3

Faecal sludge sample collection and handling

Thammarat Koottatep
Amédé Ferré
Saroj Chapagain
Krailuck Fakkaew
Linda Strande

OBJECTIVES

The objectives of this chapter are to:

- Select different sampling techniques depending on objectives
- Select sampling devices and locations
- Develop appropriate and reliable faecal sludge sampling schemes and plans
- Ensure sample representativeness and integrity
- Protect health and safety of employees and users of onsite sanitation.

3.1 INTRODUCTION

Quantities and qualities (Q&Q) of faecal sludge vary significantly along the entire faecal sludge management (FSM) service chain. Further understanding of factors such as biodegradability, nutrient content, pumpability, dewaterability, resource recovery potential, pathogens, and potential inhibitory compounds are all particularly important for effective faecal sludge planning and management. Sampling is the action or process of taking a subset of a larger volume for characterisation. This process assumes that samples are representative of the larger volume, and there are measures to put in place to help ensure this. Therefore, a proper sampling scheme and subsequent analysis of faecal sludge is paramount for sustainable FSM. As introduced in chapters 5 and 6, the modelling of onsite sanitation will also help to bring a more systematic approach to data collection and sampling, and the number of parameters of interest will continue to grow, resulting in increased demands for sampling and analytical work.

How and where samples are taken, transported, and analysed depends on the specific objectives of the sampling. Examples of sampling objectives include designing a treatment facility, planning for emptying and transport services, evaluating rates of sludge accumulation, selecting and operating treatment processes, evaluating resource recovery options, and complying with regulatory requirements. Sampling and sample handling need to be carried out in such a way that the respective traits being measured (*i.e.* volumes, characteristics) are as similar as possible during the analysis as when the sample was taken. Analysis of samples can be done either *in situ* (*e.g.* within containments), in the field, or in a laboratory after being transported. Proper preservation help ensure that no significant changes in composition occur before the analyses are made. To ensure representativeness of collected data, emphasis is also placed on proper sample collection and tracking. A preliminary site visit, or familiarity with sampling locations, is necessary prior to any survey, sampling, or analysis decisions being made. Furthermore, sampling and sample handling need to be carried out in such a way that is safe for the people collecting and analysing the samples. Examples of safety aspects that need to be considered include collapsing pit latrines, falling or tripping hazards, working in confined spaces, asphyxiation, and hygiene. These topics are all presented in more detail in this chapter.

3.2 SAMPLING OBJECTIVE

The sampling objective is the defined purpose for collecting the data, which analysis of the samples will provide. Identifying the sampling objective is the first step in a sampling campaign. The next step is to develop a sampling plan specifically to answer the question you are asking. Sampling locations, frequency, timing, tools, and methods can greatly affect the outcome. For example, if you are interested in how faecal sludge accumulates within pit latrines, it would not necessarily make sense to sample what collection trucks are discharging at a large-scale treatment facility. However, if you want to improve the operation of a treatment facility, then directly sampling what is being discharged does make sense. Faecal sludge can be sampled for analysis at each step of the sanitation service chain depending on the question, for example, directly from the containment, from the collection vehicles, or during and after treatment. Each location and sampling purpose comes with different considerations. Below are examples of sampling strategies that are relevant to different sampling objectives. These are presented in the sequence of the sanitation service chain.

3.2.1 Containment

Estimating rates of accumulation at the community to city-wide scales

If the objective is to understand actual rates of accumulation that are occurring at a community to citywide scale, then it is logical to measure *in-situ* volumes and estimate time periods for the accumulated sludge. This is in contrast to measuring what is delivered to a treatment plant, which is probably less than the total accumulated amount. Accumulation rates are important for planning purposes, and for designing treatment technologies. For more information on how to develop a sampling campaign to estimate rates of accumulation, refer to Chapter 5.

Evaluating faecal sludge stabilisation with location and time in onsite sanitation systems

If the objective is to understand how faecal sludge changes with location and time within containment in order to improve management, then sampling should take place directly within the containment, for example at various depths and/or times. However, logistically this might be quite difficult. In addition, the *in-situ* environment is altered during an emptying operation, making it very difficult to analyse what is actually occurring underground. Therefore, assumptions might need to be made; for example, that taking samples every 300 mm while the containment is being emptied is representative. This needs to be managed with logical and transparent assumptions.

3.2.2 Collection and transport

Planning of emptying services for a community

If the objective is to design emptying services, then it is important to be able to select an emptying technology that is compatible with the sludge thickness; for example, if the sludge is too thick then a gulper (or manual pump) might need to be used instead of a vacuum pump. It is also important to have adequate volumes for transport, and so estimates need to be made regarding how much faecal sludge accumulates over time. Therefore, samples should be collected within onsite containments, or during emptying operations. If water is added during emptying, then samples should be taken prior to the addition of water.

Designing a technology for emptying or treatment

For the design of different innovative technologies in the sanitation service chain, the steps will be similar. However, there may be specific requirements for the properties, number, frequency, and type of samples that need to be taken. For example, the design of an emptying technology may require information on waste content, viscosity, rheology, ash content, and moisture content. If this data is provided by sampling from trucks or collected at the delivery point of the faecal sludge treatment plant (FSTP), the final design of the technologies for emptying containments may not be applicable for all the containments in this particular area.

3.2.3 Treatment

Designing a new faecal sludge treatment plant

If the objective is to design a new FSTP), part of the design study will include evaluating the characteristics that will arrive at treatment, in order to specify design values. Samples should be taken at an existing FSTP. When there is not an existing FSTP then sludge is frequently dumped in locations around town. Potentially samples could be taken at illegal discharge locations, but this can be difficult to arrange with the emptiers since it is an illegal activity. Illegal dumping is an undesirable practice and the sampling from such locations is only for the purpose of improving the current situation, not to endorse it. For more information on estimating Q&Q at this scale, refer to Chapter 5.

Evaluating operational parameters during the start-up phase of a faecal sludge treatment plant

When commissioning a new FSTP, the start-up period can require months of continuous testing and optimisation to reach the required treatment performance and to optimise treatment capacity. During the ongoing operation, operators will need to adjust operations and loadings on a regular basis; for example, resting time of settling-thickening tanks, and loading rates and residence times on drying beds. Sampling needs to be appropriate for the targeted treatment processes; for example, at the inlet and on the drying beds to determine the optimal drying time on unplanted drying beds.

Monitoring overall faecal sludge treatment plant treatment efficiency

If the objective is to evaluate compliance with environmental regulations for effluent, then sampling should be consistent with the requirements of the regulations (*e.g.* effluent prior to discharge). If the objective is to evaluate overall treatment performance, then sampling should be done at the influent (*e.g.* truck discharge), and also effluent and the final treated solids.

3.2.4 End use

Assessing compliance with requirements for end use

If the objective is to assess compliance with requirements for end use or resource recovery, then

appropriate sampling should be done on the final product for the characteristics of concern (*e.g.* nutrients, stabilisation, calorific value, pathogens). For example, for concerns specific to use as a dry combustion fuel, see Andriessen *et al*. (2019).

3.3 REPRESENTATIVENESS

Faecal sludge varies temporally and spatially at different scales (*e.g.* within containment, within communities). Due to this high variability, obtaining a representative sample for volumes, properties or characteristics can be very challenging. The goal is to obtain a sample that has a similar composition to the whole substrate that is being sampled. When this is achieved, then the sample can be considered representative of the targeted faecal sludge. It is important to remember that it is highly unlikely to obtain a representative faecal sludge sample if it is taken only at one time and from one sampling point. A single sample will most likely not provide meaningful information to support the sampling objectives.

Factors to consider when determining representativeness include solid or liquid nature, homogeneity or heterogeneity, changes with time, and scale. Various types of containment technologies such as pit latrines, septic tanks, cess pits, and composting toilets will have different sampling requirements that need to be considered (see Example 5.1). If the containment or sampling location is stratified, then the level of stratification needs to be taken into account (*e.g.* septic tanks, wet pit latrines, stabilisation ponds). A representative sample of faecal sludge from a septic tank includes the scum, supernatant and sludge layers, which are not homogenised within the tank. These concepts are applicable to the entire faecal sludge management service chain, from collection, transport, treatment, to final end use or disposal.

3.4 SAMPLING TECHNIQUES

Once the sampling objective has been determined, the resulting sampling locations and substrates can also be identified. According to the degree of variability of the faecal sludge to be sampled, different sampling techniques are suggested.

3.4.1 Grab sampling

A grab sample, also known as a catch sample or individual sample, provides a snapshot of the current situation. This sampling technique refers to the collection of a single sample at a specific sampling location and time or over a short period of time (typically seconds or minutes). The sampling time should always be carefully determined to reduce bias and increase representativeness. Typically, grab samples are not representative of things that change with time, or a flow of heterogeneous substrates. As faecal sludge characteristics can be highly variable, care should be taken that a grab sample is representative of the whole. Discrete grab samples are taken at a selected location, depth, and time. When a source is known to be relatively constant in composition over an extended time or over substantial distances, then a grab sample may represent a larger sampling area or longer time period (Rice *et al*., 2017). Another possibility is to use a sequence of grab samples to monitor a condition over time. Samples can then be collected at suitable intervals and analysed separately to document the extent, frequency, and duration of these variations (Rice *et al*., 2017); for example, for typical diurnal or seasonal variations at a FSTP. Similarly, several grab samples across different locations can be used to monitor the condition of a larger space. In faecal sludge treatment processes such as inflow chambers, settling-thickening tanks, or outlet of the FSTP, samples need to be representative of the cross-section of the entire treatment unit. The samples will be individually analysed, and then they cumulatively represent a time series.

Grab samples are most appropriate for:

- Substrate with negligible changes in composition with time
- When other sampling techniques that require more resources would not provide significant improvement in terms of representativeness (see Section 3.4.2 on composite sampling)
- For small FSTPs, decentralised or semi-centralised treatment facilities with low flow and limited capacity and resources for continual sampling (however, it must be taken into account that variations can also be much greater in these cases), and

- For cases where obtaining a composite sample is not feasible because of limited access, for example from pit latrines, leach pits or septic tanks with access only through a small drop hole or access port.

3.4.2 Composite sampling

Composite samples provide a representative sampling of heterogeneous matrices in which the characteristics vary over periods of time and/or space (Rice *et al*., 2017); for example, the flows arriving from trucks discharging at FSTPs. A composite sample can be obtained by combining portions of multiple grab samples manually over time (Rice *et al*., 2017). Automatic sampling devices are also available for some situations, and they are often used for the sampling of wastewater in centralised, sewer-based wastewater treatment plants (WWTPs). In many cases for the sampling of faecal sludge, composite grab sampling will be the preferred method. The main advantage is analysing a composite sample instead of analysing a larger number of individual grab samples, and obtaining results that are representative of heterogeneous matrices and flows. An adequate number of grab samples is taken so that the composite is representative.

Composite samples can be prepared in different ways. Sequential (time) composite samples are made up of sub-samples of equal volume taken at specific time intervals. For example, grab samples could be sub-samples taken once an hour, which are then combined to make a single daily sample, whereas flow-proportional sampling is proportional to the flow or loading. They can be taken by mixing equal volumes of substrate collected at time intervals that are inversely proportional to the volume of flow, or by mixing volumes of substrate proportional to the flow collected at regular time intervals (Rice *et al*., 2017). This can be done manually, or with a purpose-designed sampler. For static heterogeneous substrates, a composite can be made up from randomly taken grab samples distributed throughout the entire substrate source. It should be noted that the composite samples must be comprised of grab samples that have been collected within a short period time: between a few hours and a few days. If the grab samples have been collected in longer time intervals such as a number of weeks or longer, they cannot be mixed as a composite sample and they need to be analysed separately as the characteristics may have changed significantly over this period. It is critical when compiling a composite sample to make a representative sample from the combination of all the grab samples collected. The aliquot of a composite sample needs to be well-mixed and effort must be made to minimise the possibility of sample contamination during the process.

Below are examples of composite grab sampling:

- In the case of sampling a sludge blanket layer in a septic tank, grab samples from multiple chambers and locations may be required to make a representative composite sample of the sludge contained in the tank (see Section 3.5.2).
- In the case of a liquid stream, equal volumes of a sample could be taken at time intervals to create a composite sample. For example, during truck discharge (taking one sample at the beginning, two in the middle, one at the end, see Section 3.5.2), or at the effluent of the FSTP. Another example of making a composite sample is to weight grab samples according to the faecal sludge loading patterns of each unit in a treatment chain at a plant.
- In the case of a completed or stabilised pile of compost as shown in Figure 3.1, a composite grab sample could be taken by grabbing samples distributed throughout the pile and then evenly mixing them into one composite sample. This is based on the assumption that stabilised compost is relatively solid, could be heterogeneous, and does not change with time.
- In the case of monitoring the dewatering of sludge on a drying bed, composite grab samples are taken from throughout the bed, for example using a grid system and taking one sample from each grid. It is important to take a core sample, and not only sample from the surface. Dewatered sludge on a drying bed is also relatively solid (depending on the level of dewatering), is probably heterogeneous, and does not change rapidly with time. A difficulty is if the sludge is not dry enough to walk on, in this case if only the edge of the drying bed can be reached, then the sample would not be as representative.

Figure 3.1 Stabilised pile of compost at the Niayes faecal sludge treatment plant in Dakar, Senegal, 2019 (photo: A. Ferré).

3.5 SAMPLING AND MEASURING DEVICES

Provided in Table 3.1 is an overview of the measuring devices that are described in this chapter, together with the measurements that they are suited for, and the advantages and disadvantages of each device. The devices are then described in more detail including how they can be used along the service chain. Sampling devices must be made of materials that will not contaminate or react with faecal sludge. Polypropylene, polycarbonate, high-density polyethylene (HDPE), polytetrafluoroethylene (Teflon), glass, and stainless steel are relatively inert and are all appropriate for sampling. However, the cost of Teflon and stainless steel equipment might prohibit or restrict their use, and potential for breakage of glass should be considered. If using metal equipment, depending on the analysis, galvanised or zinc-coated items should not be used as these materials will release zinc into the sample.

Table 3.1 Overview of sampling devices for faecal sludge.

Sampling device	Type of measurement	Advantage	Disadvantage
L-stick sludge and scum measuring device	• Depth of containment (septic tank) • Scum and sludge depth	• Affordable • Can be self-constructed	• Lower accuracy • Requires some training • Not suitable for thicker sludge
Core sampling device	• Characterisation of more liquid sludge • Height of scum, supernatant, and sludge layers • Visualisation of the different layers	• Easy to use • Can be self-constructed	• Not suitable for thicker sludge • Needs attention to prevent leakage at the bottom of the device (*e.g.* due to solid waste preventing watertight closure)
Vacuum sludge sampling device	• Characterisation of more liquid sludge	• Collection of sludge at a specific depth • Able to sample thicker sludge at bottom of containment • No mixing of sludge sample with other layers	• Energy required for vacuum pump • Heavy to transport • Not necessarily available on local market • Relatively expensive
Cone-shaped sampling device	• Characterisation of thicker sludge	• Suitable for thicker sludge • Possibility to sample sludge at a specific depth	• Depending on depth and thickness, cannot sample from bottom of containment
Grab sampling device, horizontal	• Characterisation of liquid flow	• Avoids contact with sludge • Easy to use • Affordable • Can be self-constructed	• Limited use (*i.e.* specific to truck discharge, effluent samples) • Reliant on emptying operation • Not suitable for onsite containments
Grab sampling device, vertical	• Characterisation of liquid flow (treatment plant)	• Adequate for homogenous liquid stream • Allows samples to be collected in deep tanks • Can be self-constructed • Affordable	• Representativeness needs to be evaluated • Not suitable for onsite containments
Automatic composite sampler	• Characterisation of liquid flow (treatment plant)	• Consistent sampling • Effective means to collect data for daily operation at treatment plants • Time-saving • Flexible sampling programs	• Energy required • Expensive • Not always locally available • Not applicable for thick sludge
Distance-laser measuring device	• Sludge and containment depth and volume	• Greater precision and accuracy • Obtains quantitative measurement	• Cannot measure extremely large/small containment sizes
Portable penetrometer	• Shear strength of faecal sludge (related to viscosity)	• Rapid estimation of total solids (requires more testing) • No need to collect sample	• Requires trained staff • Measurement takes time • Not locally available • Requires further testing

3.5.1 L-stick sludge and scum measuring device

When sampling *in situ* from septic tanks, cess pits, and 'wet' pit latrines, it is sometimes important to consider the height or depth of the sludge layer, scum layer, and supernatant separately (refer to Example 5.1). An L-stick, shown in Figure 3.2, can be used to measure these layers; it is a long stick similar to a garden or concrete hoe.

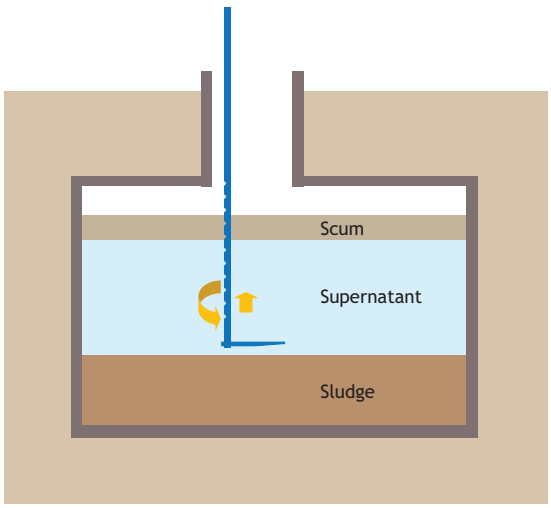


Figure 3.2 L-stick measuring device for depth of layers in a septic tank.

The stick has calibrated notches or nails to measure the depth at which it is inserted. For scum, the layer needs to be firm, with a crust, but not solid. The stick is poked through the scum, rotated 90°, and gently raised until the 'L' touches the bottom of the scum. For the sludge blanket layer, as the hoe is lowered it can be difficult to tell when the hoe first hits the sludge, and requires some practice. In some countries, L-sticks are used by emptiers to determine whether septic tanks should be emptied. The top of the sludge blanket layer is noted, and then the device is lowered to touch the bottom of the tank. One rule of thumb is that if resistance is felt from the top of the sludge blanket to halfway to the bottom, it requires emptying (Khan *et al.,* 2007). The core sampling device described in the following section is an alternative for measuring the depth of layers.

3.5.2 Core sampling device

The core sampling device shown in Figure 3.3 captures a vertical section of the substrate matrix. It is useful for sampling representative sub-samples of different layers in wet containments that have settled for many months or years, such as scum, supernatant, and thickened sludge. It can also be used to take samples from the access port of collection trucks, or tanks at treatment facilities. However, this type of sampling device is difficult to use with thicker sludge or sludge with large amounts of municipal solid waste, because it is difficult to push the device through the layers (Figure 3.3).

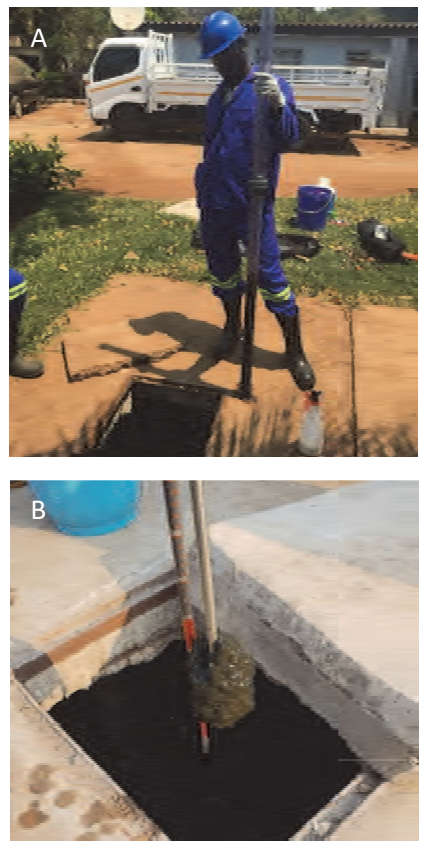


Figure 3.3 A) taking a core sample from a septic tank in Lusaka, Zambia, and B) the sampling device becomes clogged if the sludge is too thick. This example shows the collection from a 10-year old septic tank that had never been emptied. The tank was leaking, and so the supernatant leached out into the soil, resulting in a very thick sludge accumulation (photos: Eawag).

Another example of a core sampling device is shown in Figure 3.4. It consists of four transparent tubes (Figure 3.4, 1) that fit together, and four stainless steel rods (Figure 3.4, 2) that screw together inside the tubes. The device can be disassembled for transport, as well as shortened or extended as required. The tubes are graduated to measure volume. In the bottom tube the rod is attached to an airtight cover or plunger (Figure 3.4, 3) to close off the bottom of the sampler. This cover can be constructed from different materials, but it is very important that it can make a watertight seal. An alternative to the rod is a string. During sampling, the tube is inserted in the containment until the cover touches the bottom. Upon reaching the bottom, the cover should be left to settle for 30-60 seconds, allowing for any disturbed solids to settle. The hollow tube is then placed slowly over the cover, which is tightened with the string or rod (Figure 3.4, 4) to ensure a watertight seal so the sample can be removed. It is important not to make the device too large or it will be difficult to remove the sample without spilling.

3.5.3 Vacuum sludge sampling device

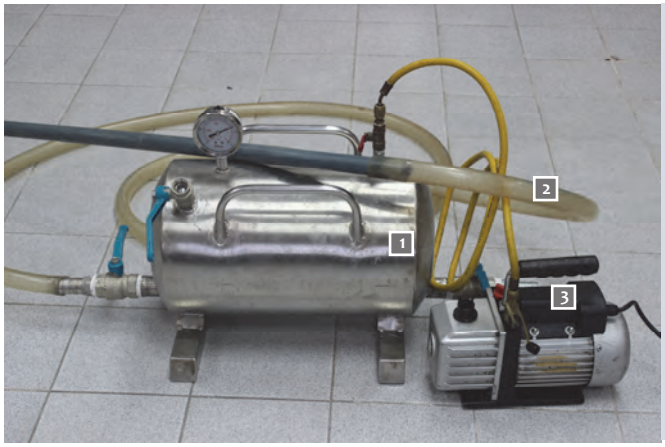
The vacuum sludge sampling device shown in Figure 3.5, also called a sampling hand-pump device, was developed by the Asian Institute of Technology (AIT). It was designed to take a sample at a designated depth with minimal disturbance to the surrounding layers. The device consists of a sample collection tank, a vacuum tank, and a hose. When taking a sample, the sample collection tank is evacuated, the vacuum pressure is set, and then the hose is placed in the exact location where the sample is desired. The suction valve of the vacuum tank is then released to collect the sample. The hose is brought back up, and the collected sample is released into a container by opening the discharge and air valves to normalise the pressure. This device is suitable for sampling from onsite containments and treatment technologies, to collect a sample at a specific depth.

1. Core sampling tubes that fit together
2. Rods that screw together inside the tubes
3. Air-tight seal to close bottom tube
4. Locking system to attach to top-most rod

Specifications (source: CDD, India):

- Self-constructed acrylic tubes in Bangalore, India made with local material.
- Used in Sircilla, Telangana to collect faecal sludge from onsite containment systems (on average total sludge = 25 g/L).
- Internal diameter: 6 mm.
- Price: approximately 85 USD (constructed in 2018 in India).

Figure 3.4 Graduated core-sampling device developed by CDD, India (Prasad *et al.*, submitted, photos: CDD, India).



1 Sample collection tank
2 Flexible hose
3 Vacuum pump

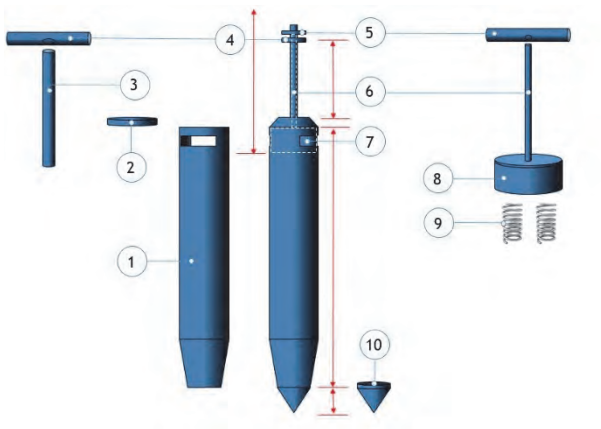
Specifications (source: AIT, Thailand):

- Vacuum pump, 0.10-0.15 kW, 220 V.
- Vacuum tank, stainless steel tank, capacity 5-10 L.
- Hose, flexible hose of 1.5 to 2.5 cm.
- Approximately price (in Thailand): 1,500 USD.

Figure 3.5 Vacuum sludge sampling device (photo: AIT).

3.5.4 Cone-shaped sampling device

The cone-shaped sludge sampling device shown in Figure 3.6 can be used to collect samples in relatively 'dry' or less liquid onsite containments. Samples can be taken at a specific depth through a controlled valve that opens to take the sample, and closes to bring the sample out. Solid waste in containments complicates the operation and obtaining a representative sample due to clogging. The cone-shaped sampler in Figure 3.6 is 3 meters high with hinged arms, to allow for sampling of onsite containments within super-structures. The sample size is approximately 1 L. Similar devices have been used in many locations in sub-Saharan Africa, including the University of Zambia (Tembo, 2019), Makerere University (Zziwa, 2019), Egerton University (Muchiri 2019), and Jimma University (Beyene *et al.,* 2019). Modifications include a hinged opening and closing instead of a valve operation. Production of one unit in sub-Saharan Africa is around 300 USD in Kenya and Zambia. An example of sampling in Lusaka is provided in Case study 3.1.



1 Sample-holding tube
2 Joint between the sample-holding tube and the extension pipe
3 Extension pipe connected to the joint
4 Handle of sample-holding tube
5 Handle used to close and open sample inlet door
6 Steel rod to hold the sample inlet closing and opening cup (extendable)
7 Sample inlet door (can be opened and closed at any depth)
8 Sample inlet closing cup
9 Two spring coils inside tube connecting closing cup and sample-holding tube (semi-automatic)
10 Pointed bottom cup - it can be tighten with a screw to facilitate the penetration and can be used to empty the sample

Figure 3.6a Schematic of the cone-shaped pit-sampling device.

Figure 3.6b Cone-shaped pit-sampling device in use in a study in Ethiopia (photo: Beyene *et al.*, 2019).

3.5.5 Grab sampling device - horizontal

The grab sampling device shown in Figure 3.7 consists of a sampling container of a known volume mounted on the end of a bar or rod.

Figure 3.7 A grab sampling device used for sample collection during truck discharge in Kampala, Uganda (photo: Eawag).

This sampling device is suitable for collecting faecal sludge at the discharge valve of the vacuum truck, as well as in some locations in treatment facilities (*e.g.* an FSTP outlet pipe). The sampling container is usually made of rigid plastic or stainless steel with a wide opening and a spout for emptying the sample. The bar or rod needs to be strong enough to avoid deformation or breaking during the sampling, because the flow from the outlet of the vacuum truck can be quite strong, and also long enough to protect the person collecting the sample from being splashed by sludge. The device allows for samples of a known volume of faecal sludge to be taken at a point in time. The sampling container is typically 1 L.

3.5.6 Grab sampling beaker device - vertical

The sampling device shown in Figure 3.8 is similar to the one shown in Figure 3.7, but the sampling container is oriented for samples to be taken vertically at depth of relatively homogenous substrates, such as supernatant in a settling tank. The length of the rod is dependent on the depth at which samples are taken. The sampling container should have a flat bottom, and the rod should be slightly flexible.

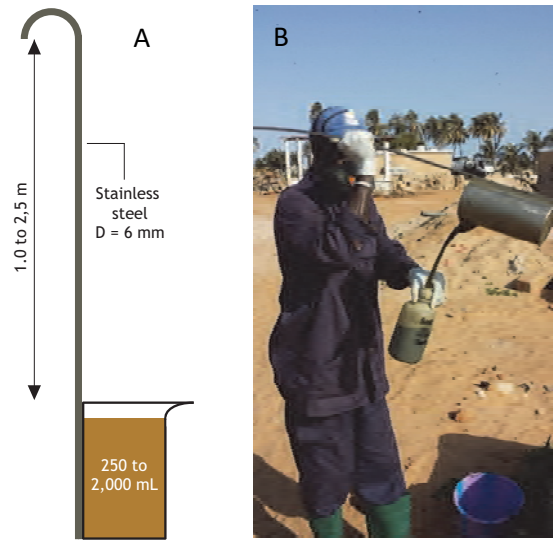


Figure 3.8a A) schematic of the grab sampling beaker device. B) at the outlet of the Cambérène FSTP, ONAS staff, Dakar, Senegal. Note: wide-mouth containers are preferable for sample allocation, as they aid sample collection without spillage (photo: Eawag).

Figure 3.8b Use of the sampling device in the liquid stream at the treatment plant (photo: IHE Delft).

3.5.7 Automatic composite sampler

Automatic composite samplers as shown in Figure 3.9 are commonly used in WWTPs, and can also be used for sampling the effluent of FSTPs. The system requires energy and is equipped with a peristaltic pump. A composite sampler usually includes several modes and sampling methods such as composite sampling (multiple samples are combined in a single large container), or sequential distribution (multiple samples are taken and stored in multiple bottles). Sample interval and time need to be selected, and can be uniform (commonly once an hour for 24 hours), or non-uniform.

Figure 3.9 An automatic composite sampling device (photo: IHE Delft).

Multiple samples are necessary when samples larger than 1,000 mL are required for analysis. As explained in Section 3.4.2, composite samples can be taken as fixed volume or flow proportional. Composite samplers include refrigeration for sample preservation. Single-bottle composite sampling is commonly used for influents and effluents, while multiple-bottle sampling is used to identify operational issues in treatment technologies.

3.5.8 Distance laser measuring device

The Volaser (*vol*ume *laser*) measuring device shown in Figure 3.10 is being developed by Eawag for measuring *in-situ* volumes of accumulated faecal sludge and volumes of containments (Andriessen and Strande, in preparation). The Volaser can be used to estimate accumulation rates as presented in Chapter 5 and Case study 3.1. The Volaser consists of a distance laser measuring unit, a tripod stand, and a probe to measure depth. The tripod is set up over a vertical access port to a containment. The laser unit is then lowered into the containment, and rotated as it measures the distance to the walls of the containment. Afterwards, the same laser unit is used to measure the distance from the top of the containment to the faecal sludge surface. A collapsible metal probe that is 3 m long is used to physically determine the depth of the containment. These measurements, along with the GPS coordinates, are recorded in a smartphone app which then automatically calculates the required volumes. The measurements take on average less than ten minutes with an accuracy of <10% error (*e.g.* ± 0.2 for a 2 m^3 containment). The Volaser device is not applicable for extreme cases (*e.g.* depth greater than 3m, access ports at an angle, or extremely large storage tanks). The Volaser can be operated by one person, and works well with a team of 2-3 people if sampling also includes characterisation and questionnaires. A version that can be locally assembled for less than 350 USD is expected by 2021 (Andriessen and Strande, in preparation). The tool can be adapted to local needs, and is applicable for all types of onsite containment technologies. Previous attempts at *in-situ* measuring devices include a laser measuring device to measure the 3D surface of sludge in pit latrines; however, further development is required due to light interference (Dahmani, 2010).

Figure 3.10 A) schematic of the Volaser with a laser measuring head that enters the containment to measure the area and distance to the sludge, with a smartphone mounted on top. Photos are from Lusaka, Zambia of (B) the prototype version used in 2019, with the Volaser placed over an access to a pit latrine (C) (photos: Eawag).

3.5.9 Portable penetrometer

The portable penetrometer shown in Figure 3.11 is intended as a relatively simple and quick *in-situ* test for shear strength of faecal sludge (related to viscosity) (Radford and Sugden, 2014). The penetrometer gives a continuous profile of how sludge varies throughout the depth of a containment. The device still requires further development, but the goal is to predict TS based on the *in-situ* penetrometer measurements, for rapid estimates at community to citywide scales. One measurement takes approximately twenty minutes with a skilled team of two to three operators.

Figure 3.11 A and B) the portable penetrometer in use in Kampala, Uganda; C) the new 'P-lite' model for easier mobility in the field which is under development (photos: J. Radford).

3.6 SAMPLING METHODS AND LOCATION

Once the sampling objective has been determined, sampling locations in the faecal sludge management service chain and the sampling methods and devices can be selected. There are specific concerns for each step in the faecal sludge management service chain, including type and usage of onsite containment, collection and transport, type of treatment processes, and final end use or disposal. The reality is that obtaining representative sampling from containments can be difficult, as they are closed, underground systems, and samples cannot always be taken exactly where preferred. When selecting the sampling location, if the preferred location is not possible, then the closest representative alternative should be selected. The decision process should be documented, and evaluated for bias. For example, if the objective is to determine *in-situ* total loadings of accumulated faecal sludge, and sampling takes place during discharge at treatment plants, it will not necessarily be reflective of the total accumulated sludge if containments are not fully emptied. Another example is if sampling can only be done when they are full and require emptying (Strande *et al.,* 2018), because as illustrated in Figure 3.12, accumulation rates of total volumes of faecal sludge in containment do not accumulate linearly due to biological, physical and chemical properties (see Chapter 5). What triggers the emptying event is typically a nuisance event such as backing up or overflowing.

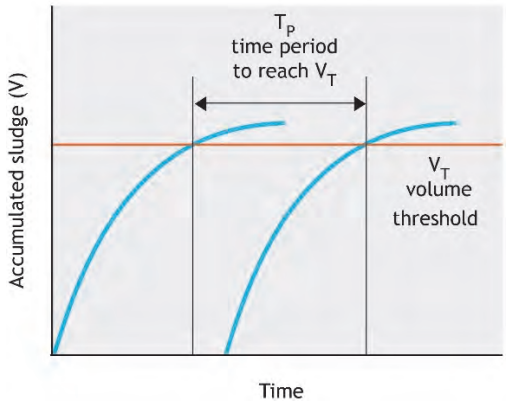


Figure 3.12 The blue lines illustrate change in the faecal sludge accumulation rate and T_P is the amount of time to reach V_T, the volume threshold where emptying is triggered.

The reality is that sampling will be dependent on the available resources. Assumptions will have to be made when designing a sampling campaign, which can be validated during implementation from different sampling locations. This is further discussed in Case Study 3.3 and Chapter 5. The following section presents examples of sampling along the service chain.

3.6.1 Sampling *in situ* from onsite containment technologies

In Chapter 2, faecal sludge is classified as liquid (total solids content <5%), a 'pumpable' slurry (total solids 5-15%), a 'spadable' semi-solid (total solids 15-25%), or a 'solid' (total solids >25%). Sampling methods are classified for more 'wet' or 'dry' faecal sludge, but in reality, in many systems or locations the faecal sludge will be a combination of types, and what is most appropriate for each situation will be context-specific, as illustrated in Case study 3.1.

In-situ sampling of a wet toilet system (faecal sludge < 5% TS)

This category can include many types of containment, including pit latrines or septic tanks, lined, unlined, or partially lined, one or multiple chambers, with or without overflows, and with soakaways or drain fields. The sampling location depends on the objective, and also on accessibility (Figure 3.14).

Figure 3.13 A septic tank located below a house, requiring the floor to be broken for emptying or sampling, Hanoi, Vietnam (photo: Eawag).

Sampling from septic tanks can be done via access ports, but they are also frequently sealed, covered over, or even located under buildings, as shown in Figure 3.13. In the latter case it can be difficult to know which part of the septic tank is being sampled.

Samples are frequently collected as core samples to collect a representative sample of all accumulated sludge layers. Grab samples of the effluent from the septic tank can also be collected to evaluate settling performance/solids removal. Examples of sampling locations in a two-chamber septic tank are provided in Figure 3.14. According to the sampling objective and strategy, a composite sample may be made from core samples from the different chambers of the wet toilet system or from grab samples collected at regular time intervals. Sampling could be also done directly through the toilet access hole in 'wet' pit latrines. In other cases, the depth of the sludge layer, supernatant, and scum layer can be measured with an L-stick.

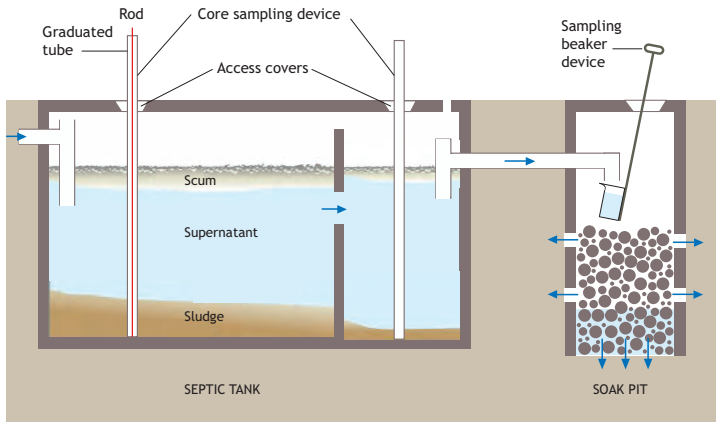


Figure 3.14 Sampling points in a septic tank: on the left is a vertical core sample in the first chamber, in the middle is a vertical core sample in the second chamber and on the right is a grab sample of the septic tank effluent (depending on configuration, e.g a distribution box or open drain).

In-situ sampling of dry containments (faecal sludge > 15% TS)

In-situ sampling of dry containments for characterisation can be done with the cone-shaped sampling device (Section 3.5.4) through the toilet access hole. Sludge volumes and depths can be measured with the Volaser measuring device (Section 3.5.8). Examples of in situ sampling are found in Case Study 3.1.

Case study 3.1 *In-situ sampling to estimate quantities and qualities (Q&Q) of faecal sludge in Lusaka, Zambia*

Eawag and UNZA conducted a study from September to December 2019 in Lusaka, Zambia to estimate quantities and qualities (Q&Q) of faecal sludge, specifically characteristics and accumulation rates (see Chapter 5). 82% of Lusaka relies on onsite sanitation, with 55-70% being pit latrines and 10-20% septic tanks (GFA Consulting Group GmbH, 2018). Observed total solids concentrations of 420 collected faecal sludge samples ranged from 0.1 to 40% measured gravimetrically, illustrating the wide range of characteristics that are present. To account for this diversity, different sampling devices were needed for *in-situ* sampling from septic tanks and pit latrines. For the design of the sampling plan see Case study 5.1.

Upon arrival at the sampling site, the containment was inspected to see if it could be sampled. A collapsible metal probe (3 m length) was used to measure the depth of the containment. For pit latrines, a cone-shaped sampler with a hinged arm was used to

collect samples, as shown in Figure 3.15. Faecal sludge up to 40% total solids could be sampled with the cone-shaped sampler, and the minimum required sludge for sampling was 50 cm. The pit latrine samples were collected directly through the opening in the toilet. A core sampling device was used for septic tanks (Figure 3.15). The core sampler was graduated, to simultaneously measure the depth of the total sludge level and the sludge blanket layer. Faecal sludge from septic tanks was sampled in the first chamber of the tank. The cone-shaped sampler and the core sampler were both 3 m long.

Figure 3.15 A) a core sampling device, B and C) a cone-shaped sampler, D) the Volaser measuring device (photos: Eawag).

To measure the total volume of the containment, the Volaser measuring device was used (Ward *et al.*, 2021). The measurement was started through the smartphone app, and the Volaser was rotated while the laser was measuring the distance to the walls, angle of rotation, and calculating the area of the containment (Figure 3.10). The distance to the sludge surface was also measured. Based on collected data including time since last emptied, it was possible to estimate the sludge accumulation rates.

Samples collected for characterisation were poured into a bucket, stirred for homogenisation, and 0.9 L was transferred to a plastic container. Samples were stored in a cooler box with ice packs during transportation and delivered to the laboratory at the end of the sampling day, where they were immediately stored in a refrigerator. Analysis included TS, VS, COD, electrical conductivity, pH, NH_4-N, capillary suction time (CST), colour, odour, foam and C/N ratio. Duplicate sampling was conducted every 5 samples and triplicate sampling every 20 samples to test the replicability of the sampling method. Following this procedure, 6-7 samples could be collected per sampling team in one day.

3.6.2 Sampling during emptying of onsite containment technologies

As discussed, *in-situ* sampling is often not possible, and so sampling is frequently conducted during emptying operations.

Sampling of dry toilet containment during manual emptying

Manual emptying occurs with all types of faecal sludge in areas where vacuum trucks cannot access due to narrow lanes or paths, where faecal sludge is too thick for vacuum pumps, or where vacuum trucks are not available. Faecal sludge is commonly emptied into barrels, which can then be transported by cart or small trucks to a treatment plant or transfer station. Figure 3.16 shows examples of manual emptying operations in Lusaka, Zambia, and in Durban, South Africa. If the sampling objective is to determine average characteristics, grab samples could be taken from the barrels, and combined into a composite sample. Examples of dry toilet systems are urine diverting dry toilets (UDDT) and dry pit latrines with total solids > 15%.

Figure 3.16 A) sampling during a manual emptying operation in Lusaka, Zambia, and B) Durban, South Africa (photos: Eawag).

If the sampling objective is to evaluate how sludge degrades over time and with depth inside a pit latrine, samples can be taken from different vertical layers during emptying. Buckley *et al.* (2008) propose that faecal sludge in dry toilet systems can be classified in

four layers as: (*i*) fresh stools, (*ii*) a partially degraded aerobic surface layer, (*iii*) a partially degraded anaerobic layer beneath the surface, and (*iv*) a completely stabilised anaerobic layer. Velkushanova (2019) and Zuma *et al.* (2015) developed their sampling methodology based on Buckley *et al.* (2008) and proposed that a dry toilet system can be further divided into two sub-sections: a back section and a front section (under the pedestal) as presented in Case study 3.2. Faecal sludge sampling should be done at different depths at the front and back of the pit, as containment of sludge in dry ventilated improved pit (VIP) latrines is not evenly distributed. In contrast to wetter sludges, it is possible to have a higher heap of sludge accumulate directly underneath the pedestal. Similarly, faecal sludge samples can be selected from both active and standing vaults of the UDDT toilets and other dry containment systems, outlined in Case study 3.2. These separations or distinctions should be considered during sampling to ensure an overall representative sample of the entire containment system, and are represented by the numbers in Figure 3.17.

Case study 3.2 *Sampling methods and locations of different dry onsite sanitation systems in Durban*

The Pollution Research Group at the University of KwaZulu-Natal (UKZN PRG), South Africa carried out a study into the properties of faecal sludge from onsite sanitation facilities in the Durban metro area, including: wet and dry household VIP latrines, household UDDTs, household unimproved pit latrines, community ablution block (CAB) VIP latrines, and school VIP toilet blocks. The goals were to provide a better understanding of the potential use of faecal sludge as a biofuel or fertiliser, to support the design and sizing of mechanical pit-emptying devices, transportation and processing systems for the excavated sludge, and the design of future onsite sanitation facilities. The study took place during 2012 and 2013.

Pit emptying

The first phase of the project involved a sampling program (Table 3.2) to obtain faecal sludge samples from selected onsite sanitation facilities in peri-urban and rural areas of Durban that are serviced by the eThekwini Municipality.

Table 3.2 Distribution of 45 samples in peri-urban and rural areas of Durban.

Facility type	Characteristics	Usage level	Number of onsite sanitation systems sampled	Location
Household VIP latrine	Dry	Low usage (<5 users/onsite system)	5	Besters
		High usage (>5 users/onsite system)	5	
	Wet	Low usage	5	Besters
		High usage	5	
Household UDDT toilet		Low usage	5	Mzinyathi
		High usage	5	
Household unimproved pit latrine	Dry	Low to high usage	2	Ocean Drive
Community ablution block VIP	Dry	High usage	9	Malacca Road
School VIP toilet block	Wet and dry	High usage	4	Mzinyathi
Total			45	

Sludge sampling

The faecal sludge in pit latrines varies widely, which makes the comparison between samples collected from the different onsite sanitation facilities challenging. In order to provide a uniform data comparison, a sampling method was developed and applied for selection of samples from different depth levels at the front and back of the pit for all dry VIPs (Figure 3.17, top left). Sample 1 represents a fresh deposit and is usually right beneath the pedestal, sample 5 is partially degraded aerobic faecal sludge but some of the fresh material may have fallen there, samples 2 and 6 are partially degraded aerobic faecal sludge, samples 3 and 7 are partially degraded anaerobic faecal sludge, and samples 4 and 8 are at the bottom of the containment and are completely stabilised and anaerobic faecal sludge.

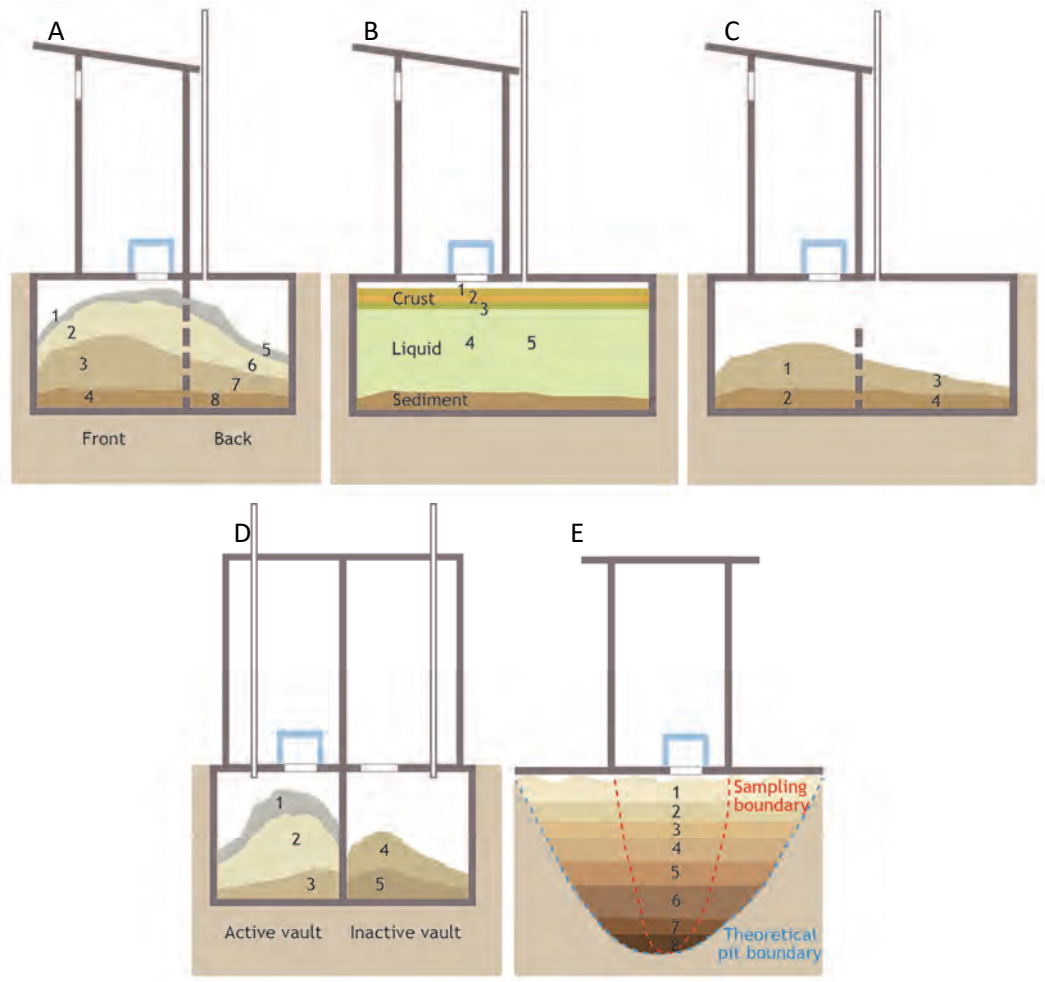


Figure 3.17 The selection of faecal sludge analytical samples used in Case study 3.1 is from: A) dry ventilated improved pit latrines (VIPs), B) wet VIPs, C) school VIPs, D) UDDT toilets, and E) unimproved pit latrines. The numbers illustrate where samples were taken.

A similar approach was followed for the UDDT toilets, where samples were selected from both active and standing vaults (Figure 3.17, bottom left). For the wet VIPs, samples were selected from the sludge crust concentrated at the top of the pit and from the liquid beneath the sludge layer but no distinction was made between the front and the back of the pit (Figure 3.17, top middle). The community ablution block VIPs did not allow for structured sampling, because of the limited accessibility for pit emptiers due to the large size of the containments and large amounts of solid waste. Samples were selected from the top sludge layer and the liquid beneath, similarly to the wet household VIPs. For the school VIP toilets, the sampling procedure was similar to the one followed for dry VIPs. Due to the shallower sludge layers, only four samples were selected from each pit (two from the front and two from the back (Figure 3.17, top right), except for one where six samples were selected in total. For the unimproved pit latrines, seven to eight samples per pit were selected as indicated in Figure 3.17 (bottom right). This procedure was followed as there was no superstructure as for the VIP toilets, hence there were no clear boundaries between the faecal sludge disposed in the pit and the surrounding soil.

On average, eight samples were selected from each dry VIP, between four and six samples from each wet VIP, two to six from each UDDT toilet, two from each CAB VIP, four from each school toilet VIP, and eight samples from each unimproved pit latrine over a period of 18 months, where 211 samples were collected in total. The selected samples had a capacity of approximately 1 litre and were stored in plastic containers at 4°C in a cold room in the UKZN PRG laboratory for further analytical tests.

Figure 3.18 Photographs of faecal sludge samples in Case study 3.2 taken from: A) a dry ventilated improved pit latrine (VIP), B) a wet VIP, C and F) a school VIP, D) a UDDT toilet, and E) an unimproved pit latrine (photos: UKZN PRG).

Sampling from collection and transport vehicles

Sampling from collection and transport trucks is another possibility, and fits the sampling objective of knowing what will be delivered to treatment. Depending on the type of truck, samples can be taken directly from the access port on the top of the truck tank or during discharge from the discharge valve (Bassan *et al.,* 2016). In the first option a core sampling device can be used, while in the second option a composite of grab samples is collected (Figure 3.19).

Figure 3.19 A) collecting grab samples from the truck discharge valve to make a composite sample, and B) collecting a core sample from a truck access port with a 180 cm length PVC core sampling device with a 5 cm internal diameter, Hanoi, Vietnam (photos: Eawag).

The composite sample usually consists of taking one sample at the beginning of discharge, two in the middle, and one at the end (Bassan *et al.,* 2013). When possible, a volume gauge on the back of the truck can be used measure volumes, and to determine when to take samples. Samples should be collected from the truck immediately after emptying, or from the discharge valve immediately upon arrival at the discharge facility. If trucks are left standing for even a short period of time, solids will rapidly start to settle out in the tank. A comparison of sampling methods is provided in Case study 3.3.

Case study 3.3 Comparison of four sampling methods in Hanoi, Vietnam

This case study is based on a Master's thesis by Amédé Ferré (2014), a collaborative project between Eawag and the Institute of Environmental Science and Engineering at Hanoi University of Civil Engineering. Sampling methods were evaluated during a characterisation study that took place between September 2013 and June 2014. More than 90% of households in Hanoi have septic tanks, with the overflow going directly to rainwater drains or sewer systems. Samples were taken from six different septic tanks with the number of chambers varying from two to three, and for each of the six septic tanks four different sampling locations were compared. Core samples were taken with a 1.8 m high PVC core sampler with an internal diameter of 5 cm. Grab samples were taken with a 1 L grab sampling device (bucket mounted on the end of a 1 m long bar).

1. Septic tank: samples were taken *in situ* from septic tanks with a core sampling device. This included from the bottom to the liquid surface (*i.e.* a core sample of sludge layer, supernatant and scum layers). However, the specific location in the septic tank where the sampling occurred could not be identified.
2. Truck access port: samples were taken with a core sampling device *in situ* from the access port on the top of the vacuum trucks, immediately following collection of septic tank sludge from households.
3. Beginning discharge: a single grab sample of 2 L taken from the truck valve at the beginning of the discharge.
4. Composite discharge: a composite sample comprised of four grab samples of 1 L each, taken from the truck valve at the beginning, middle and end of the discharge in a ratio of 1:2:1.

Presented in Figure 3.20 is a comparison of the TS and COD results for each of the sampling methods. The results illustrate the importance of sampling location depending on the objective and evaluating bias. The septic tank is more relevant if the objective is to determine sludge accumulation rates in the septic tank, whereas either the truck access port or the composite discharge is preferable for constituents of faecal sludge being delivered to treatment. In the case of thick faecal sludge (septic tanks 1 and 3), the composite discharge may be more representative than the truck access port, whereas for more liquid sludge (*e.g.* septic tank 6) the truck access port may be more suitable (*i.e.* larger supernatant volume). The beginning discharge appears to be biased to solids that settle out in the truck, and are washed out at the beginning of discharge (*e.g.* septic tanks 1, 2 and 3). Further analysis is needed to fully understand the effect of sampling location. Samples were taken from trucks, as service providers were reticent to allow sampling during discharge. There is no legal discharge location in Hanoi, and sampling would draw attention to their illegal discharge (although the businesses are legally registered). Samples were also analysed for total suspended solids (TSS), nutrients, volatile fatty acids (VFA), and proteins, and the raw data is available for download using the link provided in Englund *et al*. (2020).

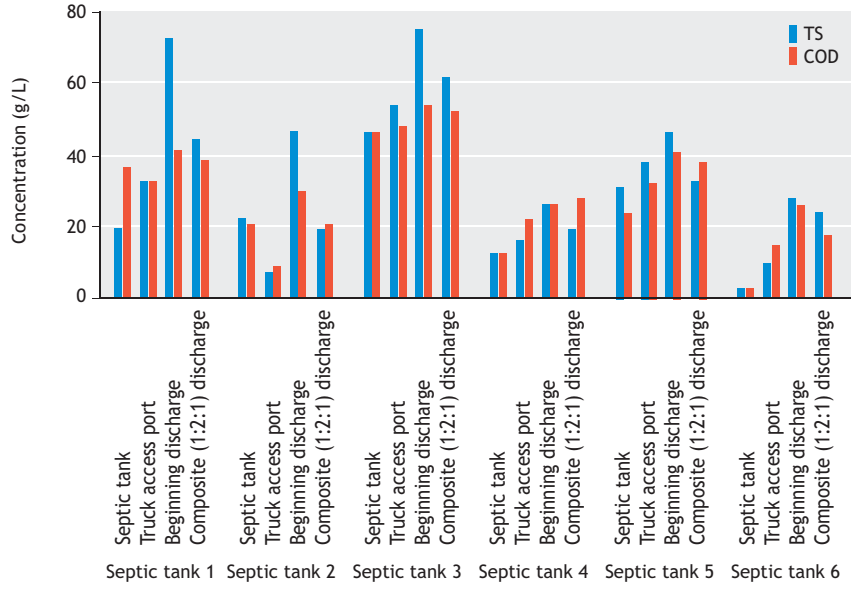


Figure 3.20 Total solids (TS) and organic matter (COD) results for six septic tank samples that were collected with four different methods.

3.6.3 Sampling at faecal sludge treatment plants

FSTPs can have combinations of various technologies such as settling-thickening tanks, drying beds, waste stabilisation ponds, and mechanical dewatering. Sampling locations and strategies will depend on the objective, for example, treatment performance, operational concerns, monitoring, resource recovery, and optimisation of loadings. In general, liquid and solid streams require different approaches to collection and analysis. For the sampling of liquid streams with similar characteristics to wastewater, refer to Meijer and Brdjanovic (2012), and the USEPA operating procedure for wastewater sampling (2017). Below are two examples of sampling at FSTPs; more information on dewatering and drying is available in Chapter 4 and Ward *et al*. (2019).

Case study 3.4 *Assessing FSTP performance*

A hypothetical FSTP in South East Asia consists of two settling tanks in parallel, planted drying beds, and vertical flow constructed wetlands. The effluent is discharged by gravity into a river. The FSTP opening hours are from 8 am to 6 pm on Monday to Saturday. The FSTP operator has defined the sampling objectives as evaluating the FSTP performance to assess future investment needs, and defined the sampling plan summarised in Table 3.3.

Table 3.3 Sampling plan to evaluate a FSTP performance in South East Asia.

Item	Sampling plan	Observation
Sampling location	• Discharge channel right after screening (laminar flow). • Manhole at the outlet of the vertical flow constructed wetlands.	• Flow and turbulence are high in the channel before screening.
Sampling technique	• Composite of 6 grab samples of equal volume taken every 2 hours. • Grab samples.	• Single daily composite. Due to limited human resources and time, interval time between 2 sampling is set at 2 hours (ideally every hour). • The outlet flow composition is assumed to be constant.
Sampling equipment	• Grab sampling device, vertical, 1 L volume with a 1 m rod to collect samples at half depth of the sludge flow in the discharge channel. • Grab sampling device, vertical, with 2 L volume and 3 m rod to access the bottom of the manhole.	• Sampling devices and containers were first rinsed 3 times with the targeted substrates (*i.e.* untreated faecal sludge or effluent). • The beaker is lowered to a depth of around 50 cm into the channel and then inclined to face the flow. It is assumed that the collected sample is representative of the flow.
Storage containers	• 6 x 500 mL PTFE plastic containers. • 2 x 2 L PTFE plastic containers. • 2 x 250 mL sterilised glass containers.	• Sterilised glass containers for further microbiological analyses. • First rinsed 3 times with the targeted substrates (i.e. untreated faecal sludge or effluent).
Sample preservation technique	• The six grab samples are immediately stored in a cool box with ice. • The effluent grab sample is transported to the lab in a cool box together with the two glass containers.	• Since microbiological parameters must be analysed within 6 hours, a single grab sample is taken specifically for these parameters.
Protective equipment	• Rubber boots, protective gown, protective glasses, active carbon filter mask, and rubber gloves.	

Case study 3.5 *Planning for measures to reduce exposure to contamination risk*

A hypothetical FSTP in West Africa consists of unplanted drying beds, each equipped with a discharge channel with a screening grid, a buffering storage tank for treated effluent reuse and a dried sludge storage area. The effluent, if not used, is infiltrated. After being removed from the drying beds, sludge is stored for one year (Figure 3.2.1). The FSTP operator has defined the sampling objective of evaluating compliance of dried sludge with agriculture reuse requirements to reduce farmers' exposure to faecal contamination risk. In order to fulfil this objective, the FSTP operator will assess the pathogen content of the dried and stored sludge, as described in Table 3.4.

Figure 3.21 Dried sludge at a faecal sludge treatment plant in West Africa (photo: A. Ferré).

Table 3.4 Sampling plan to evaluate the compliance of dried sludge with agricultural reuse requirements in West Africa.

Item	Sampling plan	Observation
Sampling objective	• Verify compliance of dried sludge with agricultural reuse requirements	• To reduce farmers' exposure to faecal contamination risk.
Sampling location	• Storage area: stabilised sludge after 1 year of storage	• See example in Figure 3.21
Sampling technique	• Composite of five random single grab samples distributed throughout the stabilised sludge pile.	• Stabilised sludge composition may vary throughout the pile.
Sampling equipment	• Grab device: tongs, spoon, gloves, etc depending on size	• Stabilised sludge is relatively inert, reaction with a plastic container has low probability.
Storage containers	• 1 L PVC container with wide opening	
Composite	• The sub-grab samples will be gently crushed in a mortar and the resulting powder will be mixed.	
Sample preservation technique	• The sample will be transported to the soil laboratory in a cool box with ice.	• No preservative required for microbiological parameters.
Protective equipment	• Rubber boots, protective gown, rubber gloves.	• Risk of ingestion is low.

3.7 SAMPLE SIZE

Guidelines on how to develop sampling and analytical plans taking into account the adequate number of duplicate samples to ensure accuracy and precision are presented in Chapter 8. A detailed plan for quality assurance and quality control (QA/QC) needs to be developed in advance of sampling to take into account the increased number of samples for duplicates and controls. In reality, there are no hard and fast guidelines for determining the 'right' number of samples, and frequently the selected sample number

will come down to available time and resources. Even with a limited number of samples, by taking them in a logical fashion with defined objectives and QA/QC procedures in place, the results will still be more meaningful than if collected without these controls in place. In Example 3.1 are sample sizes based on a normal distribution. However, as presented in Chapter 1, faecal sludge does not follow a normal distribution and a statistically valid number of samples cannot be determined until a distribution is known. This means that in reality, the samples actually have to be taken before these assumptions can be validated. It is important to keep in mind that with more samples there is increased accuracy, but the increase is not linear. How to calculate the effect of sample size on uncertainty is discussed in Chapter 5, along with further information and examples of developing sampling plans for community to citywide scales, and statistical relationships that can be used to reduce the required time and resources for analysis.

Example 3.1 *Sample sizes for normal distributions*

If the probability distribution of a sampling population is known, equations exist to determine a statistically significant number of random and independent samples. The number of samples will depend on the selected confidence interval (margin of error) and confidence level. For example, as shown in the table for a normal distribution, if a city has a population of 2,000,000, served by 70% onsite sanitation with an average of 10 users per containment, this would mean 140,000 onsite containments. Based on the values in Table 3.5 with a 90% confidence interval and 5% margin of error, this would mean 270 samples. However, Q&Q of faecal sludge will probably not follow a normal distribution, and a much lower number of samples could logically be selected with a transparent explanation of how the number and type of samples were selected.

Table 3.5 Required sample size to fulfil a confidence interval of 90% and 95% with a margin of error of 5% and 2% for normally distributed data.

	Confidence interval = 90%		Confidence interval = 95%	
Population	Margin of error		Margin of error	
	5%	2%	5%	2%
100	74	95	80	97
200	115	179	132	185
500	176	386	217	414
1,000	213	629	278	706
10,000	264	1,447	370	1,936
100,000	270	1,663	383	2,345
1,000,000	271	1,689	384	2,396
2,000,000	271	1,690	385	2,398

3.8 HEALTH AND SAFETY

It is important to have a health and safety plan in place for sample collection and transport. Personal protective equipment (PPE), as shown in Figure 3.22, must be worn to ensure protection from pathogens and other potentially harmful constituents in faecal sludge, including appropriate handling and cleaning of contaminated clothing. Other safety considerations include working in confined and dangerous spaces, toxic gasses that build up during anaerobic digestion of faecal sludge, water, and electricity, and moving components at FSTPs. The sampling area must also be kept clean to protect the general population from risk of exposure to faecal contamination. Any faecal sludge that is spilled during sampling must be immediately cleaned, and waste matter properly disposed of. For more information, refer to Chapter 8, and for a detailed overview of recommendations, refer to Health, Safety and Dignity of Sanitation Workers An Initial Assessment (World Bank 2019), and for hygiene practices to Louton *et al.* (2018).

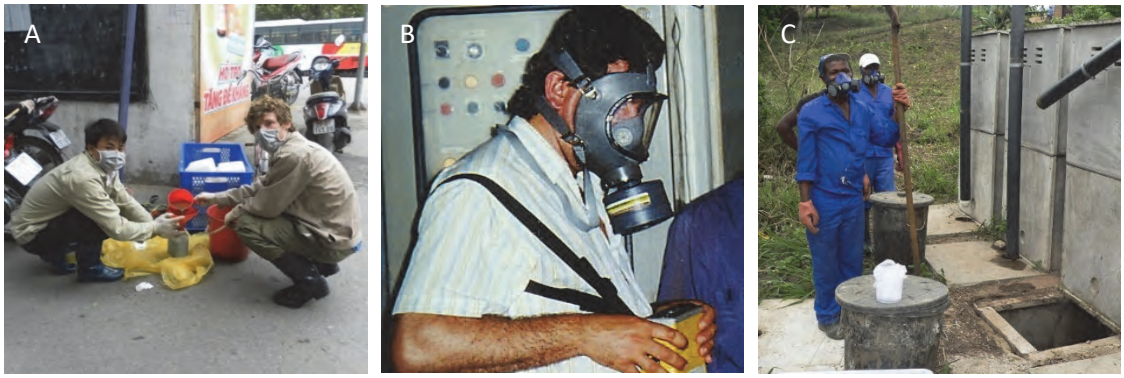


Figure 3.22 Personal protective equipment. A) transferring homogenised samples to sample containers with a plastic funnel and ground protection. B) a mask and meter/alarm for H_2S. C) collecting samples from pit latrines (photos: Eawag, M. Henze, UKZN PRG, respectively).

3.9 SAMPLE COLLECTION

Prior to sampling, arrangements need to be made with the laboratory carrying out the analysis regarding sample volume and laboratory capacity. It is important to consider transportation times, working hours, weekends, and available staff. The minimum required sample volume needs to be determined based on the number and type of analytical procedures to be carried out. An example of calculating the required volume based on planned analysis is presented in Figure 3.23. Extra sample volume should be added to account for potential spillage and other unforeseen needs during processing.

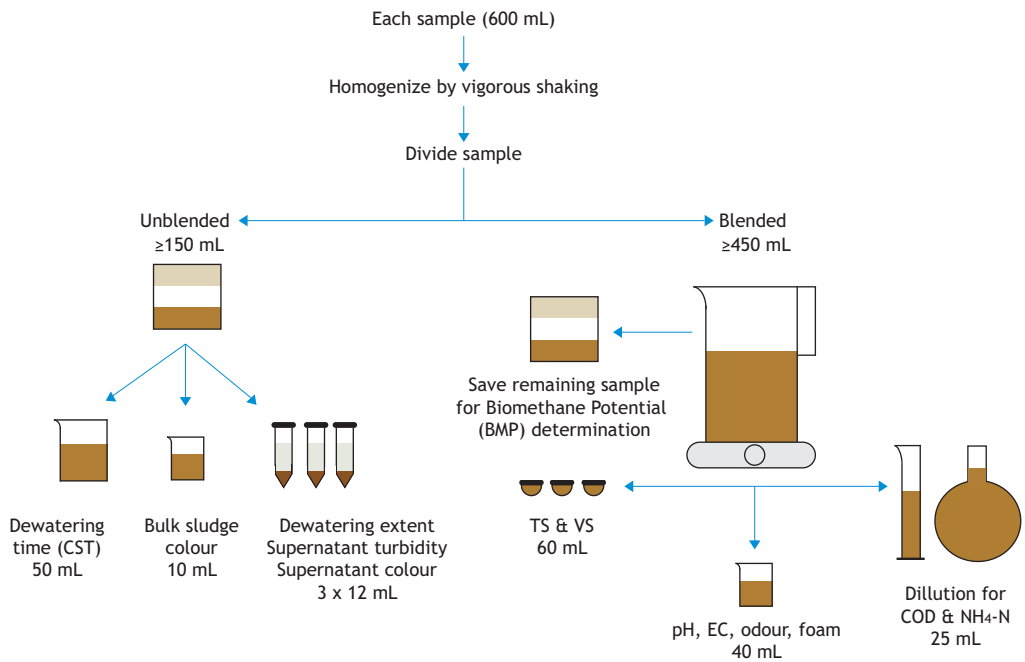


Figure 3.23 Example of how to calculate the required sample volume based on the planned laboratory analyses.

When samples will be sub-divided the sample must be homogenised. This can be done by stirring rapidly with a ladle to get all the particles in suspension and then immediately distributing to sub-sample containers. Whichever method is used, it is important to record the method, and to evaluate the accuracy and replicability. Wide-mouth sampling containers are preferred, and the use of a funnel is recommended for transfer of samples.

If making a time-related composite, all the grab samples must be stored at 4 °C until the entire sampling process is completed. If a refrigerator is not available at the sampling site, then samples should be stored in a cooler box with ice packs. In this case the composite is often prepared at the laboratory.

All the containers used to store the samples should be labelled prior to sample collection to prevent sample misidentification. Labels must be water resistant, and include at a minimum a unique sample number or code, the sampling date, nature of the sample for health and safety, and name of the laboratory where the samples will be delivered. All the sampling equipment and material has to be cleaned immediately after sampling to avoid contamination of future samples and ensure the health and safety of workers.

Equipment used to collect samples should be cleaned in the field with water and detergent. Detergent should be a standard brand of phosphate-free laboratory detergent. Under extenuating circumstances where cleaning in the field is not feasible, equipment can be containerised, bagged or sealed and cleaned upon return to the laboratory. Sampling containers must be properly cleaned prior to use or reuse and, if needed, sterilised in an autoclave. For more information on the specific procedures, methods and considerations to be used and observed when cleaning and decontaminating sampling equipment during the course of field investigations, the reader is referred to USEPA (2015).

3.10 RECORDING OF SAMPLE COLLECTION

Details on each sampling event need to be documented in a logbook immediately at the time of sampling. This documentation is useful for troubleshooting if the laboratory results are atypical or suspect; it serves to demonstrate that the proper sampling protocols were used, and is useful to interpret and compare analytical results. It is good practice to record sufficient information that the sampling procedure can be reconstructed from the logbook alone. Recorded information should include at a minimum:

- sample identification code (specific to sampling event *i.e.* type, location, date, treatment process and condition, etc.)
- number of samples and volume of sample taken,
- type of sample (*e.g.* grab, 24-hour composite), sampling equipment and a brief description of sampling procedures
- volume of sample
- date and time
- sample location, GPS coordinates
- preservatives
- analytical parameters
- name of person who performed the sampling or measurement
- special conditions or remarks, *i.e.* weather conditions at the time of sampling and other observations which could potentially impact the laboratory analytical results
- brief description of the sludge collected, *e.g.* colour, odour, viscosity, consistency.

A chain-of-custody document is required to provide a record of sample transfer from person to person including everyone involved from taking the sample until delivery at the laboratory, and at what time they had the samples. All the personnel need to sign the form with the date and time of day, along with the sample ID code (see also Chapter 8).

3.11 TRANSPORT

When analysis will be performed away from the sampling location, the faecal sludge samples must be packaged and transported. Samples should be delivered to the laboratory as soon as possible following collection, and the travel time and conditions need to be recorded. Samples typically need to be transported in a cooler with ice packs to maintain a sample temperature of 4 °C for the duration of the collection and transport. Faecal sludge sample containers must be packaged in order to protect them and reduce the risk of leakage. Containers should be held upright and cushioned from shock. For more details on samples handling reader is referred to Chapter 8 and reference literature (*e.g.* Rice *et al*., 2017 and Van Loosdrecht *et al.*, 2016).

3.12 STORAGE AND PRESERVATION

Preservation of samples is crucial to allow reliable analytical results. Sludge composition changes over time, depending on factors such as light, oxygen, temperature and microbial activity, and therefore preservation techniques are required to slow down or stop/inhibit these processes. Analyses should only be done on well-preserved samples, and within the period in which the results will be representative of the initial sludge composition as stated in methods presented in Chapter 8. Samples should always be stored at a temperature of 4 °C to limit biologically induced changes. When several grab samples are collected with the purpose of making a composite, all the grab samples must be stored and preserved at 4 °C during the whole sampling process. Some microbial analysis requires storage preservation at -20 °C or -80 °C for storage longer than 24 hours, whereas samples can be dried and stored for later analysis with acid digestion (*e.g.* heavy metals) or combustion (*e.g.* calorific value, carbon, carbon, hydrogen and nitrogen elemental concentrations). For biologically active samples, it is important to label with an appropriate warning, and to allow gases to vent to avoid explosion.

The same considerations for sample containers need to be considered as discussed in Section 3.5; sampling and storage containers must be made of materials that will not contaminate or react with the faecal sludge. Polypropylene, polycarbonate, HDPE, Teflon, glass, and stainless steel are relatively inert and are all appropriate for sampling. The cost of Teflon and stainless steel equipment might prohibit or restrict their use, and potential for breakage should be considered with glass. If using steel equipment, depending on the analysis, galvanised or zinc-coated items should not be used because these materials will release zinc into the sample. Other considerations for interaction include silica, sodium, and boron which may be leached from soft glass but not plastic, and trace levels of organics and metals may sorb onto the walls of containers. In all cases, opaque containers are recommended to protect the sample from the light.

The addition of preservatives to the sample container can increase the preservation time of the sample from a few days to a few weeks. However, preservatives also change the composition of the sample and can affect the properties, so their usage has to be carefully evaluated. In this case, it is recommended to only use preservative in a sub-sample of the original sample. Chemical preservatives should only be used when there is no interference with the analyses that are still to be made. However, all methods of preservation may be inadequate when applied to suspended matter. Preservatives should not be added if analysis of volatile, semi-volatile or microbial contaminants are to be done, unless specified methods. For solid sludge samples (‘cake’ with total solids >25%), adding a chemical preservative is generally not useful since the preservative does not usually penetrate the sludge matrix.

3.13 EXAMPLE OF SAMPLING KIT

An example of a check list for a typical sampling kit is presented in Figure 3.24. For more information on the associated paperwork and health and safety forms, the reader is referred to Chapter 8.

SAMPLING BOX CHECKLIST

Examples of items to take along when sampling

Quantity and sizes will depend on researchers and sampling campaign

Quantity	Contents
1	Mobile First Aid Kit
2	70% Ethanol – 1L
1	1L spray container for any form of disinfection(jik/bleach)
2	Boxes Latex, powder free gloves
2	Pairs plastic elbow length gloves
3	Safety glasses
1	Box PPF2 dust masks
2	Half mask respirators with filters
1	Roll paper towel
1	Pack of bin bags
2	10L square sample containers
5	500ml plastic buckets
1	Small plastic scoop
2	Markers and pens
1	Disinfection soap
1	Sampling form with emergency and contact details
To be added	**Overalls, gumboots, cap and water bottle. Increase number of contents depending on the number of researchers sampling.**

Figure 3.24 Example from the UKZN PRG of a sampling kit checklist for dry onsite sanitation systems.

3.14 OUTLOOK

The level of accuracy of data is directly linked to the way it is collected, processed, and analysed. To obtain reliable, representative and reproducible values requires a thought-out process, including defining objectives, sampling tools and locations, developing QA/QC procedures, and maintaining a proper chain of custody. Obtaining representative samples from faecal sludge remains a challenge, due to the informal nature, sampling from underground containment, limited access, and inherent high variability of faecal sludge. Hence, it is essential to correctly follow all the steps outlined in methods, and to document any diversions or modifications that occur to ensure that results are replicable. Proper sampling also requires professional training of health and safety risks and adequate personal protection measures.

As faecal sludge management is increasingly established, reliable systematic sampling will play a key role in the development of accurate models for predicting Q&Q of faecal sludge, and management and treatment solutions. Advances in understanding of physical, chemical and biological processes and transformations in the faecal sludge that take place within the onsite sanitation service chain go hand in hand with increased complexity of the descriptors of such processes. In turn, these developments will enable sanitation professionals to tackle practical problems with deeper insight, advanced knowledge and greater confidence.

REFERENCES

Andriessen N. and Strande L. (in preparation). Manual for assembling and operating Volaser measuring device.

Andriessen N., Ward B.J. and Strande L. (2019). To char or not to char? Review of technologies to produce solid fuels for resource recovery from faecal sludge. *Journal of Water, Sanitation and Hygiene for Development*, 9(2), 210-224.

Bassan M., Ferré A., Hoai A.V., Nguyen V.A. and Strande L. (2016). Methods for the characterisation of faecal sludge in Vietnam. Eawag: Swiss Federal Institute of Aquatic Science and Technology. Dübendorf, Switzerland.

Bassan M., Tchonda T., Yiougo L., Zoellig H., Mahamane I., Mbéguéré M. and Strande L. (2013). Characterisation of faecal sludge during dry and rainy seasons in Ouagadougou, Burkina Faso. Presented at 36th WEDC International Conference, Nakuru, Kenya.

Beyene A., Tesfahun E., Hailu T., Getaneh A. and Faris K. (2019). Characterisation of Pit Contents and Developing a Scientific Understanding of Processes Occurring in On-Site Dry Pit Latrine Systems in Low-Income Urban Areas in Addis Ababa, Ethiopia. Water Research Commission Project No. K5/2293/11, Pretoria, South Africa.

Buckley C.A., Foxon K.M., Brouckaert C.J., Rodda N., Nwaneri C., Balboni E., Couderc A. and Magagna D. (2008). Scientific support for the design and operation of ventilated improved pit latrines (VIPs) and the efficacy of pit latrine additives, *Water Research Commission*, Pollution Research Group, School of Chemical Engineering. University of KwaZulu-Natal, ISBN 978-1-77005-718-0.

Dahmani K. (2010). The development and testing of a portable instrument to determine the filling rates in ventilated pit latrines, University of Kwazulu-Natal and INSA Toulouse (MSc thesis).

DEP (2005). Sampling Procedures Manual, *Department of Environmental Protection*, State of New Jersey, United States.

Englund M., Carbajal J.P., Ferré A., Bassan M., Vu T.H.A., Nguyen V.A. and Strande L. (2020). Modelling quantities and qualities (Q&Q) of faecal sludge in Hanoi, Vietnam and Kampala, Uganda for improved management solutions. *Journal of Environmental Management*, 261, 110202.

GFA Consulting Group BmbH (2018) SFD Report – Lusaka, Zambia.

Kahn L., Hulls J., Allen B. and Jones J. (2007). The Septic System Owner's Manual, *Shelter Publications Inc.,* United States, ISBN 0936070404.

Louton B., Beukes L., Naidoo D. and Still D.A. (2018). Understanding and addressing the exposure of workers, the public and the environment to pathogens during pit emptying, Report to the Water Research Commission. ISBN 978143129750.

Meijer S.C.F. and Brdjanovic D. (2012). A Practical Guide to Activated Sludge Modeling. *IHE Delft*, ISBN 9789073445280.

Muchiri E.W. (2019). Characterisation of Pit Contents and Developing a Scientific Understanding of Processes Occurring in On-Site Dry Pit Latrine Systems in Low Income Urban Areas in Kenya. Water Research Commission Project No. K5/2302/11, Pretoria, South Africa.

Prasad P., Andriessen N., Moorthy A., Das A., Coppens K., Pradeep R. and Strande L. (submitted). Methods for estimating quantities and qualities (Q&Q) of faecal sludge: field evaluation in Sircilla, India.

Radford J. and Sugden S. (2014). Measurement of faecal sludge in-situ shear strength and density. *Water SA,* 40. 183. 10.4314/wsa.v40i1.22.

Rice E.W., Baird R.B. and Eaton A.D. (eds.) (2017). Standard Methods for the Examination of Water and Wastewater, 23rd edition. American Public Health Association; American Water Works Association; Water Environment Federation. ISBN: 9780875532875.

Strande L., Schoebitz L., Bischoff F., Ddiba D. Okello, F., Englund, M., Ward, B.J., and Niwagaba C. (2018). Methods to reliably estimate faecal sludge quantities and qualities for the design of treatment technologies and management solutions. *Journal of Environmental Management.* 223(1), 898-907.

Tembo J.M. (2019). Faecal sludge characterisation for enhanced sanitation provision in peri-urban areas of Lusaka. University of Zambia (doctoral dissertaton).

USEPA (2015). Field Equipment Cleaning and Decontamination Operating Procedure, U.S. Environmental Protection Agency Science and Ecosystem Support Division, Athens, Georgia.

USEPA (2017). Operating Procedure for Wastewater Sampling. U.S. Environmental Protection Agency Science and Ecosystem Support Division Athens, Georgia, US.

Van Loosdrecht M.C.M., Nielsen P.H, Lopez-Vazquez C.M., Brdjanovic D. Ed. (2016). Experimental Methods in Wastewater Treatment. *IWA Publishing*, ISBN 9781780404745 (Hardback) 9781780404752 (eBook).

Velkushanova K.V., Zuma L. and Buckley C. (2019). Mechanical properties of faecal sludge. *Gates Open Research*, 3, 1582.

Ward B.J., Gueye A., Diop B., Traber J., Morgenroth M. and Strande L. (2019). Evaluation of conceptual model and predictors of faecal sludge dewatering performance in Senegal and Tanzania. *Water Research*, 167, article 115101.

Ward, B.J., Andriessen, N., Tembo, J.M., Kabika, J., Grau, M., Scheidegger, A., Morgenroth, E., Strande, L. (2021) Predictive models using cheap and easy field measurements: Can they fill a gap in faecal sludge monitoring and process control? *Water Research.* https://doi.org/10.25678/00037X.

World Bank, ILO, WaterAid, and WHO (2019). Health, Safety and Dignity of Sanitation Workers: An Initial Assessment. World Bank, Washington, DC.

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

Zziwa A. (2019). Characterisation of Pit Latrine Contents and Developing a Scientific Understanding of Processes Occurring in On-Site Dry Pit Latrine Systems in Low Income Urban Areas: A Case Study of Kampala Suburbs. Water Research Commission Project No. K5/2301/11, Pretoria, South Africa.