrophication in water bodies, resulting in oxygen depletion, harmful algal blooms, and ecosystem imbalances (Schouw et al., 2002). Besides natural chemicals found in excreta and conventional anal cleansing material, such as water and toilet paper, solid waste disposal can introduce hazardous waste into the sanitation system. Additionally, latrines can emit toxic gases, such as hydrogen sulphide, leading to potential health risks, especially in poorly ventilated sanitation systems (Appiah Obeng et al., 2016).

2.4 FAECAL SLUDGE MANAGEMENT (FSM)

Faecal sludge management (FSM) encompasses the storage, collection, transport, treatment, safe end-use or safe disposal of FS from on-site sanitation systems (Strande et al., 2014). FSM is mostly required in highly populated regions where there is no availability of sewerage network and the covering and rebuilding of pit latrines is not possible (Koné & Peter, 2008). The FSM services are normally provided by: (i) formal and informal private sector service providers, (ii) local governments, i.e. local municipalities, (iii) water authorities, and government agencies. In many other countries, FSM services do not exist in parts of the country, such as rural areas, and in areas where they are available, they are often unregulated, unhygienic and unsafe. The risks associated with no FSM programs include: (i) health-related impact as the FS contains pathogens and therefore the primary hazard is pathogen exposure from untreated FS and (ii) surface and ground water pollution.

FSM is also referred to as the sanitation value chain. As illustrated in **Figure 2.6**, it consists of (i) on-site containment, which encompasses excreta capture and storage in different toilet systems; (ii) emptying of the containment system; (iii) transport of the collected FS; (iv) FS treatment and (v) end-use or safe disposal (Medland et al., 2016). The sanitation chain also provides a useful method to divide different technologies into their useful functions and identify the type of partners that may be required (Sanihub, 2021).

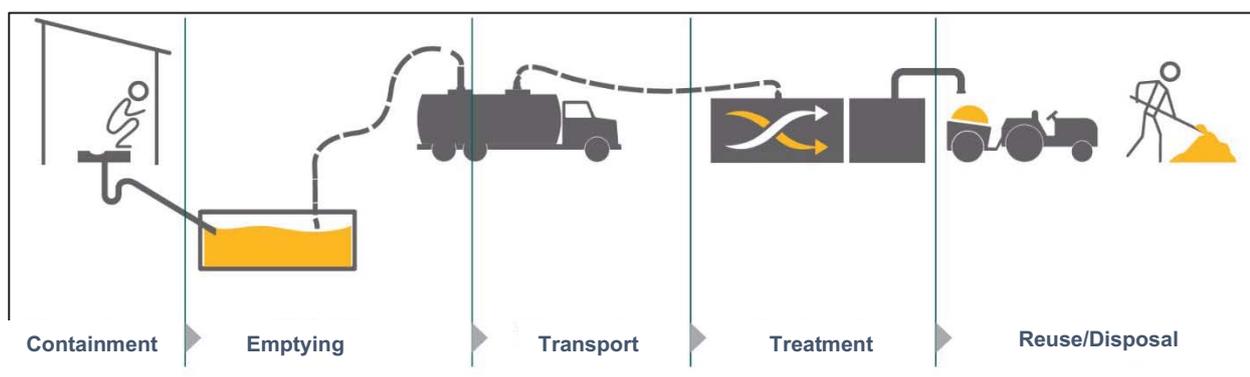


Figure 2-5: Sanitation chain (BMGF, 2010)

2.4.1 Containment

Proper containment of excreta plays a crucial role in improving household health by ensuring access to basic sanitation facilities and safely managing waste in on-site systems, keeping it away from living areas. An effective on-site sanitation solution should incorporate several key factors: a reliable barrier against disease transmission, prevention of environmental contamination, ease of construction, operation, maintenance, and repair, compliance with hygiene and safety standards, affordability, and community willingness to invest. Additionally, successful implementation requires stakeholder involvement—including landlords, residents, public water utilities, and private sector partners—along with cultural sensitivity to accommodate user values, attitudes, and behaviors (ISO, 2016).

One of the primary challenges of containment in urban areas is the lack of space for latrine construction, as many plots are fully occupied by buildings. Topographical constraints, such as high water tables or steep

slopes, further complicate excavation and installation (Medland et al., 2016). Various types of containment systems exist, including fully sealed tanks, lined tanks with impermeable walls and open bottoms, lined pits with semi-permeable walls and open bottoms, and unlined pits (Susana, 2018).

2.4.2 Emptying and Transportation

Emptying refers to the discharging/ evacuation of FS from on-site sanitation facilities. Transport is the physical moving of the FS from the sanitation facility to the treatment plant or to a disposal site (Medland et al., 2016). The emptying and transportation of FS are jointly referred to as the ‘collection’ of FS. The main objective of an FS collection service is to improve the sanitary conditions in people’s homes. The collection technologies enable FS to be collected, temporarily stored, and if appropriate, to be partially treated (ISO, 2016). The collection of FS from septic tanks or latrines is done through the use of manual and mechanised techniques that may rely upon hand tools, vacuum trucks, pumping systems, or mechanical augers.

The appropriate method is determined based on the type of on-site sanitation system, accessibility of the site, the type of equipment owned by the service provider, and the level of expertise (Strande et al., 2014). It is also important to have knowledge of the characteristics of the FS that is to be collected, to be aware of the challenges that may come along with the emptying and transportation. The important properties include the water content, the FS age, the existence of non-biodegradable material and the organic materials, among others. The key challenges with emptying and transportation are that sludge is recognised as unhygienic and a risk to the community and the operators conducting emptying and transportation (Jenkins et al., 2015). The manual emptying has been perceived as an unhygienic process and, in some instances, performed at night due to social stigma and extreme odour that is produced (Chowdhry and Kone, 2012). However, manual emptying can be done safely with use of appropriate personal protective equipment and following safe protocols (PID, 2016; Louton et al., 2018). Hygienic emptying and transportation of FS is required to decrease the exposure to faecal oral pathogens that may affect the sanitation workers and the surrounding community (Louton et al., 2018).

2.4.3 Treatment

Treatment refers to the processes that alter the physical, chemical, and biological characteristics or composition of FS, enabling the treated waste to be reused or safely disposed of following pollutant reduction (Strande et al., 2014; Medland et al., 2016). FS undergoes a series of treatment stages, initially separating the liquids from the solids, followed by the treatment of both liquid and solid streams, aiming to recover as much energy or nutrients as possible (Strande et al., 2014). The most commonly used FS treatment methods include: (i) settling-thickening ponds and tanks for FS thickening; (ii) planted and unplanted drying beds for FS dehydration through dewatering, surface evaporation, and sludge stabilisation/nutrient management; (iii) co-composting for pathogen reduction and stabilisation/nutrient management; and (iv) burial for pathogen reduction (WHO, 2006; Strande et al., 2014; Tilley et al., 2014).

Emerging treatment technologies for FS include: (i) thermal treatments such as pyrolysis, gasification, and incineration, which convert organic matter into useful by-products like biochar, heat, and energy, while reducing the volume of sludge; (ii) electrochemical treatments, where electrodes are used to oxidize or reduce organic contaminants in FS; and (iii) membrane filtration technologies, such as microfiltration, ultrafiltration, nanofiltration, and reverse osmosis, which separate solids, pathogens, and contaminants from FS. Membrane processes can produce treated effluent suitable for reuse and concentrate solids for further treatment or disposal (Mehta et al., 2014; Johannessen et al., 2016). A significant technological challenge remains the development of cost-effective, space-efficient treatment processes that render the sludge safe for disposal or further use. The FS treatment process is further complicated by the presence of additional trash (detritus) in FS from latrines (Medland et al., 2016). Still and Foxon (2012) noted that in areas lacking municipal solid waste collection, pit latrines often serve as a disposal site for solid waste, containing items such as disposable nappies, chemicals, broken glass, sharp metals, and used sanitary towels. The detritus often needs to be screened from FS to enable treatment (Harrison and Wilson, 2012).

2.4.4 End-use / Disposal

End-use/disposal refers to the different technologies and methods by which treatment products are ultimately discharged into the environment as reduced-risk materials or become end-use products (WHO, 2018). The safe disposal of FS is among the actions towards the management of the FS so that it does not contaminate the environment, water or food. Safe disposal is essential for ensuring a healthy environment and for protecting personal health. Regardless of the method used, safe disposal of FS is among the main ways of breaking the faecal-oral disease transmission cycle. End-use refers to regaining value from the sludge by making its nutritional or calorific content available for agriculture or energy, among other applications (Medland et al., 2016). With end-use products, the product has to be fully treated and can be applied or used directly. Otherwise, additional risk reducing methods are required or the product should be disposed of in a safe manner not harmful to the public or the environment (WHO, 2018).

The key aim of the end-use/disposal step is to reduce the risks to sanitation workers and the wider community from the remaining pathogen hazards (WHO, 2018). Potential end-use products derived from FS include, but are not limited to: soil conditioner fertiliser; solid fuels; building material; animal fodder; and irrigation water (Strande et al., 2014; Tilley et al., 2014; Strande, 2017). The recovery of end-use products from FS offers multiple positive economic benefits. Utilising innovative technologies for treating and transforming FS into valuable resources, such as bio-fertilisers and biogas, creates new economic opportunities. These recovered products serve as cost-effective alternatives to traditional fertilisers, providing sustainable agricultural nutrients. Extracting biogas from FS as a renewable energy source reduces dependence on conventional energy, leading to economic advantages by lowering energy costs. Furthermore, the establishment of businesses focused on recovering and utilising FS products can generate employment opportunities, fostering local economic development. Ultimately, adopting a circular economy approach in FSM not only addresses sanitation challenges but also unlocks economic value through resource recovery and sustainable practices. To

minimise and /or eliminate risk at end-use/disposal, technologies should be (i) designed for the local context, taking into consideration the characteristics of FS, local climate, and seasonal variations; and the available energy sources and human resource capacity, and (ii) the innovated technologies must be compatible with treatment and end-products (WHO, 2018).

2.5 FSM TOOL BOX

The FSM tool box (<https://www.fsmtoolbox.com>) offers a suite of tools to assess the overall FSM ecosystem in the city and plan for infrastructure improvements (FSM Toolbox, 2021).

2.5.1 Planning Tool

The planning toolkit is designed to assist users with aspects of stakeholder engagement, infrastructure improvement planning and business model selection. The stakeholder engagement planning section helps users identify and classify stakeholders in the FSM ecosystem based on their level of interest and influence (FSM Toolbox, 2021).

2.5.2 Convergence with Global Diagnostic and Decision Support Tools

The FSM tool box can aid decision makers in adopting a global approach on sector assessment and planning (FSM Toolbox, 2021).

2.5.3 Assessment Tool

The assessment tool is designed to help users undertake a 360-degree assessment of the FSM ecosystem and identify gaps across financial, infrastructure, institutional and regulatory aspects of FSM in a given region (FSM Toolbox, 2021). The assessment tool will help users generate a:

- **City Service Delivery Assessment (CSDA):** The CSDA provides a methodical approach to engaging with stakeholders to analyse the enabling environment for citywide inclusive sanitation and to deliver the findings in a clear and simple manner. It also contains an Action Checklist to assist stakeholders in identifying and prioritising immediate and follow-up measures to improve the enabling environment for the delivery and long-term operation of inclusive sanitation services throughout the city (Blackett and Hawkins, 2019).
- **Shit Flow Diagram (SFD):** also referred to as an excreta flow diagram, are a new way of visualising excreta management in cities and towns. The SFD is also described as a tool to readily understand and communicate how excreta physically flows through a city or town (Susana, 2018).

A case study -Durban Shit flow diagram

(Source: Cross and Buckley, 2016)

This Shit Flow Diagram (SFD) was created through field-based research by the WASH R&D Centre, previously Pollution Research Group (PRG) from the University of KwaZulu-Natal (UKZN), as an internship project for the final requirements of the Integrated Water Resource Management Master's program at McGill University. The collaborating partners included: eThekweni Water and Sanitation (EWS), Swiss Federal Institute of Aquatic Science and Technology (Eawag), and Sandec: Department of Sanitation, Water and Solid Waste for Development.

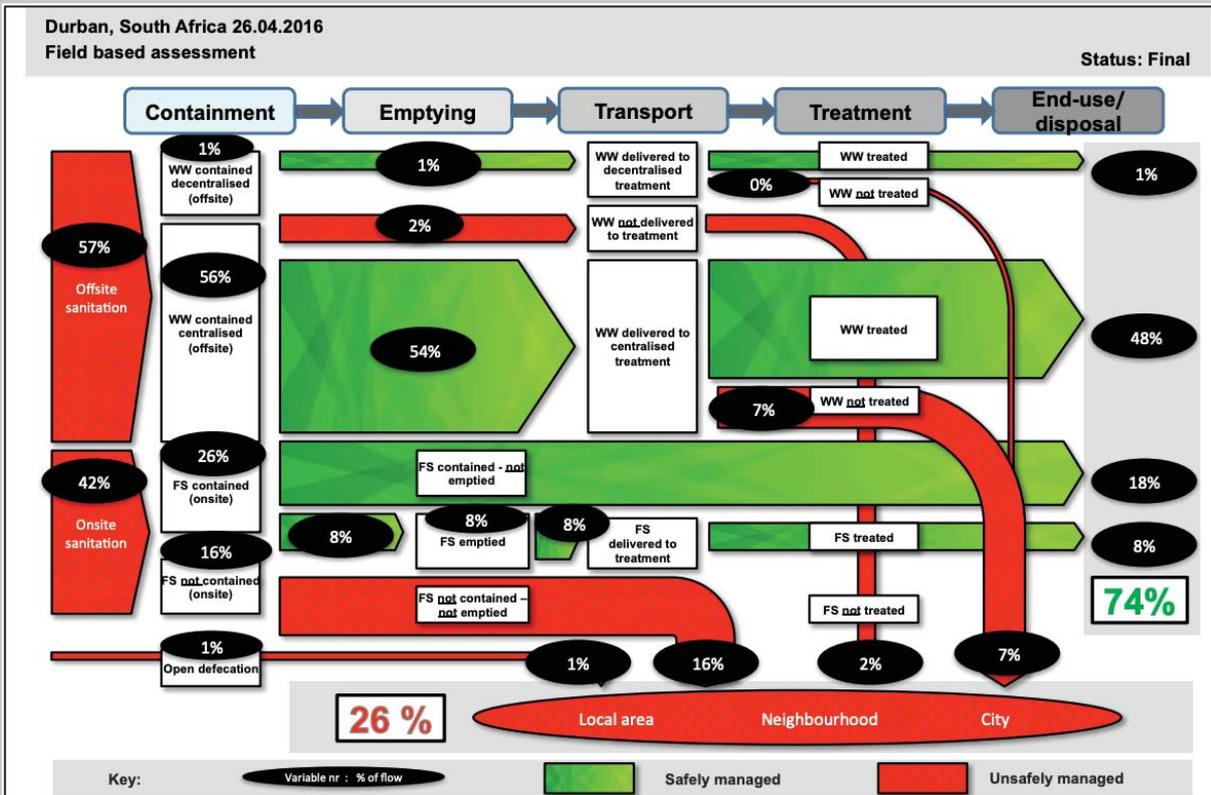


Figure 2-6: illustrating SFD for the eThekweni Metropolitan Municipality (from Cross and Buckley, 2016)

Service Outcomes

Figure 2.6 presents the SFD for the eThekweni Metropolitan Municipality, Durban, illustrating how excreta is managed. In the area, 74% of excreta is safely managed, with 48% originating from waterborne toilets connected to the central sewer network. The majority of unsafely managed excreta comes from the 17% of households lacking improved toilet facilities or access to an emptying service. This includes 16% from unimproved, community-built pits that are neither emptied nor safely buried, and 1% from open defaecation, along with estimated overflows from blocked sewer lines.

For the 42% of households relying on on-site sanitation, containment systems include septic tanks, conservancy tanks (sealed tanks), urine diversion (UD) toilets, and VIPs. In the SFD, UD toilets are categorised

as sealed tanks when faeces are collected for Black Soldier Fly (BSF) treatment or as “pits that are safely closed” when contents are safely buried on-site. The latter accounts for 18% of safely managed excreta.

The emptying and transport of FS from septic tanks, conservancy tanks, and VIP toilets are well managed, forming a robust private and public industry. Sludge from VIP toilets is treated and processed into fertiliser pellets at the LaDePa treatment facility, while other FS is transported to centralized treatment facilities. There, it is either mixed with liquid wastewater from the sewer network and discharged through a sea outfall – deemed safe under legal regulations – or treated at wastewater treatment works (WWTW). Additionally, a small portion is processed at the BSF treatment facility. Together, these methods account for 8% of safely disposed excreta.

Meanwhile, 56% of off-site sanitation is directed to the central sewer system. However, due to frequent blockages in gravity-driven sewer lines, an estimated 2% of excreta does not reach the treatment works. This estimate is based on an assumption of 140 blockages per day, with trunk sewers equivalent to 60 Ml/d being fully blocked for an average of 14 hours. Due to limited data on trunk sewer flows, further research could improve the accuracy of this estimate

2.6 SUMMARY

The available literature on FS from on-site sanitation systems such as pit latrines, septic tanks, and container-based sanitation has shown it contains a high concentration of organic matter, pathogens, nutrients (such as nitrogen and phosphorus), and varying amounts of solid waste, sand, and debris, depending on the sanitation system and user practices. Unlike wastewater sludge, which is the residual semi-solid material produced from wastewater treatment plants (WWTP), faecal sludge is typically more variable in composition, has a higher solids content and other pollutant loads, and often lacks significant dilution from greywater (from sinks, showers, and industrial sources). This makes faecal sludge more challenging to transport, treat, and manage, requiring tailored treatment approaches distinct from conventional wastewater sludge handling, which is the focus of FSM in ensuring safe collection, transport, treatment, and disposal and / or resource recovery.

In the next chapter, policy aspects around FSM are presented.

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CHAPTER 3: POLICY ASPECTS

3.1 INTRODUCTION

Faecal sludge management (FSM) is facilitated by appropriate policies, legislation, institutional framework and regulations at the international, national and local levels. This section focuses on the international policies for sanitation, i.e the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs) and the progress to date in South Africa. Furthermore, it focuses on the legislation, regulations and framework relating to the faecal sludge (FS) collection, treatment, reuse/end-use and disposal.

3.2 INTERNATIONAL POLICIES

About one third of the world's population is still using on-site sanitation facilities. The lack of suitable sanitation management systems results in poor performance of on-site sanitation technologies. Proper management of on-site sanitation technologies is essential to ensure they function adequately (Harada et al., 2016).

3.2.1 Millennium Development Goals (MDGs)

Global interventions and responsive actions have been made to eradicate open defecation and to ensure equitable sanitation for all, starting with the United Nations' (UN) Millennium Development Goals (MDG) number 7, which focused on ensuring environmental sustainability. Target 7c of MDG 7 was that by the year 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation would halve. In 2010, the world met the UN MDG target on access to safe drinking water as measured by the indicator of access to improved drinking water sources; however, more interventions were needed to achieve the target on sanitation (WHO, 2021).

3.2.2 Sustainable Development Goals (SDGs)

In 2015, the UN continued to set the Sustainable Development Goals (SDGs), which are expected to be achieved by 2030. Amongst the set SDGs, SDG 6 aims to ensure availability and sustainable management of water and sanitation for all (Sdgs.un.org, 2021). SDG 6.2 focuses on achieving access to adequate and equitable sanitation and hygiene for all and ending open defecation, paying special attention to the needs of women and girls and those in vulnerable situations (Sdgs.un.org, 2021). To achieve SDG 6 targets, there is a requirement to provide safe and hygienic FSM services to the millions of people who depend on the on-site sanitation facilities and provision of safe sanitation facilities to those without any facilities (Peal et al., 2014; Berendes et al., 2017; Capone et al., 2020). A sanitation chain that is safely managed is crucial for the protection of individuals' health, communities and the environment. The effects of unsafely managed sanitation chains, such as overflowing or leaking pit latrines, have the potential to spread diseases and pollute surface and ground water, which serve as a source of drinking water (WHO, 2018).

Progress toward achieving Sustainable Development Goal (SDG) Target 6.2, which aims to ensure access to adequate and equitable sanitation and hygiene for all, is assessed using Indicator 6.2.1. This indicator measures the proportion of the population utilising: (a) safely managed sanitation services, and (b) a hand-washing facility with soap and water. Safely managed sanitation services are defined as the use of improved sanitation facilities that are not shared with other households and where excreta are safely disposed of *in situ* or transported and treated off-site. Hand-washing facilities may include a sink with tap water, buckets with taps, tippy-taps, and jugs or basins designated for handwashing, with soap encompassing bar soap, liquid soap, powder detergent, and soapy water (U.N., *n.d.*).

This indicator addresses the normative criteria of the human right to water by integrating aspects of accessibility, acceptability, and safety. It emphasises the importance of safely managing faecal waste throughout the entire sanitation chain to mitigate public health risks associated with exposure to excreta pathogens, particularly when pits are full (WHO, 2024).

By analysing these components, Indicator 6.2.1 directs the focus of policymakers and decision-makers toward strategic investments that yield significant health, gender, and environmental benefits (U.N., *n.d.*).

3.2.3 South Africa's Obligation to the International Policies

As indicated in the National Sanitation Framework (DWS, 2016), South Africa will pursue achievement of the SDGs, focusing on sanitation services provision on ensuring sustainability. The sanitation SDGs are supported, including:

- Achieving access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations.
- Improving water quality by reducing pollution, eliminating dumping and minimising the release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally.
- Substantially increasing water-use efficiency across all sectors and ensuring sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity.
- Expanding international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies.
- Supporting and strengthening the participation of local communities in improving water and sanitation management.

3.3 NATIONAL POLICIES

3.3.1 Legislation Regulating the Collection and Transportation of Faecal Sludge

The emptying and transport of FS in South Africa is regulated by the following regulations:

- The Occupational Health and Safety Act (Act 85 of 1993)
- The National Road Traffic Act (Act 93 of 1996)
- National Environmental Management: Waste (NEMWA) (Act 107 of 1998)
- National Environmental Management: Waste (Act 59 of 2008)
- The National Environmental Management Act (Act 26 of 2014)

3.3.2 Legislation Regulating the Treatment of Faecal Sludge

The treatment of FS in South Africa is regulated by the following policies and regulations:

- Water Services Act (Act 108 of 1997)
- National Water Act (Act no 36 of 1998)
- National Environmental Management: Waste Act (Act 59 of 2008)
- National Sanitation Policy 2016 (DWS, 2016)
- The National Norms and Standards for Domestic Water and Sanitation Services (2017)

3.3.3 Legislation Regulating the Safe End-Use of Faecal Sludge

The safe end-use of FS in SA is regulated by:

- Fertilisers, Farm Feeds, Seeds and Remedies Act 36 of 1947 (Act 36 of 1947)
- National Water Act (Act 36 of 1998)
- National Environmental Management Waste Act (Act 59 of 2008)
- Guidelines for utilisation and disposal of wastewater sludge (Snyman and Herselman J, 2006; Snyman, 2010)
- National Sanitation Policy 2016 (DWS, 2016)
- The National Norms and Standards for Domestic Water and Sanitation Services (2017)

More recently, the Department of Water and Sanitation (DWS) launched the National Faecal Sludge Management (FSM) Strategy 2023 (DWS, 2023) (**see Annexure A for link**). The document provides comprehensive guidance for the safe and effective management of faecal sludge across the entire sanitation service chain. This strategy addresses the needs of South Africans who rely on on-site sanitation systems, such as septic tanks and pit latrines. The document covers operational difficulties, health and environmental risks and infrastructure limitations for FSM. A series of strategic actions is described in the document that focuses on comprehensive planning around the entire sanitation service chain, public awareness campaigns, and policy integration, especially with the National Sanitation Policy 2016, which encourages the reuse of sanitation by-products (DWS, 2016).

To further improve sanitation services, the National Sanitation Integrated Plan (NSIP) was also developed concurrently with National FSM Strategy to provide a 10-year roadmap for addressing sanitation backlogs, promoting innovative solutions, and creating economic opportunities (DWS, 2024). Given the fragmented implementation of sanitation services, the NSIP aims to coordinate efforts and ensure sustainable sanitation solutions across provinces (DWS, 2024).

3.3.4 Legislation Regulating the Safe Disposal of Faecal Sludge

The South African government promotes the beneficial use of human excreta as a resource; however, strict guidelines are enforced to mitigate contamination risks. In 2013, the Minister of Water and Environmental Affairs published the Waste Classification and Management Regulations, along with the Norms and Standards for the Assessment of Waste for Landfill Disposal, and the Norms and Standards for the Disposal of Waste to Landfill. These regulations classify waste based on its risk level, and each classification dictates specific landfill design requirements. For instance, Type 1 waste must be disposed of at a Class A landfill, while Type 2 waste is designated for Class B landfills. This classification system ensures that waste management practices align with the associated risks, thereby safeguarding public health and the environment (DEA, 2013). FS is regarded as a hazardous material and therefore it needs to be treated before it is disposed of in a landfill (Harrison and Wilson, 2012). The FS therefore falls under Type 0 it needs to be treated and re-tested to determine the risk profile for the disposal site. **Table 3.1** illustrates South African landfill classification according to the type of waste disposed of.

Table 3.1: South African landfill classification according to the type of waste disposed of (Source: DEA, n.d; DEA, 2013)

Waste Risk Level	Disposal Requirement
Type 0 Very High Risk	Disposal not allowed. The waste must be treated first and then retested to determine the risk profile for disposal.
Type 1 High Risk	Disposal is only allowed at a landfill with Class A or Hh/HH containment barrier design.
Type 2 Moderate Risk	Disposal only allowed at landfill with Class B or GLB+ containment barrier design (or Class A)
Type 3 Low Risk	Disposal only allowed at landfill with Class C or GLB+ containment barrier design (or Class B or A).
Type 4 Inert Waste	Disposal allowed at landfill with a Class D or GDB- containment barrier design.
Non-Hazardous Waste (Pre-classified)	Disposal only allowed at landfill with Class B or G S/M/L B-/B+ containment barrier design.

The disposal of FS is regulated by the following regulations:

- National Water Act (Act no. 36 of 1998)
- Environmental Conservation Act (Act No. 73 of 1989)
- Guidelines for the Utilisation and Disposal of Wastewater Sludge Volumes 1 to 5 (Snyman, 2010)

- The National Environmental Management Act (Waste Act 59 of 2008)
- The National Norms and Standards for Domestic Water and Sanitation services (2017)

3.4 LICENSING AND AUTHORISATION

Currently, in South Africa, the collection, treatment, reuse, and/or subsequent disposal of FS from on-site sanitation facilities are guided by policies and regulations from the DWS. However, in conducting or wanting to conduct this work, certain accreditations, certificates, and licensing documents may be required. The collection, emptying, desludging, and disposal of pit latrines FS within the communities is the responsibility of the municipalities. The municipality uses the tendering procurement system and appoints contractors to facilitate the work.

3.4.1 Emptying and Disposal of On-Site Sanitation Facilities

The desludging, disposal and emptying of on-site sanitation facilities is the responsibility of the municipality; however, the municipality appoints the contractors to conduct the work under the tendering procurement systems. The tender document will have its own terms and conditions, which the tenderer must comply with. Below are some of the important aspects that are usually required in a tender document:

3.4.1.1 Standard Conditions of Tender

- The conditions of tender are the Standard Conditions of Tender as contained in the Construction Industry Development Board (CIDB) Standard for Uniformity in Construction Procurement (July 2015) as published in Government Gazette No 38960, Board Notice 136 of 2015 of 10 July 2015.
- The Standard Conditions of Tender make several references to the Tender Data for details that apply specifically to this tender.
- The Tender Data shall have precedence in the interpretation of any ambiguity or inconsistency between it and the Standard Conditions of Tender.

3.4.1.2 Tender Documents

The Tender Documents issued by the Employer comprise:

(a) The procurement document.

(b) “General Conditions of Contract for Construction Works – 3rd Edition 2015” issued by the South African Institution of Civil Engineering (SAICE, 2015). This document is obtainable separately, and Tenderers shall obtain their own copies.

(c) In addition, Tenderers are advised, in their own interest, to obtain their own copies of the following acts, regulations, and standards as they are essential for the Tenderer to get acquainted with the basics of construction management, the implementation of preferential construction procurement policies, and the participation of targeted enterprises and labour.

- The Occupational Health and Safety Act No 85 and Amendment Act No 181 of 1993, and the Construction Regulations (2014).

- The Construction Industry Development Board Act No 38 of 2000 and the Regulations issued in terms of the Act (South Africa, 2000).
- The Preferential Procurement Policy Framework Act No 5 of 2000.
- SANS 1921:2004 – Construction and Management Requirements for Works Contract, Parts 1-3.
- The Employer's current Supply Chain Management Policy.
- Any other employer's Policy documents referenced in the Tender Documents.

3.5 ACCREDITATION FOR WASTE COLLECTION

An application for accreditation as a waste picker/collector must be:

- made in writing on a form prescribed by the Council and accompanied by documentation specified in that form; and
- accompanied by a prescribed fee.

Before considering an application made in terms of subsection 1. the Council may require the applicant to furnish such information as it may require.

- After considering the application in terms of subsection 2, the Council must either:
 - approve the application by issuing an accreditation permit subject to any condition that it may impose; or
 - reject the application.
- If the Council fails to consider and grant or reject an application for an accreditation permit within 60 days of its receipt of the application, it must inform the applicant of the date by which a decision will be made.

3.5.1 Terms and Conditions of Accreditation

When issuing an accreditation permit, the Council may, subject to the provisions of subsection (2), impose any condition reasonably necessary in furthering the Council's waste management policy.

An accreditation permit must:

- Specify the period for which the permit is valid and the procedure for renewing the permit;
- Contain a requirement that a permit holder must comply with, and ensure compliance by his or her employees, agents and sub-contractors, with these by-laws and applicable legislation.
- Specify the area within the jurisdiction of the Council approved for waste picking;
- Specify that a waste picker shall at all relevant times comply with the National Domestic Waste Collection Standards 2011, as amended, and other applicable health and safety legislations, regulations and policies, as amended from time to time.

3.5.2 Display of an Accreditation Permit

Upon issuing an accreditation permit, the Council must issue to the applicant an identification card bearing:

- The full names and identities of the waste picker,
- The area designated for waste picking;
- The period of validity of the accreditation; and
- Such other information as the Council may deem necessary.

3.6 ACCREDITATION FOR ISO 30500

A Non-Sewered Sanitation System (NSSS), also referred to as Non-Sewered Sanitation (NSS) – with the variation in acronyms arising from a lack of standardisation among practitioners – is a prefabricated, integrated treatment unit composed of two primary components: a front-end component (toilet facility) and a back-end component (treatment facility). The NSSS is designed to collect, convey, and fully treat the specific input within the system, ensuring the safe reuse or disposal of the resulting solid, liquid, and gaseous outputs (ISO 30500, 2018).

NSS systems operate independently of sewer or drainage networks. They may be manufactured as a single unit or as prefabricated components that can be assembled without further fabrication or modifications affecting system functionality. These prefabricated elements are intended to require minimal on-site work to enable rapid deployment and provide fully functional sanitation solutions (ISO 30500, 2018).

The inputs entering the NSSS consist of:

- Human faeces
- Urine
- Menstrual blood
- Bile
- Flushing water
- Anal cleansing water
- Toilet paper and other bodily fluids/solids

The output substances exiting the NSSS include (ISO 305000, 2018):

- The products of the backend treatment process, such as solid output
- Effluent
- Noise
- Air
- Odour emissions

3.6.1 Classes of the NSSS

NSSS Classification:

- Class 1: one front-end and non-biological back-end.
- Class 2: one front-end and back-end with one or more biological treatment processes.
- Class 3: multiple front-ends with one or more biological or non-biological back-ends.

3.6.2 SANS/ISO 30500 CERTIFICATION PROCESS

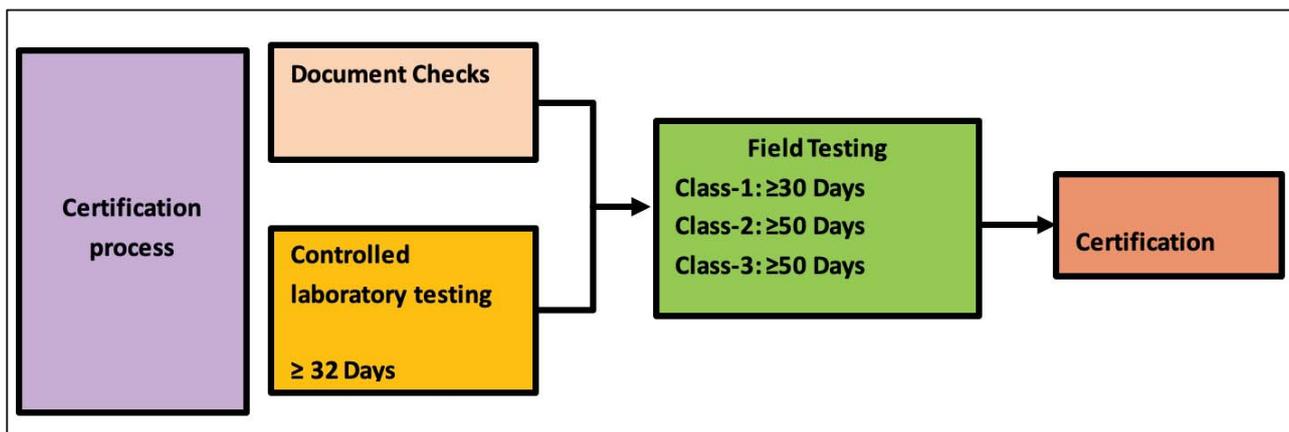


Figure 3-1: Overview of the stages of SANS/ISO 30500 certification process (Source: ISO 30500, 2018)

Details on the certification process for each NSSS are available on the ISO 30500:2018 – Non-Sewered Sanitation Systems (<http://iso.org>).

3.7 ACCREDITATION FOR ISO 31800

ISO 31800 sets performance and safety standards for community-scale treatment units serving 1,000 to 100,000 people, ensuring technical robustness and environmental safety (see Figure 3-2).

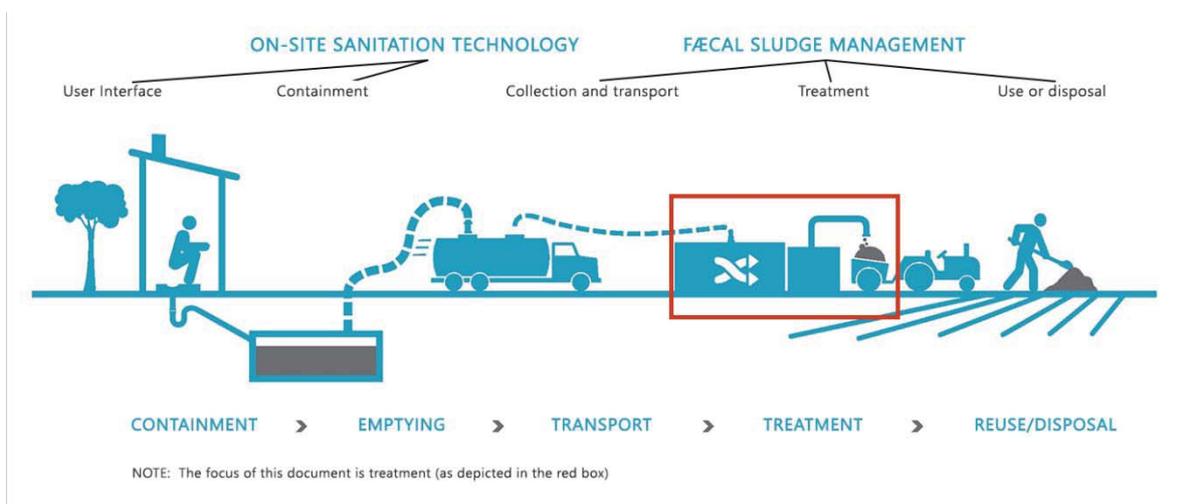


Figure 3-2: The focus on non-sewered faecal sludge treatment units as highlighted in the sanitation value chain (Source: ANSI, 2024).

The standard applies to prefabricated, off-grid treatment units designed specifically for faecal sludge. Its publication benefits manufacturers by ensuring compliance, helps regulators develop sound policies, and assures governments and operators that these units contribute to public and environmental health.

ISO 31800 benefits key stakeholders in faecal sludge treatment (ISO, 2000). These include:

- Manufacturers can certify their prefabricated treatment units as ISO 31800-compliant, boosting credibility and marketability while demonstrating environmental and cultural adaptability.
- Regulators gain a reliable framework for developing sound policies, ensuring public and environmental health protection, and accessing expert consensus without direct consultation.
- Operators and service providers can rely on ISO 31800-certified units for safe operation, cost efficiency, and global trade opportunities while ensuring health and environmental safety.

Case Study: Legislative Challenges with Faecal Sludge Disposal and Innovation Procurement

eThekweni Water and Sanitation (EWS) co-developed and tested the Latrine Dehydration and Pasteurisation (LaDePa) process to manage emptied faecal sludge (FS). The innovative technology was developed to solve a number of challenges that the municipality had faced when servicing VIP latrines. Harrison and Wilson (2012) reported that when the municipality attempted to dispose of collected VIP sludge at a local sewage treatment plant, the facility failed due to overloading (photos in EWS (2012)). Alternative disposal methods also proved challenging. VIP sludge was classified as hazardous due to its infectious nature, leading to licensing complications. Sewage sludge is considered infectious in terms of the regulations promulgated under the Environmental Management Act and, consequently, can only be disposed of at a hazardous landfill site. In addition, from an environmental perspective, they further noted that, under the Waste Management Act, licenses were required for storing and treating hazardous materials. However, sewage treatment plants processing less than 2,000 cubic meters annually were exempt from Waste License and Environmental Impact Assessment (EIA) requirements. With respect to emptying VIPs, compliance with the Occupational Health and Safety (OHS) Act posed difficulties, particularly when working with low-skilled labor (Harrison and Wilson, 2012).

Harrison and Wilson (2012) highlighted that South Africa's legislation on government procurement and environmental protection has created a legal framework that is generally unfavourable for straightforward VIP servicing solutions. While emptying and maintaining VIPs is not technically complex, making it well-suited for job creation and entrepreneurship in affected communities, the outsourcing of these services is challenging due to the high costs and complexity of treatment technologies. The Municipal Finance Management Act (MFMA) limits contracts to a maximum of three years unless special approval is granted by National Treasury. At the same time, the high capital costs associated with human faecal sludge treatment and recovery plants necessitate long-term financing, further complicating service provision (Harrison and Wilson, 2012).

3.8 SUMMARY

While South Africa has numerous plans and policies aimed at managing faecal sludge, there are often other hurdles to innovation in the sector, as illustrated by the LaDePa case study (Harrison and Wilson, 2012). The lack of specific regulatory requirements for faecal sludge reuse, the need to establish and develop markets for reuse products, which may be out of the realm of expertise for municipalities that are service-driven, the complexity of the procurement process, and the limitations on the duration of municipal contracts can stifle the development and adoption of innovative, cost-effective FSM solutions. Furthermore, the high capital costs associated with faecal sludge treatment and recovery systems hinder long-term investment in such technologies, limiting their scalability. While emptying and maintaining VIP latrines could be an opportunity for job creation and entrepreneurship, the legal and financial complexities tied to FSM restrict the potential for more innovative and sustainable approaches. Overcoming barriers to innovation in South Africa's FSM requires a multifaceted approach that includes specific regulations for FS reuse (including source-separated urine), long-term financing, innovation incentives, capacity building, circular economy integration, and strong community engagement. By aligning these efforts, South Africa can create an environment conducive to sustainable, innovative solutions that address both sanitation challenges and the broader environmental and economic goals of the country.

In the next chapter, on-site sanitation systems from which FS is collected are presented.

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CHAPTER 4: ON-SITE SANITATION SYSTEMS

4.1 INTRODUCTION

The capture and containment refers to the on-site sanitation toilet systems where faecal sludge (FS) is captured and stored. Understanding the existing on-site sanitation technologies that are used in urban, peri-urban and rural areas contributes significantly to the type of collection, treatment and/or safe disposal. In South Africa, at least 30 % of the total population relies on on-site sanitation systems (Stats SA, 2023). It is important to recognise that both 'on-site sanitation' and 'non-sewered sanitation' (NSS) refer to sanitation systems that do not rely on centralised sewer networks. NSS tends to be a broader term that encompasses any sanitation solution that is not connected to a centralised sewer system. As a result, the terms are often used interchangeably, leading to some overlap in their meaning.

The on-site sanitation facilities can be classified as either (i) dry sanitation systems and (ii) waterborne systems. **Table 4.1** below illustrates some factors that are useful when selecting an on-site sanitation system. On-site sanitation systems are more affordable options compared to centralized sewerage sanitation systems. Daudey's (2018) literature review analysis concluded that conventional sewer systems are typically the most expensive sanitation solution. Other systems follow in cost order: septic tanks, ventilated improved pit latrines (VIP), urine diversion dry toilets, and pour-flush pit latrines. Simplified sewer systems are found to be less costly than both conventional sewer systems and septic tanks. However, due to insufficient data, further comparisons with other sanitation options were not possible (Daudey, 2018).

The degradation and dehydration of faecal sludge (FS) within on-site sanitation facilities may occur to a certain extent, with variations depending on the technology employed. Factors such as topography, soil condition, local climate, and financial resources typically influence the selection and design of an appropriate on-site sanitation system and therefore the quality and quantity of FS. The ease of emptying these systems can also be conditional on several factors, including (i) accessibility to the site, (ii) viscosity of the sludge, (iii) depth of pit or vault, (iv) type of emptying method, and (v) the presence of components such as trash within the FS (Harrison and Wilson, 2012; Still and Foxon, 2012a; Still and Foxon, 2012b; Nakagiri et al., 2014; Zziwa et al., 2017; Mubatsi et al., 2021; Muoghalu et al., 2023).

4.2 DRY ON-SITE SANITATION SYSTEMS

The dry toilets that operate without flush water consist of a pedestal designed for the user to sit or a squat pan. Whether the user sits or squats, the excreta falls through a drop hole. Dry sanitation systems are classified under 3 groups (i) Urine Diversion Dry Toilets (UDDT) systems; (ii) latrine systems and (iii) Toilets with *in situ* treatment (Orner & Mihelcic, 2018; Tilley et al., 2014; Ramaraju & Shivendra, 2015). Dry toilets are mostly used in developing countries where flush toilets connected to a sewer system / septic tanks are not financially feasible (Rieck et al., 2012). Dry toilets can be beneficial to: (i) save water where there is water

scarcity; (ii) prevent pollution of surface water or ground water, if the waste is properly confined and (iii) enable safe reuse of excreta (Rieck et al., 2012; Tilley et al., 2014).

4.2.1 Urine Diversion Dry Toilets (UDDT)

In the UDDT, the urine is redirected away from the toilet and the faeces are stored in a chamber of dehydrating toilets. Depending on the collection and storage/treatment technology that follows, drying material such as lime, ash, or earth should be added into the same hole after defecating (Scott, 2002; Aburto-Medina et al., 2020). The main benefit is that there is no need for a pit, and therefore the toilet can be installed within the home if desired by the owner. Urine, which is high in plant nutrients like nitrogen, phosphorus, and potassium, may be readily collected in a container and reused as agricultural fertiliser. The faeces are placed in a shallow vault and sprinkled with ash or dry soil, which absorbs most of the moisture.

4.2.1.1 Single vault UDDT

Single vault UDDTs consist of only one vault or compartment for collecting faeces, and they include a urine-diverting system to separate urine from feces. Single vault UDDTs are generally simpler in design and construction. The single vault has a finite capacity, which may require more frequent emptying. Users may need to wait longer before the contents decompose sufficiently for safe handling.

4.2.1.2 Double vault UDDTs

Double vault UDDTs consist of two separate vaults or compartments for faeces. Users switch between the two vaults, allowing one to decompose while the other is in use. The alternating use of vaults allows for longer periods of decomposition, reducing the frequency of emptying. Users can continue to utilise the toilet even during the decomposition period. The double vault UDDT is more complex in design and construction compared to the single vault version. Due to the dual compartments and more intricate design, double vault UDDTs may be more expensive to build and maintain. **Table 4.1** illustrates the benefits and constraints of a UDDT and **Figure 4.1** illustrates the schematic diagram of UDDT options for both washers and wipers.

Table 4.1: Benefits and constraints of a UDDT (Scott, 2002; Aburto-Medina et al., 2020; Buckley et al., 2008)

Benefits	Constraints
<ul style="list-style-type: none"> • High reduction of excreta volume. • Potential for use of dried faeces as soil conditioner. • No real problems with flies or odours if used and maintained correctly (i.e., kept dry). • Can be built and repaired with locally available materials. 	<ul style="list-style-type: none"> • Requires training and acceptance to be used correctly. • Poor maintenance can quickly lead to malfunctioning. • Anal cleaning water should be kept separate. • Requires a constant source of cover material. • Manual removal of dried faeces is required. • Requires a use / discharge point for faeces and urine. • Incomplete pathogen deactivation.

Factors to consider before choosing UDDT are as follows (DHS, 2005):

- The technology is well-suited to dense urban settlements and places where environmental conditions do not favour other types of sanitation.
- Use of the toilet requires adherence to certain operational requirements, and a proper commitment from owners is required. Good user education is, therefore, especially important.
- Building materials similar to those for a VIP toilet may be used, and the toilets can be constructed by relatively unskilled persons.
- Components can also be manufactured commercially.
- The system is hygienic if it is used and maintained correctly. Safe re-use of the urine and faeces is also facilitated.
- The system can be installed inside a house, if desired.
- There may be reluctance on the part of the user to empty the vault, even though the contents are innocuous.
- The system can be regarded as a permanent sanitation solution that will never need upgrading.

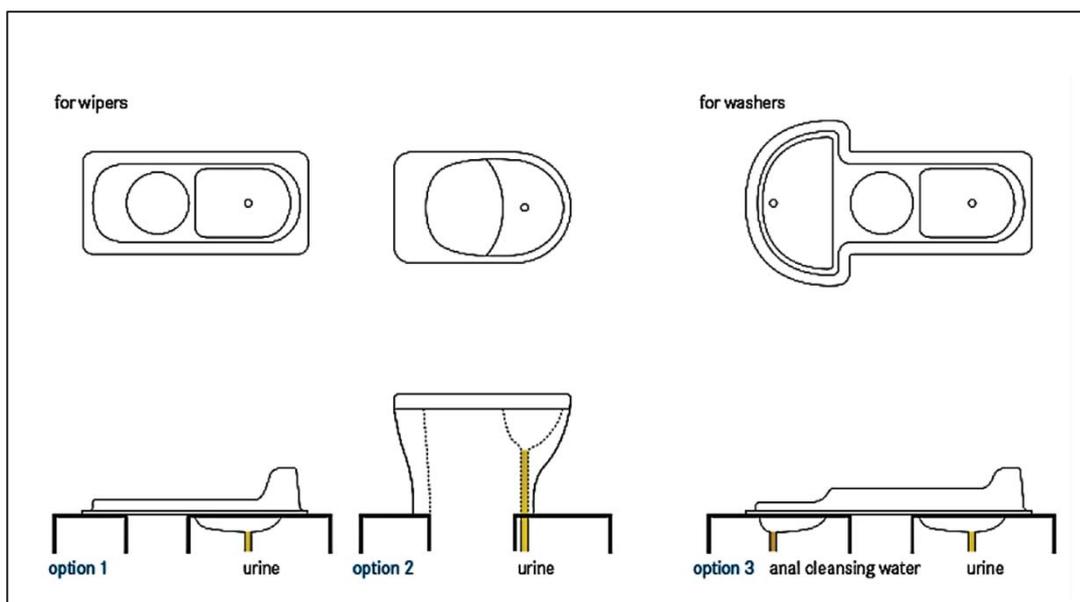


Figure 4-1: Illustrating UDDT options for both wipers and washers (Source: Tilley et al., 2014)

Case Study: UDDTs in eThekweni Municipality

In the 2000s, the eThekweni Municipality installed UDDTs in rural areas to address urgent sanitation needs. The decision to use UDDTs was based on cost-effectiveness and environmental benefits compared to flush toilets, open defaecation and Ventilated Improved Pit (VIP) latrines. The implementation was driven by the expansion of municipal boundaries, adding rural and peri-urban areas with 75,000 households, 80% of which lacked proper water and sanitation (Mudzanai et al., 2020). The urgency was heightened by a severe cholera outbreak in KwaZulu-Natal (2000–2001), which resulted in over 105,000 cases and 219 deaths. The initiative aligned with South Africa’s constitutional right to sufficient water and sanitation. From a technical perspective, UDDTs were chosen for their waterless operation, potential to separate liquid and solid and this less sludge for emptying, theories that the drier FS (than a VIP) would be easier and safer to handle, suitable for hilly terrains, and a ‘vault system which was shallower than VIP pits (Mudzanai et al., 2020).

While during its implementation, UDDTs appeared to be a technically sound solution in terms of design and efficiency, the success of the programme was heavily influenced by user habits and acceptance. If the community is not properly educated or if the solution is not aligned with local aspirations and customs, the intended benefits may not be realised. Surveys undertaken in the municipality have shown that while 97% of respondents used the UDDTs, there was a low level of acceptance and a preference for flush toilets (Mudzanai et al., 2020). A lack of education on how to use the UDDT and issues with the quality of materials were challenges highlighted in that study. Further, it emphasises the importance of community participation and education to change perceptions about ecological-style sanitation systems (Mudzanai et al., 2020). The findings mirror an earlier study, which found low satisfaction levels, with issues such as unpleasant odours and malfunctioning pedestals, and the importance of educational and promotional efforts (Roma et al., 2013). User reluctance or improper maintenance can lead to suboptimal outcomes, demonstrating that technology alone is not enough without user engagement and buy-in.

4.2.2 Latrine Systems

4.2.2.1 Simple pit latrine

The simple pit latrine system consists of a slab over a pit of 2m – 3m or more in depth. The slab should be firmly supported on all sides and raised above the surrounding ground so that surface water cannot enter the pit. If the sides of the pit are liable to collapse, they should be lined. A squat hole in the slab or a seat is provided so that the excrement falls directly into the pit (WHO, 1992; Hill, 2013; SSWM, 2019(a)). **Table 4.2** illustrates the benefits and constraints of a simple latrine.

Table 4.2: Benefits and constraints of a simple latrine (WHO, 1992; Tilley et al., 2014; WEDC, 2012; Louton et al., 2015)

Benefits	Constraints
<ul style="list-style-type: none"> • Low cost. • Can be built by a householder with locally made materials. • No need for water. • Easily understood. 	<ul style="list-style-type: none"> • Smell. • Considerable fly nuisance. • Pit located directly below toilet seat can cause fear of children using the system • Not considered improved sanitation.

Factors to consider before choosing a simple latrine are as follows (WHO, 1992; Hill, 2013; SSWM, 2019(a)):

- It is important to locate a latrine downhill from water sources wherever possible.
- The latrine pit should not penetrate groundwater and should at least be two metres above the water table.
- The latrine should be a minimum distance of six metres from the house, so it's easy to reach during bad weather but will not cause problems of odour in the house.
- Flies should be prevented from breeding in the latrine where possible.

4.2.2.2 Ventilated improved pit (VIP) toilet

A pit toilet with an external ventilation pipe serves as the VIP toilet. If correctly designed, manufactured, used, and maintained, it is both hygienic and relatively affordable. A VIP toilet must include a reinforced concrete slab to ensure stability. By lining the pit with open jointed brickwork or other porous lining, the VIP toilet can be made more permanent. The pit can then be emptied as needed with a suitable vacuum tanker and manual emptying, without the risk of the sides collapsing (WHO, 1992; Tilley et al., 2014; WEDC, 2012). **Table 4.3** illustrates the benefits and constraints of VIP Toilets.

Table 4.3: Benefits and constraints of VIP Toilets (WHO, 1992; Tilley et al., 2014; WEDC, 2012; Louton et al., 2015)

Benefits	Constraints
<ul style="list-style-type: none"> • Lasts longer than a single VIP. • Low Cost. • Can be built and repaired with locally available materials. • Small land area required. • No need for water to operate. • Easily understood. • Control of flies. • Absence of smell in latrine. 	<ul style="list-style-type: none"> • Does not control mosquitoes. • Extra cost of providing a vent pipe. • Need to keep the interior dark. • Pit located directly below toilet seat can cause fear of children using the system. • Possible contamination of groundwater

Factors to consider before choosing VIP are as follows (DHS, 2005):

- The cost of the toilet is relatively low; it provides one of the cheapest forms of sanitation while maintaining acceptable health standards.
- The toilet can be constructed by the recipients, even if they are unskilled, as very little training is required.
- Locally available materials can be used.
- If required, the components can be manufactured commercially and erected on many plots within a short space of time.
- The system is hygienic if it is used and maintained correctly.
- The system can be used in high-density areas only if a pit-emptying service exists.
- The excreta are visible to the user.

4.2.2.3 Double ventilated improved pit toilet

The double VIP has almost the same design as the single VIP with the added advantage of a second pit that allows it to be used continuously and permits safer and easier emptying. The double VIP is a relatively low-cost and simple but permanent sanitation solution for high-density areas (DHS, 2005). Two lined shallow pits, designed to be emptied, are excavated side by side and are straddled by a single permanent superstructure. The pits are used alternately: when the first pit is full it is closed and the prefabricated pedestal is placed over the second pit. After a period of at least one year the closed pit can be emptied, either manually or mechanically, and then it becomes available for re-use when the other pit is full (DHS, 2005). **Table 4.4** illustrates the benefits and constraints of double VIP and **Figure 4.2** illustrates a diagram of both a VIP and Double VIP latrine sanitation systems.

Table 4.4: Benefits and constraints of double VIP (Bester and Austin, n.d; Tilley et al., 2014; SSWM, 2019 (b); Louton et al., 2015)

Benefits	Constraints
<ul style="list-style-type: none"> • Longer life than single VIP (indefinite if maintained properly). • Excavation of humus is easier than FS. • Significant reduction in pathogens. • Potential for use of stored faecal material as soil conditioner. • Can be built and repaired with locally available materials. 	<ul style="list-style-type: none"> • No specific reuse of faeces and urine. • Not suitable for all soil conditions. • Pits are susceptible to failure/overflowing during floods. Stagnant water in pits may promote insect breeding. • Possible contamination of groundwater. • Higher capital costs than single VIP; but reduced operating costs if self-emptied. • Pit located directly below toilet seat can cause fear of children using the system.

Factors to consider before choosing this option are like those for the VIP, but include the following (DHS, 2005):

- Some training is required to ensure that the pit lining is properly constructed.
- The contents of the used pit may be safely used as compost after a period of about two years in the closed pit.
- Since the FS of pit latrine is hazardous, the user may not be prepared to empty the pit and would require appropriate training, even though the contents have composted.
- The superstructure can be a permanent installation.
- The system can be regarded as a permanent sanitation solution.
- The system can be used in high-density areas.
- The system can be used in areas with hard ground, where digging a deep pit is impractical.

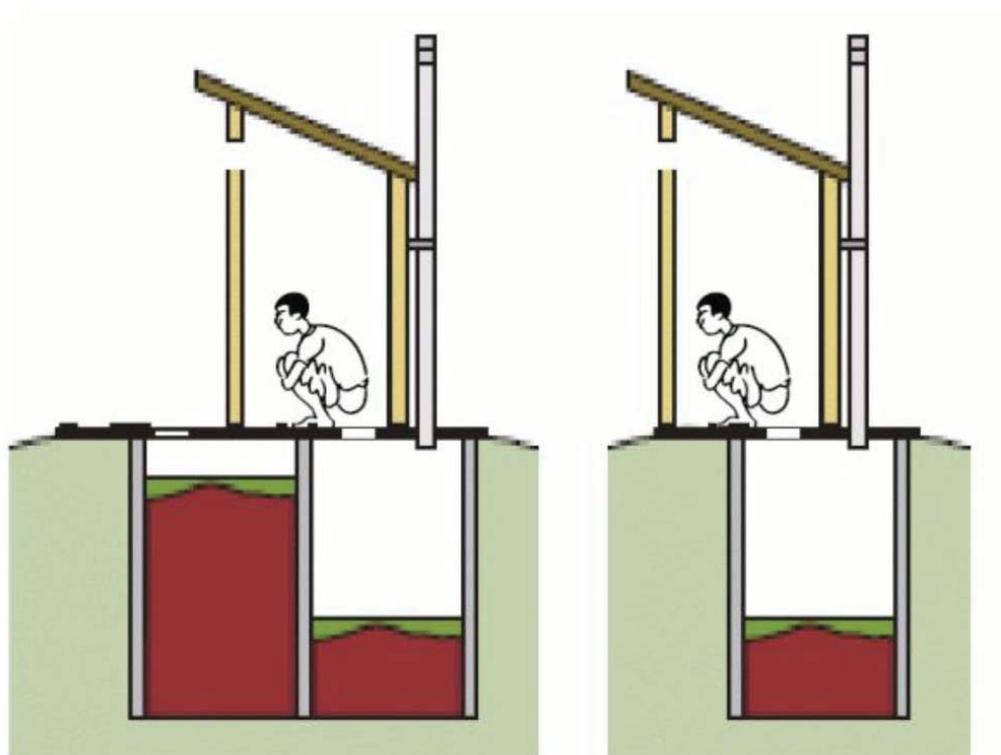


Figure 4-2: Illustrating double VIP latrine and single VIP latrine (Source: Bidira et al., 2024)

Refer to the *Protocol to manage the potential of groundwater contamination from on site sanitation* (DWS, 2003) for considerations based on your specific site characteristics. See link in Annexure A.

4.2.3 Toilets with In-site Treatment

4.2.3.1 Composting toilets

There are two types of composting latrines, where: (i) compost is produced continuously and (ii) two containers are used to produce it in batches. To provide the best conditions for thermophilic composting, dry organic material such as sawdust is added to regulate moisture content and carbon to nitrogen (25:1 C/N) ratio. There are four variables that ensure the system is operating efficiently: (a) sufficient oxygen (provided by active or passive aeration); (b) proper moisture (ideally 45 to 70% moisture content); (c) internal (heap) temperature of 40 to 50 °C; and (d) a 25:1 C:N ratio (theoretically) that can be adjusted by adding bulking material as a carbon source. Composting toilets enable the treatment of both excreta as well as organic household or garden waste, and the transformation of the waste into a beneficial soil supplement. Humus can be produced, so rural areas are convenient places to install this type on-site sanitation facilities, as they are more prone to use the produced humus, and therefore reduce environmental foot print (Berger 2011; Rieck et al., 2012; Tilley et al., 2014; SSWM, 2019(a)). **Table 4.5** shows the benefits and constraints of composting toilets and **Figure 4.3** illustrates a diagram of a composting toilet.

Table 4.5: Benefits and constraints of composting toilets (Tilley, 2022)

Benefits	Constraints
<ul style="list-style-type: none"> • Environmentally friendly. • Require less water usage • Can enhance the growth of non-edible plants in locations where soil amendment is permitted. • Well suited for remote areas. 	<ul style="list-style-type: none"> • Require more maintenance than standard toilets. • Improperly or poorly maintained systems can lead to odours, insects, and health hazards. • Usually require some type of power source. • The end product must also be removed. • Too much liquid can lead to slower decomposition.

Factors to consider before choosing a composting toilet are as follows (Tilley et al., 2014; SSWM 2019 (c)):

- Many composting systems need to be installed below the floor or in a separate building.
- Ensure the system's maintenance and emptying process is feasible.
- Create an easily cleanable area with outdoor access for compost removal.
- To operate efficiently, the system requires adequate oxygen, moisture content (45-70%), a temperature of 40-50°C, and a carbon-nitrogen ratio of 25:1.



Figure 4-3: Image of a composting toilet (Source: Biolet, 2024)

4.2.4 Arborloo

The Arborloo is a shallow pit filled with excreta and soil/ash and then covered with soil. A tree planted on top of the nutrient-rich pit will grow (SSWM, 2019(d)). A pit can be decommissioned by simply filling it with soil and covering it and the superstructure can be used to build another facility. The full pit poses no immediate health danger, and the contents will degrade naturally over time, and the household can receive value from the planted tree. **Table 4.6** illustrates the benefits and constraints of an arborloo.

Table 4.6: Benefits and constraints of an arborloo (from Tilley et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Simple technique for all users. • Low cost and risk of pathogen transmission. 	<ul style="list-style-type: none"> • Relatively labour intensive. • Not suitable with a high groundwater table. • Is only possible where there is enough space.

Factors to consider before choosing an arborloo are as follows, (SSWM, 2019(d)):

- Arborloos are suitable only in locations where a tree can grow, so users must consider the space and conditions required for a tree when choosing the pit's location.
- The pit should be 1 to 1.5 meters deep and not lined to allow space for tree growth.
- After each use, cover excreta with a mix of soil, ash, or both.
- Adding leaves improves porosity and air content if available.
- When the pit reaches capacity (usually 6-12 months), fill the top 15 cm with soil and plant a tree.
- Trees like banana, papaya, and guava can thrive on compost made from excreta.

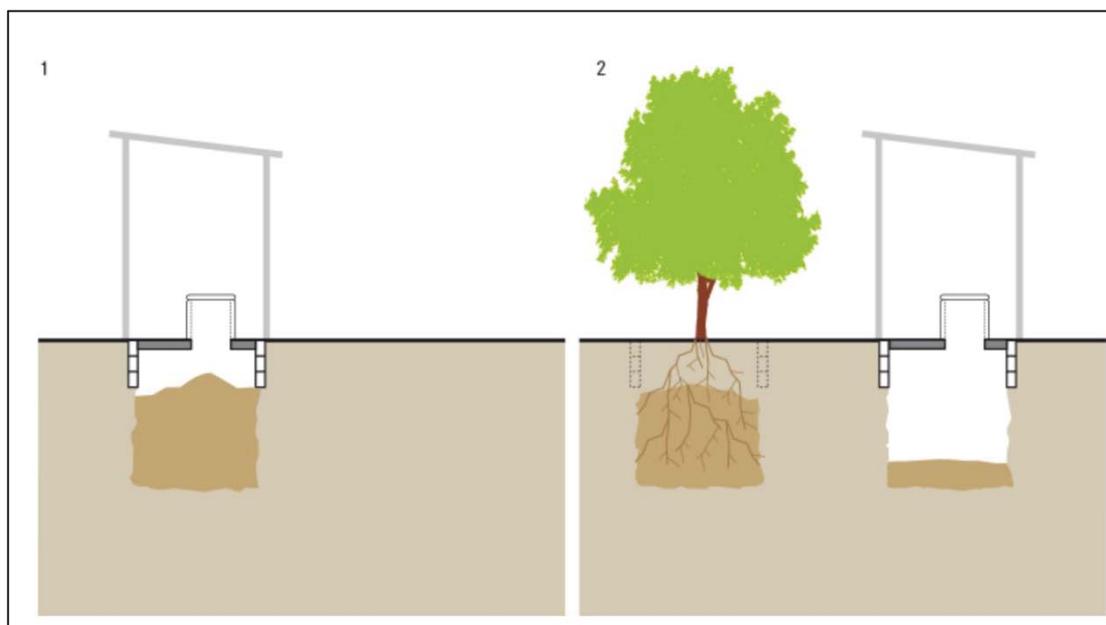


Figure 4-4: Illustrating a two-step of arborloo process (Soucre: Tilley et al., 2014)

4.2.4.1 Incinerating toilets

An incinerating toilet is a type of dry toilet that burns human waste at high temperatures, rather than using water like a conventional flush toilet. The process produces minimal waste, with only a small amount of ash, equivalent to about one teacup for four people over one week. Waste is incinerated in a sealed chamber, and combustion gases are vented through a separate pipe. These toilets offer a complete waste management solution as they eliminate the need for waste collection and transportation, though they are not widely available in South Africa. Globally, around 11 incineration toilets are available. Limited testing in South Africa showed

good process performance and a general good user acceptance (Khanyisa Projects, 2022). **Table 4.7** gives an overview of the benefits and constraints of incinerating toilets and **Figure 4.5** illustrates an image of an incinerating toilet.

Table 4.7: Benefits and constraints of incinerating toilets (US EPA, 1999; Today's Homeowner, 2024)

Benefits	Constraints
<ul style="list-style-type: none">• Conserve Water.• No Plumbing Required.• Portable.• Odourless.• Work in any climate.• Space-saving through ash production.• No waste handling, only an insignificant quantity of ash to be emptied.	<ul style="list-style-type: none">• Can be expensive (including energy costs).• Exhaust system may need adequate ventilation.• Nutrient loss.• Not entirely pollution-free – some models produce some air pollutants.• Some models cannot be used while they are doing the job of incinerating previous waste.



Figure 4-5: Illustrating a image of a incenerating toilet (Source: Cinderalla Incienration Toilet (n.d))

4.2.5 Portable Sanitation Systems

Mobile toilets and chemical toilets are both portable sanitation solutions, but they differ in their mechanisms of waste management and construction materials.

4.2.5.1 Mobile and chemical Toilets

Mobile toilets can be either flush or non-flush units and are often connected to a waste storage tank. Waste is collected in a holding tank, which may or may not use chemicals. Once the tank is full, it needs to be emptied and the waste transported to a proper disposal facility. The construction materials can vary, but mobile toilets are often made of durable, lightweight materials such as plastic or fiberglass. They are designed to be easily transported and set up in various locations. The waste in mobile toilets may be stored with or without the use of chemical additives, depending on the specific design. Some mobile toilets rely on simple storage without chemical treatments

Chemical toilets use chemical additives to break down and deodorise human waste. Chemical toilets typically have a built-in holding tank that contains a solution of chemicals to neutralise odours and aid in the decomposition of waste. Some chemical toilets also have a flushing mechanism. These toilets are specifically designed to house the chemical solution and may also be constructed from lightweight materials. The materials used in chemical toilets are chosen to be resistant to the corrosive effects of the chemicals used in waste treatment. Chemical toilets use specialised chemicals to control odours and break down waste. These chemicals often include biocides and deodorisers that aid in the decomposition of organic matter and help prevent the growth of harmful bacteria. **Table 4.6** illustrates the benefits and constraints of container based sanitation systems.

Table 4.8: Benefits and constraints of portable sanitation systems (Pioneer Plastics, 2022).

Benefits	Constraints
<ul style="list-style-type: none"> • Requires no piped water or sewer. • Compact and easy to move. • Suitable for sites where digging of latrines is not feasible or recommended. • Well suited to areas with high water table or where flooding occurs. 	<ul style="list-style-type: none"> • Collection is frequent. • Require cleaning after use.

Factors to consider before choosing portable sanitation systems are as follows:

- Typically consists of a seat on top and an easily sealable bucket beneath to contain urine and faeces. In some cases urine is diverted to a separate container.
- Adding a disinfectant may be required to reduce odour and kill pathogens.
- Workers handling the toilets need to be well trained and equipped with appropriate personal protection equipment.



Figure 4-6: Illustrating an image of a portable toilet (Source: Wiseman et al., 2024)

4.3 WATERBORNE ON-SITE SANITATION SYSTEMS

The waterborne on-site sanitation systems are the water-based systems that require regular supply of water to properly function properly. These systems include a pedestal, digestion capacity and soakaway component. These systems include: (i) pour flush toilets (Tilley et al., 2014), and (ii) low /cistern flush toilets with septic tanks and full/cistern flush toilets with septic tank.

4.3.1 Pour Flush Toilets

Pour flush toilets are a type of toilet where water does not come from the cistern above but is poured by the user. Any flush toilet where water supply is not continuous can become a pour flush toilet. Though the pour flush are convenient low cost toilets and involve easy operation and maintenance for good functioning, availability of water is required about 1- 4 litres (EAWAG, 2008; Tilley et al., 2014; Ramaraju and Shivendra, 2015). The pedestal and water-seal prevent users from seeing or smelling the excreta of previous users. Thus, it is generally well accepted. Pour-flush toilets can be connected to septic tanks. The pour-flush toilet pans are most commonly used in combination with a single- or twin pit pour flush latrine and therefore installed outside the house. The twin pits can be used to produce a partially digested, humus-like product, that can be used as a

soil conditioner (WHO, 2018). **Table 4.9** illustrates the benefits and constraints of a pour flush toilet and **Figure 4.7** illustrates a schematic diagram of a pour-flush toilet.

Table 4.9: Benefits and constraints of a Pour Flush Toilet ((Still and Louton, 2012; Ramaraju & Shivendra, 2015; Tilley et al., 2014; EAWAG, 2008; Mjoli, 2016)

Benefits	Constraints
<ul style="list-style-type: none"> • Low cost. • Control of flies and mosquitos. • Absence of smell. • Pan supported. • Can be flushed with greywater. • Pit(s) can be off-set from pedestal, eliminating the fear of small children falling in the pit. • No constant leakages due to lack of cistern for flushing. 	<ul style="list-style-type: none"> • Requires water for operation. • Detritus dumping into toilets can lead to blockages

Factors to consider before choosing a pour flush toilet are as follows (Tilley et al., 2014):

- The water seal at the bottom of the pour flush toilet or pan should have a slope of at least 25 degrees.
- Water seals should be made out of plastic or ceramic to prevent clogs and to make cleaning easier.
- The pour flush toilet is appropriate for those who sit or squat (pedestal or slab), as well as for those who cleanse with water, however, it requires an appropriate and a constant supply of water available.
- In a pour flush toilet a smaller amount of water is used, the pour flush toilet may clog more easily and, thus, requires more maintenance.
- Though it is a waterbased toilet, it requires regular cleaning to maintain hygiene and prevent the build-up of stains.
- To reduce water requirements for flushing and to prevent clogging, it is recommended that dry cleansing materials and products used for menstrual hygiene be collected separately and not flushed down the toilet.



Figure 4-7: Pour flush toilet (Source: Neetling et al., 2023)

South African Low- and Pour-Flush Case Study

In 2009, the Water Research Commission (WRC) launched a study to explore the feasibility of adapting pour flush technology for South African conditions. The goal was to develop a toilet that mirrored the appearance of a conventional flush toilet while being suitable for non-sewered environments where dry sanitation is common. A prototype, designed to use as little as one litre of water per flush (or two litres when newspaper is used), was developed and first deployed in the field in September 2010. Low- and pour-flush toilets are a sanitation solution that utilises minimal water to flush human waste into a leach pit, septic tank, or other containment system. The term ‘pour’ flush refers to manually pouring water into the toilet bowl to initiate flushing. Following successful initial installations, an additional 20 units were implemented in 2011 (Still and Louton, 2012).

A low-flush adaptation was later introduced and tested in schools near Durban, demonstrating positive user feedback with minimal instances of blockages (WIN-SA, 2014). This research and development effort disproved the assumption that low- or pour-flush technology could not be viable in Africa, proving its effectiveness. With support from commercial partners, the WRC research was used to develop commercial models, which were then later integrated with a low-flush cistern to further enhanced user convenience.

Compared to traditional latrines, these toilets offer several benefits:

- Enhanced safety: With the pedestal typically offset from the pit, users, especially parents, have noted improved safety, particularly for young children. A child seat is a standard feature in the commercial version.
- Improved hygiene: The toilet pedestal can be cleaned just like a conventional flush toilet, ensuring better sanitation.
- Reduced odours and insect attraction: A built-in water seal minimises odours and deters flies and other disease-carrying pests.
- Greater user comfort: By closely resembling urban flush toilets, low- and pour-flush systems provide a more familiar and comfortable experience.
- Easier Sludge Management: The innovative P-trap design limits the disposal of solid debris, resulting in sludge that is easier to empty and manage.

Additionally, low- and pour-flush toilets present advantages over fully sewerred flush toilets:

- Cost-effectiveness: These toilets are significantly more affordable to install and maintain than extensive sewerage networks, making them ideal for resource-limited settings.
- Suitability for rural areas: In sparsely populated regions where large-scale sewer systems are impractical, low- and pour-flush toilets provide a viable and scalable sanitation solution.
- Water conservation: Although these toilets require water for flushing, they use substantially less than traditional sewer-connected flush systems, making them a sustainable option in water-scarce areas.

Beyond pilot projects, the technology has gained traction through scientific advocacy by the WRC and commercial partners who have invested in its manufacturing, marketing, and deployment. As a result, the number of low- and pour-flush toilets in South Africa now exceeds 1,000, reflecting a growing acceptance and demand for this innovative sanitation solution (Neethling et al., 2023).

4.3.2 Full-Cistern Flush Toilets (9+ litres)

The full/ cistern-flush toilets provide a high level of convenience for the user, but they use large amounts of water. Installing this toilet system results in significantly increased water consumption by the users and the generation of large amounts of wastewater. These toilet systems can be connected to a septic tank and soak pits and these systems are the most used in off-site sanitation. **Table 4.10** illustrates the benefits and constraints of a full-cistern flush toilet and **Figure 4.8** illustrates an image of a full-cistern flush toilet.

Table 4.10: Benefits and constraints of a full-cistern flush toilet

Benefits	Constraints
<ul style="list-style-type: none"> • No real problems with odours if used correctly. • Suitable for all types of users (sitters, squatters, wipers and washers). • Easy to use and clean. • Higher user acceptance 	<ul style="list-style-type: none"> • High capital costs; operating costs depend on the price of water. • Requires a constant source of water.

Factors to consider before choosing a low-cistern flush toilet are as follows:

- Modern toilets use 6 to 9 L per flush.
- It is a safe and comfortable toilet to use, provided it is kept clean.
- Although flushwater continuously rinses the bowl, the toilet should be scrubbed clean regularly to maintain hygiene and prevent the buildup of stains.
- The cistern flush toilet must be connected to both a constant source of water for flushing and collection and storage/treatment or conveyance technology to receive the blackwater.



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Figure 4-8: Full-cistern flush toilets

4.3.3 Septic Tanks

A septic tank is a watertight chamber made of brickwork, concrete, fibreglass, PVC or plastic. Septic Tanks are connected to an infiltration system, e.g soakway and will require emptying less frequently (can vary to once every six months) and these systems can be connected to a pour-flush and/or conventional flush toilet. When a septic tank does not have an overflow to a soakway, it is considered a conservancy tank and requires

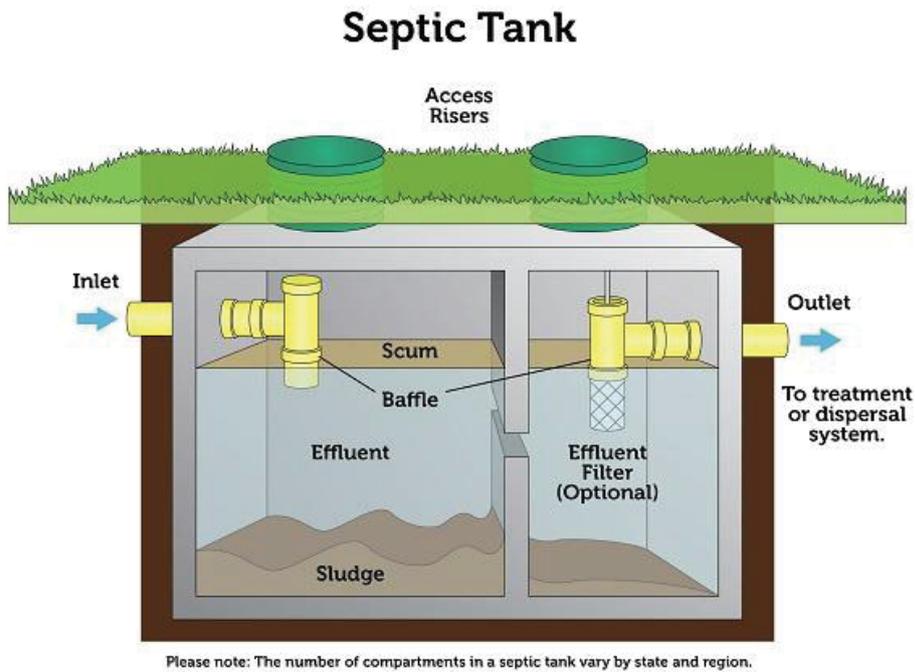
more frequent emptying. Septic tank pumping is often done once a year, this is to remove solids that build up in the system (WHO, 1992; Pradhan et al., 2011; Tilley et al., 2014). **Table 4.11** illustrates the benefits and constraints of a septic tank and **Figure 4.9** illustrates a schematic diagram of a septic tank.

Table 4.11: Benefits and constraints of a septic tank (WHO, 1992; Pradhan et al., 2011; Tilley et al., 2014).

Benefits	Constraints
<ul style="list-style-type: none"> • Can be built and repaired with locally available materials. • No real problems with flies or odours if used correctly. • Simple and robust technology. • Little space required due to underground construction. • Low operating costs and long service life. • Small land area required. • Pit(s) can be offset from the pedestal, eliminating the fear of small children falling into the pit. 	<ul style="list-style-type: none"> • Higher cost compared to dry or composting toilet systems. • Low reduction in pathogens, solids and organics. • Regular desludging must be ensured and a small amount of digesting sludge should be kept at the bottom. • Reliable and ample piped water is required, only suitable for low-density housing. • Incorporation of a cistern for flushing introduces potential for constant leakages in the system.

Factors to consider before choosing a septic tank are as follows (Tilley et al., 2014):

- A septic tank should have at least two chambers.
- A septic tank is appropriate where there is a way of dispersing or transporting the effluent.
- A vacuum truck should be able to access the location as septic tanks need to be deslugged regularly.
- Scum and sludge levels need to be monitored to ensure that the tank is functioning well.
- If the tanks have a high solids loading, then the retention time of the tank will not be sufficient to reduce pathogens to an acceptable level.



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Figure 4-9: Septic tank with 2 compartments

4.4 SELECTING ON-SITE SANITATION FACILITIES

Selecting appropriate on-site sanitation facilities is a critical decision that involves considering various factors to ensure effectiveness, sustainability, and user satisfaction. This process involves evaluating the cost, odor control, flies nuisance, water consumption, pathogen reduction, groundwater contamination risk, ease of emptying and Operation and Maintenance (O&M). Each of these factors plays a pivotal role in determining the suitability and long-term viability of a sanitation solution for a given setting. The assessment of these aspects allows for the identification of sanitation facilities that not only meet basic needs but also contribute to environmental sustainability and public health. **Table 4.12** provides a selection criterion for different on-site sanitation facilities.

Table 4.12: Summary of selection criteria for the on-site sanitation facilities (Strauss & Montangero, 2002; WHO, 2006; Tilley et al., 2014; Mara, 2018)

On-site Sanitation Systems	Cost	Odour	Flies nuisance	Water	Pathogen reduction	Groundwater contamination risk	Ease of emptying	Frequency of emptying	Potential for direct reuse	O&M
UDDT	Medium	Medium	Low	None required	High	Low	Easy	Low	High	Medium
Composting	High	Low	Low	None required	High	Low	Easy	Medium	High	High
Incinerating toilets	High	Low	Low	None required	High	Low	Easy	Medium	High	High
Bucket latrine	Low	High	High	None required	Low	Low	Easy	High	Low	Low
Simple latrine	Low	High	High	None required	Low	Medium	Medium	Medium	Low	Low
VIP	Low	Medium	Low	None required	Low	Medium	Medium	Medium	Low	Low
D-VIP	Low	Medium	Low	None required	Low	Medium	Medium	Low	Low	Low
Arborloo	Low	Medium	Medium	None required	High	High	None required	None required	High	None required
Pour flush toilets with leach pit	Low	Medium	Low	Low	Medium	Medium	Easy	Low	Low	Low
Low flush toilets with septic tanks	High	Low	Low	Low	High	Medium	Easy	Low	Medium	Low
Flush toilets connected to septic tank	High	Low	Low	High	Medium	Medium	Easy	Low	Medium	Low

Selecting a suitable on-site sanitation facility requires a comprehensive evaluation of key factors to ensure it meets both immediate and long-term needs. Cost is a critical consideration, not only in terms of initial investment but also ongoing expenses for operation, maintenance, and repairs. Affordability influences community acceptance, making it essential to balance cost-effectiveness with functionality. Equally important is odour control and the prevention of fly infestations, as these factors directly impact user satisfaction, hygiene, and overall public health. Effective sanitation solutions should incorporate measures to minimize unpleasant odours and deter disease-carrying vectors, creating a more sanitary and user-friendly environment.

Additionally, the environmental impact of the chosen facility must be carefully assessed. In water-scarce regions, minimising water consumption is essential, while preventing groundwater contamination is crucial for protecting public health. This necessitates sanitation systems that incorporate effective pathogen reduction methods. Ease of emptying and the efficiency of O&M are also vital to ensuring long-term functionality and sustainability. A well-designed, easily maintainable system reduces the burden on communities and authorities while extending the facility's lifespan. In summary, selecting an on-site sanitation facility requires a holistic

approach that considers cost, hygiene, environmental impact, and operational efficiency to provide a sustainable and effective solution for communities.

4.5 NEW SANITATION – WATER RECYCLING

The WRC is the home of the South African Sanitation Technology Evaluation Programme (SASTEP) which manages a national strategic programme with multiple stakeholders to pilot and demonstrate local and international innovative sanitation technologies. The SASTEP platform brings together key components, systems, stakeholders, and resources necessary to cultivate a growing sanitation industry in South Africa. By forging strategic partnerships with policymakers and relevant stakeholders, SASTEP aims to strengthen existing policies and regulatory frameworks, facilitating the adoption of innovative sanitation solutions by addressing barriers to implementation.

Some of the technologies that are part of the SASTEP initiative comprise of full recycle systems from containment to reuse. These technologies have been shown to be water-saving, limit sludge production and fill the gap where piped infrastructure is difficult to implement. The full recycling systems have shown promise, with a number of systems implemented through the Presidency SAFE (Sanitation Appropriate for Education) programme (van Vuuren, 2021).

4.6 SUMMARY

In the earlier phases of sanitation implementation to unserved communities, dry sanitation systems were predominantly used in rural and informal settlements due to limited access to water and centralised sewerage systems. These systems, including latrines and their variants, were initially adopted as a low-cost, water-efficient option to address basic sanitation needs. Dry sanitation technologies also provided a way to safely manage waste in areas with limited infrastructure. The simplicity of dry systems made them widely accessible, although they posed challenges in terms of user acceptance, maintenance, odour control, and hygiene, especially in high-density areas.

Aspiration for flush-type toilets drove innovation to develop and fast-track on-site flushing pedestals. These toilets use a small amount of water to flush waste into a pit or septic tank, which is ideal in areas with water access but lacking a full sewerage system.

With increasing concerns about water scarcity and the environmental impact of conventional flush toilets, South Africa has started exploring more innovative flush and recycle systems. These systems aim to reduce water usage through water recycling and less sludge production. Advances in this domain have paved the way for a more sustainable urban water and sanitation model. By reclaiming water for non-potable uses, these systems can reduce the strain on municipal water resources while also promoting sustainability in water management.

Choosing the right toilet system is crucial in South Africa, where water scarcity, uneven access to sanitation, and varying economic conditions make diverse and sustainable sanitation solutions essential. Each type of toilet system, dry sanitation, like VIPs and UDDTs, and flushing systems, like pour-flush systems and septic tanks, offers distinct advantages and limitations, depending on the local context.

In the next chapter, we look at ways in which to collect faecal sludge.

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CHAPTER 5: GUIDELINES FOR FAECAL SLUDGE COLLECTION

5.1 INTRODUCTION

The emptying (collection) and transportation (i.e conveyance) of faecal sludge (FS) refers to the transfer of FS from a sanitation system to off-site treatment and/or to an end-use/disposal (WHO, 2018). The collection of FS is essential to improve sanitary conditions in people's residences and in common public areas, such as schools, community parks / sport ground, churches, etc. Collection facilities contain human excreta that is awaiting transportation (ISO, 2016). Safe FS emptying and transportation is an essential part of safely managed sanitation (Tsinda, 2020). It is important that emptying of on-site sanitation facilities is considered before the construction of the sanitation facility. For the purpose of easy access, the on-site sanitation facility must be constructed close to a household plot boundary (Boot, 2007; Scott et al., 2017). In the case of a pit latrine and / or a septic tank, the sanitation facility must be built downwind of the property to avoid unpleasant odours and / or flies coming to the household. Adequate access to the sanitation facility must be provided to ensure that the workers / hoses do not pass through the household (Boot, 2007; Scott et al., 2017). Since manual emptying is a common practice in South Africa, often involving gardening tools such as spades and forks, shallower pits may be recommended to facilitate easier FS removal. This recommendation is based on insights from various sources (SuSanA, 2010; Harrison and Wilson, 2012; Roma et al., 2017).

It is important that the pit emptying information is recorded, i.e the number of pits emptied, the type of toilet, the duration of emptying, geographical location, and the last time of emptying e.g FSM planning tool kit. **Table 5.1** illustrates the available pit emptying technologies, for more detailed information on the available and currently being used pit emptying technologies world-wide, see **APPENDIX A for the link: A Practical guide to available pit emptying technologies** (Gurski et al., 2022).

Table 5.1: Available pit emptying technologies (adapted from Gurski et al., 2022)

Pit emptying technologies	Sludge type			Significant Trash	Costs		Type of On-site sanitation facility
	Thin	Medium	Thick		Purchase budget	Operating budget	
Vacuum truck	Fast	Slow	No	Medium	High	High	Septic Tanks & some pit latrine
ROM	Fast	Slow	No	Medium	High	Medium	Septic tanks & cesspits (modest debris)
PitVaq	Fast	Fast	No	Medium	Medium	Medium	Pit Latrines
Minivac	Fast	Fast	No	Medium	Medium	Medium	Septic tanks & pit latrines (small debris)
PuPu Pump	Fast	Slow	No	Medium	Medium	Medium	Pit Latrines
Supavac SV60; Soilidvac SV70	Fast	Fast	No	Medium	High	High	Septic Tanks and some pit latrines
Grinder	Fast	Slow	No	Medium	Medium	Low	Septic tanks
Mobile Honey Wagon	Fast	Slow	No	Low	Medium	Medium	Septic tanks (with light debris)
Trailer/pick up pump system	Fast	Slow	No	Low	Medium	Medium	Septic tanks and cesspits
Trash pump	Fast	Slow	No	Medium	Medium	Low	Septic tanks (with small debris)
Progressive Cavity pump to truck	Fast	Slow	No	Low	Medium	Medium	Septic tank & pit latrines (with thin-medium sludge)
Flexible impeller pump to containers	Fast	Medium	No	Low	Medium	Medium	Septic tank & pit latrines (thinner sludges)
Gulper	Fast	Slow	No	Low	Low	Low	Pits (less than 1.5 m deep)
Standard Manual Methods	Fast	Fast	Slow	High	Low	Low	Pits (inaccessible; low income areas)
Sludge digger to containers	No	Fast	Slow	Medium	Low	Low	Extremely thick /trash laden pits

5.1.1 Types of emptying

The styles / systems of collection of FS include:

- (i) Manual emptying;
- (ii) Manually operated mechanical emptying; and
- (iii) Fully mechanised emptying.

(i) Manual emptying

Manual emptying of FS is common in low-income communities, mostly in areas with semi-solid or solid FS. Manual emptying is done using purpose-built hand tools, including buckets, long-handled rakes, spades and corers used to dig and pull out FS. The workers do not necessarily enter the containment structure themselves. This method is effective in dealing with thick, difficult-to-pump FS and FS containing solid waste. However,

it is found to be slow when compared to mechanised collection methods. Manual emptying is a versatile option that can be applied in many different situations and is mostly considered in areas where access to the site is difficult. It is also effective where FS contains large amounts of trash, as there is no risk of blockages or mechanical failure due to trash. The operation and maintenance required in manual emptying are cleaning of tools and equipment after use, and protection from corrosion. Tools and equipment can be manufactured and repaired locally. **Table 5.2** illustrates the benefits and challenges of manual emptying FS. **Figure 5.1** shows images of manual emptying taken in the rural areas of eThekweni Metropolitan Municipality.

Table 5.2: Benefits and challenges with manual emptying of FS (Mbéguééré et al., 2010; Harrison and Wilson, 2012; Still and O’Riordan., 2012)

Benefits of Manual emptying	Challenges of manual emptying
<ul style="list-style-type: none"> • Use of simple tools and manual work is very sustainable. • Low cost. • Can effectively deal with solid waste in FS without it causing delays. • Provides a source of income for local people and ability to remove thick FS. 	<ul style="list-style-type: none"> • It is slow. • It is socially unacceptable in some contexts. • Is a potentially serious health risks to workers and community; safe protocol is required.



Figure 5-1: Images of manual emptying (WASH R&D Centre)

(ii) Manually-operated mechanical emptying

Innovative human-powered mechanical devices are improving the speed, safety, and efficiency of servicing on-site sanitation systems. Among these manually operated devices are (i) the Gulper and (ii) the diaphragm pump (Mikhael et al., 2014). The Gulper is commonly used for faecal sludge (FS) emptying, particularly for liquid FS, and is ideal for areas with restricted access, such as narrow roads and densely populated settlements. Its key advantages include (i) low capital cost, (ii) easy transportation, and (iii) simple fabrication with locally available repair solutions (Mikhael et al., 2014).

The diaphragm pump operates through an alternating push-and-pull mechanism, similar to a rubber plunger used for unblocking sinks or toilets. A strainer prevents solid waste from entering the pump, which is typically mounted on a board for stability while the operator stands on it. This pump is valued for its simple design with few moving parts and its effectiveness in rapidly pumping low-viscosity FS (Mikhael et al., 2014).

The pit screw auger, another FS emptying device, lifts waste through a pedestal into a container. However, waste must be manually assisted to fall from the auger at the outlet. This device is particularly suited for handling more solid waste. While relatively simple to use and understand, the pit screw auger has a fixed length, is heavy, and can be difficult to clean (Still and O’Riordan, 2012). **Figure 5.2** illustrates manually-operated mechanical emptying devices.

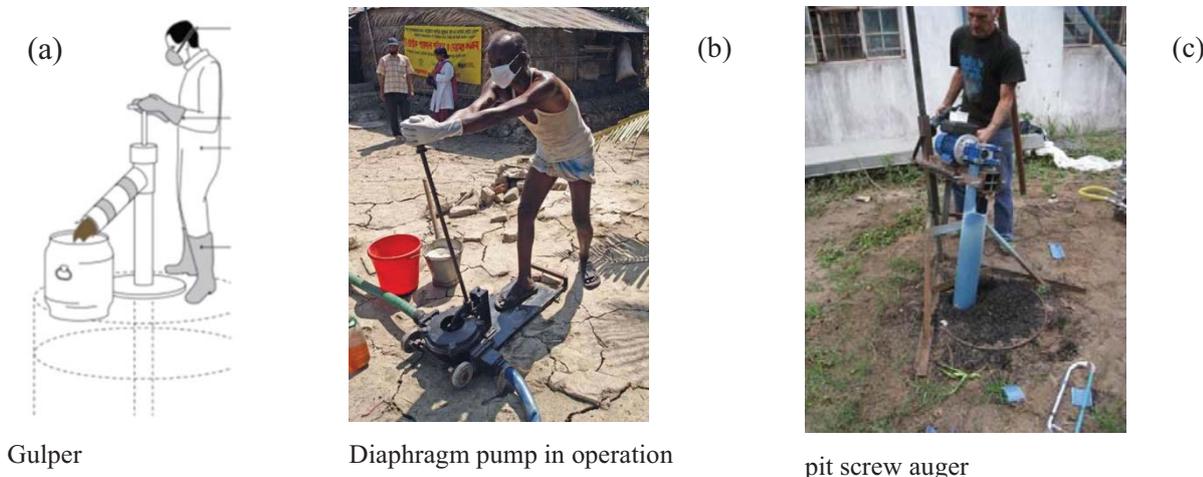


Figure 5-2: Manually-operated mechanical emptying devices

(Source (a) Tilley et al., 2014; (b) Mikhael et al., 2014; (c) Still et al., 2018)

(iii) Fully mechanised emptying

The mechanised emptying devices can be subdivided into two categories: (i) fully mechanised (e.g. vacuum pump trucks, ‘return on manpower’ (ROM)) – these devices provide a fully mechanised option, however, they cannot be used in areas that are difficult to access; and (ii) hybrid human-powered – these devices provide a mechanised option, however, they allow the pit emptying workers to get close to the pit with the small unit, and some elements are manual (e.g. filling and carrying drums to a transporting vehicle or operating valves on the machine itself). Examples include trash pump, pitvaq, etc.

The vacuum pump trucks (‘honeysuckers’) are suitable for removing low-viscosity sludge, as thicker FS can be removed using special suction techniques. The vacuum pump truck is ideal for transporting large quantities of sludge over long distances. Challenges with vacuum pump trucks include difficulty to maintain in low-income contexts due to specialised parts, high cost, difficulty accessing densely-populated or steep areas, and some tankers are not suitable with thick FS (Mikhael et al., 2014).

The motorised diaphragm pump operates with the same principle as a manual diaphragm pump but is driven by electric/ hydraulic motors/ petrol or diesel engines. It is suitable for liquid sludge containing solid particles ranging from 40 to 60 mm. The benefits of a mechanised diaphragm pump are that it is simple to use, low cost and it is easily transportable. The challenge is clogging easily when pumping FS with a high solid waste content (O’Riordan 2009; Mikhael et al., 2014).

ROM follows the same operating principle as the vacuum pump truck, however, in a miniature version. A 600 to 2,000 litre vacuum tank is mounted to a trailer with a vacuum pump, which is operated by a powered petrol (gasoline) engine. This emptying device can cope with soft and hard debris that flows easily through the suction hose; it can be used in septic tanks and cesspits containing modest debris. The vacuum pump inlet must be protected. This device cannot directly suck up over large elevations and long distances, and it is hard to reach areas that are inaccessible by a vacuum truck.

The Pitvaq, a locally developed innovation from Partners in Development (PID) and the WRC, is currently manufactured in South Africa. Previously known as the eVac, it operates using a vacuum pump powered by either a petrol engine or an electric motor, designed for sludge removal from pits and septic tanks. Its compact, modular design allows small crews to move it manually and access difficult-to-reach areas with ease.

The Pitvaq functions similarly to a vacuum tanker, using suction to extract sludge through a hose and into its tank, ensuring that no sludge passes through the pump, which reduces the risk of blockages and mechanical failure. A ball float valve in the tank and a moisture trap near the pump further prevent sludge from entering moving parts, enhancing durability. When used correctly, the Pitvaq provides a faster and more hygienic alternative to manual emptying.



Vacuum pump truck



ROM



Pitvaq

Figure 5-3 mechanical emptying devices (Source: Gurski et al ., 2022 (left and middle); Pitvaq (n.d) (right)).

5.1.2 Types of Transport

Transportation in FSM content involves the use of technologies that transport FS from the user’s home to temporary disposal, treatment or discharge sites. The objective of transporting FS is to ensure the health and hygiene of the neighbourhood. Transportation is categorised into two groups:

- (i) Manual transportation
- (ii) Motorised transportation mechanism

(i) Manual transportation

Manual transportation is suitable for transporting FS over short distances to a point accessible by a vehicle for bulk transport. The FS is transported in bins or sealed drums on standard or purpose-built hand trollies and carts (Mikhael et al., 2014). They can allow containers of up to 200 litres to be moved over short distances with relative ease. The main advantages of manual transporting are that (i) it is affordable; (ii) simple to manufacture and fix locally and (iii) permits FS to be moved from areas where access and space are restricted. The challenges are that it has moderate vehicle speed (Mikhael et al., 2014). **Table 5.3** provides details on manual transportation devices.

Table 5.3: FS transport devices

Shlifter Barrel Lifting Device	Hand cart	The Grapppler
<ul style="list-style-type: none"> The Shlifter lifts barrels containing 250 litres of sludge using a counterweight force to lift a given load of approximately 250 kg. The Shlifter is operated by 2 or 3 people to create necessary amount of force. While the Shlifter has a collapsible design and can be set up in 5 minutes, it is also heavy and bulky. 	<ul style="list-style-type: none"> The hand cart is a barrel transporting device for 150-litre barrels and 220-litre barrels. The cart uses the scissor method for lifting. A clamp attaches to the lip of the barrel, with supporting clamps on each side of the barrel, inside of two frames fixed together by a pivot. The hand cart usually requires 2 operators to move 250 kg load. 	<ul style="list-style-type: none"> The Grapppler is a small device developed to carry 50-litre drums, which consists of a main shaft with two bushes fixed to it. The bushes have a hole through them with a screw going through onto the main shaft. Bushes have a grip welded to the bottom to fit into the handles of the barrel



a) Shlifter (Source: Water for People, 2019) b) The Hand Cart (Source: Water for People, 2019) c) The Grapppler (Source: Pitvaq, 2021)

(ii) Motorised transportation

The motorised transportation of FS includes transportation by small to medium motor vehicles, including motor tricycles and pick-up trucks. The FS can be transported in individual sealed containers or in a single large tank mounted on the load bed of the vehicle. This transportation mechanism is suitable for transporting FS over a long distance (Mikhael et al., 2014). The motorised tricycles can transport up to approximately 1,000 litres of FS and the pick-up trucks can transport between 2,000 and 5,000 litres of FS. The strengths of motorised transportation mechanisms are (i) they are locally available and are multi-purpose rather than being dedicated to transporting FS and (ii) they allow transportation of FS in larger volumes and over long distances at higher speeds than manual transport (Mikhael et al., 2014).

5.2 EMPTYING TECHNOLOGIES MATRIX

Table 5.4 illustrates tips of pit emptying and device selection criteria that can be considered and **Table 5.5** illustrates types of transportation and device selection criteria that can be considered.

Table 5.4: Tips of pit emptying and device selection criteria to be considered

Emptying styles and devices	Pathogen risk	Cost	Trash handling	Emptying rate		Cleaning
				Thick /dense FS	liquid/slurry FS	
Manual	High	Low	High	High	None required	Medium
Mechanical						
Vacuum tanker	Low	High	Low	Low	High	Low
Pit Auger	Medium	Medium	High	High	High	Difficult
Gulper	Low	Medium	High	Low	High	Medium
Pitvaq	Low	Medium	Medium	Medium	High	Medium
Nibbler	Low	Medium	Medium	Medium	None required	Easy
Rammer	Low	Medium	Medium	Medium	High	Easy
Gobbler	Medium	Medium	Medium	Medium	High	Difficult
Nano-Vac	Low	High	Low	None required	High	Easy
Boot and Scoot (2009); Thye et al., (2011); Strande et al., (2014); Mikhael et al., (2014) ; Radford and Sugdens (2014); WHO (2018); Still and O’Riordan (2012).						

***Table Colour Guide**

Green	Beneficial	Red	Detrimental
Orange	Moderate	None required	

Table 5.5: Types of transportation and device selection criteria to be considered

Transport styles and devices	Pathogen risk	Cost	Transport Rate	Cleaning
Manual transport	High	Low	Low	Medium
Mechanical transport	Low	High	High	Easy
Shift barrel lifting device	Low	Low	Medium	Easy
Hand Cart	Low	Low	Medium	Easy
Grappler	Low	Low	Medium	Easy

Boot & Scoot, 2009; Dodane et al., 2012; Radford & Sugdens, 2014; Tilley et al., 2014; Kone 2010; WHO, 2018; TNUSSP, 2018.

***Table Colour Guide**

Green	Beneficial	Red	Detrimental
Orange	Moderate	None required	

5.3 EMPTYING METHODS FOR DIFFERENT FS TYPES

On-site sanitation facilities, such as pit latrines, septic tanks and mobile toilets, require regular emptying to prevent overflowing and minimise the risk of contamination. The choice of emptying method depends on several factors, including the type and size of the sanitation facility, the volume of waste to be removed, the accessibility of the site, and the availability of resources. Proper emptying of on-site sanitation facilities is critical to maintaining public health and preventing environmental contamination. **Figure 5.4** illustrates emptying methods applicable to different FS types.

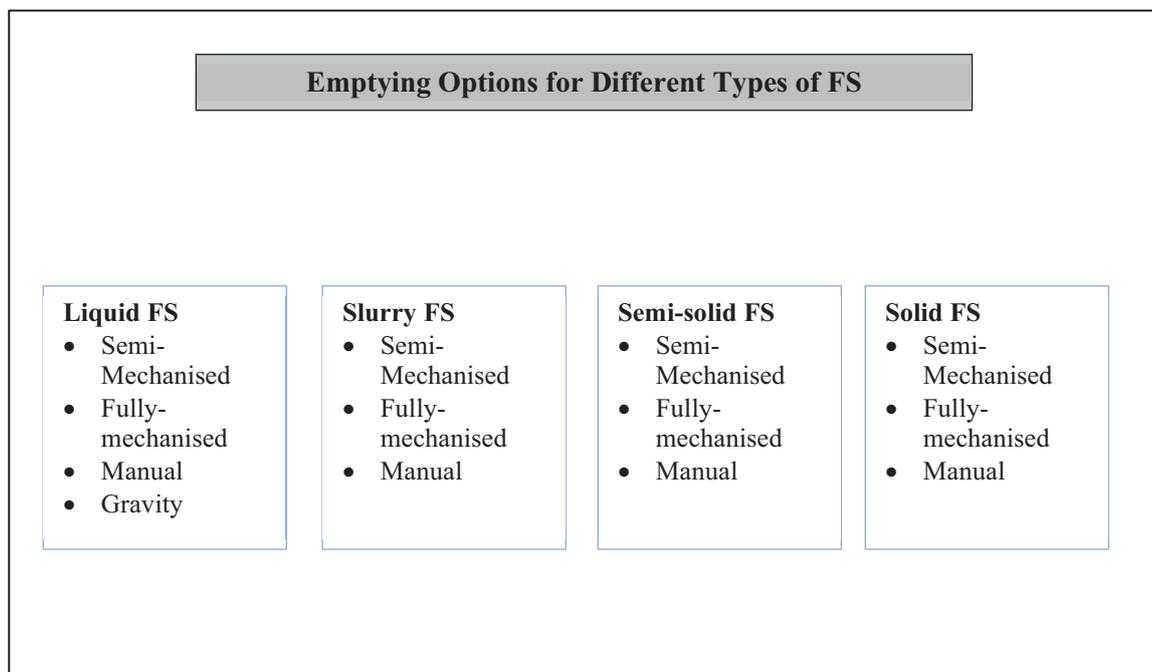


Figure 5-4: summary of emptying options for different FS types

5.3.1 Emptying Methods for Liquid Faecal Sludge

The consistency of FS is influenced by factors such as the amount of solid waste disposed of in sanitation facilities, the addition of water, water infiltration or exfiltration, and the degree of compaction or solidification (Manga et al., 2016; Simwambi et al., 2017; Semiyaga et al., 2022). According to Muoghalu et al. (2023), FS from lined pit latrines and septic tanks tends to be less ‘dense’ or ‘thick’ than that from unlined pit latrines, as it is assumed that exfiltration occurs in unlined pits. There are several methods for emptying liquid FS, each with its advantages and limitations

- **Semi-mechanised:** A semi-mechanised device is used to remove the sludge from the latrine or septic tank and transfer it to a container. Mikhael and co-workers (2014), in their review, highlighted some of these human-powered technologies: Gulper, Nibbler, etc. This method is more efficient than using a bucket and reduces the risk of health and safety hazards to the workers. However, it still requires manual labour, can be prone to blockages and can be challenging to use in areas with limited accessibility.
- **Fully-mechanised:** Full-mechanised technologies can be used to remove the sludge from the latrine or septic tanks (Mikhael et al., 2014). Operators are needed to run the pump and handle the hose, but the sludge is not physically lifted or carried by hand (Stauffer and Spuhler, 2000). This method is generally efficient and can handle large volumes of liquid sludge quickly. However, it can result in a substantial upfront investment in equipment, struggles to pump thicker FS, blockages from debris and detritus can occur, and it may be impractical in areas with restricted access (Stauffer and Spuhler, 2000).
- **Manual:** For liquid sludge, buckets could be used, though this type of activity is laborious and poses significant health risks.
- **Gravity flow:** Gravity flow involves allowing the liquid sludge to flow out of the latrine or septic tank and into a collection pit or container through a sloped pipe or channel. This method is simple and low-cost, but requires a slope gradient, which may not be possible in all areas. In South Africa, this type of context is not common unless it is from a toilet that is connected to a direct containment unit, such as a chemical toilet or, as Mikhael and co-workers indicated, from cartridge containment devices (Mikhael et al., 2014). Most on-site sanitation systems in South Africa tend to be waterless latrine variants, which produce thicker sludge (Septien et al., 2018), and thus, gravity flow situations are not common.

5.3.2 Emptying Methods for a Slurry Faecal Sludge

- **Semi-mechanised:** Slurry FS can be removed in a similar manner to liquid FS. A number of human-powered tools are available, each having its own strengths and weaknesses and suitable application (Mikhael et al., 2014; Still et al., 2018). This method is more efficient than bucket emptying and reduces the risk of health and safety hazards to the workers.
- **Fully-mechanised:** Similar to the method for liquid FS, motorised suction involves using a pump or vacuum to remove the sludge from the latrine or septic tank and transport it to a disposal site (Mikhael

et al., 2014). This method is highly efficient and can handle larger volumes of slurry FS quickly. However, it requires a significant initial investment in equipment, cannot pump thick FS, detritus may block the hose, and may not be suitable for areas with limited accessibility (Stauffer and Spuhler, 2000).

- **Manual desludging:** Manual desludging can be done with a bucket, but it is not recommended. A shovel may be used, provided the FS is thick enough (EWS, 2012). Semi-mechanised human-powered tools could also be used (Mikhael et al., 2014), but it depends on the nature of the sludge and the type of tool used (Still et al., 2018). This method is labour-intensive but can be effective for slurry FS that is too thick for manual suction, vacuum pumps or gravity flow methods.

5.3.3 Emptying Methods for a Semi-Solid Faecal Sludge

- **Manual desludging:** Similar to the method for slurry FS, manual desludging involves breaking up the FS and removing it with a shovel or other gardening tools (EWS, 2012). This method is labour-intensive but can be effective for semi-solid FS that is too thick for other methods (Harrison and Wilson, 2012).
- **Semi-mechanised:** This method is more efficient than manual desludging but requires specialised equipment and may not be suitable for all types of semi-solid FS. Partners in Development (PID) have undertaken a comprehensive review of some of the technologies that can be used in the South African context, specifically for VIP latrines (Still and O’Riordan, 2012; Still et al., 2018).
- **Fully-mechanised:** Only selected options may work without adding in water. Accessibility, blockage and expense of equipment are some constraints of this method. A review of applications that have been tested in South Africa is available (Still and O’Riordan, 2012; Still et al., 2018).

5.3.4 Emptying Methods for a Solid Faecal Sludge

There are several methods for emptying solid FS, each with its advantages and limitations (EWS, 2012; Still et al., 2018):

- **Manual desludging:** This option has been shown to be practical within South Africa in the context of VIP latrines (EWS, 2012; Harrison and Wilson, 2012; Still et al., 2018). This method is labour-intensive and can pose health and safety risks to the workers. Protocols for occupational Health and Safety are necessary (EWS, 2012). A number of workers working in teams may have to be used for emptying larger community-size volumes in what is referred to as ‘sweeping’ operations (EWS, 2012; Harrison and Wilson, 2012).
- **Semi-mechanised:** The solid-like nature may limit a number of human-powered devices.
- **Fully mechanised:** As with semi-mechanised, solid-like FS may not be conducive to vacuum or suction devices. Including water in the pit may assist with emptying operations, but this introduces another set of challenges (EWS, 2012; Harrison and Wilson, 2012).

5.4 HEALTH & SAFETY ASPECT

5.4.1 Risks Faced by Sanitation Workers

With FS being a harmful material, studies also indicate increased risks of various infections for workers exposed to sludge containing organisms that cause disease (Louton et al., 2018). All workers (involved in pit emptying) could be potentially infected with helminths, with all pits assumed to contain helminth eggs (Bonthuys, 2017). Louton et al. (2018) reported that the pit latrine sludge has proven to retain viable helminth eggs even after spending years outside of a host in the pit environment. Large quantities of *A. lumbricoides*, *T. trichiura*, and *Taenia spp.* were isolated from the face masks of pit latrine emptying employees in previous WRC-funded research (Buckley et al., 2008). Again, the risks have also been found to the workers responsible for washing buckets, who are therefore categorised as high risk for biological exposure due to their gloves and hands being heavily contaminated. It is therefore necessary for the government and sanitation practitioners to make every effort to minimise the risks workers face from contact with faecal matter. The International Labour Organisation (2012) has identified the following potential health risks which sanitation workers face that apply to pit emptiers:

- Accidents resulting in exposure to chemicals present in sludge.
- Ergonomic factors such as musculoskeletal injuries caused by over-exertion working postures (e.g. frequent bending).
- Discomfort and psychological problems related to prolonged wearing of heavy or impermeable protective clothing, feeling of working with filthy materials, feeling that the occupation is not respectable or apprehension caused by awareness of the dangers of the workplace.

Pit Emptying Health & Safety Module 1: Health threat in Shit, developed by PID, can be accessed at:

<https://www.youtube.com/watch?v=-pt81Kdi0mY&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=1>

5.4.2 Ensuring Health & Safety in Emptying

- All workers, including pit emptiers, must receive a medical examination prior to engagement, which includes the following: (i) occupational medical questionnaire; (ii) occupational medical examination; (iii) notification of result of medical examination; and (iv) exit medical examination (EWS, 2012; PID, 2016, Louton et al., 2018).
- A record of all medical exams, immunisations and treatments must be kept for each employee.
- The medical examination should include tetanus, typhoid and hepatitis A and B immunisation. Each worker should be provided with a single dose of Mebendazole deworming treatment before commencing work and after every six months of employment.
- It is recommended that the Health and Safety Officer of a service provider conducting pit emptying services communicates with the Department of Health on a regular basis regarding immunisations that should be provided.

Guidelines for Faecal Sludge Collection, Disposal and Valorisation

- Protocols to be followed by workers who experience an accident, or a work-related illness, are to be provided to workers in writing (eg, posted on the wall at the welfare facility).
- Each worker who is employed for over three months should complete an exit medical when his or her employment is terminated.
- Prospective workers found during screening to have the additional conditions should be evaluated by an occupational health professional before commencing work with sludge (Water UK, 2006):
 - Pregnant or breastfeeding;
 - Conditions which might present a risk of collapse in hazardous conditions (e.g epilepsy, diabetes);
 - Skin disorder that cannot be protected adequately with a waterproof dressing.

Health Check Forms

The eThekweni municipality has Health Check forms which are basically copies of occupational medical questionnaire, occupational medical examination and exit medical examination from eThekweni municipality (EWS, 2012). These forms can be replicated for use by other municipalities (see below).

ANNEXURE 13
OCCUPATIONAL MEDICAL QUESTIONNAIRE

NAME:	COMPANY: GRP/SLB JOINT VENTURE	JOB DESCRIPTION:
ID NO:	CO NO:	

PERSONAL HISTORY

Do you smoke? Yes No | Stopped | Number per day: _____

Do you use alcohol? Yes No | Quantity per week: _____

Do you exercise? Yes No | Specify: _____

FAMILY HISTORY

Have any of your relatives suffered from hypertension, high cholesterol, heart disease, epilepsy, diabetes, blindness, porphyria, cancer or any other hereditary disease? YES NO | Specify: _____

OCCUPATIONAL HISTORY

Company	Period	Job Description

PLEASE INDICATE IF YOU ARE CURRENTLY, OR HAVE PREVIOUSLY BEEN, EXPOSED TO ANY OF THE FOLLOWING HAZARDS

NOISE | FIBROUS | DUST | HAZARDOUS CHEMICALS | SOLVENTS | HEAVY METALS

Have you ever been found medically unfit to perform any duties? Yes No | Specify: _____

Have you ever had treatment for any occupational disorder? Yes No | Specify: _____

MEDICAL HISTORY

Have you suffered or are you suffering from any of the following?

1. Heart disease, high blood pressure, chest pain or blood clots	Yes No
2. Asthma, tuberculosis, chronic bronchitis or shortness of breath	Yes No
3. Hay fever, sinusitis or allergies	Yes No
4. Headium, peptic ulcer, vomiting of blood, blood in the stool or jaundice	Yes No
5. Gout, arthritis, back problems, conditions affecting joints, loss of a limb or loss of function of a limb	Yes No
6. Epilepsy, blackouts, dizziness or head injury	Yes No
7. Depression, anxiety, schizophrenia, alcohol dependency, drug dependency or any mental disorder	Yes No
8. Loss of hearing or vision	Yes No
9. Diabetes, thyroid problems or glandular disorders	Yes No
10. Disorders of kidneys, bladder or genital system	Yes No
11. Sores, lesions or rashes of the skin	Yes No
12. Cancer or tumors	Yes No
13. Operations	Yes No
14. Any other disorder not mentioned above	Yes No
15. Are you currently using any medication?	Yes No
16. Do you have a false limb, prosthesis, hearing aid or pacemaker?	Yes No
17. Females only: Are you currently pregnant?	Yes No

If "yes" to any of the above, please complete:

No.	Condition	Year

DECLARE THAT:

- All information in the occupational medical questionnaire is correct to the best of my knowledge.
- I have not omitted any information concerning my health | accept to undergo the relevant medical examination and tests as requested by GRP/SLB JOINT VENTURE
- I authorize the doctor appointed by GRP/SLB JOINT VENTURE to obtain any relevant medical information from my general practitioner or specialist.

Name of Employee: _____ Signature of Employee: _____ Date: _____

EXIT OCCUPATIONAL MEDICAL EXAMINATION

NAME:	COMPANY: GRP/SLB JOINT VENTURE	JOB DESCRIPTION:
ID NO:		

HEIGHT	m	WEIGHT	kg	BMI	
BP	mmHG	PULSE	min	RHYTHM	NORMAL/ABNORMAL

URINE	NAD	BLOOD	PROTEIN	GLUCOSE	LEUCOCYTES
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ABNORMALITIES

Skin or Appendages	Yes No	Gastro Intestinal System	Yes No
Ophthalmic System	Yes No	Genito Urinal System	Yes No
Ear, Nose and Throat	Yes No	Musculo Skeletal System	Yes No
Cardio vascular System	Yes No	Central Nervous System	Yes No
Respiratory System	Yes No	Endocrine System	Yes No

SPECIAL EXAMINATIONS

VISION	ACUITY R: 20'	FIELD R:	COLOR VISION Normal	Yes No	NIGHT VISION Normal	Yes No
	ACUITY L: 20'	FIELD L:	WEARING GLASSES OR CONTACT LENS			

PVC %	% FEV1%	% RATIO	% PLR	% CXR	NHL	YES	NO
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DESCRIPTION OF ABNORMALITIES

IDENTIFIED OCCUPATIONAL DISORDERS

CHRONIC DISEASES

Hypertension	Asthma	Epilepsy	Mental	Drug/Alcohol	Diabetes
Obesity	Thyroid	COPD	Cardiac	Prosthesis	Arthritis

REFERRAL

COMMENTS

DECLARATION BY MEDICAL PRACTITIONER

Signed at _____ on _____ / _____ / 2008

Name of Medical Practitioner: _____ Signature of Medical Practitioner: _____ Date: _____

(Source: EWS, 2012)

5.4.2.1 Personal protective equipment (PPE)

All workers should consistently and correctly wear personal protective equipment (PPE), particularly where manual cleaning or manual emptying is required. The personal protective equipment must include (Chowdhury-Repon et al., 2015; WHO, 2018):

- Safety water-proof boots/ calf high waterproof gumboots (with no laces or fabric);
- Protective clothing, i.e protective jackets and pants (eg, overalls);
- Elbow-length, durable, waterproof gloves;
- Disposable/permanent mask and/or gas mask;
- Safety goggles;
- Hat (for protection from the sun);
- Nail brush and towel.

Figure 5.5 illustrates the examples of PPE use during cleaning.



Figure 5-5: Examples of PPE (Source: WRC)

Pit Emptying Health & Safety Module 2: Understanding barriers and responsibilities developed by PID is available at:

<https://www.youtube.com/watch?v=ZFdWbwfdAdE&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=2>

5.4.2.2 Mandatory use of PPE

- In an applicable case, an employer shall not engage any workers in work without providing and ensuring the use of personal safety equipment, and in doing so, a record book shall be maintained as designated by the owner.
- To ensure occupational health and safety for workers in the workplace, each worker shall be made aware of the risks of the work through training.
- Sizes for Personal Protective Equipment (PPE) should be documented during hiring and purchased accordingly.
- Each item must be clearly marked with the owner's name. Workers must not share PPE.
- If any item of PPE is damaged to the extent that it no longer provides protection, it must be replaced at the welfare facility at the end of the day. For this reason, a stock of spare PPE must be kept in different sizes at the welfare facility.
- The Health and Safety Representative at each welfare facility must conduct an inventory on a weekly basis.
- When a worker leaves employment, his jacket and pants will be sterilised and either re-issued to another worker or given to him to take home. Boots and gloves will not be reissued and workers will not be allowed to take these home; they will be disposed of as hazardous waste (Chowdhury-Repon et al., 2015; PID, 2016; WHO, 2018; Jayathilake et al., 2019; Tsida, 2020).

5.5 RISK MITIGATION DURING MANUAL AND MECHANISED EMPTYING AND TRANSPORT

On-site sanitation facilities, such as pit latrines, pour flush latrines and septic tanks, often require emptying when the sludge rises to about half a metre from the top of a latrine. On-site sanitation facility emptying is influenced by several factors (Boot, 2007; Strande et al., 2014); including: (i) area where the facility is located; (ii) actual cost to the household; (iii) relative cost of building a new latrine versus the cost of emptying the existing one; (iv) health impact on workers; (v) type of latrine to be emptied; (vi) type of pit lining; (vii) method of disposal; (viii) demand for emptying and collection services and availability; and (ix) accessibility of the legal discharge or treatment site (Boot, 2007; Strande et al., 2014; Balasubramanya et al., 2016). In both the manual and mechanical emptying and transportation of FS, workers (service providers, emptiers, desludgers, and exhausters) are required to handle tools and equipment that come into contact with FS (including any liquid supernatant or effluent). Owing to the risk of injury or death from pits collapsing or inhalation of poisonous gases, workers should avoid entering pits (WHO, 2018).

5.5.1 Considerations to Minimise Risks during Manual Emptying

Manual emptying occurs mostly due to insufficient access for vacuum tankers and, in some cases, when the sludge is too thick for the mechanical emptying process to be undertaken. It is the most affordable way of removing the FS to enable the operation of the pit and does not require the use of machinery. Manual emptying often requires the workers to make use of a rope, buckets, a fork, spade and shovel to empty the pit. Again, manual emptying makes it possible to remove large trash that can be found in pit toilets, despite the waste

composition, water content or location of the pit. In the case where the FS is too viscous, the workers are required to enter the pit to remove the FS. In order to minimise health risks associated with manual emptying, the following must be considered (Boot, 2007; Strande et al., 2014; Sisco et al., 2017; WHO, 2018):

- Workers must wear PPE, including safety shoes, working clothing, safety gloves, a helmet and an oxygen mask.
- Workers should at all times ensure the availability of a safety rope to pull themselves out when done.
- Workers on the surface should be healthy, strong, and able-bodied individuals with enough strength to pull the workers inside the pit out.
- Washing facilities must be provided and must be nearby and pits should be well ventilated when the workers are inside (Boot, 2007; Strande et al., 2014; Balasubramanya et al., 2016 Sisco et al., 2017; WHO, 2018; Jayathilake et al., 2019).

5.5.2 Considerations to Minimise Risk during Mechanical Emptying

In order to reduce risks associated with mechanical emptying of sanitation facilities and to ensure a successful mechanical pit emptying process, the next steps must be considered:

- Pits must be easily accessible.
- Pits should be fully lined, as the removal of the semi-liquid material may cause unlined pits to collapse.
- Mechanical emptying technologies must be portable.
- Portable vacuum tankers specifically designed for use in slums and other areas that are difficult to reach with conventional vacuum tankers must be provided.
- In the event that FS is too thick, water can be added inside the pit to make the FS ‘pumpable’.
- Structural stability of the pit walls must be continually monitored as emptying takes place.
- To avoid having the mechanical emptying tool clogged by the trash, the pit emptier (workers) must remove trash before vacuuming, for example, using a fishing method. Fishing method refers to the process of manually removing solid debris, foreign objects, or obstructions from the contents of a pit, septic tank, or other on-site sanitation facilities. It involves using specialised tools or equipment to retrieve solid materials that may hinder the emptying process or pose a risk to the equipment used for waste extraction.
- If trash cannot be removed before the FS is removed, a mechanical emptying technology that can handle both the wide variety of trash and the FS is required. A new method called the active trash exclusion, where FS is pumped out of the pit while trash is left behind inside the latrine or septic tank, has been tested in laboratory and pilot scale (Strande et al., 2014; Sisco et al., 2017; Scott et al., 2017; WHO 2018; Jayathilake et al., 2019; Ministry of Rural Development (Cambodia), 2020; Portioli et al., 2021).

5.6 PREPARATION FOR PIT EMPTYING

This section has extensively used the guidelines provided by PID (2016), who have monitored and assessed numerous pit emptying programmes.

5.6.1 Area Depot

A welfare facility will be set up to serve workers in each process step during emptying. Each facility is either within 5 km of the work area or else transport is provided to workers between the work area and the facility at the start and end of the work.

Each depot should be equipped as follows (PID, 2016):

- one shower per 10 workers served (by gender);
- one toilet per 10 workers served (by gender);
- a “clean” change area on the entry side of the facility where workers store personal belongings; each individual will have a clearly marked bin or locker;
- a “dirty” change area (separated from the “clean” change area by showers) on the loading side of the facility where workers change into their PPE; everyone will have a clearly marked bin or locker;
- A contained area with running water and drain, for washing boots and tools;
- Facilities for washing and drying clothes (basins, covered washing line and clothes pegs);
- Facilities for cleaning vehicles (paved area with drain that can be washed down);
- Hazardous waste disposal container for equipment that is damaged or discarded.

The following supplies must be stocked and inventoried at the depot (PID, 2016):

- Lathering liquid soap for handwashing and showering at the facility;
- Toilet paper;
- Fingernail brushes;
- Cleaning cloths for wiping boots, masks, gloves, etc;
- Disposable gloves for cleaning tools and vehicles;
- Scrub brushes, buckets and basins for cleaning boots, tools, and vehicles;
- Laundry soap, washbasin, wash line and pegs for washing clothes at the welfare facility;
- Disinfectant/ bleach for cleaning boots, masks, tools, and vehicles at the welfare facility;
- Reporting forms for workers to report exposure, contamination, and other issues;
- Educational materials for householders.

5.6.2 Tools and Equipment Needed for Safety while Emptying Vaults

In addition to the regular tools which must be provided to workers for handling sludge, each vault emptying team must be provided with the following equipment and tools in order to protect the environment (PID, 2016):

- Tarpaulin/plastic sheeting (2 m x 2 m) to protect the lip of the pit and for the placement of bins or tools. This will be stored in a bin bag.
- A hand shovel, which is not to be used to handle sludge, for the purpose of handling soil. This will be transported in a plastic packet.

- A 20-litre bucket containing health and hygiene supplies will be carried by each vault emptying team on site and stocked as follows:
 - A 70% ethanol solution provided in a clearly marked spray bottle (for disinfecting skin or materials that could be damaged by sodium hypochlorite)
 - A 1:100 sodium hypochlorite solution in a clearly marked spray bottle (for disinfecting surfaces)
 - 5 litres sodium hypochlorite (10-15%) (for mixing solution for remediating spills)
 - Roll of bin bags (for disposing of contaminated paper towels or other rubbish generated on site)
 - Box of large disposable gloves (for use in the event that a work glove becomes torn or contaminated)
 - Pouch with householder education material, reporting forms, and pens.

5.7 CONSIDERATIONS FOR EMPTYING ON-SITE SANITATION FACILITIES

5.7.1 Pit Latrines

The following considerations are applicable to emptying pit latrines, i.e., simple latrines, unimproved pit latrines (UPL) and ventilated improved pit latrines (VIP):

- If the slab includes detachable sections, they should be securely sealed to prevent the presence of flies, or alternatively, the entire slab must be lifted when emptying is necessary.
- The superstructure of the latrine must aid access for easy removal
- Pit latrines are likely to have large amounts of trash in them. Therefore, if mechanised emptying is used, “fishing” may be required beforehand to avoid blockages or pump failures. This will likely be done using specially-designed tools to remove rubbish before emptying. For vacuum systems, no sludge passes through the pump; therefore, any trash that can fit through the suction hose can be pumped by the machine.
- When planning for emptying systems, lined pits are able to retain greater water volumes, which increases the flowability of the sludge.

Unlined pits constructed in unstable ground are likely to collapse when emptied, posing a risk to manual emptier / workers and the surrounding environment / community (Boot, 2007; Scott et al., 2017)

5.7.2 Pour-Flush Latrines and Offset Pour Flush Latrine

- The water seal prevents the disposal of solid waste and thus protects emptying machines. However, the water seal also prevents direct emptying; therefore, some form of separate access to the pit (e.g., removable slab) must be supplied.
- Building pour flush latrines that have an off-set pit is advantageous as access is easier, provided the pit is set in an accessible space.

5.7.3 Septic Tanks

- Septic tanks should be inspected periodically to determine if and when emptying is needed.

- Septic tanks should be emptied when the solids component of the waste fills between one-half and two-thirds of the tank.
- Septic tanks should not be completely emptied. A small amount of digesting sludge should remain in the bottom, as septic tanks rely on a balanced ecosystem of microorganisms to break down and treat the waste. These microorganisms work to decompose organic matter, allowing for the effective treatment of sewage. Leaving a small amount of sludge helps maintain the population of beneficial bacteria and microorganisms necessary for the ongoing biological treatment process.
- Completely emptying the septic tank could remove a significant portion of the active bacteria and enzymes. Leaving some sludge helps to kick-start the biological treatment process more quickly after the tank is refilled.
- A sudden removal of all sludge from the septic tank can cause a shock to the system. This shock may disrupt the balance of microorganisms and the overall biological processes within the tank.
- By leaving some sludge behind, the system can recover more smoothly, minimising the risk of disruptions to the microbial ecosystem. (Boot, 2007; Scott et al., 2017).

5.7.4 Portable Toilets (Mobile Toilets/Chemical Toilets)

Portable toilets (mobile/ chemical toilets) contain fresh faecal matter and urine, and this waste material contains organic matter and various organisms. Also, other portable toilets use chemical treatments to control odours, break down waste, and facilitate the decomposition process. These chemicals can include disinfectants, deodorisers, and enzymes. Below are considerations for emptying portable toilets:

- Regularly inspect and maintain the portable toilet to prevent leaks or malfunctions that could complicate the emptying process.
- Empty portable toilets in designated facilities, such as dump stations or sanitation stations, complying with local regulations and guidelines.
- Be aware of any specific rules regarding the disposal of waste in the area.
- If the portable toilet uses chemical treatments, follow the manufacturer's guidelines for safe emptying and disposal of treated waste.
- Before emptying, close the toilet lid securely to prevent spills during transportation.
- Connect the sewer hose securely to the portable toilet outlet and the dump station inlet.
- Empty the waste slowly to prevent splashing or spills.
- After emptying, use clean water to flush the holding tank thoroughly. Some dump stations provide rinse water for this purpose.
- Consider using environmentally friendly tank-cleaning products to maintain sanitation and prevent odours.

5.8 OPERATION AND MAINTENANCE PROTOCOLS FOR MANUAL EMPTYING

5.8.1 Pit Emptying Health & Safety

A series of health and safety videos developed by PID to demonstrate safety protocol when preparing to empty the vaults can be accessed at :

- **Pit Emptying H&S Module 3: Starting the day**

<https://www.youtube.com/watch?v=gPpuvjdTnOs&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=3>

- **Pit Emptying H&S Module 4: Preparing to empty the pit**

<https://www.youtube.com/watch?v=pLBKSAdzZDI&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=4>

- **Pit Emptying H&S Module 5: Emptying the pits**

<https://www.youtube.com/watch?v=pSE5CtxHbSc&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=5>

5.8.2 Cleaning Tools, Protective Equipment and Vehicles

Cleaning may only be done at the welfare facility. Cleaning should be done as follows (PID, 2016; Louton et al., 2018):

- **Tools:** Soak in a bucket to loosen sludge. Scrub with a brush and bleach solution. Wipe handles with bleach.
- **Tarpaulin:** Hose down in driveway while wearing mask and goggles. Scrub if needed. Spray with bleach. Hang to dry. Always fold with “down” side on the inside.
- **Vehicles:** Tires should be hosed down while wearing a mask and goggles. The bed, handles (inside and out), steering wheel, gear lever, hand brake and seats should be wiped down with a cloth soaked in bleach.
- **Plastic masks:** Soak in a basin with 1:100 bleach solution for half an hour, then rinse and hang up to dry.
- **Gloves:** Rinse, wipe with 1:100 bleach solution, rinse and hang up to dry.
- **Boots:** Stand in a basin of warm water to loosen dirt, then scrub with a brush and 1:100 bleach solution, rinse and leave to dry.
- **Clothing:** Wash weekly (if badly soiled, wash as needed) with cold water, bleach and laundry soap and hang to dry (on Friday is preferable, to allow time to dry over the weekend).

Video's that demonstrates safe cleaning protocol after emptying vaults videos developed by PID, can be accessed at:

- **Pit emptying H&S Module 8: Cleaning up at the site**

https://www.youtube.com/watch?v=JpDbdRQ_kWI&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=8

- **Pit emptying H&S Module 9: Cleaning up at the centre**

<https://www.youtube.com/watch?v=ujnvqBaNi4w&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=9>

5.8.3 Responding to Personal Exposure and Remediating Contamination On-Site

If the sludge touches any part of the body of the worker, the following must be done (PID, 2016; Louton et al., 2018):

- Wipe off any sludge from the skin with a paper towel, and throw it away in the sludge bin or bin bag.
- Spray the skin with ethanol.
- If sludge comes in contact with the eyes, nose or mouth, wash these parts well with water. To do this:
 - Remove the gloves and place them on the tarpaulin;
 - Spray the hands with ethanol;
 - Fill a bucket with enough water from the tap;
 - Wash the skin (let water fall into the sludge bin or vault);
 - Spray the tap with bleach.
- If the worker is cut by something in the sludge, she/he must let it bleed to clean it out. Then wash it well by pouring water over it, letting the water fall into the sludge bin or vault. Then spray the wound with ethanol. Wash it well with soap and water when the worker returns to the welfare facility.

If any contamination happens, the following must be done (PID, 2016; Louton et al., 2018):

- If sludge is spilled on the ground, it must be picked up with a spade used for emptying the vault and then pour bleach solution on the spot. If the sludge is wet, it must be covered with clean soil in a clean space.
- If household surfaces are touched by gloves, bins, etc., the contaminated surfaces must be wiped off any sludge with a paper towel, the paper towel must be thrown in the bin bag or disposal bin, and the surface sprayed with bleach.
- If the work steps in sludge, your boots must be wiped with a paper towel, thrown in the bin bag or sludge bin, and the bottom of your boots sprayed with bleach.

A video that demonstrates safe protocol for dealing with accidents during pit emptying, developed by PID, can be accessed at:

- **Pit Emptying H&S Module 6: Dealing with accidents**

<https://www.youtube.com/watch?v=sXdcHTUmk6U&list=PLW5g1PaPiGMoZuZiverlACWAR4urV0ujw&index=6>

5.9 OPERATION AND MAINTENANCE FOR MECHANICAL EMPTYING (PID, 2016)

- The mechanical emptying technology must be suited to the existing skills among women and men. If the skills do not exist, then either skills training must be arranged.
- The workers need to be trained on the use of equipment and the understanding of operation and basic skills required to repair and maintain the mechanical emptying device to be used.
- Basic local skills and materials for periodic repair or replacement are needed for any type of technology that will be utilised in the emptying of FS from the on-site sanitation facilities.
- Spare parts availability should be one of the main factors that decides the suitability of a particular technology. The spare parts supply must be investigated, established and assured before deciding on the technology. The supply of spare parts is better if they are manufactured within the country of use.
- All workers should consistently and correctly wear PPE.
- Hygienic operation and regular monitoring are essential to ensure successful emptying of the FS.
- Any mechanical emptying devices should have low operation and maintenance costs and the spare parts should have price stability and a reliable delivery system.
- The consumables – such as chemicals and fuel – must be available, affordable and of a quality that maintains acceptable system performance.
- Communities that are difficult to reach or have poor access to spares and repair expertise need special consideration, as motorised pumps may be inappropriate.

5.10 OPERATION AND MAINTENANCE CONSIDERATIONS FOR THE TRANSPORTATION OF FAECAL SLUDGE

After the FS has been removed from the pit, it needs to be safely transported to the disposal site or treatment site (Scott et al., 2017). Safe transportation of FS is essential to ensure the health and hygiene of the neighbourhood (ISO, 2016). Low-cost transport equipment, either standardised or customised, is often used for the transport of sludge to the disposal or treatment facility (Strande et al., 2014). To ensure safe transportation of FS and to minimise risk during the transportation, the following must be considered (Strande et al., 2014; Chowdhury-Repon et al., 2015; Sisco et al., 2017; WHO 2018; Jayathilake et al., 2019; Ministry of Rural Development (Cambodia), 2020):

- Workers engaged in transportation should be made aware of personal safety and health issues.
- Workers should be encouraged to undertake vaccination and/ or use deworming pills and do regular health checks.
- All workers should be trained on the risks of working with sanitation systems, including handling wastewater and/or FS, and be prepared to follow standard operating procedures.
- Workers must wear appropriate PPE, including rubber gloves, rubber boots, a face mask and eye protection.
- The manual transport of FS is not suitable for long distances and ideally should not be more than 3 km.
- A safe and reliable vehicle to carry the FS to the designated area is required. It is important to check its roadworthiness, maintenance, licenses and permits.
- In the case of manual emptying, it is important to transport FS in covered buckets or sealed containers to avoid spillage.
- Standard Operating Procedures (SOP), including conduct on the road and procedures to be followed at the discharge / treatment site are required to be respected.
- Spill management equipment, including shovels, disinfectants, sorbents and collection bags, must be taken for the operation.
- FS removal equipment such as hoses, pumps, augers and other tools, must be brought for the pit emptying.
- Sludge discharge into the local environment should be prohibited and workers must be made aware of the impacts of illegal disposal of FS into the environment and related health impacts.

5.10.1 Recommendations for Service Providers

FS collection and transportation service providers, whether are public or private entrepreneurs, should act in accordance with rules and regulations to ensure that business operations meet the safety regulations and maintain social, public and environmental health.

- Every service vehicle needs to comply with the following requirements (Jayathilake et al., 2019):
 - Display the company name, company logo, contact number and business registration number of the FS hauler or transporting vehicle on both sides of the vehicle.

- Display the service area (municipalities or suburbs covered by their permits) and final desludging station.
- Have a leak-proof body (tank) and a strong locking mechanism that can withstand a collision with another vehicle or any permanent structure.

5.10.2 Protocol for Transporting the Sludge

The protocol for transporting sludge and tools is as follows (PID, 2016; Louton et al., 2018):

- Always keep tools and equipment in their own bag or bin while carrying them or transporting them in the vehicle.
- Make sure full bins always have their lids on.
- Never place empty bins inside of each other.
- If sludge falls out of a bin onto the road during transport, remove it with a dirty shovel and pour bleach on the spot.
- Do not use air conditioning or a fan while travelling back from the site, as this could blow sludge particles off your clothes and you could breathe them in.

5.11 SAFE HANDLING OF SOLID WASTE FROM FAECAL SLUDGE

This section focuses on the solid waste products from on-site containments (detritus). The amount of material entering the pit, the rate and extent to which it degrades, and the circumstances that allow liquids and degraded material to exit the pit, all influence the rate at which the FS accumulates in the pit. The degradation of biodegradable material occurs through both aerobic and anaerobic processes (Still and Foxon, 2012).

However, when emptying FS in on-site sanitation facilities, there are often additional household solid waste materials (detritus). Researchers have found it impossible to estimate the composition of the material present in an individual pit without directly inspecting the contents of the pit or emptying the pit. While the pit emptying process is essential to improve sanitary conditions in people's residences and in common public areas, it has been found that in low-income countries, the financial means, skills, and political will to execute solid waste management are frequently inadequate and therefore pit latrines are commonly being utilised for solid waste disposal. Pit latrines have become a convenient trash container in areas lacking solid waste management. Many types of trash have been reported in latrines, including plastic bags, broken glass, cloth, needles, sanitary towels, clothes and newspaper (Chowdhry and Kone, 2012; Still and Foxon, 2012; Brouckaert et al., 2013). The challenges with trash in pit latrines are that (i) it shortens the life of the latrine as most solid waste material will not degrade and can hinder the degradation of the excreta; (ii) it negatively affects the mechanical emptying devices causing clogging of the devices; and (iii) it can cause troubles in the treatment of the sludge, especially if valorisation is desired (EWS, 2012; Harrison and Wilson, 2012; Still and Foxon., 2012; Sisco et al., 2017). It is anticipated that if the pit is not utilised for solid waste disposal, the life of the pit can be extended by ten years (Brouckaert et al., 2013).

Pit emptiers have had to develop strategies for managing trash in pits, such as charging more money to empty pits with trash. The trash is currently left in the sludge and either (i) processed and disposed of with the sludge or (ii) the trash is separated from the sludge during the processing. Again, the trash in the pit can either be simultaneously removed with the sludge from the pit or be manually removed prior to the sludge removal (e.g, fishing method). The removed trash is highly contaminated with faecal material and should ideally be handled and disposed of properly. The trash found in the pit can be classified as either degradable (i.e, the kitchen waste, e.g, vegetable peels) and non-degradable (e.g, sanitary towels and broken glasses). The degradable trash can be buried on-site, while the non-degradable trash needs to be treated properly, for recycling purposes or before it is mixed with other solid waste material at the landfill sites.

5.11.1 Solid waste removal tools

In South Africa, there is currently no standardized method for the removal of solid waste / trash found in the pit latrine. In some instances, after the sludge has been emptied, the solid waste found in the pit latrines is mostly co-disposed with the sludge, with the potential for disposal of other solid waste with the sludge if needed (PID, 2022). In the event that there is too much solid waste/ trash for effective pumping of the sludge, a ‘fishing’ method can be employed. Fishing refers to manually removing solid waste/ trash prior to emptying to allow more pumping options and faster emptying (Gurski et al., 2022). Different tools are used, ranging from simple hooks to more modified tools. It is important that precaution is taken to prevent unsanitary conditions and that personal protective clothing is always used when dealing with the solid waste removal at on-site sanitation facilities. Different versions of manually operated tools are used for trash removal (‘fishing’) prior to emptying with vacuum or pumping systems.

(i) The Claw (trash removal)

The Claw is a manual tool featuring four flexible steel arms that can retract into the handle. It is designed to grasp waste of various sizes and shapes and dispose of it into a bin without direct contact with the waste or sludge. Typically measuring between 1.5 to 2 meters in length, the tool works by pushing the handle down to open the claw. To collect the waste, the handle is pulled up, causing the claw to tightly close around items like bags, clothes, or bottles. This device is particularly effective for retrieving bottles, works best with thinner sludge, and is suitable for trash that is visually identifiable. Additional advantages include eliminating direct contact with waste and fitting into most latrine apertures (Gurski et al., 2022).



Figure 5-6: The Claw (Source: Gurski et al., 2022)

5.11.2 The Hook (trash removal)

Hooks are typically made up of several small metal rods welded onto a main metal pole. The operator manually maneuvers the hooks through the pit sludge to catch debris such as clothing, sanitary products, hair, and more. Once caught, the operator removes the debris by hand and places it in bins for transport. The advantages of using a hook include: (i) it doesn't require direct visibility to capture waste; (ii) it requires direct contact with the sludge or debris; (iii) it fits into most latrine apertures; and (iv) it is effective at capturing most types of trash, even in thick sludge. However, a limitation of this tool is its inefficiency in removing rigid debris like plastic or glass bottles (Gurski et al., 2022).



Figure 5-7: Hook trash removal tool (Source: Gurski et al., 2022)

5.11.3 Classification of Solid Waste Found in On-Site Sanitation Facilities

For the classification of the solid waste found in the on-site sanitation facilities, a hosepipe to aid with the, a source of water and a polythene sheet for storage of separated waste components are required. It is important that the solid waste collected from on-site sanitation facilities is classified as either degradable or non-degradable so that a proper disposal method is followed. **Table 5.7** illustrates the classification of trash that is found during an emptying process of on-site sanitation facilities.

Table 5.6: Classification of trash found in on-site sanitation facilities (Sources: Chowdhry and Kone, 2012; Still and Foxon, 2012; Brouckaert et al., 2013)

Degradable	Non-degradable
Kitchen Waste, e.g. vegetable peels, chicken feathers	Sanitary towels, e.g., pads and tampons
	Plastic bags
Papers, e.g. newspaper	Metallic materials such as cans
	Broken glasses
	Needles
	Clothes

5.11.4 Mixing the Trash with Other Solid Waste

The non-degradable trash cannot be buried, and it is therefore recommended that the trash should be first treated/ cleaned before mixing/ combining with other solid waste material, since it is contaminated with FS.

Trash must be mixed with other solid waste as follows:

- The trash must be soaked in water and Jik (sodium hypochlorite) solution to destroy any surviving pathogens for at least 24 hours.
- The trash must be put in a bucket of water or washed off using a hose pipe over a drainage system close by.
- The wastewater can be discarded in a drainage system close by.
- The trash must be thoroughly air-dried for at least 48 hours to allow complete air drying.
- After the waste has been dried, it must now be manually sorted using clean and dry rubber gloves.
- The sorting can be into different categories, i.e, plastic, paper, glass, metals, textile, personal waste, etc.
- The trash can then be treated as normal solid waste and mixed with other solid waste

5.12 MANAGEMENT ASPECTS

5.12.1 Roles and Responsibilities with Regards to the Health and Safety

Figure 5-8: Roles and responsibilities for personnel with regards to health & safety (Sources: PID, 2016; Louton et al., 2018)

Workers
<ul style="list-style-type: none">• Adhere to all health and safety protocols and guidelines given during training.• Take responsibility for her own health and safety, as well as that of team members, the public, and the environment, following disease prevention principles in situations where no specific protocol has been provided.• Immediately report any accidental exposure, contamination, violations of health and safety requirements by other workers, or any other relevant incidents on the same day.
Team Leader
<p>The leader of each vault-emptying team carries the same responsibilities as each worker, as well as the following additional responsibilities:</p> <ul style="list-style-type: none">• Ensure that the appropriate and sufficient equipment and supplies are brought to the site.• Enforce compliance with protocols and provide support while on site.• Document and address violations, demonstrating proper practices.• Immediately report any serious contamination or exposure incidents to the Health and Safety Officer (HSO).• Submit written reports completed on site and make verbal reports to Health and Safety Representatives (HSR).
Health and Safety Officer (HSO)
<ul style="list-style-type: none">• Develop a Health and Safety Plan that aligns with the Health and Safety criteria of the Occupational Health and Safety Act (OHSA) and the contract, outlining all systems and tools required for implementation.• Ensure that all workers receive training according to the requirements.• Keep health provisions for workers up to date.• Ensure that necessary facilities, equipment, and other health and safety provisions are maintained in good working order and available to workers.• Monitor worker compliance with Health and Safety requirements both on site and at the welfare facility, addressing non-compliance and work practice issues.• Revise and update protocols and management tools as necessary to ensure continued Health and Safety compliance.• Provide weekly and monthly reports to the Contractor.• Communicate daily with Health and Safety Representatives and address any issues they raise.• Hold weekly meetings with workers to discuss and resolve any concerns.• Receive and respond to worker reports of exposure, contamination, illness, complaints, and suggestions.• Track Health and Safety issues for each worker and for the pit emptying programme as a whole.
Health and Safety Representatives (HSR)
<ul style="list-style-type: none">• Enforce compliance and provide support to workers while at a welfare facility.

Guidelines for Faecal Sludge Collection, Disposal and Valorisation

- Take reports (written and verbal) from team leaders on incidents/issues that arose during the day.
- Conduct an inventory of H&S equipment and supplies on a weekly basis and report items to be ordered to HSO.
- Report serious incidents or accidents to HSO daily; work with HSO to identify the causes of incidents.
- Be available to workers for H&S issues, present issues raised by workers to HSO and the contractor.
- Advise HSO and contractor regarding hazards that are not adequately understood and the effectiveness of H&S measures.
- Monitor compliance of workers with H&S requirements both on site and at the welfare facility and address non-compliance and work practice problems.
- Meet with HSO weekly and HSO/Contractor monthly to address H&S issues.

Contractor

- Appoint a suitably qualified Health and Safety Officer (HSO).
 - Make provision for the election of a Health and Safety Representative per the OHSA Act.
 - Review the Health and Safety Plan drafted by the Health and Safety Officer against the contract and the OHSA Act.
 - Require the Health and Safety Officer to report weekly on Health and Safety, and address issues as required.
 - Meet with the Health and Safety Officer and the Health and Safety Representative on a monthly basis and address issues as required.
 - Report serious incidents (injury, exposure to biohazards, environmental contamination) to the Department of Labour inspector as per the OHSA Act.
 - Monitor the implementation of the Health and Safety Plan and the performance of the Health and Safety Officer and address performance problems.
 - Set up and decommission welfare facilities
-

5.13 SUMMARY

South Africa has developed significant standard operating procedures and protocols for pit emptying, aimed at ensuring safe, efficient, and environmentally responsible management of faecal sludge. These protocols are designed to guide the emptying process, reduce health risks, and ensure compliance with regulatory requirements. Over time, the country has engaged in extensive trial and error with different pit-emptying tools and techniques, learning valuable lessons from testing various methods in different environments. For instance, the testing of mechanical and manual pit-emptying tools, including manual suction pumps and specialised sludge removal equipment, helped identify the most effective tools for varying pit types and site conditions. This process of experimentation and iterative improvement allowed municipalities and sanitation service providers to refine their approaches, leading to better decision-making and the development of optimised tools for pit emptying. Ultimately, these trial-and-error approaches, combined with evidence from real-world testing, have shaped South Africa's pit emptying protocols, ensuring that they are both practical and effective in managing faecal sludge across diverse locations across the country. In this chapter, international practice and research have also been included, should the user encounter a situation different from the norm.

In the next chapter, guidelines for FS treatment are presented.

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CHAPTER 6: GUIDELINES FOR FAECAL SLUDGE TREATMENT

6.1 INTRODUCTION

Treatment of faecal sludge (FS) is the processing that changes the physical, chemical and biological characteristics or composition of FS so that it is of a quality fitting for the intended reuse or disposal (Buckley, 2005; Strande et al., 2014), taking into account additional barriers in place at the end-use/disposal step. Each technology has different fields of application and can be used for the co-treatment with organic material (Strande et al., 2014). The treatment of FS helps to prevent possible risks to public health and the environment (Tsida, 2020). The treatment of FS can be categorised into: (i) those comprising *in-situ* treatment technologies during the containment in on-site sanitation systems (e.g. composting toilets) and (ii) those comprising technologies for the treatment of sludge off-site. Technologies have been developed across the globe with the aim of treating FS, producing value-added products while promoting the livelihood of people using on-site sanitation facilities.

Conventional treatment of FS is often through a series of treatment steps in the Faecal Sludge Treatment Plant (FSTP) where the first step is to separate the liquids from the solids, and then treat both the liquid and solid trains while recovering as much energy or nutritive value as possible (Strande et al., 2014). There are currently existing, non-pilot FSTPs in South Africa, despite the large number of households using on-site sanitation systems and producing FS. An example of a conventional treatment method consists in drying beds that can be used for dewatering and drying. Drying bed are often part of the FSTP, as they are an inexpensive and simple method to dry FS (Moritz, 2018).

Innovative/emerging technologies include: (a) technologies that can produce a dried or carbonised solid fuel from FS, such as drying, pelletising, hydrothermal carbonisation, and slow pyrolysis; convert the FS along with certain fractions of sewage sludge or municipal solid waste to produce energy or fuel (Diener et al., 2014, WIN-SA, 2014).

The quality of the products from FS is highly dependent on the characteristic of the initial feedstock. The FS characteristics are highly variable, depending on residence time in containment, differences in sanitation technologies and practices, oxygen availability, temperature and pH, nutrient balance, particle size and texture. End-products from the treatment of FS can serve as an incentive for appropriate Faecal Sludge Management (FSM) and assist in financing the sanitation value chain (Diener et al., 2014; WIN-SA, 2014; Mallory et al., 2020).

6.1.1 Factors for the selection of a treatment technology

Various treatment technologies are available and the decision makers should carefully assess them based on the selection criteria and then decide on a suitable technology:

- Decision makers need to know and understand the advantages and disadvantages of the treatment technology.
- Decision makers should assess how much mechanisation is required to run the treatment plant or treatment technology.
- Decision makers should also assess the geological condition of the site and requirements of CAPEX and OPEX for the treatment technology.
- A full life cycle cost of the plant should be worked out for the technology, as the city should be able to operate and maintain it.
- Certain treatment technologies may necessitate pre- and post-treatment of the FS, adding an additional aspect that must be taken into account during the selection process
- When choosing a FS treatment technology, the level of local expertise plays a critical role in ensuring effective implementation and long-term maintenance.
- The availability of spares is a pivotal factor to consider when selecting a FS treatment technology, as it directly impacts the system's operational resilience and uptime.
- Understanding the diverse sludge characteristics is fundamental for selecting the most suitable FS treatment technology that can efficiently handle variations in organic content, moisture levels, and contaminant concentrations.
- The intended reuse type or disposal method heavily influences the choice of FS treatment technology, as it determines the necessary treatment levels and regulatory compliance measures tailored to meet specific end-use requirements.

This section is divided into 5 parts, presenting the biological, physical, thermal, thermochemical and chemical FS treatment methods. The biological treatment methods allow the removal and transformation of organic constituents, nutrients and pathogens through the activity of microorganisms (Strande et al., 2014) and the use of insects such a Black Soldier Fly (BSF) larvae and tiger worms (Water for People, 2019). The physical treatment methods include settling-thickening, which are widely used in FSM and have been considered robust (Strande et al., 2014). The thermal treatment method refers to the addition of thermal energy, which can be provided by hot air or flue gas, radiation (microwave, infrared), solar radiation, among others (Diener et al., 2014; Andriessen et al., 2019). The thermochemical treatment mechanism is through carbonisation and is basically used to convert dried biomass into a fuel that more closely resembles coal and can improve the energy density (calorific value) of the fuel (Andriessen et al., 2019). Again thermochemical process consists of a process where the material undergoes chemical modifications at high temperature. The pyrolysis, hydrothermal carbonisation and combustion are the common technologies that can produce biochar as an end-product from FS (Andriessen et al., 2019). Chemical treatment of FS involves the application of chemical agents or processes

to alter its composition, neutralise pathogens, reduce odours, and facilitate the separation of solids and liquids for improved treatment and disposal. **Table 6.1** illustrates the different types of treatment technologies of FS and **Table 6.2** gives an overview of the summary of some technical criteria.

Table 6.1: Types of FS treatment processes

<p>Biological Treatment Mechanism</p> <ul style="list-style-type: none"> • Anaerobic digestion • Black soldier fly larvae • Composting • Co-composting • Vermicomposting • Deep Row Entrenchment 	<p>Chemical Treatment Mechanism</p> <ul style="list-style-type: none"> • Alkaline stabilisation • Urea Treatment • Caustic soda
<p>Thermochemical Treatment Mechanism</p> <ul style="list-style-type: none"> • Pyrolysis • Hydrothermal Carbonisation • Combustion • Supercritical oxidation • Subcritical oxidation 	<p>Physical Treatment Mechanism</p> <ul style="list-style-type: none"> • Planted Drying bed • Unplanted drying Bed • Settling Thickening Tank • Dewatering <p>Thermal Treatment Mechanism</p> <ul style="list-style-type: none"> • Thermal Pasteurisation, eg viscous heater • Thermal drying

Table 6.2: Summary of technical selection criteria

Treatment Technologies	Volume Reduction	Pathogen Reduction	External Energy Source	By-products reuse potential	O&M	Established
Anaerobic digestion	Medium	Medium	Medium	High	Medium	3
Black soldier fly larvae	Medium	Medium	Low	High	Low	1
Composting	Medium	Medium	Low	High	Low	3
Vermicomposting	Medium	Medium	Low	High	Low	2
Deep row entrenchment	Medium	Medium	Low	Medium	Low	1
Planted drying beds	Medium	Medium	Low	High	Low	2
Unplanted drying beds	Medium	Medium	Low	Medium	Low	3
Settling thickening tank	Medium	Low	Low	Low	Medium	3
Dewatering	Medium	Medium	Medium	Medium	Low	2
Drying	High	High	High	High	High	0
Pyrolysis	High	High	High	High	High	2
Hydrothermal carbonisation	High	High	High	High	High	2
Combustion	High	High	High	High	High	2
Super Critical Oxidation	High	High	High	High	High	2
Subcritical Oxidation	High	High	High	High	High	2
Thermal Pasteurisation	High	High	High	High	High	2
Alkaline stabilisation	Low	Medium	Low	Medium	Low	2
Urea Treatment	Low	Medium	Low	High	Low	0
Caustic Soda	Low	Medium	Low	Medium	Low	0

Green	Beneficial
Orange	Moderate
Red	Detrimental
None Required	

Table Colour Guide

Established
3 = Yes, Proven and widely used in South Africa
2 = Yes, Proven and widely used elsewhere in the world
1 = Piloted but not demonstrated
0 = Only Understood in theory / laboratory scale

Terminology

Volume reduction	Refers to means of those methods, including, but not limited to, biological, chemical, physical and thermal methods used to reduce the amount of FS. Where High means large amount of sludge is reduced (green _beneficial). Medium means neither a large nor small amount FS is reduced (Orange _ moderate). Low means that an insignificant amount of FS is reduced (Red -detrimental).
Pathogen reduction	Refers to the potential of the treatment technologies to reduce /destroy the pathogens in the FS. Where High means a large amount of pathogens are destroyed, no need for secondary treatment. Medium means neither a large nor small amount of pathogens is destroyed, secondary treatment may be required. Low means that an insignificant amount of pathogens is destroyed, secondary treatment is required.
External energy source	Refers to the external capacity of doing work that is sourced, such as electricity, nuclear, etc., where High means that the treatment technology consumes and requires large amounts of energy of outsourced energy to operate. Medium means that the treatment technology consumes and requires moderate amounts of outsourced energy to operate. Low means that the treatment energy is consumed and requires a small amount of outsourced energy.
By-product re-use potential	Refers to the ability for all the materials that are generated to be used, resource-like. High means there is a high probability of the generated material to be used. Medium means neither high nor low probability of the generated material to be used. Low means the is very little chance of using the generated material.
O&M	Refers to the functions, duties and labour associated with the daily operations and normal repairs, replacement of parts and structural components, and other activities needed to preserve an asset so that it continues to provide acceptable services.

6.2 BIOLOGICAL TREATMENT TECHNOLOGIES

Biological treatment of FS make use of the metabolism of microorganisms naturally occurring in the faecal matter. Under controlled conditions, the microorganisms and insects can provide the desired outcomes, such as degradation of organic matter and reduction of odour and pathogens (Bassan et al., 2014). Important factors that affect the activity of the microorganisms are the temperature of the sludge, the amount of biodegradable material and inhibitors as well as the level of nutrients and oxygen in the sludge. The potential end products are the stabilised organic matter that can be used as a soil conditioner which also contains nutrients which can have a benefit as a long-term organic fertiliser.

6.2.1 Anaerobic Digestion

The basic principle of anaerobic digestion involves a consortium of microorganisms, primarily bacteria, that work together in a series of biochemical reactions to decompose organic matter. These microorganisms thrive in an oxygen-deprived environment and function in four main stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The organic matter is transformed to biogas during anaerobic digestion, and the residual sludge is referred to as slurry or digestate. The digestate from biogas is relatively safe to handle and can be utilised as a soil conditioner. Biogas is mostly composed of methane and carbon dioxide (Strande et al., 2014). Anaerobic waste and wastewater treatment is less expensive and easier to operate than aerobic procedures

since no energy is required for the aeration system, and the sludge volume is reduced due to conversion of organic matter into biogas. The liquid digestate is richer in nutrients than chemical fertilisers (Song et al., 2012; Strande et al., 2014). **Table 6.3** shows the benefits and constraints of anaerobic digestion and **Table 6.4** displays the techno-economic aspects of anaerobic digestion.

Table 6.3: Benefits and Constraints of anaerobic digestion (Song et al., 2012; Bakare, 2014; Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Produces biogas while stabilising FS • Reduces sludge volume and odours 	<ul style="list-style-type: none"> • Design and construction relatively difficult. • Operation and Maintenance (O&M) of anaerobic digesters requires a relatively high level of skilled operation. • May not be applicable to aged sludge

Table 6.4: Techno- economic aspects of anaerobic digestion (Song et al., 2012; Strande et al., 2014; Gensch et al., 2018)

Design Considerations	<ul style="list-style-type: none"> • The main design parameters for anaerobic digesters are the Hydraulic Retention Time (HRT), the temperature and the loading pattern. • Operating conditions that play an important role in the design and operation of anaerobic digesters include: Solids Retention Time (SRT); HRT; temperature; alkalinity; pH; toxic / inhibiting substances; and bio-availability of nutrients and trace elements. • When designing an anaerobic reactor, it is important to know the organic load that can be expected, in order to allow for a long enough HRT for degradation to occur. • FS tends to more complex organic matter and therefore designs may require a larger HRT to prevent hydrolysis limiting steps.
Operation and maintenance	<ul style="list-style-type: none"> • To prevent blocking and corrosion, the accumulated water should be periodically emptied from the system's water traps. • Trained personnel must regularly check gas pipelines, fittings and appliances.
Costs	<ul style="list-style-type: none"> • This is a low to medium-cost treatment option in terms of capital and operational costs. • Additional costs related to the daily operations needed by the reactor need to be taken into consideration. • Community installations tend to be more economically viable, as long as they are socially accepted. • Costs for capacity development and training for operators and users must be budgeted for until the knowledge is well-established
Health Aspects	<ul style="list-style-type: none"> • The biogas produced is primarily composed of methane and carbon dioxide, with lesser amounts of hydrogen sulphide, ammonia, and other gases, depending on the material being digested. Each of these gases has safety issues. • Overall, biogas risks include explosion, asphyxiation, disease, and hydrogen sulphide poisoning.

Case Study: Does Anaerobic Digestion Work Well for VIP Latrine Sludges?

In a study conducted in eThekweni Municipality, VIP latrine sludge was collected and analysed by Bakare (2014). The conditions of the VIP latrines are generally quite dry, with no free liquid surface typically found on top of the pit contents. Bakare (2014) discovered that all analytes related to biodegradable material, such as Chemical Oxygen Demand (COD), volatile solids fraction, and biodegradable COD, showed a significant decrease between the surface sample (top layer) and the third sample (approximately 1 meter below the surface). The surface layer had higher degradable FS, which decreased up to around 1 metre in depth. Below this, there was no significant difference between the 1-meter sample and the bottom sample. At this section, the FS reaches a stable composition that does not undergo further substantial degradation over time. If the pits examined have been in use for a long time, the FS from the bottom is likely to be well-stabilised due to the extended residence time the material has spent in the pit.

The results inferred from results indicate that anaerobic digestion may not be conducive to the treatment of aged and stabilised VIP sludge. Indeed, these findings have been replicated elsewhere in South Africa, which showed poor digestability of aged VIP sludge (Berner et al., 2019; Laubscher et al. 2019). Should anaerobic digestion be used as a primary treatment step, freshly collected FS should be used.

6.2.2 Black Soldier Fly

The conversion of organic waste by the larvae of the Black Soldier Fly (BSF), *Hermetia illucens*, into useful prepupae is a recycling technology with the potential to give waste a significant value (Strande et al., 2014). The BSF larvae are used as a conventional protein and fat source for poultry and fish feed. This method is based on BSF's natural growth cycle as the larvae are kept in a compartment where they are fed with organic matter (such as FS) during the larval stage, then migrate for pupation, and finally are not fed during the adult stage. The chances of the BSF becoming a disease vector are extremely low, as it is not attracted to decomposing organic waste when it can fly (Sheppard et al., 1994). Because the pupae are abundant in protein and fat, they make excellent animal feed (Still et al., 2015). The waste products can be used as a soil conditioner. The end-products are: (i) oil that is extracted from the larvae and can be processed to produce biodiesel; (ii) solid residue that is rich in protein and can be used as animal feed (Gounden and Alcock, 2017; Grau et al., 2019). The remaining FS that is non-digested can be treated in different ways, e.g pyrolysis or composting. The stages of the lifecycle of the BSF are shown in **Figure 6.1**. **Table 6.5** illustrates the benefits and constraints of BSF larvae and **Table 6.6** gives the techno-economic aspects of BSF larvae.

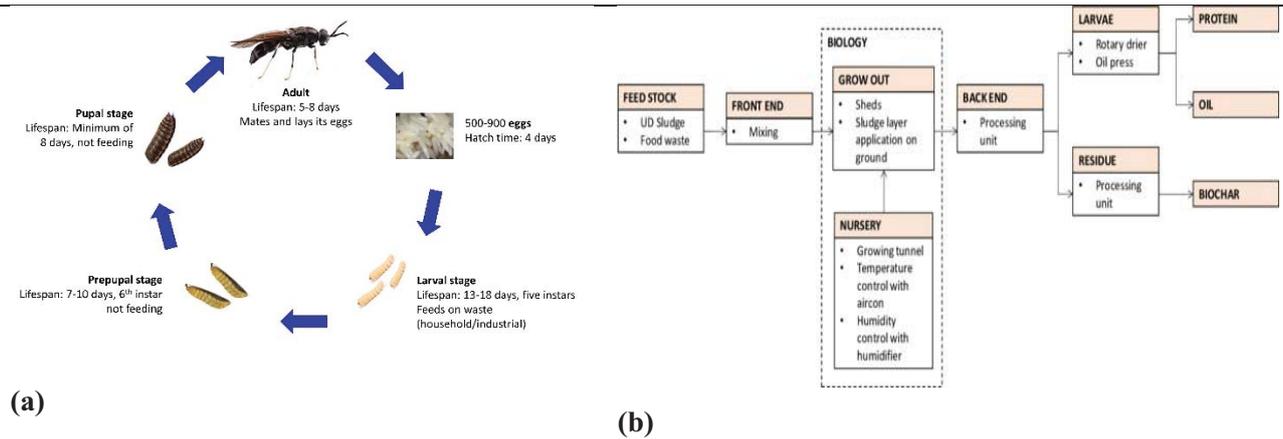


Figure 6-1: (a) Life cycle of the BSF (Encyclopedia, 2023) and (b) example of a process flow chart of a BSF technology for FS processing (Grau et al., 2019)

Table 6.5: Benefits and constraints of the black soldier fly treatment (Maleba et al., 2016; Gounden & Alcock, 2017)

Benefits	Constraints
<ul style="list-style-type: none"> • Can achieve treatment of FS with and without mixing with other organic waste. • Has the ability to convert waste into protein and fat, which can be used for animal feed. • Achieve a reduction of organic waste volumes of up to 75% together with the removal of nutrients such as nitrogen and phosphorus. 	<ul style="list-style-type: none"> • Upscaling experience in low- and middle-income countries is not yet available.

Table 6.6: Techno-economic aspects of black soldier fly (Maleba et al., 2016; Gounden & Alcock, 2017; Grau et al., 2019)

Design consideration	<ul style="list-style-type: none"> • The FS is mixed with primary sewage sludge and market waste to increase the moisture levels and nutritional content for the larvae. • For successful faecal matter reduction and prepupal production, the key rearing parameters are: climate control, feed composition, moisture content, feeding rate, and larval density. • Batch process is easier for maintenance as the larvae can be left with the sludge for a certain amount of time. • Screening of FS to remove inorganics and detritus.
Operation and maintenance	<ul style="list-style-type: none"> • This process requires removing trash from the sludge and increasing the moisture content to the desired level. • Sorting of the food waste or any other additives to the desired particle size. • Must maintain colony by harvesting eggs and feeding them and including the substrate sourcing the food for the colony. • Must be separation of the larvae after bioconversion (the drier the residue, the better).
Costs	<ul style="list-style-type: none"> • The black soldier fly larvae for the processing of FS are relatively inexpensive. • Climate control measures make up around 80% of the costs

6.2.3 Composting and Co-Composting

Composting is a managed biological process in which microorganisms break down organic matter, such as faecal sludge (FS) and other waste materials, similar to natural soil decomposition. Co-composting involves processing FS alongside organic waste streams like municipal solid waste, resulting in a stable humus-like product suitable for soil enrichment (Strande et al., 2014; Tilley et al., 2014).

There are two main composting systems: open and closed. In open systems, organic matter is arranged in heaps (windrows) or enclosed in composting boxes, allowing aerobic decomposition while optimising space. Closed systems use containers such as vessels or drums to process waste in a controlled environment (Strande et al., 2014).

To ensure safe handling, maintaining pile temperatures between 60–70°C effectively reduces pathogen levels (Strande et al., 2014; SSWM, 2021). Further details on the advantages, limitations, and economic aspects of composting can be found in **Tables 6.7** and **6.8**.

Table 6.7: Benefits and constraints of composting and co-composting (Strande et al., 2014; Tilley et al., 2014; SSWM, 2021)

Benefits	Constraints
<ul style="list-style-type: none"> • Significant reduction in pathogens; • Compost can be used as a soil conditioner; • No real problems with flies or odours if used and maintained correctly (i.e., kept dry); • Organic solid waste can be managed concurrently; • Long service life; • Low operating costs if self-emptied. 	<ul style="list-style-type: none"> • Requires well-trained user or service personnel for monitoring and maintenance; • Compost might require further treatment before use; • Leachate requires treatment and/or appropriate discharge; • Requires expert design and construction; • May require some specialised parts and electricity; • Requires constant source of organics; • Manual removal of compost is required.

Table 6.8: Techno-economic aspects of composting and co-composting (Strande et al., 2014; Tilley et al., 2014; SSWM, 2021)

Design consideration	<ul style="list-style-type: none"> • A composting chamber can be designed as either a closed system or an open system, depending on its construction and management practices. • A closed composting chamber requires four main parts: a reactor (storage chamber); a ventilation unit to provide oxygen and allow gases (CO₂, water vapour) to escape; a leachate collection system; and an access door to remove the mature product. • A composting chamber can be designed in various configurations and constructed above or below ground, indoors or with a separate superstructure. • Design value of 300 L (of FS)/person /year can be used to calculate the required chamber volume. • Ventilation channels (air ducts) under the heap can be beneficial for aeration. • A sloped bottom and a chamber for compost withdrawal facilitate access to the final product. • A drainage system is important to ensure the removal of leachate. • The use of a Urine-Diverting Dry Toilet (UDDT) or urinal can improve the quality of the compost.
Operation and Maintenance	<ul style="list-style-type: none"> • There are four factors that ensure the good functioning of the system: (a) sufficient oxygen, provided by active or passive aeration; (b) proper moisture (ideally 45 to 70% moisture content); (c) internal (heap) temperature of 40 to 50 °C and (d) a 25:1 C:N ratio (theoretically) which can be adjusted by adding bulking material as a carbon source. • The moisture must be controlled, the C:N ratio must be well balanced and the volume of the unit must be such that the temperature of the compost pile remains high to achieve pathogen reduction. • It is important to turn the material from time to time to boost the oxygen supply. • The average period for emptying a composting chamber can vary depending on several factors, including the size of the chamber, the rate of organic waste input, the efficiency

of the composting process, and the desired quality of the compost produced. Generally, the time it takes to empty a composting chamber and harvest the finished compost can range from several weeks to several months.

Costs	<ul style="list-style-type: none"> Costs to consider include the potential transport from the toilet to the field and costs for labour and PPE.
Health Aspects	<ul style="list-style-type: none"> In a well-designed composting chamber, the users will not have to handle the material during the first year. If there is ample bulking material and good ventilation, there should be no problems with flies or other insects. A well-functioning composting chamber should not produce odours. When removing the final product, it is advisable to wear protective clothing to prevent contact with (partially) composted material.

A case study – Composting of FS

Background

Water For People commissioned a Decentralised Faecal Sludge Treatment Plant (DEFAST) in Kitgum Municipality in December 2016, which has a capacity to receive 8m³/day of FS. The DEFAST has been designed with the aim of reducing the volume of the sludge and, at the same time, inactivating the pathogen agents present in the FS. The sludge is collected on a daily basis by local entrepreneurs, commonly known as gulpers, from several sites located in the Kitgum Municipality. Water For People, together with its partner, UNICEF Uganda, sought to add value to the sludge by turning it into compost.

New FS composting process

Water For People, in partnership with UNICEF and their partners Korkia Ventures and Insights, developed a new process of composting the FS that involved heaps instead of crates and sought to improve the degradation conditions, quality and safety of compost. The composting process is illustrated in **Figure 6.2** and **Figure 6.3** displays the overall composting process (Lugali 2019).

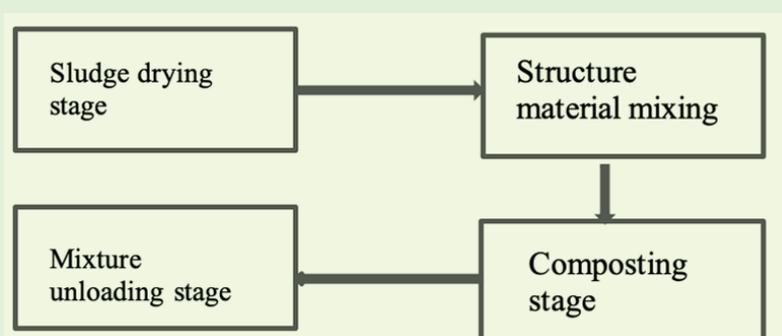


Figure 6-2: Composting process (Source: Lugali, 2019)



Figure 6-3: Composting process (Source: Lugali, 2019)

6.2.4 Vermicomposting

Vermicomposting is a process that uses earthworms to break down organic waste (such as FS) into nutrient-rich compost. This process involves creating a suitable environment for earthworms to consume organic matter and convert it into vermicompost through digestion and excretion. The earthworms ingest the organic material, which is then broken down by their digestive enzymes and microbial activity in their gut, resulting in nutrient-dense castings that serve as a valuable soil amendment. Proper moisture, aeration, temperature, and carbon-to-nitrogen ratio are essential for successful vermicomposting, which can be done in containers or outdoor beds. Vermicomposting is amongst the innovative technologies for FS treatment. The maximum temperature for vermicomposting is as low as 35 °C and cannot be carried out in thermophilic temperatures as composting (Strande et al., 2014). **Table 6.9** shows the benefits and constraints of vermicomposting, and **Table 6.10** the techno-economic aspects of vermicomposting.

Table 6.9: Benefits and constraints of vermicomposting (Strande et al., 2014; Gensch et al., 2018)

Benefits	Constraints
<ul style="list-style-type: none"> • Produces a good soil conditioner that provides potential for income generation • Reduces volume of organic waste • Relatively low capital cost • Can be built and maintained with locally available materials 	<ul style="list-style-type: none"> • Technology is still in development • Cannot be carried out at the thermophilic temperatures of co-composting • If adequate pathogen reduction is not achieved during treatment, further treatment steps are required • Requires a large area

Table 6.10: Techno-economic aspects of vermicomposting (Strande et al., 2014; Gensch et al., 2018)

Design consideration	<ul style="list-style-type: none"> • The design of a vermicomposting facility is similar to co-composting using vessels and with the addition of earthworms. • Vermicomposting can be combined with other treatments, e.g. the digestate from anaerobic digestion. • Vermicomposting tanks can be made from local materials (bricks or concrete) and the prefabricated composting vessels of different sizes are available on the market. • Worms are required, and three species to date have been successfully used: <i>Eisenia fetida</i>, <i>Eudrilus eugeniae</i> and <i>Eisenia andrei</i>. • It is not possible to find worms in the local environment; it is recommended to buy /import them from vermicomposting businesses or import.
Operation and maintenance	<ul style="list-style-type: none"> • A vermicomposting facility requires a well-trained maintenance staff to carefully monitor the quality and quantity of the input material and the worms' health as well as manage moisture and oxygen content. • Organic waste must first be sorted so it is free from plastics and other non-organic materials. • Turning must be periodically done with either a front-end loader or by hand using a pitchfork or shovel.
Costs	<ul style="list-style-type: none"> • Costs of building a vermicompost facility vary depending on the method chosen and the cost of local materials. • The main costs to consider are the overall operation requirements, including transport and supply of FS, organic solid waste and removing the composted material.
Health Aspect	<ul style="list-style-type: none"> • If adequate pathogen reduction is not achieved during treatment, further treatment steps are required. • The production of worms can be beneficial, provided there is a market for them.

6.2.5 Deep Row Entrenchment

Deep row entrenchment is a process of burying FS in deep trenches where odours are eliminated and the risk of exposure to pathogens is reduced. Burial of sludge represents one of the most cost-effective and practical treatment options, provided it is done correctly (Gounden and Aloccock, 2017). Trees that demand high nitrogen content are planted on top of the buried sludge (Strande et al., 2014). Entrenchment provides a practical and useful method to deal with the problem of disposal of potentially dangerous FS from pit latrines (Still et al., 2014). Over time, the sludge buried in the soil dehydrates, decomposes and becomes difficult to distinguish from the surrounding soil. Compared to other conventional methods, such as spraying FS on trees, the deep row entrenchment process allows for an increased amount of FS, where a trench is filled with between 250 mm and 500 mm of sludge to 300 mm of the surface and then backfilled with a heaped overburden (Still et al., 2014). Deep row entrenchment is the simplest and most economical method for the disposal of sludge. Burial deals with the problems of odours and insects and protects people from accidental contact with the pathogens in the sludge. The nutrients in the sludge act as fertiliser for trees, and the organic matter from the sludge provides a long-term benefit to soil health. The contents can be dug out and used as a soil conditioner after a few years. Trees are the simplest and most practical crop to grow on entrenched sludge, but other crops, such as beans or maize, can be grown as well (Still et al., 2014; PID, 2022). The deep row entrenchment of FS planted with trees can provide effective management of risks that would be involved with landfill disposal of FS (PID, 2022):

- Direct entrenchment of sludge and burial the same day prevents contamination of surfaces or equipment with pathogens.
- Dedicated sites with restricted access provide control of a hazardous waste landfill without the red tape.
- Research by PID suggests that movement of contaminants in soil is limited and that nitrogen is stabilised in the soil within 4 years (Neethling and Still, 2022). The risk of groundwater contamination depends on site-specific characteristics (e.g. % of clay in soil, groundwater depth).
- Planting of trees creates a nutrient sink, reducing the movement of potentially harmful nutrients from the trench.

Utilisation of sludge by trees allows for repeated disposal of sludge at the same site over cycles of entrenchment and harvest, unlike landfills, where re-use of the site can only be done by adding additional layers. **Figure 6.4** demonstrates photographs of the deep row entrenchment process, where (a) shows the burial of FS for deep row entrenchment and (b) shows trees grown from the deep row entrenchment.



Figure 6-4: Photographs of deep row entrenchment process (a) burial of FS for deep row entrenchment and (b) trees grown from the deep row entrenchment in KZN, South Africa, (Neethling and Still, 2022)

Table 6.11: Benefits and constraints of deep row entrenchment (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Requires no expensive infrastructure or pumps that are very susceptible to poor maintenance. • Simple and low-cost FS disposal method. • Operations can be handled by a single small entrepreneur. • Minimal overhead and infrastructure required. • Minimal skills required for daily operation. • Timber or fruit trees can be grown to benefit the local community. 	<ul style="list-style-type: none"> • Availability of land in an area with a low enough groundwater table. • Nutrients (nitrogen and phosphorus) may leach into groundwater in specific conditions.

Table 6.12: Techno-economic aspects of deep row entrenchment

Design consideration	<ul style="list-style-type: none"> • Deep row entrenchment is usually constructed with a backhoe. • Suggested dimensions are 800 mm deep and about 0.6–1 m wide and with a length of several meters, depending of the space available. Depth can be increased if space is limited. • Space between rows can be 2 m or more edge-to-edge. • The trench is filled with sludge to within 0.3 m of the surface and then backfilled with a heaped overburden to allow for settling. • Trees or other vegetation are planted on or between trenches. • Burial on a household scale does not require special permission, but entrenchment on a decentralised community scale may require special permission from DWS and / or Department of Forestry, Fisheries and the Environment (DFFE). • Variables to consider are trench dimensions, spacing, method of filling (layered with soil or co-composted with vegetable matter), species, composition and density of vegetation and end purpose.
Operation and maintenance	<ul style="list-style-type: none"> • There is little maintenance associated with a closed pit or trench other than taking care of the tree or plant. • If entrenchment is done on a community-scale, periodic monitoring of groundwater may be required, depending on the initial site conditions. • Trees planted in filled pits and trenches should be regularly watered. • Small fences should be constructed around saplings to protect them from animals and humans.
Costs	<ul style="list-style-type: none"> • Deep row entrenchment is a low-cost solution. • The main cost items are tools, machinery and labour to dig the pits or trenches. • Trees and edible crops can generate income or reduce food expenses, along with contributing to the environment.
Health Aspect	<ul style="list-style-type: none"> • There is minimal risk of infection if the filled trench is properly covered and clearly marked. • Users do not come in contact with the faecal material and, thus, there is a very low risk of pathogen transmission.

Links to a study on deep row entrenchment are available in APPENDIX A: The Guideline for deep row entrenchment of faecal sludge and secondary wastewater sludge developed by PID and the WRC (Neethling and Still, 2022).

6.3 CHEMICAL TREATMENT MECHANISM

Chemicals can be added to FS to improve the performance of other physical mechanisms (for example, adding a cationic polymer to promote flocculation and settling efficiency) or to inactivate pathogens and stabilise the system. Chemical additions can result in a large rise in the overall cost of treatment; thus the benefits must be carefully considered. Alkaline treatment is the most common chemical treatment.

6.3.1 Alkaline Treatment

Alkaline treatment is a process that involves raising the pH level of the sludge by adding alkaline substances such as lime (calcium hydroxide or sodium hydroxide). This treatment method is employed to reduce pathogens, control odours, facilitate nutrient recovery, and minimise environmental impact. The alkaline treatment can be (i) hydrated lime treatment, urea treatment or caustic soda treatment. The hydrated lime treatment is a cost-effective chemical treatment for FS from pits and trenches. It uses hydrated or slaked lime (calcium hydroxide: $\text{Ca}(\text{OH})_2$) as an additive to create a highly alkaline environment, making it no longer a viable habitat for pathogens. It significantly reduces the public and environmental health risks of sludge. The optimum dosage to reach a recommended pH of above 12 should be between 10–17 g lime/kg of FS with a contact time of at least 2 hours (Gensch et al., 2018). Urea treatment can be used on FS, blackwater, or urine and faeces that have been separated at the source. Urea, $(\text{CO}(\text{NH}_2)_2)$, is used as an addition to assist in sanitising sludge by creating an alkaline environment in the sludge storage device. When urea is introduced to FS, the enzyme urease, which is found in faeces, catalyses the decomposition of urea into ammonium and carbonate. The alkaline pH (above 7) caused by urea breakdown affects the equilibrium between ammonia and ammonium, favouring the creation of ammonia gas. The caustic soda treatment makes use of caustic soda, also known as lye (sodium hydroxide: NaOH), as an additive to create a highly alkaline environment with pH levels above 12 and thereby sanitises sludge from human waste. It significantly reduces the public and environmental health risks of sludge (Gensch et al., 2018). **Table 6.13** gives the benefits and constraints of an alkaline treatment and **Table 6.14** gives the techno-economic aspects of alkaline treatment.

Table 6.13: Benefits and constraints of alkaline treatment (Ronteltap, 2014; Lindberg and Rost, 2018)

Benefits	Constraints
<ul style="list-style-type: none"> • Effective in reducing pathogen levels, including bacteria, viruses, and parasites. • Helps control foul odours associated with FS. • Relatively simple operation and maintenance compared to more complex treatment systems. • Provides a safer and more hygienic solution for FSM, contributing to improved public health outcomes. 	<ul style="list-style-type: none"> • High chemical input and high running costs. • Appropriate storage area. • Additional post-sludge treatment may be required. • Potential health risks if not handled properly; • Requires proper pH control and monitoring to ensure effective pathogen reduction.

Table 6.14: Techno-economic aspects of alkaline treatment (Gensch et al., 2018)

Design Considerations	<ul style="list-style-type: none"> • Selection of appropriate alkaline agent is required (e.g., lime, sodium hydroxide or caustic soda) based on local availability, cost, and effectiveness. • Design of treatment facilities to prevent environmental contamination and ensure compliance with regulations. • Must consider factors such as sludge characteristics, treatment capacity, and treatment duration.
Operation and maintenance	<ul style="list-style-type: none"> • Pumps used for mixing must be maintained on a regular basis. • To ensure efficient operation and prevent downtime, maintenance of treatment infrastructure is highly recommended, including pumps, mixers, and dosing systems. • Due to health dangers associated with handling alkaline agents, the process necessitates the use of competent employees who adhere to health and safety regulations and wear suitable Personal Protective Equipment (PPE). • Regular monitoring of pH levels to ensure treatment effectiveness and compliance with regulatory standards.
Cost	<ul style="list-style-type: none"> • Alkaline treatment is a relatively inexpensive treatment option. • Costs may vary depending on the availability and costs of local materials and urea. • Initial investment required for equipment and infrastructure for pH adjustment and monitoring.
Health Aspect/Acceptance	<ul style="list-style-type: none"> • Alkaline agents may be hazardous when they come into contact with skin or eyes (irritant), ingestion or inhalation and may be combustible at high temperatures. • Washing with cold water is recommended for affected skin and eye areas, followed by rinsing with borax-boric acid buffer solution. • Precautions are needed when removing sludge from the tank. • PPE (such as masks, gloves, aprons and long-sleeved clothing) must be worn when handling urea to prevent irritation to eyes, skin, and the respiratory system.

6.4 PHYSICAL TREATMENT PROCESS

6.4.1 Settling-Thickening Tank

Settling-thickening tanks are used to achieve a separation of the liquid and solid fractions of FS (Dodane et al., 2014). Settling-thickening tanks are a low-cost technology for treating FS. Other benefits include: low operating costs; can be built and repaired with locally available materials and no energy is required (Tsida, 2020). For the purpose of FS treatment, the settling-thickening is done by rectangular tanks where FS is discharged into an inlet at top of one side and the supernatant exits through an outlet situated at the opposite side, while settled solids are retained at the bottom of the tank and the scum floats on the surface. The heavier particles settle out and thicken at the bottom of the tank due to gravitational forces while lighter particles including fats and oil float to the top of the tank (Dodane et al., 2014). **Table 6.15** shows the benefits and constraints of the settling-thickening tank, **Table 6.16** illustrate the techno-economic aspect of settling thickening tank and **Figure 6.5** shows a structure of the settling-thickening tanks.

Table 6.15: Benefits and constraints of settling-thickening tank (Dodane and Bassan, 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Efficient primary treatment. • Achieve solid-liquid separation. • Relatively robust and resilient. • Reduce the volume of sludge for subsequent treatment steps. 	<ul style="list-style-type: none"> • Settled sludge has high water content and requires further dewatering. • Pathogen removal is not significant. • The end-products of settling tanks cannot be discharged into water bodies or directly used in agriculture.

Table 6.16: Techno-economic aspects of the settling-thickening tank

Design Considerations	<ul style="list-style-type: none"> • The tank design is based on the estimated volume of FS, and the resulting supernatant flow, and the production of scum and thickened sludge layers. • An adequate design needs to include regular and efficient removal of the scum and thickened sludge, which needs to be considered to optimise the solids-liquid separation. • The length of the tank needs to be sufficient and have adequate hydraulic distribution to ensure that the entire tank surface area is used, and that particles have enough time to settle • Once the surface area of the tank has been determined, the volume can be calculated, considering the depth of the four layers (i.e, the scum layer, supernatant layer, separation layer and thickened layer) in metres. • It is necessary to plan for the reduction in depth that will occur due to the accumulation of scum and thickened sludge, which will result in solids washed out with the supernatant if underestimated. • Trash removal must be undertaken before the loading of FS into the settling-thickening tanks in order to facilitate maintenance.
.Operation and maintenance	<ul style="list-style-type: none"> • At least two settling-thickening tanks should be operated in alternance, in order to allow for sludge removal as tanks should not be loaded during this time. The loading of FS, and the compaction and removal of the thickened sludge and scum comprise the main phases of an operating cycle. • These periods allow for the expected solids-liquid separation and thickening operations. • Trained staff member for operation and maintenance is required. The maintenance is not intensive. • The thickened sludge must be mechanically removed (with a frontend loader or other specialised equipment) after it has sufficiently thickened; alternatively, it can be pumped if it is still sufficiently liquid. It is essential to plan for sludge removal and allocate financial resources for it.
Costs	<ul style="list-style-type: none"> • Considering the land required, the construction costs and the need for sludge removal equipment, the capital costs are relatively expensive. • The operating costs are low, with the major expense being the regular sludge removal.
Health aspect	<ul style="list-style-type: none"> • Both incoming and thickened sludge are pathogenic.

	<ul style="list-style-type: none"> Workers should be equipped with proper personal protective equipment (boots, gloves, and clothing).
References	Dodane et al., 2014; Strande et al., 2014; Gensch et al., 2018

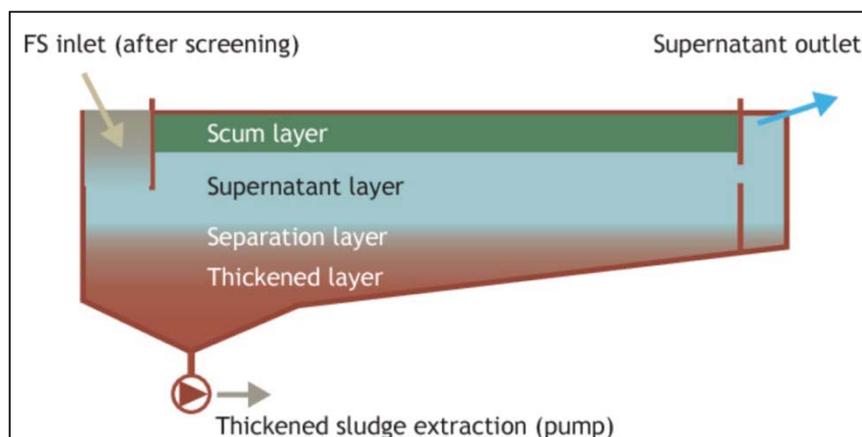


Figure 6-5: Settling-thickening tank

6.4.2 Unplanted Drying Beds

The unplanted drying beds consist of layers of filtration media such as coarse gravel, fine gravel, sand, and sometimes geotextile fabric, designed to dewater sludge and separate solids from liquid without the presence of vegetation. The coarse gravel layer is the bottom layer of the drying bed and consists of coarse gravel or rocks. It provides structural support and facilitates drainage by allowing water to flow freely through it. The fine gravel layer is above the coarse gravel layer; it helps in further filtration and provides additional support for the subsequent layers. The sand layer is usually placed above the fine gravel layer. It acts as the primary filtration medium, trapping suspended solids and allowing water to percolate through. The geotextile fabric or membrane may be placed above the sand layer to prevent fine particles from migrating into the sand and gravel layers below. It helps maintain the integrity of the filtration system. The raw or pre-settled FS is loaded on the bed and moisture from the sludge is evacuated by percolation at the bottom and evaporation at the top surface. The dehydrated sludge is suitable for disposal. Further treatment for pathogen removal is essential if the dried sludge is to be reused (Jayathilake et al., 2019; Tsida, 2020). The unplanted drying bed takes too long for dehydration, as the final moisture content after 20 to 25 days of drying should be approximately 30 - 50% and needs to be desludged before fresh sludge is applied (Jayathilake et al., 2019). **Table 6.17** illustrates the benefits and constraints of unplanted drying beds and **Table 6.18** gives the techno-economic aspects of the process and **Figure 6.6** illustrates the image of an unplanted drying bed and its filter media (Strande et al., 2014).

Table 6.17: Benefits and constraints of unplanted drying beds (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> Low operating costs; Built and repaired with locally available material; Requires no energy; 	<ul style="list-style-type: none"> The solids are not hygienically safe as insects (worms, cockroaches, etc) can be found in the solids; Protection against rainfall is needed;

Guidelines for Faecal Sludge Collection, Disposal and Valorisation

- Simple mechanical operation and maintenance;
 - Good dewatering efficiency in dry and hot climates.
 - Require large footprint;
 - Presence of odours and flies.
 - Long processing times;
 - Incomplete pathogen reduction;
 - Potential contamination of the surrounding area by the transport of aerosols formed from the sludge.
- (Jayathilake et al., 2019; Tsida, 2020)
-

Table 6.18: Techno-economic aspects of unplanted drying beds Strande et al., 2014; Gensch et al., 2018

Design	<ul style="list-style-type: none"> • Drying beds require the availability of gravel and sand of the correct grain size.
Considerations	<p>Furthermore, piping for the drainage is needed.</p> <ul style="list-style-type: none"> • The drainage pipes are covered by three to five graded layers of gravel and sand. • The bottom layer should be coarse gravel and the top layer fine sand (0.1 to 0.5 mm effective grain size). • The top sand layer should be 20 to 30 cm thick because some sand will be lost each time the sludge is removed. • To optimise the process, sludge application can be alternated between two or more beds. • The inlet should be equipped with a splash plate to prevent erosion of the sand layer and to allow for even distribution of the sludge. The bed surface depends essentially on the characteristics of the local sludge and its capacity to dry, and on the weather. • The design of the unplanted drying beds must ensure access to people and trucks for discharging the sludge and removing the dried sludge. • If installed in wet climates, the facility should be covered with a roof and special caution should be given to prevent the inflow of surface runoff after rainfalls.
Operation and maintenance	<ul style="list-style-type: none"> • Trained staff for operation and maintenance is required. • Dried sludge can be removed after 20 to 25 days, depending on climatic conditions. It can be removed with shovels and wheelbarrows. • Because some sand is lost with every removal of sludge, the top layer must be replaced when it gets thin. • The discharge area must be kept clean and the effluent drains should be regularly flushed.
Costs	<ul style="list-style-type: none"> • This is an option with relatively expensive capital costs and low operating costs. As there is considerable space required, the land costs might be high.
Health Aspect	<ul style="list-style-type: none"> • Both the incoming and dried sludge are pathogenic. Workers should be equipped with proper personal protective equipment. • The dried sludge and effluent are not sanitised and may require further treatment or storage, depending on the desired end-use. • Unplanted drying beds may cause a nuisance for nearby residents due to bad odours and the presence of flies. Thus, it should be located away from residential areas

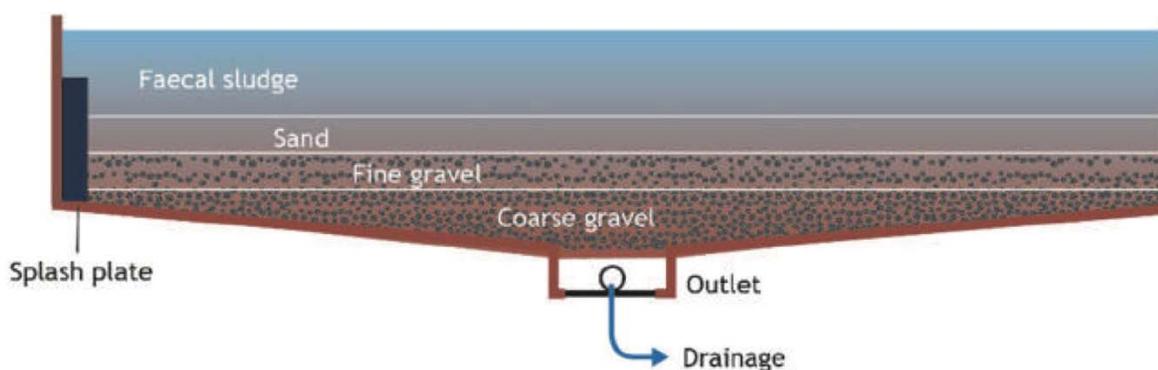


Figure 6-6: Cross section of an unplanted drying bed with its filter media (Strande et al., 2014)

6.4.3 Planted Drying Beds

Planted drying bed functions by allowing sludge to drain and percolate through layers of soil and gravel, where microorganisms and plant roots naturally break down organic matter and remove pathogens. It consists of three key layers:

1. Gravel Layer – The bottom layer, composed of gravel or coarse aggregate, facilitates drainage, allowing excess water to flow out while supporting the upper layers.
2. Sand Layer – Positioned above the gravel, this layer provides additional filtration, helping to remove fine particles and contaminants as the sludge percolates through.
3. Soil Layer – The top layer serves as the primary treatment medium, hosting microorganisms that degrade organic matter and pathogens. It also supports plant roots, which absorb nutrients and contribute to sludge treatment.

Unlike unplanted drying beds, planted drying beds incorporate vegetation such as reeds (*Phragmites* sp.), cattails (*Typha* sp.), antelope grass (*Echinochloa* sp.), and papyrus (*Cyperus papyrus*). These plants enhance treatment through transpiration, which accelerates sludge drying. As the sludge dehydrates, nutrients are absorbed by the plants, and the remaining solids can be periodically removed for safe disposal or reuse.

A key advantage of planted drying beds is that they do not require desludging after every feeding/drying cycle. Fresh sludge can be applied directly on top of previous layers, preserving plant root structures that help maintain the filter's porosity. Desludging is only necessary every 5 to 10 years, and the removed sludge serves as a nutrient-rich soil amendment suitable for agricultural use.. **Table 6.19** shows the benefits and constraints of planted drying beds and **Table 6.20** gives techno-economic aspects of the planted drying beds and **Figure 7.6** illustrates a drying bed with its filter media.

Table 6.19: Benefits and constraints of planted drying beds (Tilley et al., 2014; Spuhler, 2019)

Benefits	Constraints
<ul style="list-style-type: none"> • Can handle high loading; • Can be built and repaired with locally available materials; • Offer a better sludge treatment than unplanted drying; • Relatively low capital costs and operating costs. • Production of biomass that can be valorised 	<ul style="list-style-type: none"> • Requires a large land area; • Odours and flies may be noticeable; • Long storage times; • Labour-intensive removal; • Requires expert design and construction; • Leachate requires further treatment.

Table 6.20: Techno-economic aspects of planted drying beds (Tilley et al., 2014; Strande et al., 2014; Gensch et al., 2018; Spuhler, 2019)

Design	A general design for layering the bed is (i) a gravel layer (bottom layer) with a depth of approximately 10-20 centimeters; (ii) a sand layer (middle layer) with a depth of around 30-50 centimeters; and a topsoil layer with a depth of 20-30 centimeters.
Considerations	<ul style="list-style-type: none"> • Free space (1 m) should be left above the top of the sand layer to account for about three to five years of accumulation; a classic accumulation rate under tropical conditions is 20–30 cm/year. • Reeds (<i>Phragmites sp.</i>), antelope grass (<i>Echinochloa sp.</i>) and papyrus (<i>Cyperus papyrus</i>) are suitable plants for the filter. Local, non-invasive species can also be used if they grow in damp. • Sludge should be applied every three to seven days in layers between 7 to 10 cm thick, depending on the sludge characteristics, the environment and operating constraints. Sludge application rates of 100 to 200 kg total solids/m²/year have been reported in warm tropical climates. In colder climates, loading rates from 50 to 70 kg total solids/m²/year are common. • Two or more parallel beds should be alternately used to allow for sufficient degradation and pathogen reduction of the top layer of sludge before it is removed. The leachate drained by the drainage pipes must be treated properly.
Operation and maintenance	<ul style="list-style-type: none"> • Trained operation and maintenance staff are required. • Staff should be trained to distribute the sludge on the different beds properly and to manage the plants. • The plants should be grown sufficiently before applying the sludge. • The acclimation phase is crucial and requires much care. • Plants should be periodically thinned and/or harvested. • After five to ten years, sludge can be removed, manually or mechanically. • Drains must be maintained, and the effluent properly collected and subjected to further treatment.
Costs	<ul style="list-style-type: none"> • Planted drying beds require medium capital and have low operating costs. • The main capital costs are for civil engineering work and for appropriate filter media. Additional costs are for sludge removal and replanting.

- Health aspect**
- Due to the hazardous nature of FS, workers are required to use personal protective equipment.
 - Depending on the desired end-use, further storage and drying might be required.
 - The planted beds may attract wildlife, including snakes.
 - The treatment process being aerobic, the odours are not strong and are mainly generated during the discharge from the trucks

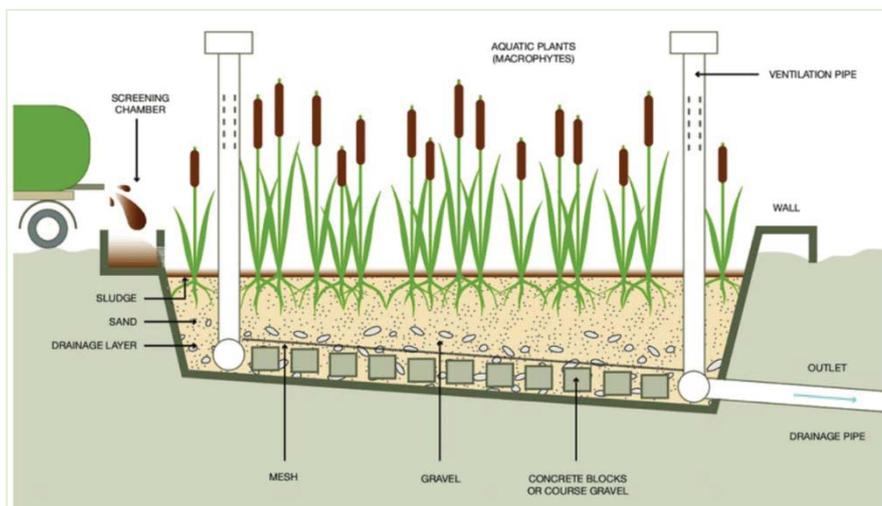


Figure 6-7: Planted drying beds with its filter media (Josiane et al., 2014)

6.4.4 Dewatering

Dewatering involves the mechanical separation of water from sludge to reduce its volume and increase the concentration of solids. This process is vital in FSM systems, particularly in resource-constrained settings where sophisticated treatment infrastructure may be lacking. Dewatering serves as a crucial initial step in the treatment of FS, facilitating subsequent processes such as composting, anaerobic digestion, or thermal treatment. By removing excess water, dewatering enhances the sludge's handling, transportation, and treatment efficiency (Strande et al., 2014). Common mechanical dewatering methods include the use of filter presses, centrifuges, belt presses, and screw presses, each employing pressure or centrifugal force to separate water from the sludge (Strande et al., 2014). This results in a drier, more concentrated sludge product that is easier to manage and treat further. **Table 6.21** illustrates the benefits and constraints of dewatering and **Table 6.22** illustrates the techno-economic aspects of dewatering.

Table 6.21: Benefits and constraints of dewatering (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Efficient water removal, leading to volume reduction • Concentration of solids, enhancing further treatment; • Preparation for subsequent treatment processes. 	<ul style="list-style-type: none"> • Energy-intensive process; • Maintenance requirements for dewatering equipment; • Sensitivity to variations in sludge characteristics

Table 6.22: Techno-economic aspect of dewatering (from Strande et al., 2014)

Design Considerations	<ul style="list-style-type: none"> • Selection of appropriate dewatering equipment (e.g., filter presses, centrifuges) must be based on sludge characteristics and treatment goals. • The design of infrastructure for dewatering operations should encompass provisions for sludge feeding, management of dewatered sludge, and wastewater handling. • Space requirements, environmental factors, and adherence to regulatory standards must be taken into account during the design phase.
Operation and maintenance	<ul style="list-style-type: none"> • Regular monitoring of dewatering performance is necessary, which includes solids content of dewatered sludge and quality of wastewater. • Regular maintenance of dewatering equipment is essential, which includes tasks like cleaning, lubrication, and replacing parts as necessary. • Training of operators in safe and efficient dewatering practices, including handling of equipment and compliance with health and safety guidelines.
Costs	<ul style="list-style-type: none"> • The initial capital expenditure required involves the procurement and installation of dewatering equipment and infrastructure. • Operational costs include energy consumption, maintenance, chemical additives (if required), and labour.
Health aspect	<ul style="list-style-type: none"> • Effective management of sludge and wastewater is necessary to mitigate potential health hazards linked to pathogens, odours, and chemical contaminants. • Need for implementation of measures to protect workers and surrounding communities from exposure to hazardous materials and airborne pollutants.

6.5 THERMAL TREATMENT PROCESSES

Drying FS using different technologies can achieve up to 90% of dry solids (Diener et al., 2014). Drying methods are classified as passive or active, where passive drying is dependent on natural mechanisms of evaporation such as wind and solar radiation, in drying beds. Passive drying in drying beds takes time, about few weeks depending on the FS content, loading rate, climate and treatment design (Andriessen et al., 2019). Active drying methods, also referred to as thermal drying, involve the addition of energy in terms of heat, which can be hot air or flue gas, radiation (microwave, infrared), and solar radiation (e.g in a greenhouse with mechanical ventilation) (Andriessen et al., 2019).

6.5.1 Thermal Pasteurisation

Thermal pasteurisation is based on the principle of heat treatment to kill pathogens and reduce the microbial load in the sludge. The process involves heating the sludge to a specific temperature for a defined period, effectively destroying harmful microorganisms while retaining organic matter and nutrients. Thermal pasteurisation typically involves heating FS to temperatures ranging from 70°C to 80°C for a duration of 30 minutes to 1 hour. This combination of temperature and time is sufficient to achieve pathogen inactivation, making the treated sludge safer for subsequent handling, disposal, or reuse (Strande et al., 2014). The basic principle behind thermal pasteurisation is based on the sensitivity of pathogenic microorganisms to heat. By

subjecting the sludge to elevated temperatures, pathogens such as bacteria, viruses, and helminth eggs are rapidly inactivated, reducing the risk of disease transmission associated with untreated sludge (Strande et al., 2014). **Table 6.23** illustrates the benefits and constraints of thermal pasteurisation and **Table 6.24** gives techno-economic aspects of thermal pasteurisation.

Table 6.23: Benefits and constraints of thermal pasteurisation (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none">• Preservation of organic matter and nutrients;• Effective pathogen inactivation;• Reduction of odours and attraction of insects and flies	<ul style="list-style-type: none">• Energy-intensive process;• High initial investment in equipment;• Requires proper temperature monitoring and control;

Table 6.24: Techno-economic aspect of thermal pasteurisation (Strande et al., 2014)

Design Considerations	<ul style="list-style-type: none"> • Proper sizing of pasteurisation equipment to accommodate sludge volume and achieve required temperature levels.
Operation and maintenance	<ul style="list-style-type: none"> • Regular calibration and monitoring of temperature controls, along with the upkeep of heating elements and insulation.
Costs	<ul style="list-style-type: none"> • The initial capital outlay for pasteurisation equipment, as well as the continuous expenses related to energy consumption and maintenance.
Health aspect	<ul style="list-style-type: none"> • Must ensure proper handling procedures to prevent exposure to hot sludge, and adherence to safety protocols.

6.5.2 Thermal Drying

Thermal drying of FS is a treatment process that involves the application of heat to reduce the moisture content of sludge, thereby rendering it more stable and suitable for disposal or reuse. This method utilises various thermal drying technologies such as direct dryers, indirect dryers, fluidised bed dryers, and paddle dryers to evaporate moisture from the sludge through the application of heat (Strande et al., 2014). Thermal drying relies on the transfer of heat energy to the sludge, which increases the temperature of the sludge and facilitates the evaporation of water. As moisture is removed, the sludge becomes drier and more concentrated, making it easier to handle, transport, and dispose of. Thermal drying can also contribute to the reduction of pathogens and organic matter in the sludge, thereby improving its environmental safety and stability. **Table 6.25** gives the benefits and constraints of thermal drying and **Table 6.26** gives the techno-economic aspect of thermal drying.

Table 6.25: Benefits and constraints of thermal drying (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Significant moisture reduction; • Pathogen reduction; • FS Volume reduction; • Potential for sludge reuse or beneficial use; • Improved handling and transportability. 	<ul style="list-style-type: none"> • Energy-intensive process; • High initial investment in equipment; • Potential emissions and environmental concerns; • Operational complexities and maintenance requirements

Table 6.26: Techno-economic aspect of thermal drying (Strande et al., 2014)

Design Considerations	<ul style="list-style-type: none"> • Ensure proper sizing of drying equipment to accommodate sludge volume and achieve desired drying rates. • Select appropriate drying technology based on sludge characteristics, space availability, and environmental factors.
Operation and maintenance	<ul style="list-style-type: none"> • Regular monitoring of temperature, airflow, and residence time to ensure optimal drying conditions.
Costs	<ul style="list-style-type: none"> • High initial investment in drying equipment, including purchase, installation, and site preparation. • Ongoing operational costs, including energy consumption, maintenance, and labor expenses.
Health aspect	<ul style="list-style-type: none"> • Implementation of safety protocols to prevent exposure to hot surfaces and potential emissions. • Ensuring proper handling procedures to minimise health risks associated with handling and disposal of dried sludge

A Case Study - Latrine Dehydration and Pasteurisation (LaDePa)

The Latrine Dehydration and Pasteurisation (LaDePa) system was developed by eThekweni Water and Sanitation (EWS) in collaboration with Particle Separation Solutions (Pty) Ltd (PSS) and piloted between 2009 and 2012 (Still et al., 2015). It was designed to address challenges in Durban, South Africa, where thick sludge from VIP latrines containing solid waste required treatment. The LaDePa process converts faecal sludge with 20% to 35% dry solids into sanitised and nutrient-rich pellets (Septien et al., 2018).

The existing LaDePa machine is a scaled-down prototype, operating at a 1:10 ratio compared to the full-scale model but functioning in a similar manner. The process begins with sludge extrusion to form pellets, which are placed onto a porous steel conveyor belt. These pellets are then transported into a heating zone, where they are exposed to thermal radiation from two medium-wave infrared (MIR) emitters. A vacuum chute ensures continuous airflow to facilitate moisture removal. Finally, the processed pellets exit the system via a discharge chute. **Figure 6.8** illustrates a schematic diagram of a LaDePa process and **Table 6.27** presents the benefits and constraints of LaDePa.

Operation and Maintenance of LaDePa

- **Stage 1:** The LaDePa process separates the FS from the solid trash material by compressing the mixture in a screw compactor with lateral ports, through which the FS is extruded (Stage 1). The trash material exits from the end of the screw conveyer.
- **Stage 2:** The sludge is placed onto a porous moving steel belt in a 25 to 40 mm thick layer of extruded cylinders (of 6 mm diameter). To pre-dry the sludge, hot exhaust gases from the plant's internal combustion engine travel upwardly through the belt (Stage 2).

- **Stage 3:** The sludge is subsequently dried and pasteurised under vacuum using medium wave infrared radiation (MWIR). The sludge on the belt has a residence time of 8 minutes (4 minutes under upward exhaust gas flow at 500 °C and 4 minutes under MWIR under vacuum at 750 °C) (Harrison & Wilson 2012).

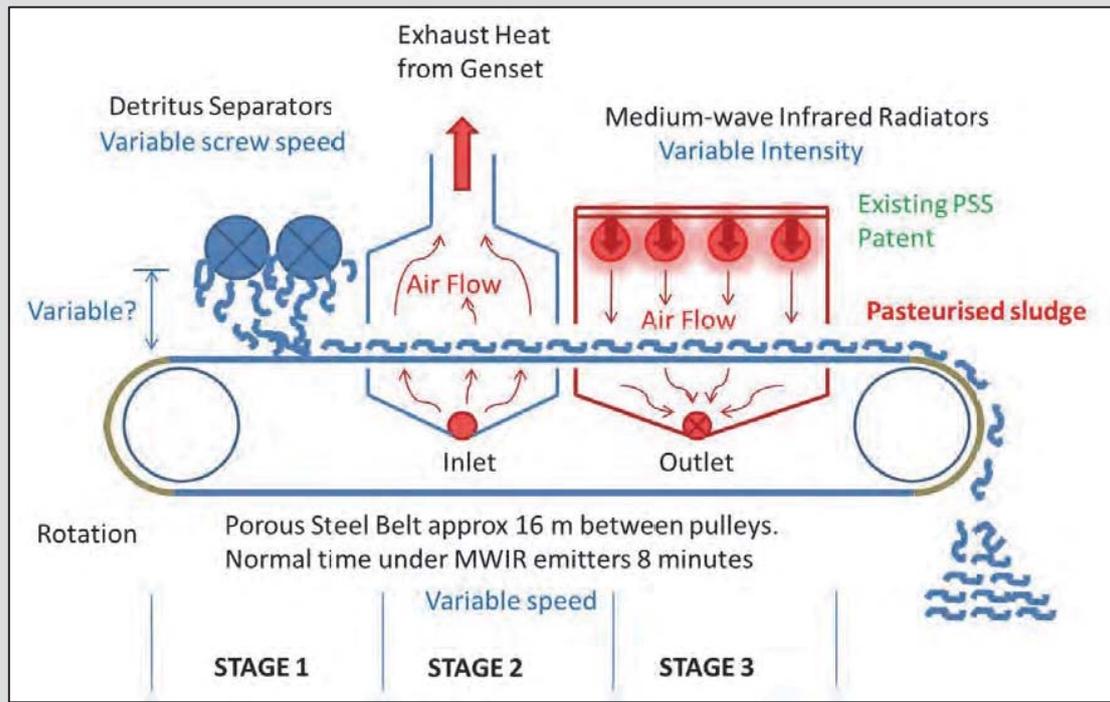


Figure 6-8: Schematic diagram of the LaDePa Process (Cottingham, 2013)

Table 6.27: Benefits and constraints of LaDePa(Harrison and Wilson, 2012)

Benefits	Constraints
<ul style="list-style-type: none"> • Uses infra-red thermal treatment to destroy pathogens. • Reduces FS impact on human health. • Reduces transport and disposal costs of FS. • Produces pellets that can be used as soil additives, therefore improving agricultural production • Reduce impacts on the limited hazardous material landfill capacity. 	<p>Relatively new and has not been deployed on a large scale.</p> <p>The LaDePa is neither a simple nor cheap technology.</p>

6.6 THERMOCHEMICAL TREATMENT PROCESSES

Carbonisation is used to convert dried biomass into a fuel that more closely resembles coal, and can improve the energy density (calorific value) of the fuel (Andriessen et al., 2019). The pyrolysis, hydrothermal carbonisation, combustion and supercritical oxidation are technologies that have the potential to produce biochar as an end-product from FS. Biochar is the charcoal-like material that is obtained through carbonisation processes. It can be produced for environmental applications such as soil improvement to aid in carbon sequestration, used as biofuel and used as an adsorbent for water and wastewater treatment. The production of biochar from FS offers complete destruction of pathogens due to high processing temperatures and a high value-added treatment product (Krueger et al., 2020).

6.6.1 Pyrolysis

Pyrolysis is a thermochemical conversion of biomass into biochar, tars and gases, such as carbon dioxide, carbon monoxide and light hydrocarbons, in the absence of oxygen (Gold et al 2018). The absence of oxygen leads to the production of carbon-based products (Strande et al 2014). Pyrolysis is divided into 2 categories, fast pyrolysis and slow pyrolysis. The fast pyrolysis involves rapidly heating biomass to temperatures typically ranging from 300°C to 700°C in the absence of oxygen, resulting in the rapid decomposition of organic compounds into bio-oil, a volatile liquid, and biochar. Fast pyrolysis processes are characterised by short residence times, typically on the order of seconds to minutes, and produce higher yields of bio-oil compared to biochar. Slow pyrolysis takes place in a temperature range of 300°C to 550°C. Slow pyrolysis processes have longer residence times, ranging from hours to days, allowing for more thorough decomposition of organic materials. Slow pyrolysis produces higher yields of biochar and lower quantities of bio-oil compared to fast pyrolysis, making it more suitable for biochar production and carbon sequestration applications. In the pyrolysis for biochar production, the biomass (FS) is exposed to a slow heating rate at a given residence time. The benefits and constraints of pyrolysis are presented in **Table 6.28**, and the techno-economic aspects are presented in **Table 6.29**.

Table 6.28: Benefits and constraints of pyrolysis (Strande et al., 2014; Gold et al., 2018)

Benefits	Constraints
<ul style="list-style-type: none"> • Effective pathogen reduction. • Fast treatment time. • High reduction of sludge volume. • Production of biochar. • Production of tar that can be used to recover energy. 	<ul style="list-style-type: none"> • High energy input needed. • High O&M costs.

Table 6.29: Techno-economic aspects of pyrolysis (Ward et al., 2014; WIN-SA, 2014; Gold et al., 2018; Water for People, 2019)

Design Consideration	<ul style="list-style-type: none"> • The operating temperature for pyrolysis ranges from 300 to 700°C, which is regarded as sufficient to inactivate pathogens. • In these processes char is produced, which can be used in furnaces and kilns in the same way as coal. • Pyrolysis reactors can be constructed with locally available materials (e.g. oil drum, locally produced burner) on a small scale.
Operation and maintenance	<ul style="list-style-type: none"> • Highly skilled workers are needed to operate and maintain a pyrolysis reactor. • Since high temperatures are reached, only trained staff should operate and maintain the reactor and be in the vicinity.
Costs	<ul style="list-style-type: none"> • Capital costs for small-scale pyrolysis reactors are low to medium while O&M costs are relatively high as specialised personnel is needed.
Health aspect and/or social acceptance	<ul style="list-style-type: none"> • Along with heat, by-products of pyrolysis include several pollutant gas, as well as tar and soot (pollutant aerosol). • These byproducts need further treatment or safe disposal, as they might be hazardous to human and environmental health.

6.6.2 Hydrothermal Carbonisation (HTC)

Hydrothermal carbonisation (HTC) is a thermochemical process for converting biomass that is high in moisture content (75% to 90%) into carbonaceous solids, commonly called hydrochar (Diener et al., 2014; Fakkaew et al., 2015; Afolabi et al., 2017). HTC operates over a short period of time, between 1 to 12 hours at a relatively low temperature range of 130 to 250°C with high pressures of up to 20 bars (Fakkaew et al., 2015). Energy contents of the hydrochars from primary sewage sludge carbonised at 140-200°C for 4 h ranges from 21.5 to 23.1 MJ/kg (Danso-Boateng et al. 2013) while the biochar caloric value for sewage sludge ranges from 12 to 18 MJ/Kg (Ahmad et al., 2016) and caloric value of biochar from FS ranges from 11 to 16 MJ/kg (Sun et al., 2014; Krueger et al., 2020). The energy content of the hydrochar is comparable to lignite with energy content of 15 MJ/kg and sub-bituminous with energy content of 18.2 MJ/kg. **Table 6.30** illustrate the benefits and constraints of HTC and **Table 6.31** illustrate the techno-economic aspects of HTC.

Table 6.30: Benefits and constraints of HTC (Fang et al., 2019; Musvoto et al., 2022)

Benefits	Constraints
<ul style="list-style-type: none"> • Conversion of sludge into biochar and biogas. • Pathogen reduction. • FS volume reduction. • Reduction in odours and flies and insect attraction. • Biochar can be used as an activated charcoal substitute 	<ul style="list-style-type: none"> • High energy requirements. • Possible emissions of volatile organic compounds.

Table 6.31: Techno-economic aspects of HTC (Fang et al., 2019)

Design Considerations	<ul style="list-style-type: none"> • Selection of appropriate reactor size and configuration to accommodate sludge volume and achieve the desired carbonisation rate.
Operation and maintenance	<ul style="list-style-type: none"> • Monitoring and control of process parameters such as temperature, pressure, and residence time to ensure optimal carbonisation efficiency. • Regular inspection and maintenance of reactor components, including seals, valves, and heating elements.
Costs	<ul style="list-style-type: none"> • The initial capital is required for reactor infrastructure, encompassing procurement, installation, and site preparation. • Ongoing operational costs, including energy consumption, maintenance, and labor expenses.
Health aspect	<ul style="list-style-type: none"> • Require the implementation of safety protocols to minimise exposure to high-pressure steam and potential emissions.

6.6.3 Combustion

Combustion involves the rapid oxidation of organic matter in FS at high temperatures (typically between 800°C to 1,000°C) in the presence of oxygen. This process is commonly carried out in incinerators or fluidised bed reactors, where sludge is subjected to intense heat, resulting in the conversion of organic components into ash, gases, and heat. The high temperatures achieved during combustion effectively destroy pathogens and reduce the volume of sludge (Strande et al., 2014). **Table 6.32** gives the benefits and constraints of combustion and **Table 6.33** gives the techno-economic aspects of combustion.

Table 6.32: benefits and constraints of combustion (Strande et al., 2014)

Benefits	Constraints
<ul style="list-style-type: none"> • Effective pathogen inactivation; • FS volume reduction; • Reduction in organic matter and odour. 	<ul style="list-style-type: none"> • Potential emission of pollutants; • High energy requirement; • Ash disposal and management challenges.

Table 6.33: Techno-economic aspects of oxidation (Strande et al., 2014)

Design	<ul style="list-style-type: none"> • Selection of appropriate combustion technology and reactor design is necessary to accommodate sludge volume and achieve desired combustion efficiency.
Considerations	<ul style="list-style-type: none"> • integration of emission control systems to mitigate air pollutants and odours.
Operation and maintenance	<ul style="list-style-type: none"> • Continuous monitoring of combustion parameters such as temperature, oxygen levels, and residence time to ensure optimal treatment efficiency. • Regular inspection and maintenance of combustion equipment, including burners, boilers, and exhaust systems.
Costs	<ul style="list-style-type: none"> • Require initial investment in combustion equipment, including procurement, installation, and site preparation. • Ongoing operational costs, including fuel, electricity, maintenance, and regulatory compliance expenses.
Health aspect	<ul style="list-style-type: none"> • Recommend implementation of safety protocols to minimise exposure to combustion by-products, including particulate matter and volatile organic compounds.

6.6.4 Supercritical Oxidation

Supercritical oxidation (SCO) is a thermochemical process that employs high temperatures (above 374°C) and pressures in a supercritical water environment to oxidise organic compounds present in FS. Under supercritical conditions, water acts as both a solvent and an oxidising agent, facilitating the rapid oxidation of organic matter into water, carbon dioxide, and other by-products. SCO is known for its effectiveness in pathogen inactivation and the reduction of organic pollutants (Fang et al., 2018). **Table 6.34** gives benefits and constraints of SCO and **Table 6.35** gives the techno-economic aspect of combustion.

Table 6.34: Benefits and constraints of supercritical oxidation (Fang et al., 2018)

Benefits	Constraints
<ul style="list-style-type: none"> • Effective pathogen inactivation. • Reduction in organic pollutants. • Potential for resource recovery. • Reduced sludge volume. • Minimisation of odours and emissions. 	<ul style="list-style-type: none"> • High energy requirements. • Complex system setup and operation. • Cost and complexity of maintenance. • Requirements for specialised equipment and skilled personnel.

Table 6.35: Techno-economic aspect of supercritical oxidation (Fang et al., 2018)

Design Considerations	<ul style="list-style-type: none"> • Require appropriate selection of reactor size and configuration to accommodate sludge volume and achieve desired oxidation rates.
Operation and maintenance	<ul style="list-style-type: none"> • The monitoring and control of process parameters like temperature, pressure, and residence time are essential to guarantee optimal oxidation efficiency.
Costs	<ul style="list-style-type: none"> • Initial investment in reactor infrastructure, including procurement, installation, and site preparation. • Ongoing operational costs, including energy consumption, maintenance, and labor expense.
Health aspect	<ul style="list-style-type: none"> • Implementation of safety protocols to minimise exposure to high-pressure steam, supercritical water, and potential emissions.

Case Study: The Centre for Science and Environment (CSE) India: Evaluation of FSTPs and Sewerage Treatment Plants (STPs)

In India, a large-scale evaluation of 69 treatment plants across eight states was conducted over two years, which included both Faecal Sludge Treatment Plants (FSTPs) and Sewerage Treatment Plants (STPs), with an installed capacity of 1.6 million liters per day (MLD). A variety of faecal sludge treatment technologies were tested, including Decentralised Wastewater Treatment (DEWATS), geotubes, moving bed bioreactor (MBBR), pyrolysis, and electrocoagulation. Additionally, co-treatment with STPs using technologies such as sequencing batch reactor (SBR), activated sludge process (ASP), upflow anaerobic sludge blanket (UASB), and waste stabilisation ponds was evaluated. Telangana (with 10 FSTPs and 2 STPs), in particular, demonstrated a wider adoption of diverse technologies compared to other states (Vijayan et al., 2023).

A significant issue noted during the study was that many FSTPs were operating below their designed capacity, largely due to inconsistent faecal sludge collection, which impacted treatment efficiency. Despite this, most plants were successful in reducing the Biochemical Oxygen Demand (BOD), meeting the prescribed limit of 30 mg/L by reducing raw sludge BOD from an average of 8,143 mg/L to 127 mg/L. Six FSTPs did not meet the BOD standard, which represents a small proportion of plants evaluated. However, a large number of plants did not meet the Chemical Oxygen Demand (COD) limit of 50 mg/L, highlighting the need for improved secondary treatment processes. Plants in general received high COD feed concentrations (average from all plants was around 50 g COD/L) (Vijayan et al., 2023).

Pathogen removal, specifically the reduction of faecal coliforms, was another area of concern. The study found that pathogen removal was inconsistent across different technologies, pointing more to operational and maintenance issues than to the technologies themselves. Even though many plants employed chlorination units for microbial load reduction, numerous STPs failed to meet the microbial discharge limits. One of the critical gaps identified was the lack of consistent faecal coliform testing, despite regulatory standards being in place (Vijayan et al., 2023).

The operational challenges were largely attributed to variability in the availability of faecal sludge and inadequate maintenance, particularly in systems like DEWATS and MBBR. Furthermore, solids were often stored at the treatment sites without undergoing further treatment or reuse, leading to incomplete pathogen removal. A key takeaway was the need for better nutrient recovery and pathogen-free sludge reuse to make FSM more sustainable. Overall, the performance of FSTPs was deemed satisfactory when properly managed, but the choice of treatment technologies depended on various factors, including land availability, capital expenditure, human resources, and the availability of technical expertise (Vijayan et al., 2023).

6.7 SUMMARY

South Africa is in the early stages of scaling decentralised FS treatment and can draw key lessons from India's experience. In this chapter, we included a plethora of technologies that are available. Based on CSE report (Vijayan et al., 2023), South Africa should learn from other country approaches. South Africa should explore multiple treatment technologies suited to local conditions rather than relying on a single approach. Key to the success of FSTPs in South Africa will be to have a coordinated system of faecal sludge collection and transport strategies that are linked to the treatment system. As was seen in India, underloading systems could be a possibility if this chain is not properly managed (Vijayan et al., 2013). Plant overloading could be a possibility if it receives too much feed FS. In this scenario, having space to stockpile to feed the plant according to design specifications could be a possible option. But this would need to be timed with the emptying and transport contract (if separate). Harrison and Wilson (2012) have also noted the importance of managing the emptying and transport with the treatment of FS, and have proposed different contracting models for achieving FSM in South Africa.

With respect to performance compliance, coliform indicators were mostly above limits in India. South Africa must ensure effective post-treatment and regular microbial testing to prevent similar issues. Municipal capacity and financial capability to ensure compliance requirements of FSTPs need to be evaluated in addition to municipal requirements for Blue and Green Drop Certification. Proper operation and maintenance, alongside adequate training and technical capacity, are crucial for the success of FSTPs. India's limited reuse of treated sludge suggests that South Africa should prioritise FS resource recovery strategies alongside implementing FSTPs to enhance sustainability. By addressing these issues proactively, South Africa can avoid common pitfalls and build a robust, scalable FSM system.

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CHAPTER 7: GUIDELINES FOR SAFE END-USE / DISPOSAL OF FAECAL SLUDGE

7.1 INTRODUCTION

The key principle of the end-use/disposal step is to reduce the risks to sanitation workers and the wider community to the eventual remaining pathogen hazards (WHO, 2018). End-use of faecal sludge (FS) refers to the safe and beneficial use of human excreta, i.e. faeces and urine from on-site sanitation technologies. The type of end-use should decide the level of treatment, while disposal of FS refers to the ultimate discharging of FS into the environment as a low risk material (Government of Bihar, 2018; WHO, 2018). There are different options for FS reuse, particularly as a fertiliser, soil conditioner (land application in raw form or as compost or co-compost or as a biochar), building material (cement mixture), protein source (e.g. animal feed via the black soldier fly) and biofuel (biogas, char briquettes and biosolid) (Ward et al., 2017, Appiah-Effah et al., 2014, Gitau et al., 2020). End-use products may provide a source of revenue, which has the potential to improve business models (Government of Bihar, 2018). **Table 7.1** shows the end-use products that can be obtained from the various treatment processes and also includes a description of the end-use products, the recovered resource and the likely pathogen level of each end-use product based on the treatment technology (WHO, 2018).

Table 7.1: Selection criteria for end-use products (Strande et al. 2014; Tilley et al. 2014 and Strande, 2017)

Treatment Product	Resource Recovery	End-use technology/ Product	Re-use description	Pathogen level
Untreated Sludge buried	Organic matter, Nutrients	Soil conditioner, fertiliser	Untreated sludge buried and used to grow trees	Low to high, depending on FS characteristics
Dewatered Sludge	Organic matter	Soil conditioner fertiliser	Dewatered sludge applied to land	High
Dried Sludge	Energy	Solid fuels	Pellets, briquettes, powder to be burned	Null
Compost (powder/ pellets)	Organic matter, Nutrients	Soil Conditioner, Fertiliser	Compost, powder or pellets applied to land	Low to medium
Biochar	Energy	Solid fuel; soil amendment	briquettes	Null
Biogas	Energy	Gaseous fuel	Renewable energy source	Null

7.2 END-USE PRODUCTS

Valuable resources can be recovered from FS in a variety of methods after treatment (Gold et al., 2016; Nikiema et al., 2014; Diener et al., 2014). The most popular end-use product is in the agriculture sector, where it is used as a fertiliser and soil improver. Sludge valorisation can also be in the form of other varieties of products, including biochar, biogas, protein, building material and biofuels. **Figure 7.1** illustrates the types of reuse and recovery of resources from FS.

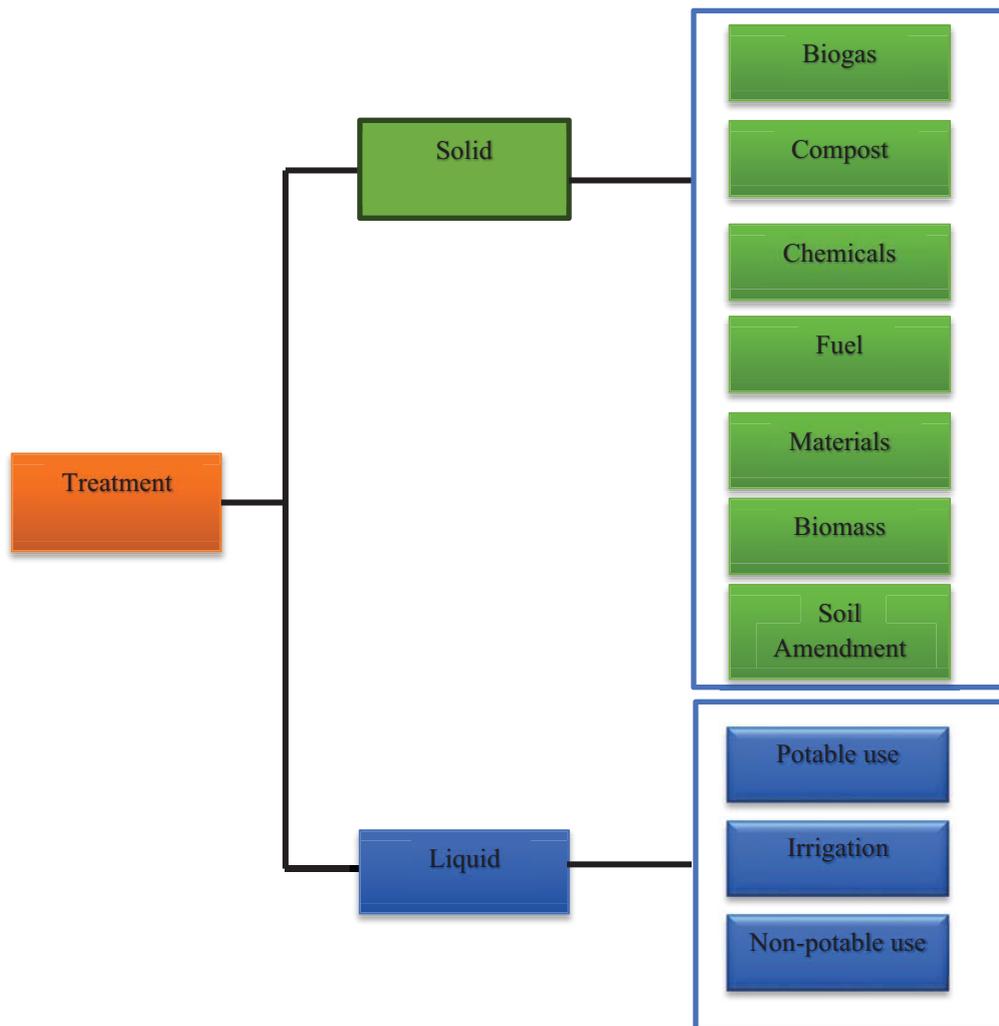


Figure 7-1: Types of reuse and recovery of resources from faecal sludge (adapted from Mallory et al., 2022)

7.2.1 FS Treatment By-products

FS treatment produces several by-products, which can vary depending on the treatment process used. **Table 7.2** illustrates the FS treatment by-products. These by-products of FS treatment have the potential to be valuable resources if managed properly. They offer opportunities for resource recovery, energy generation, and environmental sustainability, contributing to the circular economy and improving sanitation practices worldwide

Table 7.2: FS treatment by-products (Strande et al., 2014; adapted from Mallory et al., 2020)

Resource Recovery	End-use technology/ Product
Recovered water	Irrigation
	Not potable use
	Recharge
Urine	Struvite
	Liquid fertiliser
Building material	Construction
Food	Animal fodder
	Protein feed
Nutrients	Irrigation water
Biogas	Heating
	Energy generation
Fuel	Biochar
	Biodiesel
Compost	Agriculture gardening
Aquaculture	Plants or fish from treatment ponds

7.3 APPLICATION OF FS IN AGRICULTURE ACTIVITIES

The application of FS in agriculture represents a promising approach to closing the sanitation loop, improving soil fertility, and supporting sustainable food production systems while addressing public health and environmental challenges. **Table 7.3** gives an overview of the benefits and constraints of the application of FS in the agriculture sector. The application of FS in agriculture involves using treated and sanitised FS as a soil conditioner/ amendment, fertiliser, compost, pit humus, land application and the use of wastewater originating from FS for irrigation purposes, all these applications are to improve soil fertility and support plant growth.

Table 7.3: Benefits and constraints of application of FS in agriculture activities (WHO, 2006)

Benefits	Constraints
<ul style="list-style-type: none"> • Nutrient-Rich: Provides essential nutrients, such as nitrogen, phosphorus and potassium to improve soil fertility and crop yields. • Organic matter: Enhances soil structure and moisture retention, promoting better plant growth and water uptake. • Waste Management: Provides a sustainable solution for managing faecal waste. • Cost-effective: offers a low-cost alternative for soil amendment, minimising expenses associated with chemical fertilisers. • Carbon sequestration: Contribute to carbon sequestration and climate change mitigation efforts by enhancing soil organic carbon content. 	<ul style="list-style-type: none"> • Pathogen Contamination: FS may contain pathogens such as bacteria, viruses and parasites posing health risks if not properly treated and handled. • Odour & aesthetic concerns: FS emits unpleasant odours during storage, treatment and application, which potentially cause discomfort to nearby communities and workers. • Environmental Pollution: Improper application and runoff of FS can contaminate water sources, leading to waterborne diseases and the degradation of the ecosystem. • Regulatory compliance: Agricultural application of FS must comply with government regulations and guideline standards to ensure environmental & /public health. • Social acceptance: Cultural and social taboos may hinder acceptance of FS use in agriculture, requiring extensive community engagement efforts.

7.3.1 Soil Conditioner

Soil conditioners aid in the breaking up of compacted clay soils, which lack adequate air and water, both of which are necessary for microorganisms to thrive and plant roots to grow (Bloom Soil, 2022). The most common use of FS is as a soil conditioner and an organic fertiliser, due to the rich plant nutrients and organic material found in the excreta. The soil conditioner from FS can be derived from a variety of treatment technologies, including untreated sludge, dewatered sludge, compost, dried sludge, digestate from the anaerobic digestion process and solid residual from a black soldier fly process (Strande et al., 2014).

Benefits of soil conditioner:

- Soil conditioners are low cost compared to chemical fertilisers.
- They require very little skill to use properly.
- Usually contain a significant amount of micronutrients.
- Improve soil physical condition and stimulate the beneficial soil microorganisms.
- The phosphorus in organic fertilisers is less prone to soil tie-up than that from chemical fertilisers, making it more available to plants.

7.3.2 Fertiliser

The use of FS as a fertiliser is a practice that has gained attention in recent years as a sustainable way to manage waste and improve soil fertility. FS contains organic matter, nutrients, and microorganisms that can be beneficial for soil health and plant growth when properly treated and applied. FS contains valuable nutrients such as nitrogen, phosphorus, potassium, and micronutrients that are essential for plant growth. These nutrients can contribute to improving soil fertility and enhancing crop productivity. However, before FS can be used as a fertiliser, it must undergo treatment to reduce pathogens and minimise health risks associated with microbial contamination. Treatment processes such as composting, anaerobic digestion, and thermal treatment can help in reducing pathogens to levels safe for agricultural use.

Successful implementation of FS reuse in agriculture requires community engagement, awareness-raising, and social acceptance. Education on safe handling practices, proper treatment methods, and the benefits of using treated FS as a fertiliser can help in gaining community support and participation.

7.3.3 Irrigation (Liquid fraction)

Reusing the liquid fraction of FS for irrigation can be a viable option for managing the by-products of FS treatment, provided that proper precautions are taken to ensure environmental and public health protection. The liquid fraction of FS may contain nutrients such as nitrogen, phosphorus, and potassium, which can serve as valuable fertilisers for crops when applied through irrigation. However, it is important to consider the nutrient composition and balance the application rates to avoid nutrient imbalances or over-fertilisation, which can lead to environmental pollution and water quality issues. Before the liquid fraction of FS can be used for irrigation, it should undergo appropriate treatment to reduce pathogens and minimise health risks associated with microbial contamination. Treatment processes such as filtration, settling, oxidation, and disinfection can help in removing or inactivating pathogens present in the liquid fraction. The suitability of using liquid FS for irrigation depends on soil characteristics, crop type, and local agricultural practices. Conducting soil tests and crop suitability assessments can help in determining the compatibility of liquid FS with specific soil-crop systems and optimising irrigation practices for maximum benefit.

7.3.4 Land Application of FS

The digested or stabilised sludge can be applied on the land for agricultural purposes or landscaping, subject to the treatment type and also the quality of the FS. The treated sludge, such as from the planted drying beds, can be used in agriculture as it has high water retention properties and slow release of nutrients compared to chemical fertilisers (Komakech et al., 2020). **Table 7.4** gives the techno-economic aspects of land application of FS.

Table 7.4: Techno-economic aspect of land application of FS

Design consideration	<ul style="list-style-type: none"> • Solid sludge is spread on the ground surface using conventional manure spreaders, tank trucks or specially designed vehicles. • Liquid sludge (e.g. from anaerobic reactors) can be sprayed onto or injected into the ground.
Operation & maintenance	<ul style="list-style-type: none"> • The equipment used for applying sludge requires maintenance. • The amount and rate of sludge application should be monitored to prevent nutrient overloading of both the soil and water bodies.
Costs	<ul style="list-style-type: none"> • The main cost to consider is the potential transport of the sludge to the fields. • The application of sludge contributes to revenue generation by increasing agricultural yields • The application of sludge can save money if it replaces commercial fertilisers.
Health aspect and/or acceptance	<ul style="list-style-type: none"> • Workers should wear personal protective equipment • Even after treatment, sludge may not be really pathogen-free. The WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater should be consulted regarding the security measures needed to protect public and environmental health.
References	<ul style="list-style-type: none"> • Gensch et al., 2018



Figure 7-2: Application of raw or treated sludge

7.3.4.1 Application of compost

Compost is a soil-like substance resulting from controlled aerobic degradation of organic material, such as in co-composting facilities. Compost can be applied in agricultural activities as a soil conditioner/amendment, which aids in improving the soil structure by enhancing aeration, water holding capacity, and nutrient availability. The compost can be mixed into the soil before crops are planted. **Table 7.5** gives the techno-economic aspects of the application of FS as a compost and **Figure 7.3** shows a compost.

Table 7.5: Techno-economic aspect of the application of FS as a compost

Design consideration	<ul style="list-style-type: none"> • It has been shown that the productivity of poor soil can be improved by applying equal parts compost and topsoil. • Materials required for application of compost are locally available in most situations and include wheelbarrows, shovels, spades, rakes, and personal protective equipment (PPE).
Operation & maintenance	<ul style="list-style-type: none"> • Workers should wear PPE. • Conducting training on the best methods of gardening and food production may be required.
Costs	<ul style="list-style-type: none"> • The capital costs for tools to compost are generally low. • Additional infrastructure, such as greenhouses or poly-tunnels, or irrigation systems, may also be required which would increase costs. • The operating costs are low if self-managed.
Health aspect and/or acceptance	<ul style="list-style-type: none"> • Social acceptance may be a challenge for communities that are not familiar with using compost. • Conducting training and demonstration activities that promote hands-on experience can effectively show their non-offensive nature and their beneficial use.
References	<ul style="list-style-type: none"> • WHO 2006; Gensch et al., 2018



Figure 7-3: Compost (<https://www.sede.veolia.com/en/communities/waste-recovery/composting/composting-process> (Accessed: 05 February 2024).

7.3.4.2 Application of pit humus

Pit humus is the nutrient-rich, hygienically improved, humic material that is generated in double pit technologies (double VIP latrines, twin pits for pour-flush toilets) through dehydration and degradation. The

various natural decomposition processes taking place in alternating pits can be both aerobic and anaerobic in nature, depending on the technology and operating conditions. The pit humus can be used as a soil amendment in agricultural activities. **Table 7.6** gives the techno-economic aspects of pit humus.

Table 7.6: Techno-economic aspect of pit humus

Design consideration	<ul style="list-style-type: none"> Materials required for the application of pit humus are locally available in most situations and include wheelbarrows, shovels, spades, rakes, and personal protective equipment (PPE).
Operation & maintenance	<ul style="list-style-type: none"> Pit humus must be allowed to adequately mature before being removed from the system. It can then be used without further treatment. Matured pit humus will be dewatered and consolidated, making it quite difficult to remove by mechanised methods. Workers should wear PPE. Conducting training on the best methods of gardening and food production may be required.
Costs	<ul style="list-style-type: none"> The capital costs for tools to apply pit humus are generally low.
Health aspect and/or social acceptance	<ul style="list-style-type: none"> Pit humus, particularly from double pit systems that are not used correctly, poses a risk of pathogen transmission. If in doubt, material removed from the pit should be further composted in a regular compost heap before being used. Social acceptance may be low in some areas.
References	<ul style="list-style-type: none"> WHO, 2006

7.3.5 Use of Biochar

The use of biochar derived from FS in agricultural activities offers several benefits and opportunities for sustainable soil management and crop production. Biochar is a carbon-rich material produced through the pyrolysis (thermal decomposition) of organic biomass, including FS. Biochars are produced for environmental applications such as soil improvement or to aid in carbon sequestration. The use of biochar in pit latrine sludge treatment in most developing countries is still limited. This is primarily due to a lack of awareness in communities relying on pit latrines on the contaminant immobilisation potential of biochar. When amended with soil, biochar can raise soil pH, which is essential for the mitigation of micro-organic pathogens such as *E. coli* and faecal coliform bacteria (Lehmann & Joseph 2015). An increase in the organic matter, pH, conductivity, and dissolved organic C in a sandy soil using poultry manure biochar resulted in decreased soil *E. coli* and faecal coliforms migration (Mamera et al., 2021). Biochar has the ability to adsorb and immobilise heavy metals, organic pollutants, and pathogens in the soil, reducing their availability for uptake by plants and minimising environmental contamination risks. Utilising biochar derived from FS provides a sustainable solution for managing organic waste materials, closing the nutrient loop, and promoting circular economy principles in agriculture.

7.4 USE OF FAECAL SLUDGE AS AN ENERGY SOURCE

Energy production can be recovered from FS through biological and thermal processes. Biological processes such as anaerobic digestion have the potential to produce biogas, heat and a digestate. Thermal processes such as pyrolysis and hydrothermal carbonisation yield biochar, oils and gases. The quality of the solid fuels produced from FS is highly dependent on the characteristics of the initial FS. FS characteristics are highly variable, depending on residence time in containment, differences in sanitation technologies and practices, among numerous other factors. Valorisation of FS to produce solid fuels can be in two different types of processes, i.e.: (i) non-carbonised biofuel, which involves processes such as drying; (ii) carbonised biofuel, which involves processes such as pyrolysis and hydrothermal carbonisation (HTC).

7.4.1 Use of Biogas Produced through Anaerobic Digestion of FS

FS is digested anaerobically, resulting in a combination of gaseous chemicals known as 'biogas', which is composed of 50-7% methane (CH₄) and 25 - 50% carbon dioxide (CO₂) and 2-8% nitrogen. Biogas is also produced through the treatment of FS with organic solid waste through anaerobic digestion. The biodigestors operating with food waste are widely spread. The amount of gas produced is determined by operating parameters such as sludge stability, COD, and temperature. Because methane has a high calorific value, biogas has a high energy content and can therefore be used as a fuel. On average, the calorific value of biogas is approximately 20 to 25 megajoules per cubic meter (MJ/m³), calorific value is comparable to natural gas, making biogas a valuable source of renewable energy for cooking, heating, and electricity generation (Balat, 2011; Strande et al., 2014; Mladenović et al., 2016). **Table 7.7** gives ranges of gases produced through the anaerobic digestion process, **Table 7.8** illustrates the benefits and constraints of using biogas and **Table 7.9** gives the techno-economic aspect of biogas.

Table 7.7: Anaerobic digestion gases (Rasi et al., 2007)

Gas	Percentages
Methane (CH ₄)	50 - 70
Carbon dioxide (CO ₂)	30 -40
Nitrogen (N ₂)	0 - 1
Hydrogen (H ₂)	0 – 1
Hydrogen Sulfide (H ₂ S)	0 - 3

Table 7.8: Benefits and constraints of the use of biogas

Benefits	Constraints
<ul style="list-style-type: none"> • Relatively inexpensive source of energy compared to other energy sources; • Renewable energy source, provides renewable energy for cooking, heating, and electricity generation. • Can substitute fuel wood and other sources for cooking; • Comparably few operation skills and little maintenance required. 	<ul style="list-style-type: none"> • Initial Investment: Requires significant initial investment for the setup and maintenance of anaerobic digestion facilities. • Requires technical expertise and proper operation to maintain optimal biogas production. • Biogas can only be stored for several days (low energy density) and needs to be used daily; • Biogas lamps have lower efficiency compared to kerosene lamps.

Table 7.9: Techno-economic aspect of the use of biogas

Design consideration	<ul style="list-style-type: none"> • Appliances required depend on how the biogas will be used. • Many appliances have to be designed specifically for use with biogas and these are not always widely available. • However, conventional gas-burning stoves can be easily modified for use with biogas.
Operation & maintenance	<ul style="list-style-type: none"> • To prevent blocking and corrosion, the accumulated water should be periodically emptied from the system's water traps. • Trained personnel must regularly check gas pipelines, fittings and appliances. • Cooking stoves should be kept clean and the burner ring should be checked for lockages.
Costs	<ul style="list-style-type: none"> • The costs depend on the chosen application for the biogas and the appliance required. • Piping is required and generally available in local markets.
Health aspect and/or social acceptance	<ul style="list-style-type: none"> • Users find cooking with biogas acceptable as it can immediately be switched on and off (unlike wood and coal). • It burns without smoke, and, does not contribute to indoor air pollution. • Biogas generated from faeces may not be appropriate in all cultural contexts.
References	<ul style="list-style-type: none"> • Balat, 2011; Strande et al., 2014; Mladenović et al., 2016

7.4.2 Use of Solid Fuels

The solid fuels consist of both the dry solid (DS) and moisture content (MC). The combustible organic matter and incombustible ash are found in the dry solids. The energy content/density within the solid fuels are described in the form of a calorific value (MJ/kg), which is described as the heat generated during the process of combustion of a specific mass of fuel (Gold et al., 2018). In the DS, the combustible matter contributes to the energy content; therefore, the higher the incombustible ash the lower the energy content (Gold et al., 2018). Treatment of FS to produce solid fuels can be in two different types of processes, i.e., (i) carbonisation that involves processes such as pyrolysis and hydrothermal carbonisation (HTC); and (ii) non-carbonisation

process that involves processes such as drying and pelletising (Andriessen et al., 2019). Drying of FS, whether using infrared drying or convective drying, does not change the nutrient concentration of FS and does not affect the calorific value (Septien et al., 2020). The calorific value in FS is due to factors affecting the FS material during storage in the containment, which include the breakdown of energy-dense bonds in readily degradable organic material over time, and mixing with inert materials.

7.4.2.1 Biochar production

Biochar is a charcoal-like material that is obtained through thermochemical (pyrolysis, gasification) or hydrothermal processes. The production of biochar from FS offers complete destruction of pathogens due to high processing temperatures and a value-added treatment product (Krueger et al., 2020).

Biochar can potentially be used as an activated carbon for waste and wastewater treatment. **Table 7.10** gives an overview of the benefits and constraints of biochar and **Table 7.11** gives the techno-economic aspects of biochar. **Figure 7** is a diagram of biochar production for FS treatment.

Table 7.10: benefits and constraints of biochar

Benefits	Constraints
<ul style="list-style-type: none"> • Soil Fertility: Enhances soil fertility by improving nutrient retention, water holding capacity, and microbial activity. • Carbon Sequestration: Acts as a carbon sink, mitigating greenhouse gas emissions and contributing to climate change mitigation efforts • Soil Structure: Enhances soil structure, porosity, and water infiltration, reducing soil compaction and erosion. • Pathogen Reduction: Helps mitigate micro-organic pathogens such as E. coli and faecal coliform bacteria, contributing to soil and food safety. 	<ul style="list-style-type: none"> • Contaminant Risks: If not properly produced and managed, biochar from FS may contain contaminants such as heavy metals and pathogens. • Public Perception: Social and cultural perceptions regarding the use of biochar from FS in agriculture may affect its acceptance and adoption. • Cost: Production and application costs of biochar from FS may be relatively high, especially compared to other soil amendments • (Lehmann, & Joseph 2015; Park et al., 2011)

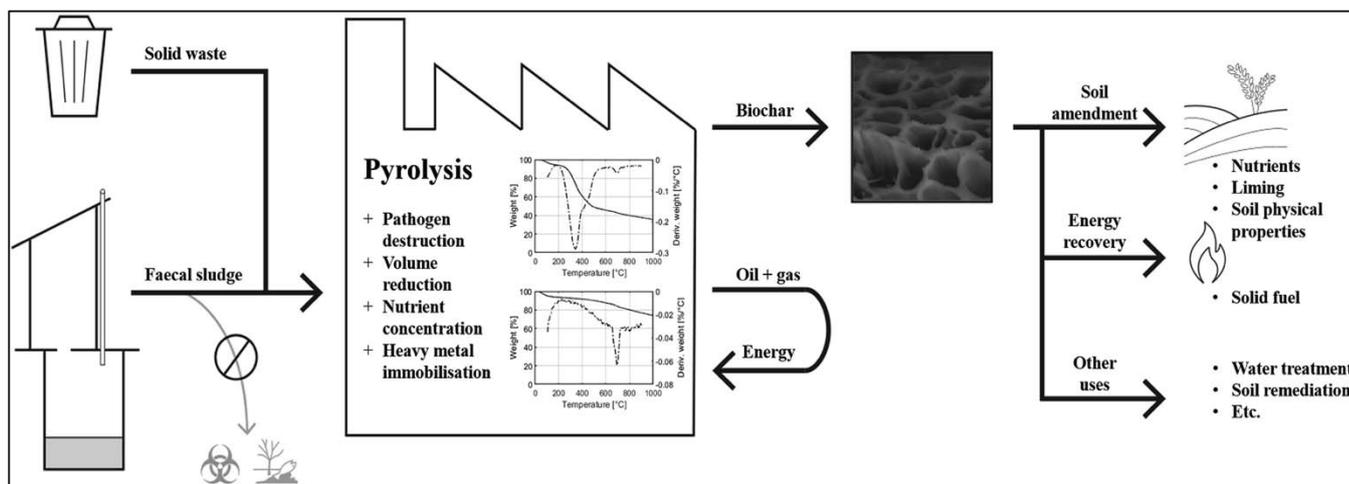


Figure 7-4: Conceptual diagram of biochar production for FS treatment (Krueger et al., 2020)

Table 7.11: Techno-economic aspect of producing biochar as FS treatment

Design consideration	<ul style="list-style-type: none"> • Ensure consistent and appropriate feedstock selection considering moisture content, particle size and organic composition. Optimise pyrolysis conditions, residence time and temperature control for effective biochar production. implementing emission control measures to minimise air pollution and comply with regulations. • Choose appropriate locations for biochar production, considering environmental and community impacts.
Operation & maintenance	<ul style="list-style-type: none"> • Maintaining optimal pyrolysis temperatures for efficient biochar production is required. • Regularly monitor process parameters such as temperature and residence time. • Regularly clean and maintain equipment to prevent the build-up of residues to ensure optimal performance.
Costs	<ul style="list-style-type: none"> • The initial costs include investment in pyrolysis equipment, shredders and other machinery as well as safety gear and labour costs • Operating costs include energy consumption and labour costs • Costs associated with acquiring FS include transportation and storage expenses
Health aspect and	<ul style="list-style-type: none"> • Implementing measures to reduce pathogen presence during the production and handling of biochar from FS. • Ensure workers wear appropriate respiratory protection equipment to minimise inhalation of potentially harmful emissions. • It is necessary to train workers on safe handling, use and storage of biochar and related equipment to prevent accidents
References	<ul style="list-style-type: none"> • Lehmann, & Joseph 2015; Park et al., 2011

7.4.2.2 Pellets

Pellets from FS are produced from the pelletisation process involves compressing the dewatered sludge into cylindrical or spherical shapes using high pressure and/or heat. Binders or additives may be added to the sludge to improve pellet formation and stability. The pelletisation process is a secondary process following a drying process, involving the compressing of biomass to form pellets (Adriessen et al., 2019). The dried pellets are described as an option for FS processing, leading to an end-product that is easy to transport, has reliable characteristics for end-use, and is safe for handling depending on the level of treatment (Strande et al., 2014). Pellets were produced from dewatered FS from drying beds. **Table 7.12** gives the benefits and constraints of pellets and **Figure 7.5** illustrates the briquette press in use in Uganda.

The pellets can be used in different forms:

- (i) for combustion as a biofuel;
- (ii) as a soil amendment and fertiliser.

Table 7.12: Benefits and constraints of FS pellets

Benefits	Constraints
<ul style="list-style-type: none"> • Can be used as a renewable energy source for heating, cooking, and electricity generation, reducing reliance on fossil fuels; • Provides a sustainable solution for managing faecal waste and reducing environmental pollution and public health risks; • Pellets are easy to transport; • Pellets release nutrients at a steady rate; • Are effective in decreasing soil and nutrient losses from agricultural fields; • Reduces dust during handling. 	<ul style="list-style-type: none"> • Challenges related to energy recovery from FS vary depending on the characteristics of the sludge, with one concern being the elevated ash content, which often exceeds 35%; • A pelletising device is required, which can be expensive; • FS pellets may emit unpleasant odours and present aesthetic concerns during storage, handling, and application. <p style="text-align: right;">(Nikiema et al., 2013; Cofie et al, 2017)</p>



Figure 7-5: Briquettes from FS
Source: Water for People (2019)

7.4.3 Reuse of Faecal Sludge to Produce Protein and Fats

The larvae of the black soldier fly (BSF) (*Hermetia illucens*) can be utilised as a traditional protein and fat source for poultry and fish feed, and could easily replace fishmeal as a key component of animal feed. The larvae feed on organic matter such as FS and organic wastes to thrive. The prepupa at the last larval stage is rich in protein and fat (St-Hilaire et al., 2007; Strande et al., 2014). It has been successfully established that FS may be used as a feed source for larvae (Nguye, 2010). **Figure 7.6** shows Black soldier fly larvae in FS and **Figure 7.7** illustrates the products of a BSF larvae process.



Figure 7-6: BSF larvae in FS from Durban, South Africa (WASH R&D Centre, South Africa)

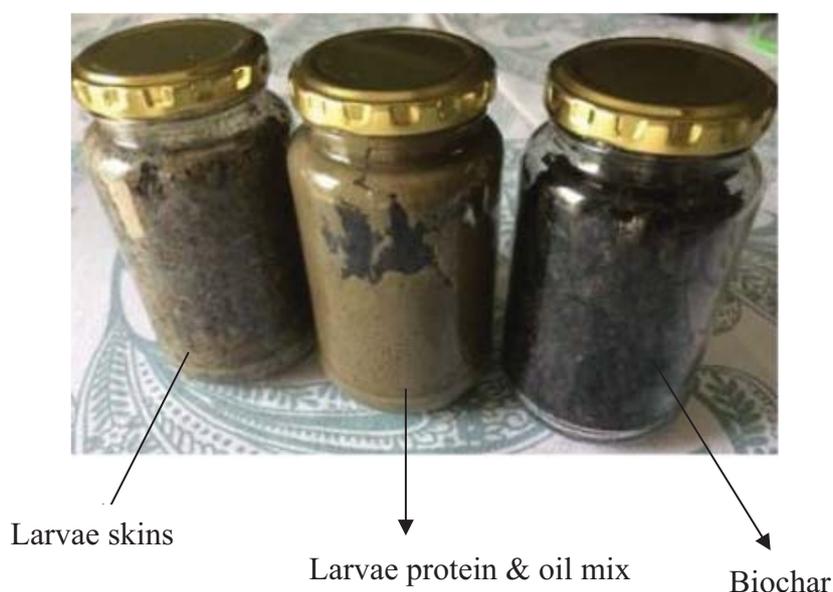


Figure 7-7: Products of BSF Larvae from Durban, South Africa (WASH R&D Centre, South Africa)

A Case Study of Black Soldier Fly Larvae (BSFL) Process in South Africa and Kenya

Black Soldier Fly Larvae (BSFL) processes have been piloted and tested in both South Africa and Kenya. In South Africa, the BSFL system was explored in the eThekweni Municipality as a sustainable solution for treating faecal sludge, particularly from urine-diverting dry toilets (UDDTs) and pit latrines (Grau et al., 2019). A preliminary business model for a BSFL processing plant was developed drawing on prior research, with the facility planned for the municipally owned Isipingo Wastewater Treatment Works, located 25 km from the city of Durban. A Public-Private Partnership (PPP) was formed between the eThekweni municipality and the private operator, The BioCycle. The model envisioned the plant processing up to 20 tons of faecal and other organic waste streams per day. Revenue would be generated from both the sale of BSFL-derived products and residue, as well as a municipal gate fee per ton of sludge treated. Capital costs were covered through a grant with Khanyisa Projects serving as the implementing agent (Grau et al., 2019).

The study assessed the technical and economic viability of a Black Soldier Fly Larvae (BSFL) plant for processing faecal sludge from urine diversion toilets in Durban, South Africa. It found that high levels of inorganic contamination, poor climate control, and inefficient separation systems limited operational performance, while the business model showed the plant was not yet profitable under baseline assumptions. Processing costs were high, and revenues from larvae products and municipal gate fees could not cover operating expenses (OPEX), resulting in net losses. However, the analysis highlighted that viability could be achieved by improving feedstock preparation, optimising climate control, increasing sludge moisture content, raising gate fees, expanding markets for BSFL products, and developing value-added uses for residues. Overall, while not immediately cost-effective, BSFL processing presents a promising alternative to landfill disposal if key operational and financial factors are addressed (Grau et al., 2019).

Sanergy has been using Black Soldier Fly (BSF) systems to treat and upcycle organic waste into agricultural products and biomass briquettes (ISF-UTS and SNV, 2021). In Nairobi, Kenya, Sanergy uses BSFL as part of a circular-economy system to treat and repurpose organic and faecal waste. They deploy container-based sanitation (CBS) toilets (“Fresh Life Toilets”) to segregate and collect faecal sludge. This is then fed to BSFL to convert it into protein-rich insect biomass (for animal feed), and the frass residue (excrement from insect larvae) can be composted into fertiliser following further treatment. Waste reduction by weight can be up to 80%. Sanergy supplements BSF treatment with thermophilic composting and even produces briquettes from the residue. They have installed thousands of toilets across informal settlements and built a waste logistics chain from collection, transport, to treatment, while ensuring pathogen reduction, regulatory compliance, and financial sustainability. Key challenges include maintaining ideal environmental conditions for larvae, securing policy support, working with communities, and funding ongoing R&D and infrastructure expansion (ISF-UTS and SNV, 2021).

7.5 FODDER AND PLANTS

Plants from drying beds can be used in (i) biofuel production; certain plant species grown in drying beds, such as cattails and reeds, contain high levels of cellulose and can be processed to produce biofuels such as ethanol or biogas. These biofuels can be used for heating, electricity generation, or as transportation fuels. (ii) Compost, where the dried plants can be composted along with other organic materials to create nutrient-rich compost, or as livestock fodder. The plants that will be produced in the beds should be chosen with the local climate and market in mind. In this approach, the species that will thrive in drying beds and have the most potential for profit will be planted (Strande et al., 2014). Also, the reuse of deep row entrenchment trees offers multiple benefits, including nutrient removal, contaminant remediation, biomass production, habitat creation, and recreational opportunities. These trees play a vital role in sustainable water management practices and ecosystem restoration initiatives.

7.6 DISPOSAL OF FAECAL SLUDGE

The disposal of FS can differ significantly depending on whether resource recovery is considered as part of the process. In traditional FS disposal practices without resource recovery, the primary objective is to remove the sludge from the sanitation system and dispose of it in a manner that minimises environmental and public health risks whereas FS disposal with resource recovery aims to extract valuable resources from the sludge while managing its safe disposal, thereby promoting sustainability and circular economy principles. The disposal of FS refers to the ultimate discharging of FS into the environment as a low risk material (WHO, 2018). When the FS has been removed from the pit, it has to be transported to the treatment site to reduce pathogen levels and then disposed of safely (Scott et al., 2017). Safe disposal of FS is essential to eliminate and reduce environmental pollution. Two basic goals of treating sludge before final disposal are to reduce its volume and to stabilise the organic materials. Stabilised sludge does not have an offensive odour and can be handled without causing a nuisance or health hazard. Lower sludge volume reduces the costs of transport and storage. Pit latrine sludge disposal has become a major issue for several towns, especially in South Africa, where a substantial number of pits are expected to exceed capacity shortly.

7.6.1 Methods for FS Disposal

The various methods proposed for the safe disposal of FS include (ISO, 2016; EWS, 2012):

- Discharge into nearby waterborne sewer / wastewater treatment works;
- Burial of sludge on-site;
- Burial off-site (deep row entrenchment);
- Discharge to sea outfall.

7.6.1.1 Discharge into a Waterborne Sewer / Wastewater Treatment Works

When the FS is more liquid and a sewerage system is nearby, it can be loaded into a trunk sewer or transported to the wastewater treatment plant (WWTP). Discharging the FS into the sewer can overload the WWTP and cause failure within the plant, leading to operational challenges, reduced treatment efficiency, and potential environmental and public health risks (EWS, 2012; Harrison and Wilson, 2012). Therefore, plant monitoring is encouraged while discharging the FS. Permission from the local sewage authorities is also needed for discharging FS into the sewer system. The challenges encountered in other parts of the country with regard to discharging FS in the sewer or WWTP include:

- No nearby sewer;
- Settling out of solids and grit in the sewer;
- No nearby water connection for liquification of sludge, i.e diluting thick sludge;
- FS arrives at treatment works and causes problems such as clogging the pipes at works;
- Unless the stormwater drains are already contaminated, FS should not be drained into them (ISO, 2016; Scott et al., 2017).

7.6.1.2 Burial of sludge (on-site)

The on-site burying is only possible in rural areas where the on-site sanitation facilities are not built up in highly dense areas. With the burial of FS on-site, there has not been an environmental problem as the FS is stabilised (digested) (WRC, 2021). The burial of sludge deals with the issues of odour and insects, and eventually protects people from accidental contact with pathogens in the sludge (Still et al., 2015). The benefits of sludge burial are: (i) on-site burial has the potential to grow plants/crop and the nutrients in the sludge can potentially act as a fertiliser for crops such as sugarcane, fruit trees and timber; and (ii) sludge burial is cheaper than landfill disposal. The risks associated with sludge burial are that the nutrients (i.e nitrates and phosphates) in the sludge can leach into the groundwater if the soil is sandy and the groundwater table is high, therefore negatively impacting the environment. However, FS buried in a trench on site does not pose any more risk than sludge remaining in an open-joint on-site containment system. Pathogens in the sludge should be inactivated after four years (Still et al., 2015). Therefore, if sludge is dug up before then, there is a risk of exposure to pathogens. The following protocol is recommended for the burial of sludge on-site for service providers and households.

SLUDGE MUST BE BURIED AS FOLLOWS (PID, 2016):

Choose a burial site:

- Make sure there is enough space so that the site will not be disturbed by daily household activities.
- If water appears as you dig, or if the sludge is wet, bury the sludge in several smaller holes higher on the site.
- Do not bury if the soil is very sandy or gravelly.
- Do not bury where the ground is eroded or cut away.
- Do not bury within 15 metres of a stream.
- If you are not sure about whether to bury or where to bury contact the Health & Safety Officer (HSO).

Dig a big enough hole that you can cover the sludge with 300 mm clean soil. The hole can be:

- 2 m long x 1 m wide x 1.3 m deep, or
- 1.4 m long x 1.4 m wide x 1.3 m deep, or
- 8 m long x 0,5 m wide x 0.8 m deep.

Holes must be dug with clean tools, not the tools used for vault emptying.

- Place the tarpaulin on the edge of the hole so that no sludge can fall on the ground between the bin and the hole. Place bins and tools on the tarpaulin.
- After the sludge has been transferred, shake any sludge on the tarpaulin into the hole.
- Cover the hole with 300 mm of clean soil using a clean spade.

7.6.1.3 Burial Off-Site / Deep Row Entrenchment

Entrenchment is a process of burying FS in deep trenches, where odours are eliminated and the risk of exposure to pathogens is reduced. The trees that demand high nutrient content are planted on top of the buried sludge (Strande et al.,2014). Entrenchment provides a practical and useful method to deal with the problem of disposal of potentially dangerous FS from pit latrines and wastewater treatment works (Still et al, 2014). Over time, sludge buried in the soil dewater, decomposes, and becomes difficult to distinguish from the surrounding soil. Compared to other conventional methods, such as spraying FS on trees, the deep row entrenchment process allows for a larger volume of FS that is applied at one time. Below is a case study of using the untreated sludge to plant trees using deep row entrenchment.

A case study of using untreated FS to plant trees using deep row entrenchment, Durban South Africa

PID (2014) conducted an investigative study on entrenchment of pit latrine and wastewater sludges, investigating the costs, benefits, risks and rewards. From the study, a few experiments were conducted; the first one involved using pit latrine sludge as a fertiliser and soil conditioner around new fruit trees, which were planted, at the homesteads. Citrus and peach trees were selected for the experiments and it was found that the citrus trees, which were planted with FS, grew noticeable larger and yielded more fruit. In another experiment, pit latrine sludge estimated to be over thousand cubic metres was buried in old oxidation pond in Durban metro area. Eucalyptus and wattle trees were planted over the sludge and five monitoring boreholes were drilled between the site and the in the nearby river. No significant changes were detected in the groundwater over a two year monitoring period. Samples of the sludge were taken from time to time and assessed for physical properties and pathogen content. After three years the sludge was hard to distinguish from the surrounding soil, the organic matter had virtually all decomposed and the pathogens (using *Ascaris* as a marker) had all died. Still et al, 2014 concluded that by far the entrenchment is the simplest and most economical method for the disposal of sludge. Burial of sludge deals with the problems of odour and insects, and protects people from accidental contact with the pathogens in the sludge. And the nutrients in the sludge can potentially act as fertiliser for crops (e.g. sugarcane, fruit trees or timber).

The possible risk associated with deep row entrenchment are that there is a chance of nitrates and phosphates in the sludge to leach into the groundwater therefore having a negative impact on the environment around the burial site. There might also be a concern that the pathogens in the sludge will remain active and likely to pose a long term risk if the sludge is later dug up. Important factors that also need to be considered are soil type and porosity, ground water depth, proximity to drinking water sources, and background nutrient concentration.

7.7 SUMMARY

The Water Research Commission (WRC) produced a range of evidence-based faecal sludge treatment and disposal products focused on sustainability, public health and environmental protection, and resource recovery. These have been summarised in this chapter. For costing and guidance on how to classify sludge and dispose of sludge according to existing Sludge Guidelines, please refer to Neethling (2015):

C2023-2024-01290: What are municipalities doing with their municipal sludge?

Understanding the current practices and the cost associated with municipal sludge disposal with case studies by Neethling (2025).

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CHAPTER 8: CONCLUDING REMARKS & RECOMMENDATIONS

A large portion of the population in South Africa is currently making use of on-site sanitation. The technical choice of no water flushing toilets was due to the water scarcity in the country and a large unserved population who did not have the means to afford waterborne reticulated systems. Large-scale infrastructure programmes led to the proliferation of Ventilated Improved Pit (VIP) and other latrine variants. Design assumptions that these systems would not fill have been dispelled. More challenging has been the servicing of these systems and the lack of specific guidance and options for managing the waste material – faecal sludge (FS) – which differs significantly from wastewater sludges, which tend to be more diluted.

This Faecal Sludge Management (FSM) guideline project originates from Directed Terms of Reference (ToR) from the Water Research Commission (WRC) to fill the gap and support the recently published Department of Water and Sanitation (DWS) National FSM Strategy and the National Sanitation Implementation Plan (NSIP). It is essential to ensure the safe and effective handling of FS, particularly in urban areas with inadequate sanitation infrastructure. Unlike wastewater treatment, which is typically managed through centralised sewerage systems, FS from on-site sanitation systems requires a different approach for collection, transport, treatment, and disposal or resource recovery. Without clear guidelines, improper FSM can lead to environmental pollution, health risks, and the spread of waterborne diseases.

This guideline provides a framework for best practices, regulatory compliance, and technological solutions that enhance FS collection, emptying, and treatment and / or reuse while promoting sustainability. The guideline supports the National FSM Strategy and NSIP aims of capacity building, investment in sanitation services, and facilitating the integration of circular economy principles, such as nutrient and energy recovery from FS.

The manual and mechanical means of faecal sludge (FS) collection are both applicable and accepted in South Africa. Both manual and mechanical emptying and transportation have a high potential of creating jobs in South Africa. Manual emptying of FS is advantageous because of the wide variety of waste that can be removed, such as thick sludge; however, it presents health risks to the workers due to direct contact with hazardous material and therefore it is recommended that it be practiced with caution, extensive training, and implementation of health and safety measures. It is important that safety protocols are followed and that the workers (pit emptiers) are fully vaccinated before going to sites and wear appropriate personal protective equipment during both manual and mechanical emptying and transportation of FS. The mechanical emptying and transportation of FS is a safer option for pit emptiers because there is less contact with the hazardous material. However, it can be expensive for entrepreneurs or individual households, but government-subsidised services can make it more affordable for households. In the selection of mechanical emptying devices, it is

recommended to consider the type of FS to be emptied, i.e, whether the FS is dense/thick or it is a liquid /slurry FS and the trash content. In some cases, removal of trash before emptying of FS is required. The mechanical emptying is more efficient in the emptying of liquid /slurry sludges, however, emptying devices, such as pit auger and gulper, have high potential of trash handling and can empty thick/dense sludges. In reality, a pit emptying team or programme will benefit from having multiple emptying techniques in its “tool belt”, which can be used to address different conditions and sludge characteristics that come up along the way. This ensures that the team can work as efficiently as possible and use each tool where it's most appropriate. After the emptying process it is important that the surfaces are kept clean and that the protocols for safe transportation of FS is followed and that the environment is not contaminated with FS.

The FS treatment methods that have been used in South Africa include: deep row entrenchment, and composting to produce compost and / or soil conditioner product that can be utilised for agricultural purposes. Biological treatment methods such as composting, are a good option for South Africa as the treatment processes are low cost with high volume reduction and high pathogen reduction, they do not require electricity, and they are low maintenance. The use of compost/ soil conditioner for agricultural purposes also reduces reliance on chemical fertilisers.

South Africa's energy supply is dominated by coal, crude oil and nuclear, which are all non-renewable resources and are insufficient to meet South Africa's energy demand. As a result, South Africa is facing an energy crisis with frequent loadshedding leading to blackouts in communities. The thermal treatment processes and incineration can produce biochar and hydrochar, which can also be a good energy alternative for South Africa. These processes are not inexpensive but can be a good investment, provided further testing and demonstration is carried out. The biochar /hydrochar made from FS provides total pathogen removal as well as a value-added treatment product. Some African countries are in the early stages of commercialization of briquette products from FS-derived biochar. These procedures produced biochars that can be used as a soil amendment and as a source of energy. The energy content of both hydrochar and biochar is comparable to lignite, with an energy content of 15 MJ/kg and sub-bituminous with an energy content of 18.2 MJ/kg. Again, converting FS into biosolids through the drying process is a valuable approach in faecal sludge management (FSM). The drying process involves reducing the moisture content of FS to create a stable and sanitised end product suitable for beneficial reuse. Drying methods include solar drying, mechanical drying, and thermal drying. Once dried and stabilised, the biosolids can be used for various beneficial reuse applications such as soil amendment and an energy source.

Taking into account rural areas, the treatment of FS needs to be practical, cost-effective, and sustainable, given the limited resources (water and energy) and infrastructure. Therefore in rural areas it is recommended to:

- (i) encourage the use of septic tanks as a primary treatment option for on-site sanitation systems in rural areas, as septic tanks are relatively simple to install and maintain, requiring periodic desludging to remove accumulated sludge;

- (ii) promote the use of anaerobic digestion systems as a secondary treatment option for septic tank effluent. Anaerobic digesters can be constructed using locally available materials and are effective in reducing pathogens and odours while producing biogas for energy generation.
- (iii) consider the use of constructed wetlands as a natural treatment method for FS. The constructed wetlands have been introduced in the rural schools of KZN. They can provide passive treatment by promoting biological and chemical processes that remove contaminants and improve water quality and can be integrated into existing landscapes.
- (iv) encourage the option of composting FS to produce nutrient-rich fertiliser for agriculture. Composted sludge can be safely applied to croplands, enhancing soil fertility and organic matter content.
- (v) Provide education and training and capacity-building programs to local technicians, sanitation workers, and community members on FSM practices, treatment technologies, and safety protocols. Empower communities to take an active role in the operation and maintenance of treatment systems

In urban areas, where population density is high and sanitation infrastructure is more developed, the treatment of FS requires a more comprehensive and centralised approach. It is recommended that:

- (i) There is a development of centralised FS treatment facilities equipped with advanced treatment technologies to handle large volumes of sludge efficiently. These facilities can include mechanical and biological treatment processes to remove solids and contaminants from the sludge, and anaerobic digestion or thermal treatment methods such as incineration or pyrolysis to further stabilise the sludge, reduce pathogens, and recover energy.
- (ii) Expand and upgrade sewerage networks to collect and convey FS from households, industries, and commercial establishments to centralised treatment facilities.
- (iii) Explore opportunities for resource recovery from FS, including biogas production, composting, and nutrient recycling. Encourage the use of treated sludge as a valuable resource for agriculture, energy generation, and soil improvement. Implement policies, incentives, and market mechanisms to promote the sustainable reuse of FS-derived products and minimise environmental pollution.

Another important aspect in selecting a treatment method is establishing the creation of incentives and turnover through treatment methods, such as the return of nutrients from human excreta as safe agricultural inputs for farmers. Treatment methods that are low cost, do not negatively affect the environment and have a high by-product relevance are recommended for South Africa as they provide economic opportunities for local enterprises, driving down the cost of sanitation to make safe sanitation more widely accessible. However, the barriers include:

- (i) The lack of regulation and policies is a barrier to the implementation of sustainable practices. One of the primary challenges is the absence of comprehensive guidelines and standards for good practices in FS treatment and resource recovery in South Africa. Without clear regulatory

frameworks, there is limited guidance for stakeholders on the safe and effective management of FS, leading to inconsistencies and uncertainties in implementation.

- (ii) The lack of social acceptance poses a barrier to the adoption of innovative solutions and technologies, as communities may resist changes to traditional practices or express concerns about potential health and environmental risks.
- (iii) Emerging issues such as micropollutants, including compounds of emerging concern, endocrine-disrupting compounds, and microplastics, present complex challenges for FS treatment and reuse. The absence of regulations and policies addressing these contaminants hinders efforts to mitigate their impact on human health and the environment, highlighting the urgent need for regulatory action and policy development to address these barriers and promote sustainable FSM practices.

The re-use /disposal of FS in South Africa is an important aspect of FSM.. The re-use of FS in agriculture is the most common approach in South Africa. The re-use of FS /excreta in agriculture which aids in providing safe nutrient-rich soil amendments, has the potential to contribute to Sustainable Development Goal 2, whose goal is by 2030, to eradicate all kinds of hunger and malnutrition and for all people, particularly children, to have access to sufficient and nutritious food throughout the year. This entails promoting sustainable agriculture, assisting small-scale farmers, and ensuring that all people have equal access to land, technology, and markets. The reuse of human excreta as a fertiliser is therefore an attractive solution to both the sanitation crisis and the nutrient depletion of soils in SA. Other re-use options, such as the black soldier fly larvae, are good options for sludge volume reduction and producing proteins for fish feed. Other attractive reuse options include the production of fuels, which would relieve the energy industry. Though this process is not easily affordable, it would be a great investment to address the energy and climate change crises.

Currently, an important portion of the FS in South Africa is discharged to existing wastewater treatment plants and landfills, a practice that is not advised. Deep row entrenchment is a resource recovery and sustainable method for the disposal of FS that not only addresses the immediate need for sanitation but also considers environmental aspects in the long term. It is, however, recommended that sustainable disposal strategies should involve active participation and engagement of local communities, ensuring that solutions are culturally appropriate, socially acceptable, and responsive to community needs and preferences. Community involvement fosters ownership, accountability, and sustainability of FSM initiatives.

ANNEXURE A

Effective faecal sludge management (FSM) in South Africa requires a well-coordinated approach guided by key policies, strategies, and technical guidelines. A range of documents provides essential frameworks for ensuring the safe collection, transportation, treatment, and disposal of faecal sludge while protecting public health and the environment. These documents, developed by international and national organisations, outline best practices, regulatory requirements, and innovative solutions tailored to the country's unique sanitation challenges. The following list highlights crucial references that support FSM planning and implementation.

SUPPORTING DOCUMENT LIST

- “The National Faecal Sludge Management Strategy 2023” developed by South Africa's Department of Water and Sanitation (DWS), provides comprehensive guidance for the safe and effective management of faecal sludge across the entire sanitation service chain. The National Faecal Sludge Management Strategy 2023 is available for download from the Department of Water and Sanitation's official website: <https://www.dws.gov.za/Documents/PRINTERS%20FINAL%20=%20FSM%20Strategy%202023.pdf>.
- The “Protocol to Manage the Potential of Groundwater Contamination from Sanitation Practices,” published by South Africa's Department of Water Affairs and Forestry in March 2003, provides guidelines to protect groundwater resources from contamination due to sanitation activities. It emphasizes the importance of proper site selection, design, construction, and maintenance of sanitation facilities to minimize risks to groundwater quality. The protocol outlines assessment procedures to identify potential contamination sources and recommends management practices to mitigate these risks, aiming to ensure the safety and sustainability of groundwater supplies: <https://www.dws.gov.za/groundwater/Documents/GWprotocolMar03.pdf>
- “The Practical Guide to Available Pit-Emptying Technologies” by Gurski et al. provides detailed insights into the various technologies available for safely and efficiently emptying pit latrines and septic tanks. This guide explores a range of methods, from manual techniques to more advanced mechanized solutions, emphasizing the importance of choosing the right technology based on local context, including the scale of the community, geographical factors, and financial constraints. It also addresses key challenges in pit emptying, such as health risks, environmental impacts, and the need for appropriate training and infrastructure. By offering practical solutions and best practices, the guide aims to support effective faecal sludge management in resource-limited settings, improving sanitation services and public health outcomes. <https://www.triangle-environmental.com/wp-content/uploads/2022/08/A-Practical-Guide-to-Available-Emptying-Technologies.pdf>
- Pit Emptying Health and Safety videos:
 - [Pit Emptying H&S Module 1: Health Threats in Shit](#)
 - [Pit Emptying H&S Module 2: Understanding Barriers and Responsibilities](#)
 - [Pit Emptying H&S Module 3: Starting the Day](#)

- [Pit Emptying H&S Module 4: Preparing to empty the pit](#)
- [Pit Emptying H&S Module 5: Emptying the pit](#)
- [Pit Emptying H&S Module 6: Dealing with accidents](#)
- [Pit Emptying H&S Module 7: Taking a break](#)
- [Pit Emptying H&S Module 8: Cleaning up at the site](#)
- [Pit Emptying H&S Module 9: Cleaning up at the centre](#)
- [Pit Emptying H&S Module 10: Reporting, Health Care, Penalties and Rewards](#)
- [Pit Emptying H&S Module 11: Wrapping up](#)
- Deep row entrenchment by Neethling et al. 2022
https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/2899_final.pdf
- Sludge classification and costing tools by Neethling, 2025
<https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/Foecal%20sludge%20management.pdf>
https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/Rethinking%20wastewater%20sludge_A5%20WEB.pdf

