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Estimating quantities and qualities (Q&Q) of faecal sludge at community to city-wide scales

Linda Strande
Miriam Englund
Nienke Andriessen
Juan Pablo Carbajal
Andreas Scheidegger

OBJECTIVES

The objectives of this chapter are to:

- Explain the importance of being able to reasonably estimate Q&Q of faecal sludge
- Define the six stages in the faecal sludge service chain where Q&Q of faecal sludge can be estimated
- Summarise the existing state of knowledge and future prospects for making projections of Q&Q of faecal sludge
- Provide an overview of a methodology to estimate Q&Q of faecal sludge on a scale relevant for the planning of management and treatment solutions, from community scale to city-wide planning.

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5.1 INTRODUCTION

The goal of this chapter is to present steps for collecting and analysing data to make reasonable projections for faecal sludge loadings at larger-scales that are relevant for planning of city-wide inclusive sanitation. Reasonable projections for quantities and qualities (Q&Q) of faecal sludge that accumulate in given areas, are fundamental for the design of appropriate and sustainable management and treatment solutions. The methodology is based on the hypothesis that **d**emographic, **e**nvironmental, and **t**echnical forms of data that can be referenced or presented in **spa**tial formats (SPA-DET) can be used in planning as predictors of Q&Q of faecal sludge. SPA-DET data can come from existing sources, and also from collection of information with questionnaires during a sampling campaign. The methodology is designed to make adequate estimates for planning, with a reasonable amount of resources. A simple analysis of the data collected in this fashion, can provide projections and trends of Q&Q of faecal sludge. Additional possibilities for analysis of the collected data are numerous, and include sophisticated and advanced modelling approaches. The required steps are identical for any scale, from small communities to entire cities, and are applicable anywhere. The methodology has been continually evolving, from the ideas for sludge production or sludge collection estimates as presented in Strande *et al.,* 2014, to what is presented here. The method will continue to be refined over time to meet the rapidly growing demand for implementing faecal sludge management systems.

This chapter does not consider the complexities of what is fundamentally occurring with physical, chemical, and biological transformations at the micro-level inside individual onsite containments, but rather levels out these complexities to determine total amounts of faecal sludge that need to be managed on a larger scale. With the current state of knowledge, trying to make community to citywide estimates based on the perspective of what is happening within each individual containment would not be sensible due to time, financial and other practical constraints. However, in the future, as more is known at both the macro- and micro-levels, large-scale projections could also be reinforced by insights obtained by the use of models at the individual containment level. As presented in Chapter 6, models at the level of onsite containment will also be useful to describe processes that influence individual rates of sludge accumulation.

What is needed for planning are coarser, larger-scale estimates. This is similar to considering entire populations or community dynamics in ecology. Analogously, to learn about the movement of a population of crickets through an agricultural area, it would not be helpful to inspect one cricket in the laboratory under a microscope. It would instead require zooming out to consider the entire population. As presented in Figure 5.1, in centralised, sewer-based wastewater treatment the design of wastewater treatment plants is based on relatively more homogenised values for entire communities, with less fluctuation due to mixing during transportation in the sewer. In faecal sludge management however, the complexity of what is occurring at the level of individual household or containment is transmitted to the treatment plant. Projections for loadings of faecal sludge are therefore more complicated, due to the unknown nature of the underground containments, together with the widely varying Q&Q of faecal sludge. The methodology presented here, has been developed to address these complex needs.

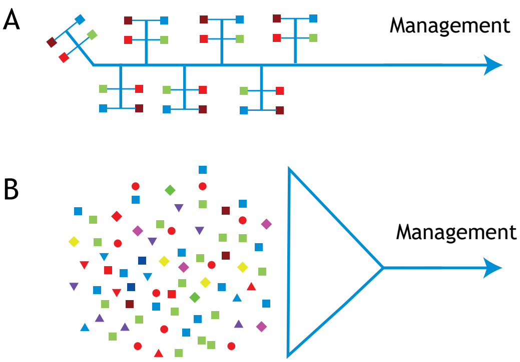

Figure 5.1 A) schematic of wastewater transported through sewer to treatment plant, where it is somewhat homogenised during transport. Squares represent level of each individual connection (*e.g.* household, business). B) schematic of faecal sludge, which is collected, transported, and delivered to treatment plant at the level of individual, onsite containment, without homogenisation. Shapes also represent level of individual onsite containments.

This chapter presents relevant background information, followed by an implementation section for practitioners with guidelines on how to apply this methodology in the field, and a section on future possibilities of how the methodology can continue to advance with future developments. This chapter focuses on projections for faecal sludge loadings at large-scales, and does not address treatment processes or effluent quality, as other mass balance-based methods already exist for that purpose.

5.2 BACKGROUND

Urban areas of low- and middle-income countries are experiencing rapid growth, creating a constant demand for upgrading faecal sludge collection and transport services and treatment infrastructure. As illustrated in Figure 5.2, in addition to planning for total population growth, adaptive management plans are necessary that take the complex and dynamic citywide sanitation context into account.

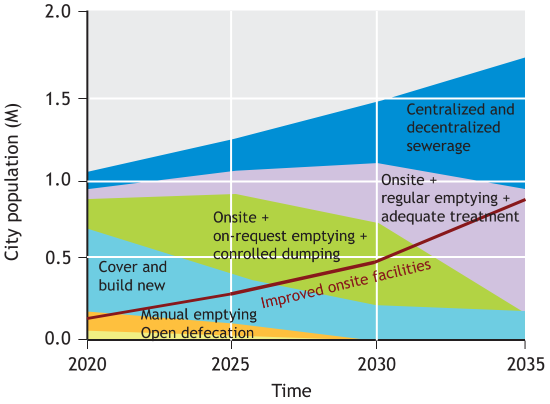

Figure 5.2 SanMix (time-technology diagram) example of adaptive, long-term planning (source: Eawag, 2020).

This requires informed projections along the entire sanitation service chain. An example of the dynamic nature of citywide sanitation, is planning for a new faecal sludge treatment plant to be built in an area where previously there were no legal options available for the discharge of faecal sludge. If projections for the new treatment plant design were based on existing collection and transport practices, the treatment plant would most likely be at capacity or overloaded within a short period after commissioning. This is because once the treatment plant is commissioned, for the first time collection and transport companies will have a legal and affordable place to discharge sludge. With a legal option, formal service providers will likely start collecting and transporting sludge, leading to competition and lower prices. This could subsequently increase the demand for emptying at the household level, creating a much different, higher loading than what was previously projected. Projections are important, as sub-optimal design (both under- and over-sizing) results in risks to public and environmental health, and waste of financial resources.

5.2.1 Scenario projections for planning and management

Implementing adaptive management for complex and dynamic citywide inclusive sanitation requires appropriate projections. In the case of faecal sludge management, this entails characteristics or qualities of the faecal sludge, together with the rates of accumulation. Qualities of faecal sludge include properties, and are often measured as concentrations. Examples of quality parameters include organic matter, solids, nutrients, and dewaterability (Ward *et al.,* 2019, Gold *et al.,* 2018). These parameters are useful for the design of treatment technologies, collection and transport technologies (*e.g.* pumpability as solids or rheological properties), and estimating public and environmental health impacts (*e.g.* pathogens, degradable organic matter, nutrients). Quantities of faecal sludge are expressed as flows, or volumes per time (*e.g.* L/cap.yr). Q&Q together represent loadings (M). For the design of treatment and handling facilities loadings are needed, not quantities or qualities alone. Figure 5.3 is a schematic of how projections for loadings estimated with this methodology would fit into overall planning strategies and projections. Additional examples are developing citywide sanitation plans that include infrastructure plans for faecal sludge treatment plants; community planning for a regularly scheduled desludging program; design of an interim transfer station; designing and sizing a faecal sludge treatment plant; or considering different treatment options based on sludge loadings.

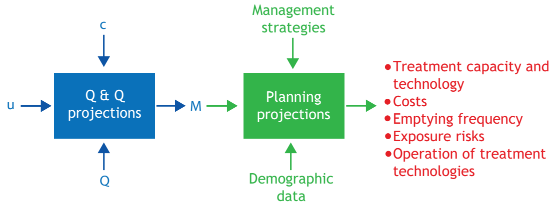

Figure 5.3 Examples of how inputs for scenario projections for Q&Q of faecal sludge can be used in citywide sanitation planning. Q = loading rate, c = concentrations, u = total number of units, M = total loadings, and are further defined in the following section.

It is important to keep in mind that scenario projections provide rough estimates, not exact numbers. This is partly because they are based on accumulation rates and concentrations obtained from field sampling, which are themselves widely variable, but also due to the inherent uncertainty of future scenarios. Furthermore, scenarios are based on the assumption that accumulation rates and concentrations for given categories are stable over time, which will not always be true. For example, assuming that faecal sludge characteristics remain constant during different seasons. This assumption is especially important to consider with changes in infrastructure that will affect accumulation rates and concentrations. For example, if water was provided by stand pipes in an informal settlement during data collection, and then later piped water is delivered, the projections will most likely no longer be valid. In this case, assumptions, data collection and the projection scenarios would have to be revisited.

As is further described in Section 5.3, to make simple projection models the objectives of the study must first be specified , which will then shape the data collection. This includes: (*i*) the defined region boundaries (*e.g.* neigborhood or city or district); (*ii*) accumulation rates and characteristics of interest; (*iii*) categories of SPA-DET data; and (*iv*) estimated future growth of total units (*i.e.* containments). The following values that are required for projections are then collected during sampling:

x_i	the categories of data around which the sampling plan and data analysis will be developed (*e.g.* a combination of containment type and income level)
$\bar{Q}(x_i)$	the average accumulation rate of sludge per unit category x_i
$\bar{c}(x_i)$	the average concentration of parameters of interest in sludge of category x_i
$u(x_i)$	the number of units in category x_i that results will be extrapolated to (*e.g.* total number of pit latrines and septic tanks)

Once these values are obtained, projections for total loads are calculated in two steps, first the load that a single unit produces is calculated for every category of data x_i:

$$M(x_i) = \bar{Q}(x_i) \cdot \bar{c}(x_i) \tag{5.1}$$

Second, the total load is then calculated with the total number of units of containments estimated for the defined area:

$$M_{total} = \sum_{i=1}^{K} u(x_i) \cdot M(x_i) \tag{5.2}$$

As shown in Figure 5.4, the calculations of these loading projections are easily carried out with common spreadsheet software. For example, to size a faecal sludge treatment plant that serves two communities, the average accumulation rate and TS concentrations per sampled data categories could be used to extrapolate the total TS loading generated by the communities. These loadings could then be used with further information on collection and transport services, to estimate the loading that will actually be delivered to the treatment plant in order to size it. Further details on how to obtain average accumulation rates and concentrations are provided in Section 5.3. The following section presents locations along the service chain where Q&Q of faecal sludge could be calculated.

Figure 5.4 Example calculation of total solids (TS) loading projections for total accumulated faecal sludge in two communities.

Category x_i		Accumulation rate	Concentration	Community A		Community B	
Type	Income	$Q(x_i)$ (L/cap.yr)	$c(x_i)$ (gTS/L)	Number of units $u(x_i)$ (-)	Loading $M(x_i)$ (gTS/cap.yr)	Number of units $u(x_i)$ (-)	Loading $M(x_i)$ (gTS/cap.yr)
(1)	(2)	(3)	(4)	(5)	(6)=(3)·(4)·(5)	(7)	(8)=(3)·(4)·(7)
Pit latrine	Low	50	23	200	230,000	5,000	5,750,000
Pit latrine	Medium	70	19	2,000	2,660,000	3,000	3,990,000
Pit latrine	High	95	12	1,500	1,710,000	2,000	2,280,000
Septic tank	Low	100	8	300	240,000	900	720,000
Septic tank	Medium	180	6	1,000	1,080,000	400	432,000
Septic tank	High	200	2	2,000	800,000	200	80,000
Total					6,720,000		13,252,000

5.2.2 Mass balance: quantifying loadings of faecal sludge

From a mass balance perspective, there are six stages along the faecal sludge management service chain where it is logical to estimate loadings (M), as illustrated in Figure 5.5.

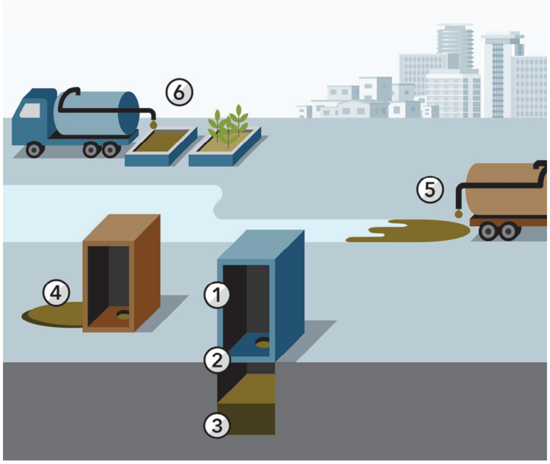

Figure 5.5 Illustration of six stages for mass balance calculations: 1. excreta production; 2 faecal sludge production; 3. faecal sludge accumulation; 4. faecal sludge emptied, not collected; 5. faecal sludge collected, not delivered to treatment; and 6. faecal sludge collected, delivered to legal discharge/treatment (image: Strande *et al.*, 2018).

It is important to distinguish the six stages and estimate them separately for management purposes. Although they are interrelated, they measure very different accumulation rates, concentrations, and environmental fates. Hence, values for the same parameter will vary significantly between them. Pit latrines, mechanical emptying with trucks, and treatment with drying beds are depicted in the figure, but the stages and concept are the same for all arrangements of the faecal sludge management service chain, including manual emptying, all types of onsite containment and treatment technologies, and all methods of collection and transport.

As illustrated in Figure 5.6, stages one and two represent production of excreta and faecal sludge, stage three the accumulation of faecal sludge, and stages four, five and six together the fate of accumulated faecal sludge. When planning for the total amount of faecal sludge that will need to be managed in a community or city, it is most important to consider stage three, the total amount of faecal sludge that is accumulating (*i.e.* total latent demand). However, it is also the most difficult to estimate, as net accumulation rates depend on a large number of factors that are too complex to account for individually. Hence, the estimation of what is actually accumulating in onsite containment is the focus of the methodology in Section 5.3. The following is an overview of each of the six stages.

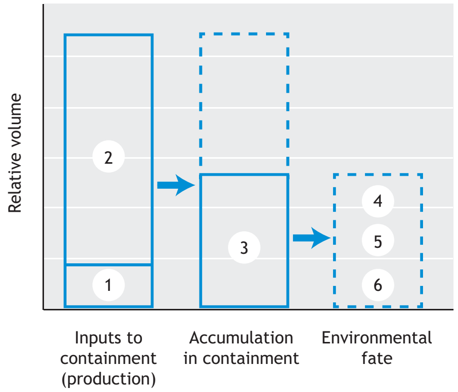

Figure 5.6 Comparison of the relative volume of the six stages, stages one to three represent production and accumulation of excreta and faecal sludge, whereas stages four to six are the fate of faecal following emptying. As illustrated by the dashed line, the total volume of excreta and faecal sludge produced is not the same as the accumulated amount due to biological, physical, and chemical factors that result in a change in the volume of faecal sludge. 4, 5, and 6 cumulatively add up to 3, but volumes of each depend on the local context.

5.2.2.1 Production of excreta and faecal sludge

Excreta production (M_1)

The total load of excreta production (M_1) is the sum of the loads from urine and faeces production from all users of a facility, as represented by equation 5.3.

$$M_1 = M_{urine} + M_{faeces} \tag{5.3}$$

M_1 is not particularly useful for faecal sludge management, other than potentially for the design of container-based sanitation, because as explained in the following sections, excreta alone does not represent faecal sludge. Reasonable estimates for Q_1 and c_1 for excreta could be made based on literature, with adaption for the local context. Further details of ranges of characterics and volumes of produced excreta are provided in Chapter 7 (Penn *et al.*, 2018).

Faecal sludge production (M_2)

The total load of faecal sludge production (M_2) is the sum of the loading from excreta production (M_1) in addition to anything else that is going into the containment (M_{in}), as represented by equation 5.4.

$$M_2 = M_1 + M_{in} = M_{urine} + M_{faeces} + M_{in} \tag{5.4}$$

The total Q&Q of faecal sludge that are produced is dependent on technical factors such as existence and type of flush systems and water connections, and social, economic and political factors, such as available municipal solid waste services and cleansing materials, as explained in more detail in Chapter 2. Estimations for Q_2 could start with existing municipal information on water usage and solid waste, if it is available, together with data from literature, field visits and questionnaires, whereas c_2 would need to be determined through a sampling campaign.

Although the amount of solid waste or garbage in onsite containment can be significant, total amounts will be very context specific. Economic and political factors will play a role, for example in informal settlements in Kampala, Uganda faecal sludge emptying services are paid for by residents, whereas in eThekwini in Durban, South Africa, emptying services are paid for by the municipality. The indirect result is that there is much greater solid waste accumulation in eThekwini than in Kampala where solid waste tends to be dumped outside of pit latrines (Nakagiri *et al.*, 2015, Buckley *et al.*, 2008). Technical factors also play a role, for example there will in general be less solid waste in containment associated with flush toilets such as septic tanks, as it is difficult to pass through the water seal syphon.

5.2.2.2 Accumulation of faecal sludge

Accumulation of faecal sludge (M_3)

M_3 is the load of the total faecal sludge that accumulates with time. From a fundamental perspective, to be able to calculate loadings for total faecal sludge accumulation (M_3) would require knowing total faecal sludge production (M_2), in addition to rates of degradation and accumulation for the biological, physical, and chemical (M_{BPC}) factors that result in reduction of volumes of faecal sludge, as represented by equation 5.5.

$$M_3 = M_2 - M_{BPC} = M_{urine} + M_{faeces} + M_{in} - M_{BPC} \tag{5.5}$$

As a result, every onsite system has different values for M_3, which is why the developed methodology for averaging out complexities is required. Biological factors affecting accumulation include degradation of organic matter, growth of microorganisms, and nutrient cycling, which are affected by many parameters including varying levels of oxygen, water content, and temperature. Physical processes include infiltration and inflow of groundwater or the liquid fraction in containment, and infiltration of soil and sand, which can be affected by construction, soil type and groundwater level. Other factors explained in Example 5.1 that affect the variability of accumulation include how the containment is designed, constructed, used, and maintained, and sludge age and hydraulic retention time. It is important to recognise that loadings from total faecal sludge production (M_2) are not equivalent to loadings from faecal sludge accumulation (M_3), since M_3 is what remains in containment over time (storage) and in most cases the volume, and hence Q_3, will be much smaller (see Figure 5.6). Using instead estimations from any of the other five stages would greatly over- or under-estimate the total faecal sludge that currently needs to be managed. To illustrate the effect that the different volumes have on accumulation rate, excreta production (Q_1), total faecal sludge production (Q_2) and faecal sludge accumulation (Q_3), estimates based on examples from the literature are presented in Table 5.1.

Table 5.1 Estimates based on values in literature for rates of accumulation of excreta production (Q_1), faecal sludge production (Q_2), and faecal sludge accumulation (Q_3) for Kampala, Uganda; Hanoi, Vietnam; and Durban, South Africa.

Location	Excreta production (Q_1)	Faecal sludge production (Q_2)	Faecal sludge accumulation (Q_3)
Kampala (Uganda)	600 L/cap.yr(1,2)	24,480 L/cap.yr(1,2,3,4)	270-280 L/cap.yr(5)
Hanoi (Vietnam)	600 L/cap.yr(1,2)	34,070 L/cap.yr(1,2,5,7)	30 L/cap.yr(8)
Durban (S. Africa)	600 L/cap.yr(1,2)	31,260 L/cap.yr(1,2,9)	21-200 L/cap.yr(10,11,12)

[1]Rose *et al.,* 2015; [2]Brown *et al.,* 1996; [3]Fichtner, 2015; [4]Ojok *et al.,* 2012; [5]Strande *et al.,* 2018, [6]De Bercegol *et al.,* 2017; [7]Otaki *et al.,* 2013; [8]Englund *et al.,* 2020; [9]Van Zyl *et al.,* 2007; [10]Brouckaert *et al.,* 2013; [11]Still and Foxon, 2012; [12]Still *et al.,* 2005[1].

In addition, to illustrate the large variability for values of Q_3, rates reported in the literature for Q_3 from different cities throughout the world are presented in Figure 5.7 (left).

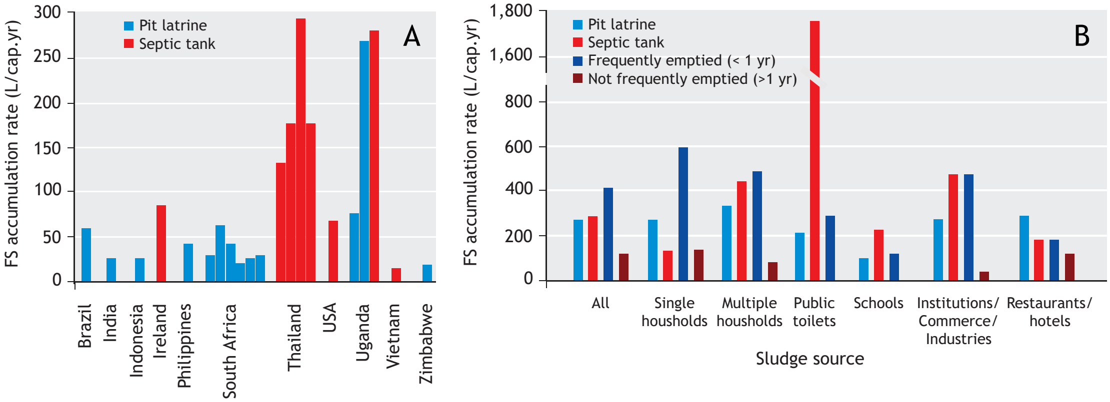

Figure 5.7 Reported diversity of accumulation rates between different cities, and within one city, reproduced from Strande *et al.* (2018). A) Reported accumulation rates in the literature categorised by country in alphabetical order (Brazil and India (Wagner *et al.*, 1958), Indonesia (Milles *et al.*, 2014), Ireland (Gray, 1995), Philippines (Wagner *et al.*, 1958), South Africa (Brouckaert *et al.*, 2013; Stills and Foxon, 2012; Still *et al.*, 2005), Thailand (including cesspits) (Koottatep *et al.*, 2012), Uganda (Lugali *et al.*, 2016; Strande *et al.*, 2018), USA (Howard, 2003), Vietnam (Harada *et al.*, 2014), Zimbabwe (Morgan *et al.*, 1982). B) Estimated accumulation rates for Kampala, Uganda, by containment type, emptying frequency, and usage, raw data fully available in Englund *et al.* (2020).

The values in Figure 5.7 (left) range from 15 to 300 L/cap.yr. In addition, a study of 30 cities in Asia and Africa reported rates from 36 to 959 L/cap.yr (Chowdhry and Koné 2012) and a recent study in Accra, Ghana reported accumulation rates up to 4,137 L/cap.yr (Sagoe *et al.,* 2019). Also presented in Figure 5.7 (right), are projected values for Q_3 for different types of land usage, all within Kampala, Uganda, to illustrate the high variability of Q_3 even on a citywide scale. Also important to note, is the relation between greater emptying frequency and Q_3. The reported variability of two orders of magnitude for Q_3, illustrates the importance of looking at Q_3 for the specific context, and the need for a standardised approach for determining total amounts of faecal sludge that need to be managed.

5.2.2.3 Fate of faecal sludge

Faecal sludge emptied, but not collected (M_4)
Faecal sludge collected, not delivered to treatment (M_5)
Faecal sludge collected, and delivered to treatment (M_6)
M_4, M_5 and M_6, cumulatively represent the fate of M_3, and will have different values depending on the local context, as represented by Eq. 5.6, and depicted in Figure 5.6.

$$\sum M_3 = M_4 + M_5 + M_6 \tag{5.6}$$

Examples of faecal sludge that is emptied but not collected (M_4), include when containment technologies are designed to drain out into the surrounding environment (or are intentionally broken to do so), or when difficult to access containments are emptied with shovels and buckets into the immediate area or into another pit dug for the purpose. Pit latrines that are abandoned or backfilled are also included in this category, as in dense urban areas this results in a similar fate in the environment. M_4 is difficult to quantify, as it is typically an illegal activity. A rough estimate can be developed through observational site visits, key informant interviews with emptiers and households, and questionnaires. The most important reason to estimate M_4 is for advocacy purposes. The focus should be put on eradication, as it is never an acceptable form of faecal sludge management.

Faecal sludge that is collected but not delivered to treatment (M_5) typically occurs when there is no legal discharge location available, or costs associated with travel and discharge make illegal dumping for emptiers more attractive. Estimates for M_5 can be useful for managing the current situation, for example setting up intermediate transfer or receiving stations until longer-term solutions are implemented. M_5 is also difficult to quantify due to its illegal nature, and is also never an acceptable form of faecal sludge management (Bassan *et al.,* 2013a,b, 2014).

Loadings of faecal sludge that is collected and delivered to legal discharge or treatment facilities (M_6) can be more straightforward to estimate based on existing operating records. However, in reality frequently records do not exist, and there are in general inadequate laboratory resources (Schoebitz *et al.,* 2014). If reports are available, whether there is an incentive to under- or overestimate the amount being discharged should be considered, for example in the case where fees are charged per volume discharged. Instituting a manifest or ledger-based system at treatment plants that includes information such as truck volumes, sludge volumes, emptying frequency, and origin or source of sludge is important for proper design and operation of treatment plants, and could also provide very valuable information for estimating citywide rates of accumulation.

5.3 STEPS FOR IMPLEMENTATION

The first step prior to any implementation is to build a qualified team. Implementation should include a sanitary engineer who is familiar with both faecal sludge management and sewered sanitation solutions[1]. The overall approach of this methodology for making projections of Q&Q of faecal sludge is presented in Figure 5.8. Limited resources should not result in skipping any of the steps, rather the depth of analysis should be adjusted. In this way, the steps can be applied iteratively as new resources become available. In general, it is recommended that projections are revisited in iterations of the approach with progressively deeper rounds of data collection as more information becomes available about the status of

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[1] https://sanitationeducation.org/alumni-community/

sanitation within a city. Knowledge of previous sampling campaigns can be used to further tailor sampling plans to increase accuracy, and projections can be gradually refined bringing in additional statistical relationships as they are developed.

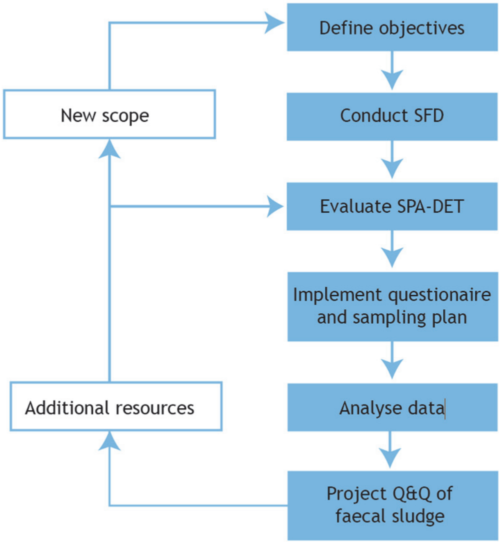

Figure 5.8 Flow diagram including the six steps (blue boxes) of the Q&Q methodology presented in Section 5.3, for data collection and analysis for projections of Q&Q of faecal sludge.

Step 1. Define objectives and region of interest

Planning for different technical and management solutions requires different forms of data collection, so it is necessary to define clear regional boundaries, and objectives for how the Q&Q data is to be used. Based on the defined objectives and local context, how rates of accumulated faecal sludge will be defined and measured is a very important distinction. Refer to Example 5.1 for a discussion of defining accumulation rates. At this initial step, the types of laboratory analysis and analytical data that will be needed to fulfil the objectives should also already be defined.

Example 5.1 *Defining accumulated faecal sludge*

Defining boundaries for values of sludge accumulation will depend on the objective of the study, as further discussed in Chapter 3. Objectives could include knowing what will be delivered to treatment, or researching *in situ* sludge accumulation, or recommending emptying frequency for septic tanks. Regardless of the objective, it is important to keep in mind that evidence suggests that accumulation rates in urban areas are much greater than the historic design filling rates for pit latrines of 42 L/cap.yr that were based on use in rural areas, with five users and an emptying frequency of 10-15 years (Wagner and Lanoix, 1958). This is because onsite containments in dense urban areas have much different usage patterns, a much greater number of users per toilet, and more frequent emptying (refer to Table 5.1 and Figure 5.7). In addition, typically the current reality in low-income cities is little to no level of standardisation for construction of onsite containments. This translates into a wide variety of types of containments, ranging from properly to inappropriately and haphazardly constructed. Most likely, it will not be entirely known beforehand what can be expected, or will be encountered while sampling. Therefore, assumptions about containment type and construction quality will have to be made and then validated during sampling. Prior to making these assumptions and determining sampling locations, it is important to consider how faecal sludge is actually expected to accumulate within the containments.

Septic tanks

Theoretically, the total volume of faecal sludge in septic tanks with an outflow is fixed, with a sludge blanket layer that accumulates as solids settle out, a supernatant zone, and a scum layer (Figure 5.9). Hence, historically the sludge blanket accumulation rate was most commonly estimated as the faecal sludge accumulation rate. Although this is accepted practice, there is a lack of detailed, evidence-based information on actual in-field operating conditions, and in reality, most septic tanks do not operate as intended. They are frequently only emptied upon emergency events such as clogging, extreme odor, or backing up into the house or drains. This means that distinctly different layers cannot necessarily be expected. Therefore, in some cases, it is more relevant to consider the total (fixed) volume when estimating the accumulation rate based on what is emptied over time (L/cap.yr), together with concentrations, to be able to predict loadings that arrive at treatment plants. This is an example of managing the current (not ideal) situation, *versus* improved future solutions that are desired. In areas where septic tanks are properly maintained and operated as designed, it could be more useful to determine rates of sludge blanket accumulation in order to be able to recommend emptying frequencies. However, sludge blanket accumulation is difficult to measure, and can vary a lot over time depending on the operating conditions of the septic tank. In Sircilla, India, no distinguishable change could be measured based on monitoring of sludge blankets in new septic tanks conducted six times over eight months (Prasad *et al.,* 2021). Containments with outflows provide a clear example of how total faecal sludge production is many times greater than actual accumulation within the tank.

Fully lined tanks

In some cities, fully lined tanks emptied at frequent intervals are common for containment in industrial areas, for example for employees working at a factory, or large-volume generators such as hotels, or hospitals (Figure 5.9). This can result in very high accumulation rates, as nothing is leaching out into the surrounding area, and in this case can be as high as total production (Figure 5.6). However, in other cities, industrial areas have been observed to have lower accumulation rates than households (Prasad *et al.* 2021), illustrating the importance of considering the local context. For these types of tanks, accumulation of the total volume of faecal sludge is relevant, as that is what is accumulating and needs to be emptied and treated. It is important to consider non-household types of faecal sludge in any Q&Q study, as they can represent a significant proportion of total flows. In Kampala, Uganda, non-household sources were observed to be up to 50% of the total flow delivered to treatment, and the population of the city doubles during the day due to people commuting in for work (Strande *et al.,* 2018). Fully lined tanks are also sometimes used in flood-prone areas at the household level, with or without overflows.

Partially lined pit latrines

'Dry' faecal sludge in partially lined pit latrines may not have such distinct layers of solids and liquid fractions, but as discussed in Chapter 3, could have layers of different levels of stabilisation (Figure 5.9). In this case, it is relevant to estimate the total volume that accumulates in the pit, or the total volume that is emptied and delivered to treatment. Partially lined pit latrines can also accumulate a very dense layer at the bottom that will never be emptied. However, it needs to be kept in mind that in many cities around the world, partially lined pit latrines are commonly used for all types of faecal sludge, including very 'liquid' faecal sludge (<5% TS).

Cesspits

Cesspits, leach pits, and leaking septic tanks are also very common in urban areas (Figure 5.9). Operating conditions can be assumed to be somewhere between septic tanks and partially lined pit latrines, although in general they have not been studied, and represent an enormous range of possible conditions. Due to a wide range of local terminology, they are also frequently referred to as septic tanks. For management purposes, as there is no way of knowing what processes are occurring inside, accumulation rate of the total volume of faecal sludge is probably most interesting.

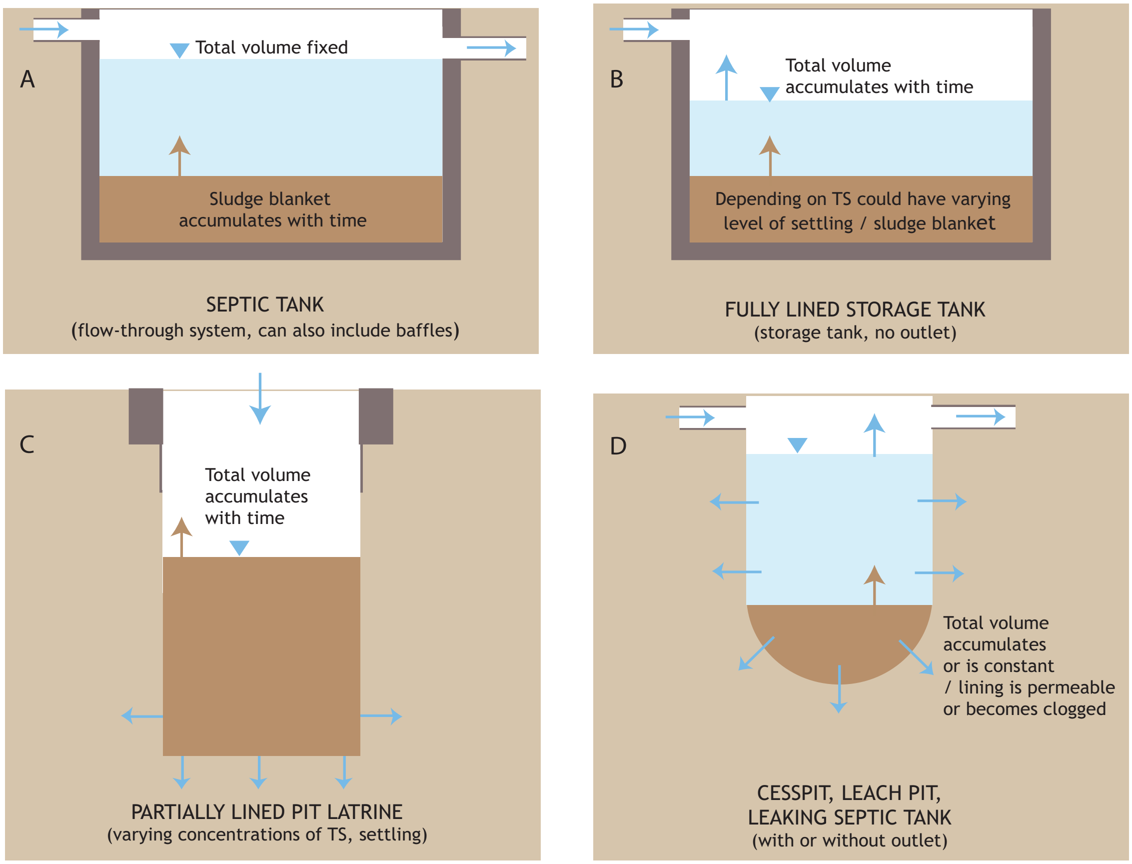

Figure 5.9 Schematic of faecal sludge accumulating in various types of onsite containments: A) septic tank, B) fully lined storage tanks, C) partially lined pit latrines, and D) cesspits (or leach pit, or leaking septic tank).

Step 2. Excreta or Shit Flow Diagram (SFD)

To be able to make reasonable assumptions for sampling plans, data collection, and scenario models, a certain level of expert knowledge is needed. The SFD methodology can be implemented to obtain background information. The SFD is a standardised methodology to collect adequate information to obtain a holistic view of the existing sanitation situation in a city, and producing a report with a diagram for dissemination (Peal *et al.,* 2020). The methodology includes assessing the enabling environment, analysing the sanitation service chain, engaging with stakeholders, and evaluating the credibility of data sources. Through this process, one will become familiar with the types of information that are available for a city.

The SFD approach provides a standardised method to track and document the fate of safely and unsafely managed fractions of total excreta produced by the population through faecal sludge management or sewer-based sanitation, also including open defecation. The SFD diagram itself is meant to be a communication tool that provides an overview of the current sanitation situation in a simple and non-technical fashion. The width of each arrow on an SFD diagram is proportional to the percentage of the population whose excreta contribute to that flow as a proxy for pathogen flows and therefore public health hazard. It is very useful for communicating to decision makers the need for sanitation policy and infrastructure to protect public health. However, it is important to note that the SFD does not estimate quantities of faecal sludge, but rather contributing populations. Depending on the level of implementation, the SFD requires less resources than the Q&Q approach, as the fractions of excreta can be based on expert knowledge, while quantifying faecal sludge loadings requires in field sampling and laboratory analysis. The SFD method is available for download at the SFD Promotion Initiative website[2].

Step 3 Evaluate available SPA-DET data, identify what needs to be collected

SPA-DET data, as defined in the introduction, is used to design the sampling plan, and to build up projections of Q&Q of faecal sludge. Based on field experience, it is observed that Q&Q of faecal sludge can be distinctly different for different categories of demographic (*e.g.* income level), environmental (*e.g.* geology/ground water) and technical (*e.g.* containment type) forms of data. Hence, the hypothesis was developed that forms of DET data can be used as proxies to predict Q&Q of faecal sludge. This idea has been tested in Kampala, Uganda; Dar es Salaam, Tanzania; Hanoi, Vietnam; Sircilla, India; Kohalpur, Nepal; and Lusaka, Zambia (Strande *et al.,* 2018; Englund *et al.,* 2020; Esanju, 2018; Marwa, 2017; Prasad *et al.,* 2021, Andriessen *et al.,*in preparation (b)). The spatial distribution of DET data is important when designing the sampling plan, and when used for scenario planning projections to identify trends and patterns, to identify different infrastructure or interventions needs, and to know the locations and transport distances of existing infrastructures. Because the data is spatially analysable, it can be used to derive citywide projections for Q&Q of faecal sludge, or break them out by community or neighbourhood. An example of SPA-DET data is presented in Figure 5.10, with a spatial distribution of income category and access to sewer network in Kampala, Uganda.

SPA-DET data do not necessarily require a direct cause-effect relationship on Q&Q of faecal sludge to serve as predictors, as long as consistent statistical relationships are observed. For example, significant differences with Q&Q of faecal sludge based on income level were observed in Kampala, Uganda (Case study 5.2). Income level is not the direct cause, but could be explained by factors such as access to water and quality of construction. Examples of SPA-DET data are provided in Table 5.2. Based on previous implementation experience, categories of data in Tier 1 of the table have been good predictors. Examples of building types or usage are: household, multiple household, institution/industry, hotel/restaurant, school, or public toilet. Examples of containment type are: septic tank, partially lined pit latrine, fully lined tank, and cess pit (see Example 5.1).

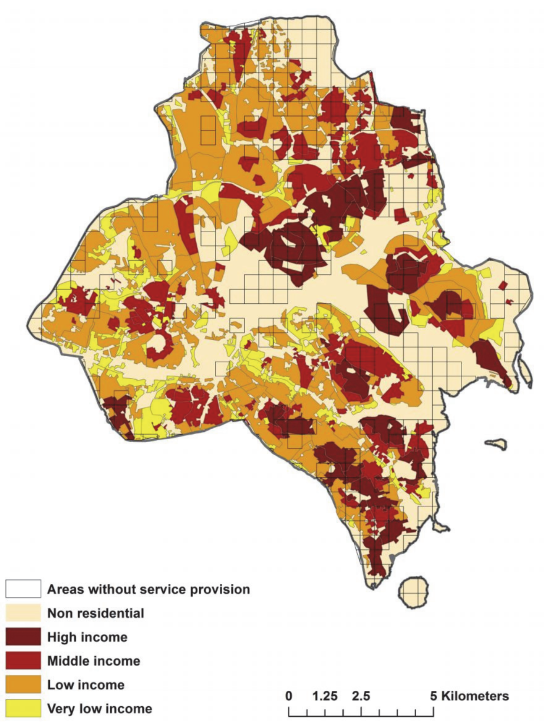

Figure 5.10 Spatial distribution of DET data in Kampala, Uganda. Income categories and non-residential areas shown by color, and areas unserved by sewers shown by outlined grids (image: Schoebitz *et al.,* 2017).

Tier 2 of the table is categories of data that specifically need to be collected to make loading projections based on accumulation rates and characteristics. Tier 2 data is collected during field implementation together with GPS points, so that the

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[2] http://sfd.susana.org/

data is spatially analysable and can be evaluated for statistical relations to Tier 1 (and Tier 3). Methods for taking *in situ* samples for characteristics of faecal sludge include the core sampler and cone shaped sampling device, and for *in situ* volumes of faecal sludge include the Volaser measuring device (Andriessen *et al.,* in preparation a). Samples can also be taken during emptying operations, or at delivery to treatment plants. Obtaining reasonable estimates for the sludge age or time since last emptied, are very important in estimating accumulation rates, but is most likely one of the most difficult values to obtain accurate values for, as official records typically do not exist. Until there is better recording, this information will have to be obtained through a questionnaire (refer to Step 4). Relevant details for sampling plans, techniques and methods are covered in detail in Chapter 3.

In Tier 3 of the table are categories of data that have not yet been tested or are in the process of being tested, and based on intuition also seem like potential candidates. Further information on which are the best predictors, and potentially new categories that have not yet been considered, will continue to be developed with future implementations. SPA-DET data that is used in each study will depend on what can be obtained in each specific city, together with what is deemed relevant based on expert knowledge. For example, in Case study 5.2 in Kampala, ground water or soil type were not considered because it was simply not available. In Sircilla, household connection to water was not considered, as all households had water connections (Prasad *et al.,* 2021). In addition, under the umbrella of the 'Swachh Bharat' mission, many new containments have been constructed in Sircilla in the past few years, and are documented in an online database owned by the municipality. Information was available for the sampling team on type of containment, GPS location, and a picture from before, during and after construction. This was useful in designing a sampling plan and analysing the data.

Table 5.2 Categories of SPA-DET data grouped by whether they have been tested, are required for projections of accumulation rates and loadings, or are currently being tested / of potential interest.

SPA-DET		
Demographic	Environmental	Technical
Tier 1. Have been tested		
• Building type/usage • Income level • Number of users	• Geology • Seasonal flooding	• Age of system • Containment type • Water connection • Emptying frequency • Types of wastewater (grey/black)
Tier 2. Required for projections of accumulation rates and loadings		
		• Volume of accumulated sludge • Time since last emptied • Sample for laboratory analysis
Tier 3. Currently being tested / of potential interest		
• Employment rate • Family size • Housing density • Land usage • Population density • Property value	• Elevation • Groundwater • Hydrology • Soil characteristics • Proximity to water • Topography	• Flush • Emptying frequency • Emptying method • Overflow pipe • Piped water • Truck volume • Truck full following emptying • Containment fully emptied • Water added during emptying • Containment fully lined/water tight • Volume of containment • Number of chambers

Tier 1 and Tier 3 SPA-DET data can be collected prior to sampling through desk-based methods, and during sampling through the questionnaire (Step 4). Presented in Table 5.3 are examples of where SPA-DET data can be found.

Table 5.3 Potential sources of SPA-DET data

- Academic institutions (*e.g.* civil engineering department, urban planning department)
- Geographical tools (*e.g.* Google Maps satellite view[3], BORDA City Sanitation Planning[4])
- Census data (*e.g.* population, housing, land use)
- International non-government organisations (NGOs) (*e.g.* UN, WHO, World Bank, JMP SDG reporting)
- Communities of practice (*e.g.* SuSanA, local WASH networks)
- Local NGOs (*e.g.* national WASH missions)
- Contractors (*e.g.* construction and installation of containment)
- Ministries (*e.g.* housing and urban affairs[5], economics, sanitation)
- Call centers (*e.g.* desludging, latrine contractors, plumbing)
- Municipality offices (*e.g.* local assembly, district offices)
- Desludging businesses (*e.g.* trade associations, call centers)
- National bureau of statistics (*e.g.* statistical year books)
- Environmental protection authorities or agencies (*e.g.* soil, elevation, groundwater maps)
- Private sector players (*e.g.* environmental consultancy firms)
- Faecal sludge treatment plants (FSTPs)
- Public water and sanitation utilities

The first step in evaluating SPA-DET data, is to determine whether access to the categories listed in Table 5.2 is easily available . If they are not accessible, evaluate if they can be obtained through the possible sources listed in Table 5.3. If they cannot be obtained, then they will need to be included in the questionnaire-based data collection (Step 4) together with the field sampling.

Based on expert knowledge, and insight gained during the SFD process, a list can then be made of other relevant and interesting categories of SPA-DET data. The list should contain clear links or reasons as to why they might be predictors of Q&Q. For example, 'size of building' is probably interesting because it could be related to accumulation rates, whereas "color of building" is probably not. The listed categories can then be evaluated as to whether they should be included in the study, based on whether or not they are already available, can be easily obtained, or can be readily collected using a questionnaire. Increasing the number and type of SPA-DET data should not significantly increase the cost of data collection, however it can increase the complexity of data analysis. Selecting how many categories of SPA-DET data are feasible to analyse, will be a tradeoff between available time and resources, and more detailed or insightful results. Information that is available by neighbourhood or community can be entered into GIS database during data collection (eg. QGIS[6], or other similar open-source software programs).

Step 4. Location-specific questionnaire

Following collection of available SPA-DET data, a context specific questionnaire-based data acquisition plan needs to be developed based on the study objectives and taking account of available information. Questionnaires can be used to interview customers, service providers during emptying operations or sludge delivery, and treatment plant operators. The person conducting the survey in the field needs to be adequately trained, with an appropriate level of expertise in faecal sludge management to be able to evaluate the validity of answers, fact-check collected information, and to make field observations (refer to Chapter 3 for information on data validation). To reduce costs, if a larger water, sanitation and hygiene (WASH) scoping study will be implemented, a carefully thought out questionnaire could be used to 'piggy-back' onto existing studies, and improve estimates for Q&Q. However, questionnaires have to be conducted at the same location and time point as measurements for Q&Q. Further ideas for reducing costs are presented in Section 5.4.3 and Case study 5.3.

Examples of questionnaires and scoping studies that can serve as a starting place are available online, such as the World Bank's FSM Tools[7] and the Joint

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[3] www.google.com/maps

[4] http://citysanitationplanning.org/

[5] http://www.smartcities.gov.in/content/

[6] https://www.qgis.org/en/site/

[7] https://www.worldbank.org/en/topic/sanitation/brief/fecal-sludge-management-tools

Monitoring Program's (JMP) Core questions on water, sanitation and hygiene for household surveys[8]. It is important to consider data resolution when adapting questionnaires to the specific context. It is better to have boxes that the interviewer can check or insert numbers, *versus* qualitative observations. Except for truly categorical variables (*e.g.* septic tank *versus* pit latrine, household *versus* non-household), it is usually recommended to ask for actual numbers. Numbers can be grouped later in categories if desired for the analysis, but not the other way around. 'Slider' responses are one way to ask for continuous response variables, that let respondents rate an item on a numerical scale by indicating values on an interactive slider.

Waypoints (GPS points) need to be recorded during data collection so that the data can be represented spatially. The most efficient way of carrying out surveys is with the help of mobile-based applications on smartphones and tablets (Figure 5.11). There is a wide array of free to use software that is available for mobile data collection (*e.g.* KoboToolbox[9], Akvoflow[10], Open Data Kit[11]). Advantages compared to traditional paper based questionnaires are that data is available immediately, constraints help to ensure the quality of collected data, and coordinates can be obtained automatically via GPS. Factors to be specifically addressed in a Q&Q approach are outlined in Table 5.4.

Figure 5.11 Implementation of a questionnaire in Karnali Province, Nepal. Trained enumerators conducted interviews using smart phones loaded with Open Data Kit (ODK) software to assess households' access to and perceptions of basic services. In the photo, a study participant discusses her feelings of ownership for local communal infrastructure using a 5-point visual scale (photo: M. Vogel).

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[8] https://washdata.org/monitoring/methods/core-questions

[9] https://www.kobotoolbox.org/

[10] https://akvo.org/

[11] https://opendatakit.org/

Table 5.4 Factors to be included in context specific questionnaires developed for Q&Q studies

Factors	Description
User level	
• Type of onsite containment	Examples of types of onsite containment include septic tanks, pit latrines, and cess pits. It is important to capture as realistic a picture, or sense, as possible of what is existing, as common usage for these terminologies vary widely. Important points to capture include is the containment fully lined (watertight), partially lined, or unlined? For this section, refer to the SFD manual (SFD Promotion Initiative 2018), and the sanitation technology compendium (Tilley *et al.,* 2014).
• Fate of faecal sludge in local environment	If faecal sludge is not transported to treatment, what is its fate following emptying? For example, dumped in local proximity of emptying operation, or transported away?
• Volume of onsite containment (m^3)	The validity of this answer will depend on the context. In general, users of onsite sanitation do not necessarily have any idea of the volume. However, if the respondent was responsible for paying for construction, they most likely have a very good idea of the volume. This can be validated and/or collected during emptying operations, and with tools such as the Volaser measuring device (Chapter 3).
• Outlet	How do liquids leave the containment, is there an outlet pipe, are there multiple containment in series, is there a leach pit, does it go to an open drain?
• Land usage	Possibilities include household, school, industry, commercial (e.g. hotel, restaurant, shop), place of worship, or public toilet. Q&Q will vary depending on land use. For example, industries frequently have larger containment volumes, high number of users, more frequent emptying and different characteristics.
• Number of users (population equivalent)	This can be difficult to evaluate, as records most likely will not exist for number of users of non-single household toilets. Inadequate access to sanitation, and large commuting populations, can result in very high values. Techniques like counters on doors can also be used to validate results. Do not use default values.
• Income	To obtain accurate values for income data, proxy indicators of wealth are potentially more accurate than asking households for income data, but need to be adapted for the local context. See for example Filmer and Pritchett (2001), and the World Bank's tools for measurements of living standards[12].
• Water availability	Increased water access will in general increase volumes of faecal sludge produced. Evaluate whether houses have piped water, stand pipes, or no access.
• Wastewater streams	Water streams connected to the containment will also increase volumes produced. Evaluate whether there are flush or no-flush toilets, if users cleanse with water or paper, and if greywater sources are connected to containment.
• Solid waste	Solid waste in containment can increase the volume produced, but even if it is not a contributor, it could correlate to Q&Q. Flush toilets will tend to have less solid waste in containment due to the water seal.
• Quality of construction	What types of materials are used (*e.g.* concrete, plastic, fiberglass), is it self-constructed or standardised?
Environmental	
• Fact check SPA-DET data	Environmental data will be difficult to collect during a survey, but important to fact check or ground truth in the field. Some data such as percent sand, silt or clay for soil characteristics, or proximity to surface water is feasible to be collected.
Emptying operation	
• Emptying method	Is collection of faecal sludge conducted manually, mechanically, or mechanically assisted. By whom? Is water added during collection, and how much?
• Time since last emptied	The time since last emptied is required for estimating rates of accumulation. Could be measured in days, weeks, months or years.
• Typical emptying interval	This can provide useful information on the management of the containment. Could also be measured in days, weeks, months or years.
• Volume emptied (m^3)	The volume is also important in estimating rates of accumulation. It is important to have multiple ways to evaluate this to ensure accuracy. For example, check for a gauge on the truck, or barrels of standard size.
• Fully emptied	This is important to validate whether the volume emptied is equivalent to the volume of containment.
• Truck volume	This can correlate to Q&Q, as different types of trucks tend to empty containment for different types of land uses, and can also be used to validate containment volume.
• Truck full	This is also important to validate the size of containment.
• Number of containments	Did the truck empty more than one containment? Commonly, operation will be optimised for costs, meaning operators will empty one containment per trip, with a truck that is a similar size to the containment. But will depend on local context, and could include one truck emptying multiple containments, or multiple truck loads for one containment.

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[12] http://surveys.worldbank.org/lsms

Step 5. Sampling plan

Once all of the above decisions have been made on the categories of data that need to be collected, and how best to collect it, then the required number and distribution of samples needs to be determined. The recommendations given here are based on theoretical considerations and are only intended as guidelines, as in reality decisions will have to be made based on available resources and practical constraints, an example is provided in Case Study 5.1. The sampling plan is derived through the following steps:

a) Defining categories of SPA-DET data to sample
b) Determining the number of samples
c) Allocating the distribution of samples
d) Building data validation into sampling plan

a) Defining categories of SPA-DET data to sample

a1) Based on expert knowledge, identify the most relevant categories of SPA-DET data (x_i). A category may also be defined by a combination of multiple variables, for example, a given containment type and income level. A larger number of categories allows for finer variation in the scenarios used for projections, but also requires a larger number of samples. Therefore it is recommended to limit the number of categories.

a2) Allocate the number of samples to take in each category. In the simplest case the same number is used for every category. However, in some cases this can be further optimised, as explained in the following section, *Allocating the distribution of samples*

a3) Identify the units to sample from by first identifying all units of a category, and then *randomly* selecting the ones for sampling. However, in many cases a category is defined by information that is not known prior to sampling. For example, if a category is "single-story building + septic tank", depending on the situation, it might be possible to obtain information about the building type prior to sampling, but not information on the containment type. In this case, it is best to randomise over unknown factors. For this example, that would mean simply sampling randomly over all single-story buildings. Randomisation is a very important technique to avoid biases. For example, imagine that the sludge quality in pit latrines varies across the city due to groundwater influence, but this influence is not yet known, and groundwater maps are not available. If samples are randomly selected across the entire area, the sampled average would still be correct. However, if all samples were taken in a region that had a similar groundwater influence, the results would be biased.

b) Determining the number of samples

It is not possible to provide a hard or simple rule on how many samples are required. The number of samples collected during a study will be dictated by the objective of the study, knowledge gaps to be covered, the desired level of accuracy, and available resources. The more samples that are taken, the greater the accuracy of the results. However, this relationship is not linear, meaning that there are diminishing returns with increased sample number, as discussed in Example 5.2. For Q&Q of faecal sludge, the variability between sampled units will typically be quite large, but results will depend on the specific local conditions and number of categories. The absolute minimum number of samples should be selected to reduce the uncertainty to at least 25 %. However, regardless of the sample size, a carefully designed sampling plan is needed to obtain meaningful results that are not biased to increase the reliability of estimates for Q&Q of faecal sludge. In most cases, it is therefore recommended to decide on as many samples as possible depending on the available budget, and then distribute them optimally over the categories. This is another example of the value of implementing incremental studies in the Q&Q approach. In the future, as more implementations of the Q&Q approach are conducted, and distributions of data are better understood, estimates for sample size and distribution should become more straightforward. To facilitate this learning process, open sharing of raw data sets should be encouraged. Sharing of raw research data will benefit the design of future studies, development of statistical methods, and reproducibility, transferability, and learning from results.

Example 5.2 *Influence of sample size*

The loading calculations are based on the *average* accumulation rates $\bar{Q}(x_i)$ and concentrations $\bar{c}(x_i)$. The uncertainty of these averages depends on the standard deviation, or variability, of the accumulation rates sd(Q(x_i)) and of the concentrations sd(c(x_i)) *of the individual samples*, and the number of samples taken, n. More samples will reduce the uncertainty. However, this effect is not linear, meaning taking twice as many samples will reduce the uncertainty by less than half (Figure 5.1.1). The exact relationship for accumulation is represented by equation 5.7. The same equation can be applied for concentrations.

$$\mathrm{sd}\left(\bar{Q}(x_i)\right)=\frac{\mathrm{sd}\left(Q(x_i)\right)}{\sqrt{n}} \tag{5.7}$$

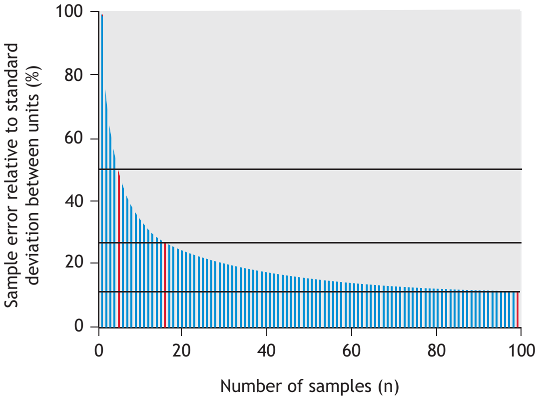

Figure 5.11 Associated reduction of uncertainty with increasing number of samples.

c) Allocating the distribution of samples

If the distribution of samples is going to be adjusted, it can be done based on educated guesses (that are ideally based on data) for the expected averages $\bar{Q}(x_i)$, $\bar{c}(x_i)$ of each category, and the total number of units $u(x_i)$. How much variability is expected between the accumulation rates $Q(x_i)$ of individual categories is also estimated, expressed as $\varepsilon\left(Q(x_i)\right)$, the relative standard deviation of $Q(x_i)$. The same estimations are also made for concentrations. Based on these assumptions, an optimal fraction of samples to be allocated to each category x_i can be determined with equation 5.8.

$$w_i=\frac{u(x_i)\bar{Q}(x_i)\bar{c}(x_i)\sqrt{\varepsilon\left(\bar{Q}(x_i)\right)+\varepsilon\left(\bar{c}(x_i)\right)}}{\sum_{j=1}^{K}u(x_j)\bar{Q}(x_j)\bar{c}(x_j)\sqrt{\varepsilon\left(\bar{Q}(x_j)\right)+\varepsilon\left(\bar{c}(x_j)\right)}}$$

(5.8)

Not every quantity in equation 5.8 of the scenario projection will have the same influence on the result. Intuitively, it is clear that an error in the accumulation rate for a category with a small number of units is less relevant than if this number is large. In addition, there will be more variability within some categories than others. Therefore, it is sensible to take more samples from units of the influential categories and/or categories with more variables. However, this technique is typically not suitable for the first iteration of a sampling campaign, unless there is reliable existing expert knowledge about the variability and the average of the Q&Q. However, if in doubt, an equal number of samples per category should be used. In subsequent iterations of sampling, the necessary information to make these decisions will then be more readily available.

d) Building data validation into sampling plan

Any sampling plan requires data validation to verify the accuracy and precision of obtained values, but this is especially important with the high intrinsic variability of faecal sludge. The accuracy of the overall estimation will only be as good as the least accurate parameter. Therefore, the number of samples in the sampling plan and laboratory analysis will have to be increased (or reduced total number of sampling sites) to validate the collected data and assumptions, and the results. An example of sampling for Q&Q of faecal sludge from *in situ* containments *versus* during collection and transport is presented in Case study 3.3. Guidelines on quality assurance and quality control (QA/QC) for 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, section 2.2: Quality assurance. Another example is determining the number of users of a public toilet in an informal settlement, a large factory, or a toilet at a public market is difficult to assess with a questionnaire. Records might not exist, and the number of users will also need to be converted to daily population equivalents if per capita flows are going to be estimated. One example could be to place a counter on the toilet door to validate questionnaire data (Zakaria *et al.,* 2018). However, any effort (*i.e.* time and money) spent on improving measurements must take into account specifically the required level of accuracy of collected Q&Q data.

Case study 5.1 *Development of Q&Q sampling plan in Lusaka, Zambia*

The University of Zambia (UNZA) and Eawag implemented a Q&Q study in Lusaka, Zambia between September and December 2019. In total, samples were collected from 421 onsite containments together with a questionnaire and laboratory analysis (Ward *et al.* 2021). The following steps were taken to develop the sampling plan.

For households:

- ArcMap was used to develop the sampling plan, as shown in Figure 5.12. The boundaries of the study were set as the official Lusaka city boundaries, in addition to any areas served by the Lusaka Water and Sewerage Company (LWSC) outside of these boundaries. Areas where service is provided through the sewer network were excluded, in addition to the airport.
- A layer was added with information on geological formations, and the area was separated by the three different rock formations that are present in Lusaka (Cheta limestone, Dolomite and Schitst/Quartzite). It is known that risk of disease from groundwater varies by these locations (Museteka *et al.,* 2019) so sample locations were assigned from all three.
- A one square kilometer grid layer was added to the area. Sampling locations for the field team were randomly selected by assigning one point to each grid with ArcMap. Quadrants with no, or only a few, households were excluded, in addition to the industrial area, and the area served by the sewer.
- High density areas were identified based on expert knowledge and visual inspection. They are highlighted in green on the map. In these areas, two sampling locations were randomly selected per quadrant.
- During implementation, the field team always went to one of the randomly selected points. If for some reason it was inaccessible this was documented, and then the sample was always taken at the next location *to the right* if facing the building. In this way, the randomness of the sampling was maintained. During sampling, the sampling locations were marked in Google Maps.

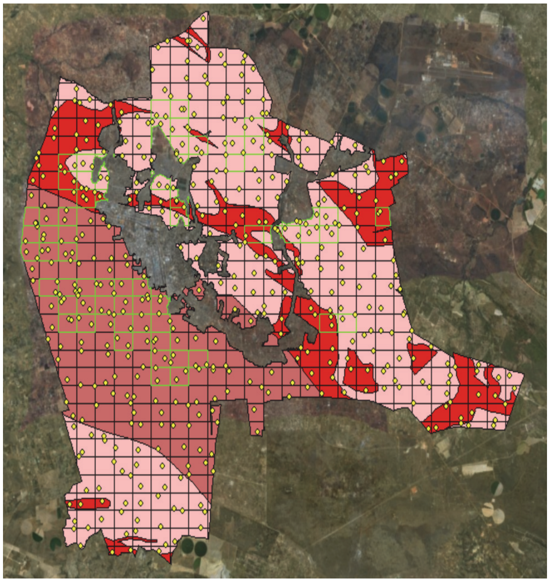

Figure 5.12 Sampling plan for Lusaka, Zambia developed in ArcMap.

For non-households:

- Samples for commercial areas were separated into four categories: public toilets, office buildings, schools, and malls. These were selected because they were determined to be the most relevant for Lusaka based on local expert knowledge.
- For each of these categories, the goal was to obtain 15 samples spread evenly throughout the boundaries.
- Non-household sampling points were selected based on local expert knowledge. Malls and schools could be identified on Google maps, public toilets and office buildings were identified by the sampling teams and local knowledge (*e.g.* sampling team drivers, city council members, community leaders).
- The spread of the commercial sampled points was monitored during the sampling campaign.

Step 6. Data analysis

Once data collection is completed, then the planned projections can be made. Recommended steps for data analysis include first a visual examination of the data, and verifying whether all of the results seem reasonable based on expert knowledge. This includes:

- Identifying minimum and maximum values, and evaluating them as to whether they are feasible.
- Visually identifying extreme values, and checking to see if any recorded data points look suspicious (*e.g.* missing decimal points, wrong units, number entered in wrong field).
- Visually checking if expected correlations can be found in the data (*e.g.* higher income level expected to be associated with a higher proportion of flush toilets).
- Excluding suspicious data from further analysis based on the inspections above. This requires expert judgment, as no hard and fast rules exist to decide what is an outlier and what not. This process needs to be clearly and transparently documented and reported.

Data analysis and reporting of projections will depend on the defined objective(s) for the Q&Q study. Recommended steps for evaluating categories of SPA-DET data to use in projections include the following:

- Evaluate whether there are relevant differences between categories of SPA-DET data (*e.g.* type of containments, income levels, building type). For an example, see Case study 5.2.
- Investigate what combinations of categories of SPA-DET data make sense to combine for the specific study region and objectives, and evaluate different scenarios. Depending on the amount of collected data, and relevant differences, it is recommended to select at most a few significant categories and to avoid cross-correlations. For example, if “water connection” and “containment type” exhibit significantly different relations to measured parameters, but all buildings with water connections have septic tanks, it does not make sense to include both “water connection” and “containment type”. However, if there are also pit latrines with water connections, then it could make sense. Summarise in a table the most relevant combinations of categories of SPA-DET data (Table 5.5).
- Evaluate if there are differences in loadings for different regions of a city. This is important, to identify potential indicators of loadings that were not considered or known during study implementation. For example, as discussed in Step 5, this could help to identify areas of groundwater intrusion when groundwater maps are not available.

Table 5.5 Example of breaking down loadings based on categories of SPA-DET data.

	Pit latrine	Septic tank
Households	$M_{PL,HH}$	$M_{ST,HH}$
Non-households	$M_{PL,NHH}$	$M_{ST,NHH}$

As discussed in the introduction, the projections for total loadings at the community to city-wide scale can now be used along with management strategies and demographic data for planning projections, such as selecting treatment capacity and technologies (Figure 5.3). Further options for data analysis are introduced in Section 5.4.

Case study 5.2 *Evaluating Q&Q of faecal sludge in Kampala, Uganda*

This case study is described in detail in Strande *et al.* (2018) and the complete raw data set is available for download at https://doi.org/10.25678/0000tt. From December 2013 to March 2014, in total 180 faecal sludge samples were collected in Kampala, Uganda, spanning both the dry and (short) rainy season. Categories of SPA-DET data were found to be significantly different for Q&Q of faecal sludge in Kampala, Uganda. Presented in Figure 5.13 are results for TS concentrations for the categories of collected data. Differences were determined by evaluating the confidence interval around the median (notches in the boxplots), calculated by equation 5.9, where IQR is the interquartile range and n is the sample size.

$$\text{Confidence interval} = \pm\frac{1.58\cdot \text{IQR}}{\sqrt{\text{n}}} \tag{5.9}$$

For each set of potential indicators, if confidence intervals of the median did not overlap they were considered to be statistically different. High-income areas had lower median TS concentration (7 gTS/L faecal sludge) than low-income areas (29 gTS/L faecal sludge). Other observed predictors were black water only, solid waste, number of users, containment volume, emptying frequency, and truck size. The average accumulated faecal sludge for the entire city was projected as 270-280 L/cap.yr (Figure 5.7).

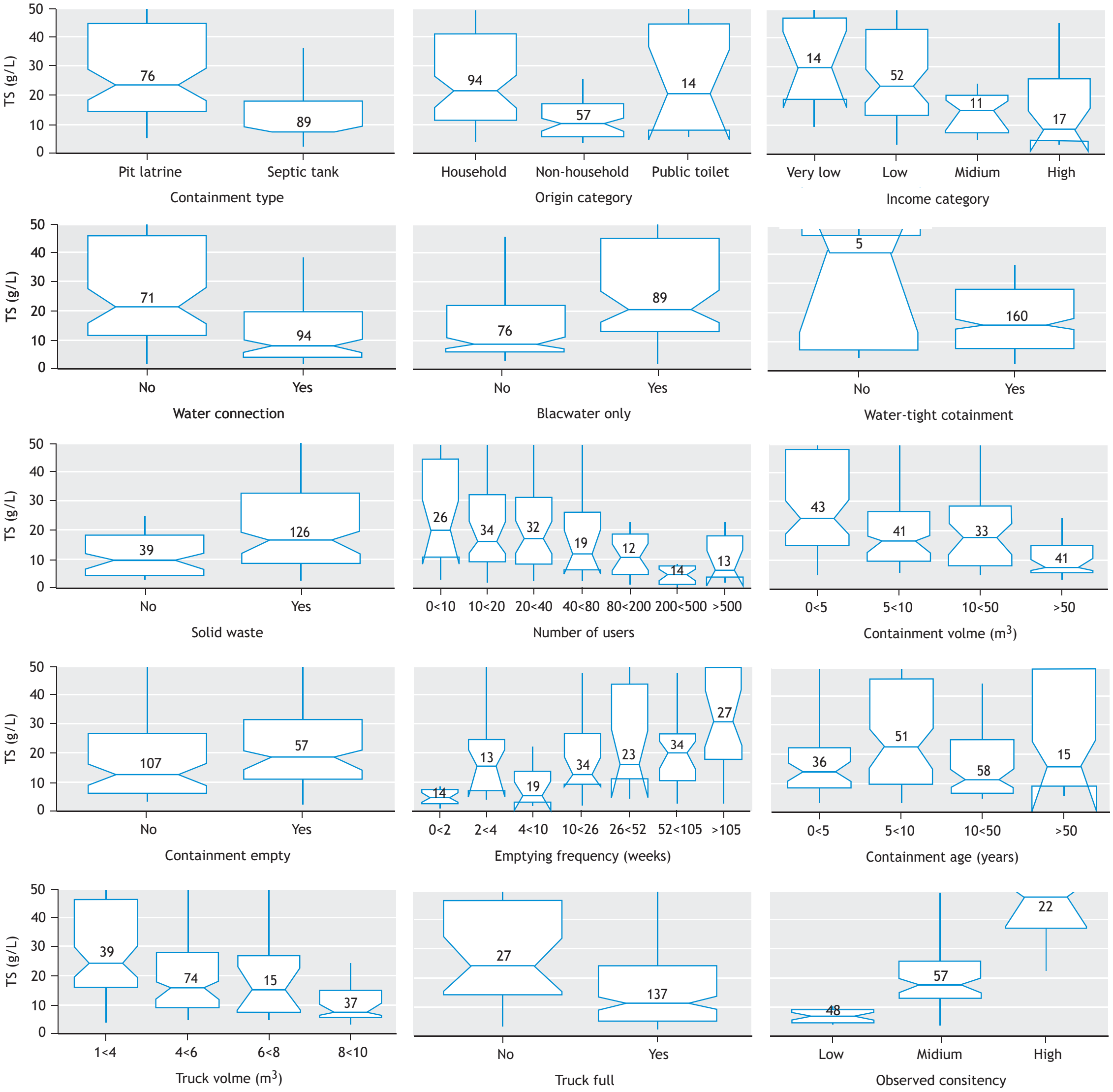

Figure 5.13 Total solids (TS) concentration of faecal sludge, based on collected categories of SPA-DET data in Kampala, Uganda. Number on box plots is number of samples in category.

5.4 FURTHER RESEARCH AND ANALYTICAL POSSIBILITIES

The methodology presented in this chapter includes steps for data collection that can then be used to build up estimations or projections of Q&Q of faecal sludge with straightforward and non-complicated calculations. As implementations and experience with the methodology increase, it will also continue to evolve and become more refined and sophisticated. Tools that are currently being evaluated in research activities of Eawag are described in this section.

5.4.1 Remote sensing

There is a general lack of available SPA-DET data in low- and middle-income countries. To help fill this gap, the use of Earth observation data and remote sensing-based indicators are being explored as a strategy to derive such missing information (Baud *et al.,* 2010; Kohli, 2015). Eawag and the Department of Geoinformatics (Z_GIS) University of Salzburg investigated whether SPA-DET information could be derived from Earth observation data in Lusaka, Zambia, and evaluated it for statistical relations with Q&Q data collected in the field (Nödel 2020). Presented in Figure 5.14 is the example of building density, based on building footprints extracted from satellite imagery. Data was also collected for land use, roof type, distance to green space, distance to water bodies, and distance to treatment.

Referring back to Figure 5.12, it can be seen that areas of high building density are similar to the high density areas designated on the sampling plan. Based on the results, the main findings from this exploratory study were that Earth observation data can be useful to inform sampling plan design for future Q&Q studies, and could indicate focus areas for sanitation planning, providing useful information for decision makers. None of the indicators had statistical relations to quantities, however, building density, building size, street condition, and building use were predictors of TS (Nödel 2020).

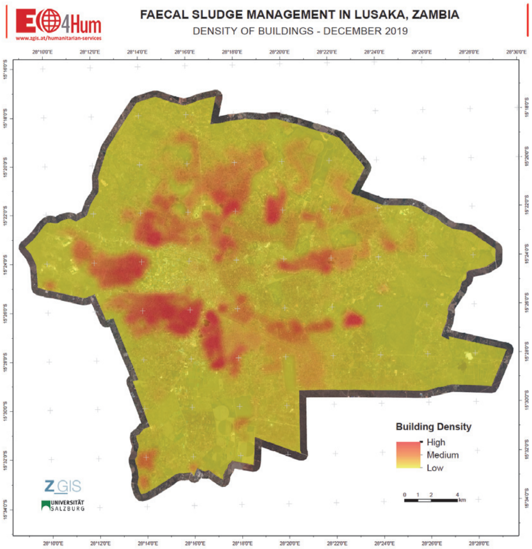

Figure 5.14 Building density in Lusaka, Zambia (map generated by Johannes Nödel and Barbara Riedler). Density calculations were based on data integration of building footprints derived through (*i*) semi-automated, object-based extraction using a very high resolution Pleiades satellite imagery from 2018, (*ii*) OpenStreetMap, and (*iii*) field data provided by GIZ. Values of building density range from low (0 buildings/ km²) to high (4,800 buildings/km²).

5.4.2 Additional spatial analysis

Plotting of results from Q&Q studies in GIS software provides another method of visual inspection of data. By evaluating the results visually it can help to identify further relationships that affect loadings, or identify areas that have significantly different results than expected. For example, as discussed in Step 5 of the sampling plan, this could help to identify areas of groundwater intrusion when groundwater maps are not available.

5.4.3 Interrelationships between sludge characteristics

In wastewater treatment, ratios of constituents in wastewater have been empirically established and are commonly used as rough guidelines during design and selection of treatment technologies. For example, untreated wastewater with a VSS/TSS ratio of 0.85, or a BOD/COD ratio of 0.5 or higher can be considered treatable by activated sludge (Tchobanoglous *et al.,* 2014; Henze and Comeau, 2008). These types of relationships have not yet been empirically established for faecal sludge, due to the relative lack of experience and data. Potentially, as more and more Q&Q studies are conducted, these types of relationships could also be established for faecal sludge. However, with the current state of knowledge, empirical relationships for specific types of faecal sludge, or for specific regions, cannot be transferred to other scenarios, as is also recommended for wastewater with correlations of TOC and COD (Rice *et al.,* 2017).

One potential application for established empirical correlations, could be to reduce the cost of characterisation studies, which are quite resource intensive. For example, if consistent COD/TS ratios are observed in an area, all samples could be analysed for TS (which does not require chemicals) and only a fraction measured for COD (see Case study 5.3). Such approaches could also lead to the development of lower cost qualitative methods for rough estimations. For example developing a color chart or smart phone app that indicates the level of stabilisation of faecal sludge (Ward *et al.,* 2021), or an in-field portable penetrometer that could predict TS as a metric of viscosity (see Chapter 3, section 3.5.9).

Case study 5.3 *Further analysis of statistical relationships within data, COD/TS*

Over the past five years, researchers from Eawag have collected 1,000 samples during implementation of Q&Q studies in six cities[13]. This data is currently being analysed to evaluate trends and relationships within cities, across multiple cities, and for categories of data such as pit latrine or septic tank. The example of COD/TS is presented in Figure 5.15a and Figure 5.15b. Relatively good correlations for COD/TS were observed in Dar es Salaam, Hanoi, Kampala, Ougadougou, and Sircilla, but *the relationships were different in each city*. This pattern was also observed in a study employing the Q&Q methodology in an informal settlement in Nairobi, Kenya (COD = 0.86·TS, with R^2 = 0.93) (Junglen, *et al.* in preparation). In contrast, observed correlations in Lusaka were relatively weak, and were slightly improved by breaking down correlations by categories of collected SPA-DET data (Ward *et al.,* 2021). These examples illustrate that even if empirical relationships are established within cities, the results from the different cities are not necessarily transferable. Note: TS for Lusaka is reported as % TS determined gravimetrically, whereas the TS for the other cities is reported as concentration (g/L).

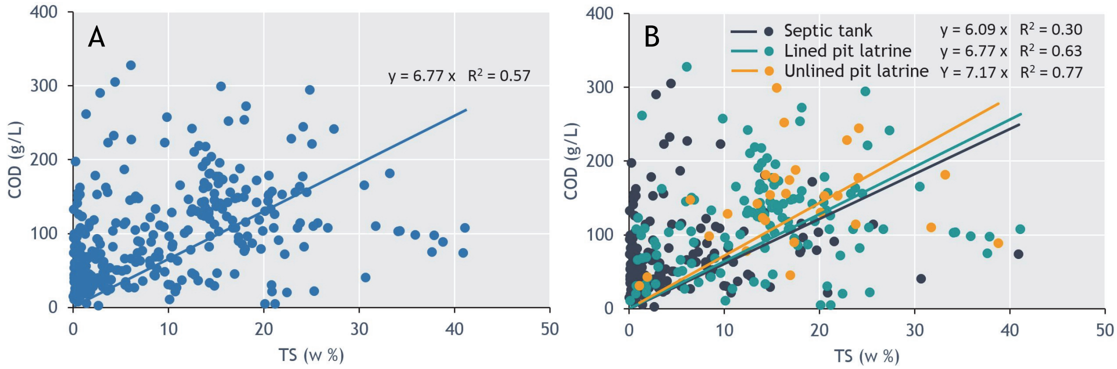

Figure 5.15a A) COD/TS for Lusaka (n=360). B) COD/TS for Lusaka based on type of containment.

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[13] For complete data sets see: Englund *et al.* (2020), Strande *et al.* (2018), Ward *et al.* (2021), Prasad *et al.* (2021), and Andriessen *et al.* in preparation.

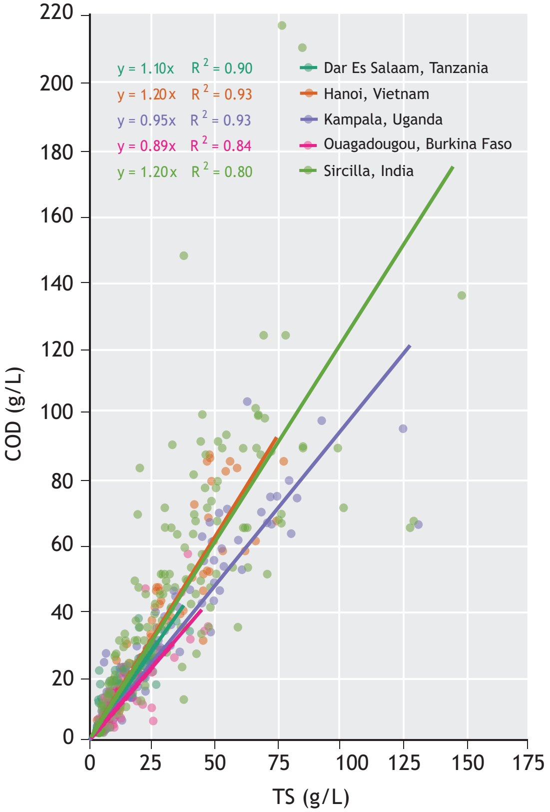

Figure 5.15b City-specific correlations for COD/TS for Kampala (n=180), Dar es Salaam (n=76), Sircilla (n=180), Ouagadougou (n=53), and Hanoi (n=60).

5.4.4 Evaluating categories of data to evaluate separately

Decision trees are models with the main advantage that they are very easy to visualise (Figure 5.16) as they consist of a series 'if' statements separating data that follows different patterns (Safavian and Landgrebe, 1991). The resulting trees should always be compared with expert knowledge for validation. Decision trees could be used to automatically define categories of data that are relevant to analyse separately, instead of only relying on observational experiences and expertise in the field, as was done in the presented methodology. Data analysis can include investigating where and how to break out results for large areas or sample sizes for separate analysis based on categories of SPA-DET data, such as household – non-household and septic tank – pit latrine (Figure 5.16). If the differences are distinct enough, and the sample size large enough, then the SPA-DET data could be analysed separately among these two types of data categories to increase the power and accuracy of predictions.

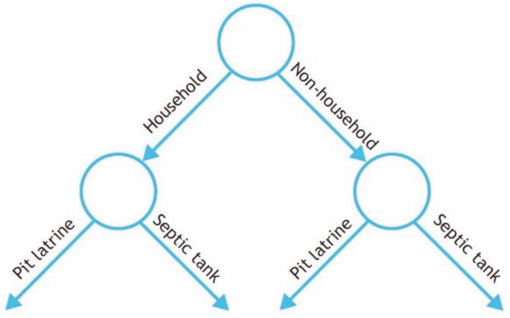

Figure 5.16 Decision tree based on land use patterns (household and non-household) and containment technology (septic tank and pit latrine).

Like any model, the use of decision trees requires adequate input variables. Attempts to train decision trees should start with input variables that are most readily and affordably available. For example, satellite or aerial image analysis can readily be used to distinguish residential and non-residential land use for an entire area. If differences among Q&Q of faecal sludge are expected based on land use, land use should be used as input variable to increase the accuracy of the model. Other variables such as the containment technology are relatively straightforward to obtain, but could require primary data collection depending on the level of information that is available for a city.

The use of decision trees is also useful to test and inform knowledge. Much of the current state of knowledge in faecal sludge management is based purely on observations in the field and it is often not clear which categories are important to analyse separately and which should not be disaggregated. For example, 'public toilet' is frequently grouped as being characteristic of one type of faecal sludge, but analysis shows this is not necessarily valid, for example, in Kampala the type of containment technology was more relevant (Strande *et al.,* 2018).

5.4.5 Predictive models

Statistical models with the aim of predicting a quantity with given inputs can range from simple linear regressions (Case study 5.3) to complex non-linear machine learning models (Case study 5.4). The construction and calibration of such models requires a certain level of expertise, especially since the data collected for Q&Q of faecal sludge can be quite 'noisy'. However, financially the hurdle for such data analysis is quite low when compared to laboratory analysis, as free software, tutorials and online courses are available[14]. The main advantage of machine learning algorithms is that they can identify statistical relationships that are not always noticed by visual inspection. Since relationships can be noisy, care needs to be taken to avoid 'overfitting', to avoid creating a model that just describes the noise of the data. The usefulness of predictive models are application and data dependent. A basic decision tree model can be useful when estimates do not require a high-level of precision. Where higher-resolution predictions are needed, other tools such as machine learning can be used to improve accuracy and reduce error in predictions (Ward *et al*., 2021) However, the precision will still depend on the available data (Case study 5.4). Stochastic models could be advantageous to predict the loading of faecal sludge at treatment plants, as they also describe peak loadings (a similar application for urine collection is presented in Rossboth, 2013). Using predictive models for data exploration can also lead to deeper learning from results, which can in turn lead to the development of mechanistic models. Mechanistic models are discussed further in Chapter 6.

5.4.6 Sensitivity analysis and error propagation

Sensitivity analysis aims to identify the most critical input of a scenario analysis. Various techniques exist, from simply changing one input at a time to more sophisticated approaches that also reveal interactions (*e.g.* Saltelli, 2004). Error propagation can be applied in cases where the uncertainty of the inputs can be quantified (or guessed) to investigate how these uncertainties influence the model outputs. A common and easy to apply technique is Monte Carlo simulations.

Case study 5.4 *Predictive Models for Hanoi, Vietnam, and Kampala, Uganda*

This case study is based on Englund *et al.* (2020) and the complete raw data set is available for download at https://doi.org/10.25678/0000tt. This study was conducted to evaluate whether SPA-DET data could be used to build predictive models for faecal sludge management. Two data sets from Hanoi and Kampala were used. The data includes 60 field samples and questionnaires from Hanoi and 180 from Kampala, results of the characterisation from Hanoi are presented in Figure 5.17.

Software tools were used in an iterative process to predict TS and emptying frequency in both cities. City-specific data could be predicted with types of SPA-DET data as input variables, and model performance was improved by analysing septic tanks and pit latrines separately. Individual city models were built for TS concentrations and emptying frequency. In addition, a model was built across both cities for emptying frequency of septic tanks based on number of users and containment volume (Figure 5.18). The data appears to be consistent across the two cities, despite the fact that the range of input variables is quite different, indicating that in the future predictive models could potentially be relevant for multiple cities. However, it is important to note that these two cities only represent two data points, and general assumptions for other cities cannot be drawn without validation. Number of users, containment volume, truck volume and income level were identified as the most common variables for the correction function. Results confirm the high intrinsic variability of faecal sludge characteristics, and illustrate the value of moving beyond simple reporting of city-wide average values for estimations of Q&Q.

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[14] e.g. https://www.r-project.org/, https://scikit-learn.org/stable/

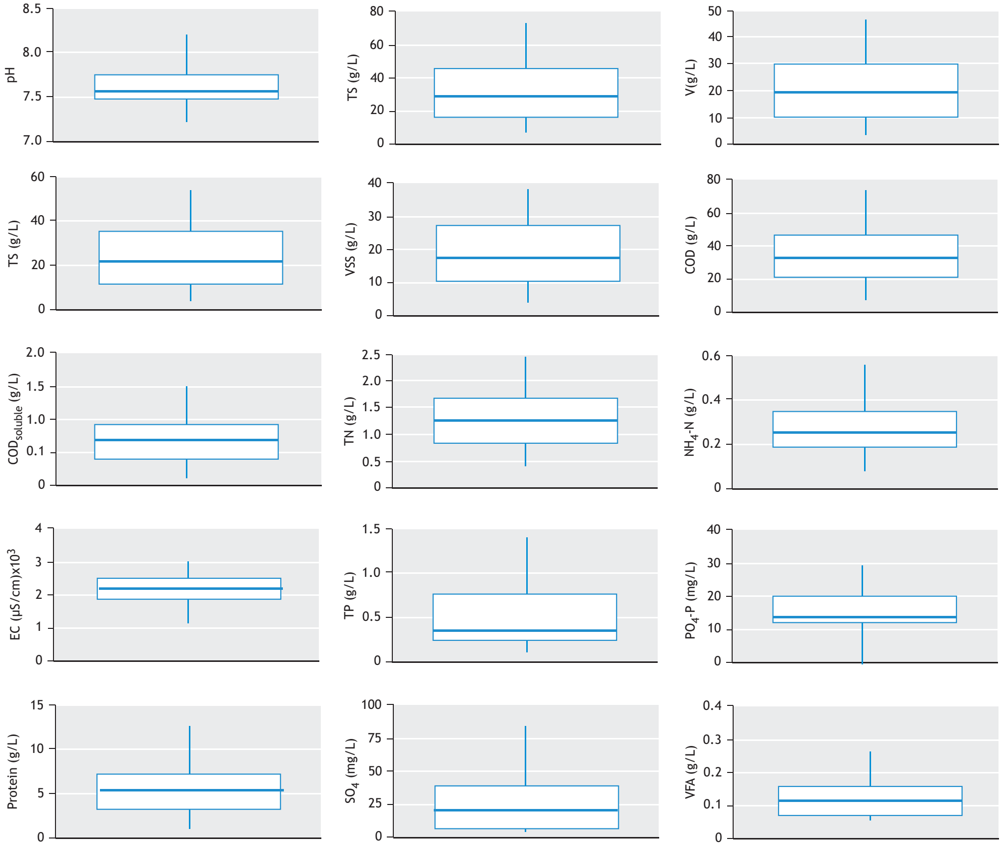

Figure 5.17 Characterisation results for 60 samples taken from household septic tanks in Hanoi, Vietnam (Englund *et al.* 2020).

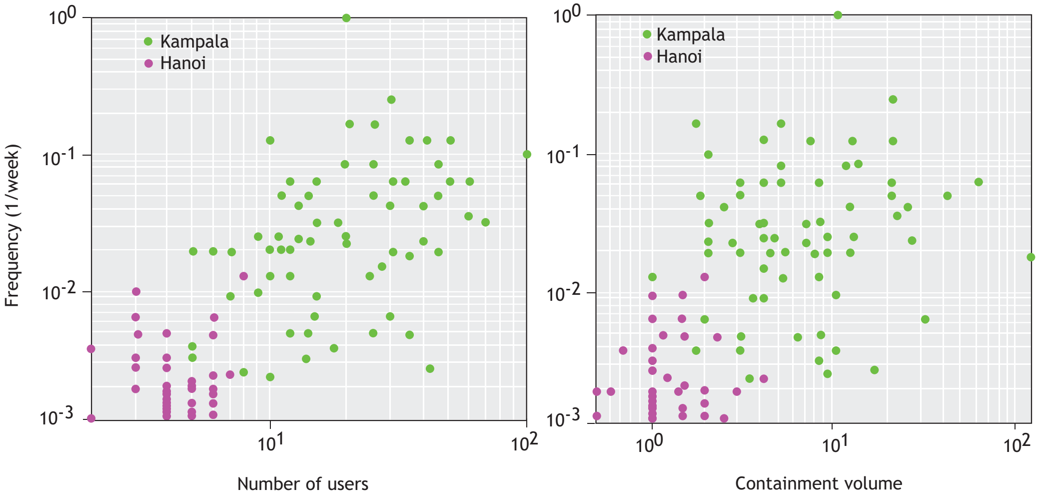

Figure 5.18 Predicted emptying frequency of septic tanks from single and multiple households, showing fit to data from Hanoi and Kampala, the plots are in log-log scale (Englund *et al.* 2020).

5.5 OUTLOOK

The management of faecal sludge is dynamic and complex. Sustainable long-term management requires adaptive planning for population growth and changing infrastructure. The methodology presented in this chapter for the projection of faecal sludge loadings at the community to citywide scale, is a structured, iterative process. The methodology can be implemented with available resources, and revisited with progressively deeper and more data-rich campaign rounds as resources become available. In this way, projections can be improved with time, and additional statistical relationships can be established. Data collected in this fashion will be representative for making projections of Q&Q of faecal sludge, and as more data becomes globally available, that is collected in a logical, replicable, comparable, and transparent fashion, it will allow for greater transferability and learning among cities, countries, and regions.

Important lessons learned include:

- Use of historical accumulation rates intended for the design of pit latrines in rural areas are not transferable to dense urban areas (Strande et *al.* 2018).
- Faecal sludge Q&Q data do not follow a normal distribution (Chapter 1), hence, only reporting values for averages and standard deviations is not adequate. Summary statistics should include at a minimum averages, standard deviations, medians and interquartile ranges, and ideally, complete raw data sets should be shared (Andriessen *et al.* in preparation(b)).
- It is important to clearly identify the goal of a Q&Q study prior to defining system boundaries of onsite containment technologies. Resulting metrics should be determined based on these definitions, together with the availability of resources (Prasad *et al.* 2021).
- The resolution of planning projections only needs to be as precise as the decision-making process requires. City-wide inclusive sanitation planning does not require the same level of precision as process control or optimisation of treatment plants (Ward et *al.*, 2021, Englund et *al.* 2020).
- When designing faecal sludge treatment plants, it is crucial to keep in mind, that even with more reliable predictions for loadings, daily operation still needs to be able to adapt to highly variable influent loadings (Klinger et *al.* 2019).

REFERENCES

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

Andriessen N., Scheidegger A. and Strande L. (in preparation b). Projections of quantities and qualities (Q&Q) of faecal sludge for management and treatment: comparison of data from six cities in Africa and Asia.

Bassan M., Mbéguéré M., Zabsonre F. and Strande L. (2013a). Integrated faecal sludge management scheme for the cities of Burkina Faso. *Journal of Water, Sanitation and Hygiene for Development,* 3, 216-221.

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

Bassan M., Dao N., Nguyen V.A., Holliger C. and Strande L. (2014). Technologies for sanitation: how to determine appropriate sludge treatment strategies in Vietnam. *37th WEDC International Conference,* Hanoi Vietnam, 2014.

Brouckaert C., Foxon K. and Wood K. (2013). Modelling the filling rate of pit latrines. *Water SA*, 39.

Brown D., Butler, D., Orman, N. and Davies, J. (1996). Gross solids transport in small diameter sewers. *Water Science and Technology*, 33(9), 25-30.

Buckley C.A., Foxon K.M., Brouckaert C. J., Rodda N., Nwaneri C.F. and Balboni E. (2008). Scientific support for the design and operation of ventilated improved pit latrines (VIPS) and the efficacy of pit latrine additives, *Water Research Commission,* South Africa.

Chowdhry S. and Koné,D. (2012). Business Analysis of Fecal Sludge Management: Emptying and Transportation Services in Africa and Asia. *Bill & Melinda Gates Foundation*, Seattle, USA.

De Bercegol R., Cave J. and Huyen A.N.T. (2017). Waste Municipal Service and Informal Recycling Sector in Fast-Growing Asian Cities: Co-Existence, Opposition or Integration? *Resources-Basel,* 6(4), 10.

Eawag-Sandec (2020). Training course on Consultant Capacity Development (ConCaD) for City-wide Inclusive Urban Sanitation, Module 3.3.

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.

Esanju M.M. (2018). Assessment of the applicability of data collection methodology for estimating quantities and qualities of faecal sludge (Q&Q model) in Dar es Salaam. Master's thesis, *University of Dar es Salaam*.

Fichtner Associates GmbH., (2015). Kampala Sanitation Master Plan Update. Volume 1: Report, JV Fichtner *Water & Transportation.*

Filmer D. and Pritchett L.H. (2001). Estimating wealth effects without expenditure data-or tears: an application to educational enrollments in states of India. *Demography,* 38(1), 115-132.

Gold M., Harada H., Therrien J.-D., Nishida T., Cunningham M., Semiyaga S., Fujii S., Niwagaba C., Dorea C., Nguyen V.-A. and Strande L. (2018). Cross-country analysis of faecal sludge dewatering. *Environmental Technology.* 39(23), 3077-3087.

Gray N. F. (1995). The Influence of sludge accumulation rate on septic tank design. *Environmental Technology,* 16(8), 795-800.

Harada H., Nguyet P.-A., Nguyen V.-A. and Fujii S. (2014). Influential factors on septage composition: A case study in Hanoi, *In proceedings*: *FSM3 - International Faecal Sludge Management Conference*, Hanoi, 2014.

Henze M. and Comeau Y. (2008). Wastewater Characterisation. Book chapter in Henze M., Van Loosdrecht M.C.M, Ekama G.A., Brdjanovic D. (eds.), Biological Wastewater Treatment: Principles, Modelling and Design. IWA Publishing, London, UK.

Howard T.L. (2003). Solids accumulation rates for onsite sewage treatment and disposal systems: A Focus on Charlotte County, Florida. *University of Florida*, Master's Thesis.

Junglen K., Rhodes-Dicker L., Ward B.J., Gitau E., Mwalugongo W., Stradley L. and Thomas E. (2020). Characterisation and prediction of fecal sludge parameters and settling behavior in informal settlements in Nairobi, Kenya. *Sustainability*, 12(21), 9040.

Klinger M., Gueye A., Manandhar Sherpa A. and Strande L. (2019). Scoping Study: Faecal Sludge Treatment Plants in South-Asia and Sub-Saharan Africa. eFSTP Project Report. *Gates Open Research* 2019, 3, 1716 (document) (https://doi.org/10.21955/gatesopenres.1116557.1)

Koottatep T., Surinkul N., Paochaiyangyuen R., Suebsao W., Sherpa M., Liangwannaphorn C. and Panuwatvanich A. (2012). Assessment of faecal sludge rheological properties, Report.

Lugali Y., Zziwa A., Banadda N., Wanyama J., Kabenge I., Kambugu R. and Tumutegyereize P. (2016). Modeling sludge accumulation rates in lined pit latrines in slum areas of Kampala City, Uganda. *African Journal of Environmental Science and Technology,* 10(8), 253-262.

Marwa L.I. (2017) Development of potential predictors for faecal sludge characterisation on a community scale, the case study of Mlalakua Community, Dar es Salaam. University of Dar es Salaam (MSc thesis).

Mills F., Blackett I. and Tayler K. (2014). Assessing on-site systems and sludge accumulation rates to understand pit emptying in Indonesia. In *WEDC International Conference*, Hanoi, Vietnam, 2014.

Morgan P.R., Mara D.D. and Mundial B. (1982). Ventilated improved pit-latrines: recent development in Zimbabwe. *World Bank*, Vol. 3.

Museteka L., Petulo P., Karen M., Fahle M. and Godau T. (2019). Groundwater Vulnerability Map of Lusaka Province / Zambia. https://www.whymap.org/EN/Themen/Wasser/Projekte/laufend/TZ/Zambia/map_hygeo_zambia_lusaka-vm.html

Nakagiri A., Kulabako R.N., Nyenje P.M., Tumuhairwe J.B., Niwagaba C.B. and Kansiime F. (2015). Performance of pit latrines in urban poor areas: A case of Kampala, Uganda. *Habitat international*, 49, 529-537.

Nödel, J.M. (2020). Indicator-based city zoning using Earth observation for sanitation management in Lusaka, Zambia. Master's thesis, Interfaculty Department of Geoinformatics-Z_GIS, *Paris-Lodron-University of Salzburg.*

Ojok, Koech M. and Okot-Okumu J. (2012). Rate and quantities of household solid waste generated in Kampala City, Uganda. Science *Journal of Environmental Engineering Science*. 2013, **doi:** 10.7237/sjeer/237.

Otaki Y., Otaki M., Bao P.N., Nga T.T.V. and Aramaki T. (2013). Micro-component survey of residential water consumption in Hanoi. *Water Science and Technology - Water Supply*, 13(2), 469-478.

Peal A., Evans B., Sangaralingam A., Ban R., Blackett I., Hawkins P., Schoebitz L., Scott R., Sleigh A., Strande L. and Roda O. (2020). Estimating safely managed sanitation in urban areas, lessons learned from a global implementation of excreta-flow diagrams. *Frontiers*, https://doi.org/10.3389/fenvs.2020.00001.

Prasad P., Andriessen N., Moorthy A., Das A., Coppens K., Pradeep R. and Strande L. (2021). Field-testing of the methods for estimating quantities and qualities (Q&Q) of faecal sludge: field evaluation in Sircilla, India. *Journal of Water, Sanitation and Hygiene for Development.*

Penn R., Ward B.J. Strande L. and Maurer M. (2018). Review of synthetic human faeces and faecal sludge for sanitation and wastewater research. *Water Research*, 132, 222-240.

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.

Rose C., Parker A., Jefferson B. and Cartmell E. (2015). The characterisation of faeces and urine: A Review of the literature to inform advanced treatment technology. *Critical Reviews in Environmental Science and Technology*, 45(17), 1827-1879.

Rossboth T. (2013). Model-based systems analysis of the collection management of source-separated urine in Ethekwini Municipality/South Africa. University of Natural Resources and Life Sciences, Vienna, Austria. (MSc thesis).

Safavian S.R. and Landgrebe D. (1991). A survey of decision tree classifier methodology. IEEE *Transactions on Systems, Man, and Cybernetics*. 21(3), 660-674.

Sagoe G., Danquah F.S., Amofa-Sarkodie E.S., Appiah-Effah E., Ekumah E., Mensah E.K. and Karikari K.S. (2019). GIS-aided optimisation of faecal sludge management in developing countries: the case of the Greater Accra Metropolitan Area, Ghana. *Heliyon*, 5(9).

Saltelli A., Tarantola S., Campolongo F. and Ratto R. (2004). Sensitivity analysis in practice a guide to assessing scientific models, *John Wiley*, Chichester, England.

Schoebitz L., Niwagaba C., Francis O., Bischoff F. and Strande L. (2014). FAQ: Faecal sludge quantification and characterisation - Kampala. *Sandec News*.

Schoebitz L., Bischoff F., Lohri C.R., Niwagaba C.B., Siber R. and Strande L. (2017). GIS analysis and optimisation of faecal sludge logistics at city-wide scale in Kampala, Uganda. *Sustainability,* 9(2), 194.

SFD Promotion Initiative *SFD Manual Volume 1 and 2*, 2018. http://sfd.susana.org/

Strande L., Ronteltap M. and Brdjanovic D. (2014). Faecal Sludge Management - Systems Approach for Implementation and Operation. IWA Publishing: London, UK.

Strande L., Schoebitz L., Bischoff F., Ddiba D. 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.

Still D. and Foxon K. (2012). Tackling the challenges of full pit latrines, *Water Research Commission South Africa*, 1745/2/12.

Still D., Salisbury R., Foxon K., Buckley C. and Bhagwan J. (2005). The challenges of dealing with full VIP latrines, *Proceedings WISA Biennial Conference & Exhibition*, Durban ICC, South Africa.

Tchobanoglous G., Burton F.L. and Stensel H.D. (2014). Wastewater Engineering: Treatment and Reuse. *Metcalf & Eddy* (Boston) 5th ed, McGraw-Hill Higher Education, New York.

Tilley E., Ulrich L., Lüthi C., Reymond P. and Zurbrügg C. (2014). Compendium of sanitation systems and technologies. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland, 2nd revised edition.

Van Zyl H., Van Zyl J., Geustyn L., Ilemobade A. and Buckle J. (2007). Water consumption levels in selected South African cities, *WRC* Report No 1536/1/06.

Wagner E.G. and Lanoix J.N. (1958). Excreta disposal for rural areas and small communities, *World Health Organisation*.

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 planning, monitoring, and implementing faecal sludge management solutions? *Water Research.* https://doi.org/10.25678/00037X

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, 115101. https://doi.org/10.1016/j.watres.2019.115101

Zakaria F., Ćurko J., Muratbegovic A., Garcia H.A., Hooijmans C.M. and Brdjanovic D. (2018). Evaluation of a smart toilet in an emergency camp. *International journal of disaster risk reduction,* 27, 512-523.

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Figure 5.19 Faecal sludge collection and transport by a Tanzanian entrepreneur in Kigamboni, Dar es Salaam (photo: Eawag).