Research Paper

Methods for estimating quantities and qualities (Q&Q) of faecal sludge: field evaluation in Sircilla, India

Prerna Prasad, Nienke Andriessen, Anantha Moorthy, Amrita Das, Kayla Coppens, Rohini Pradeep and Linda Strande

ABSTRACT

Estimates of accumulated quantities and qualities (Q&Q) of faecal sludge are essential for developing city-wide management plans. However, standardized approaches are lacking, and examples in scientific literature make use of diverse methodologies and parameters, making their comparability and transferability difficult. This study field-tested an approach for estimating Q&Q in Sircilla, India, and compared three methods for measuring accumulated sludge: (1) faecal sludge accumulation rate from *in situ* measurement with a core sampler; (2) faecal sludge accumulation rate with volume emptied by desludging truck; and (3) sludge blanket accumulation rate *in situ* with a core sampler. Measurements were taken at households and commercial establishments, samples were analysed for characteristics, and demographic, environmental, and technical data were collected with a questionnaire. The median total solids (TS), volatile solids (VS), and chemical oxygen demand (COD) concentrations for all containments were 26.8, 17.8, and 32.0 g/L, respectively. The median faecal sludge accumulation rate estimated with the core sampler and truck were 53 and 96 L/cap·year, respectively. The median sludge blanket accumulation rate was 17 L/cap·year. Continued data collection in this fashion will lead to a better understanding of what is accumulating in onsite containments at regional levels.

Key words | accumulation rate, method evaluation, pit latrine, sanitation, septic tank, sludge blanket

Prerna Prasad
Anantha Moorthy
Amrita Das
Rohini Pradeep
Consortium for DEWATS Dissemination Society,
Survey No. 205 Kengeri Satellite Town,
Bengaluru,
Karnataka 560060,
India

Nienke Andriessen
Kayla Coppens
Linda Strande (corresponding author)
Swiss Federal Institute of Aquatic Science and Technology,
Überlandstrasse 133,
8600 Dübendorf,
Switzerland
E-mail: *linda.strande@eawag.ch*

HIGHLIGHTS

- Comparison of methodologies to estimate the total faecal sludge and sludge blanket accumulation rate.
- The selection of Q&Q measurement methods should be based on defined objectives and available resources.
- Q&Q studies conducted in this fashion will lead to more locally relevant accumulation rates than standard values.

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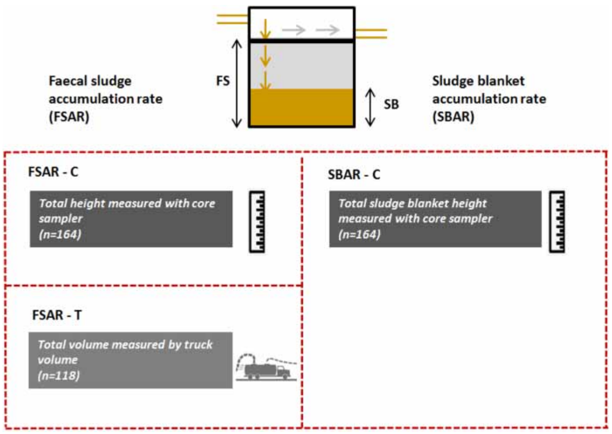
GRAPHICAL ABSTRACT



INTRODUCTION

Integrated faecal sludge management is a key component of achieving city-wide inclusive sanitation (Gambrill *et al.* 2020; Schrecongost *et al.* 2020). Planning management solutions at a city scale require reasonable estimates for the qualities and quantities (Q&Q) of faecal sludge accumulating in onsite containments, in order to ensure adequate service capacity, prevent overloaded treatment plants, and reduce resource waste. Models for predicting Q&Q of wastewater exist (Martin & Vanrolleghem 2014), but estimating Q&Qs of faecal sludge is not yet established (Englund *et al.* 2020). Difficulties include faecal sludge being much more variable and heterogeneous than wastewater, which is in comparison relatively homogenized during transport through a sewer (Strande *et al.* 2021). Additionally, onsite containments are often not constructed, operated, or maintained according to standards (Bounds 1997; Nam *et al.* 2006; CSE 2018), which also contributes to the variability of faecal sludge (e.g. varying user practices, storage conditions, environmental factors, etc.) (Still & Foxon 2012). Q&Q of faecal sludge also vary extensively between different locations (Koottatep *et al.* 2021), and thus, locally determined estimates are needed. Earlier attempts to estimate Q&Qs of faecal sludge have largely relied on average values reported in the literature; however, due to the high spatial variability of Q&Q, this method is often inaccurate (Strande *et al.* 2021). To fill this gap, studies have evaluated whether statistical relationships between demographic, environmental, and technical data with Q&Q of faecal sludge can be used to make projections (Englund *et al.* 2020; Strande *et al.* 2021; Ward *et al.* 2021). However, further validation of measured values is necessary prior to scaling up.

Although the most difficult to reasonably estimate, rates of faecal sludge accumulation are essential because it represents the total (latent) amount of faecal sludge that needs to be managed (Strande *et al.* 2018). However, there is no standard for methods used to determine accumulation rates reported in the literature. Examples include measuring *in situ* volume using a sludge sampler and tape measure (Lugali *et al.* 2016) or a laser-based measuring device (Still & Foxon 2012; Todman *et al.* 2015) and then calculating accumulating rate with questionnaire data; *ex situ* measurements using the truck volume gauge combined with questionnaire data (Strande *et al.* 2018); models and mass balances (Brouckaert *et al.* 2013; Lugali *et al.* 2016); and standard design values for filling rates (Wagner & Lanoix 1958; Bureau of Indian Standards 1985, 1987). In addition to the confusion of not knowing if these different methods produce comparable values, it is not relevant to use design values for filling rates of pit latrines in rural areas to the actual reality of faecal sludge management in dense urban areas (Strande *et al.* 2021). This makes it difficult to design onsite containment technologies and develop management plans that are context-specific. In addition to these methods on 'how' things are measured, it is not always clear 'what' is being measured. For example, total amounts accumulated (liquid and solid layers; Strande *et al.* 2018) or settled sludge accumulated (solid layer; Mills *et al.* 2014). These rates are defined and measured differently, but frequently used interchangeably.

To address these issues, and to move towards a more consistent method of comparing accumulation rates, the objective of this study was to evaluate relations between demographic, environmental, and technical data and Q&Q of faecal sludge in Sircilla, India, for making city-wide projections. Additionally, three different methods for estimating volumes of accumulated faecal sludge for pit latrines and septic tanks were used in order to be able to compare the results of different methods.

METHODS

Study area

This study was conducted in 2018 in Sircilla, India, a town in Telangana state. Sircilla has a population of approximately 83,000 (Eawag & CDD 2019) and depends entirely on onsite sanitation. All the faecal sludge collected in Sircilla was previously disposed untreated in the peripheral areas of the town. To address this gap, a faecal sludge treatment plant was constructed in 2019. 40% of onsite containments are pit latrines and 60% septic tanks with only blackwater entering the containments with greywater flowing directly into open drains (Eawag & CDD 2019). Pit latrines are constructed by assembling pre-cast concrete rings that are semi-permeable between each ring, with an unlined base through which infiltration can occur. In this study, they are referred to as 'circular' in contrast to septic tanks, which are either rectangular or elliptical. Rectangular septic tanks are constructed with bricks or poured concrete and have a baffle. Elliptical septic tanks are constructed with poured concrete and have a baffle that extends from the top of the tank halfway down. All septic tanks have a free-flowing outlet connected to the stormwater drain, and in the centre of Sircilla, some lined pit latrines are also connected to drains. In the Sircilla municipality, containment types vary with differing levels of affordability and space constraints. Elliptical tanks are the standard containment type for new buildings due to their construction efficiency. The soils in Sircilla have tan brown porphyritic granite deposits underlain by gneissic complex, which is overlain by basaltic lava flows and granites, dolerites, pegmatites, and quartzites (Eawag & CDD 2019). The geology of the region allows for the groundwater to be replenished during the Monsoon period (June to September). Households in Sircilla use boreholes. During the dry season, the drinking water supply comes from groundwater. Sampling in this study was done in the dry season (post-monsoon), from the end of August 2018 to the end of March 2019.

Experimental set-up

Samples were collected from 164 onsite containments (134 households and 30 commercial), and the complete raw dataset is available at https://doi.org/10.25678/0002VH. Commercial containments included public toilets, businesses, theatres, office buildings, academic institutions, and hospitals. At the time of each measurement, a questionnaire on KoBo Toolbox was used to collect demographic, environmental, and technical information from the emptier and the user of the containment system (e.g. number of users, income, home ownership, type of water connection, toilet type, domestic water use, containment age, desludging interval, containment type, etc.). The same questionnaire was used as in Strande *et al.* (2018).

For definitions of faecal sludge used in this paper, refer to Velkushanova *et al.* (2021). Quantity of faecal sludge was defined as *in situ* rate of accumulation for septic tanks (commonly referred to as 'septage') and pit latrines. This was calculated both for the total amount of faecal sludge in containment, and on the sludge fraction that was settled out (referred to here as a sludge blanket). As shown in Figure 1, a 4 m long segmented core sampler was used to measure the height of total accumulated faecal sludge and the sludge blanket. The bottom of the core sampler had an airtight closure to retain the captured sludge profile. The core sampler was assembled onsite, put into the containment, locked, and taken out, after which it was allowed to settle until a clear demarcation was visible between the sludge and supernatant

Figure 1 | Core sampler used for measuring the height of the sludge blanket and the total height of faecal sludge.

layer. The detailed sampling procedure is provided in Koottatep *et al.* (2021).

The faecal sludge (total amount) accumulation rate (FSAR) was measured using two different methods (Figure 2). *In situ* volumes were measured by (1) depth of faecal sludge (solids + liquid layers) by the core sampler (FSAR-C) multiplied by the area of the containment as measured with a tape measure on the outside and (2) the volume of the emptying truck multiplied by the number of trips made, and by reading the volume gauge on the truck if it was not completely full. The volumes were then divided by the number of users and the time since last emptied.

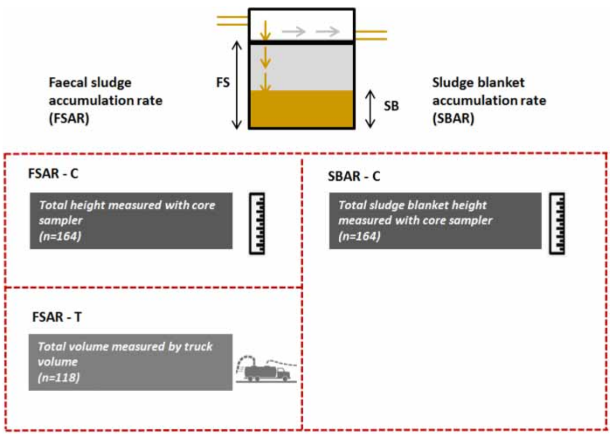


Figure 2 | Summary of the methodologies used for field-testing quantities.

$$\text{FSAR} - \text{C}\ (\text{L/cap} \cdot \text{year}) = \frac{\text{Height of faecal sludge meashured using core sampler (m)} \times \text{Area of onsite containment (m}^2) \times 0.001}{\text{Number of users} \times \text{Time since last emptying (years)}} \quad (1)$$

$$\text{FSAR} - \text{T}\ (\text{L/cap} \cdot \text{year}) = \frac{\text{Total volume of faecal sludge inside containment system measured using truck volume (L)}}{\text{Number of users} \times \text{Time since last emptying (years)}} \quad (2)$$

The sludge blanket accumulation rate (SBAR-C) was calculated as the depth of the sludge blanket measured with the core sampler, multiplied by the area of the containment, and divided by the number of users and time since last emptied.

$$\text{SBAR} - \text{C}\ (\text{L/cap} \cdot \text{year}) = \frac{\text{Height of sludge blanket (m)} \times \text{Area of onsite containment (m}^2) \times 0.001}{\text{Number of users} \times \text{Time since last emptying (years)}} \quad (3)$$

In addition, to validate measurements with the core sampler, the total height of faecal sludge was measured six times over a period of 8 months for 28 elliptical septic tanks, 5 of which were emptied at the beginning of the study. Sludge blanket was also measured at these time points, to understand how sludge blanket accumulated over shorter time intervals.

Analytical methods

For qualities (characteristics), chemical oxygen demand (COD), total solids (TS), and volatile solids (VS) were analysed. A composite sample was taken from the vacuum truck during discharge, 2L at the beginning, the middle, and the end of discharge (Koottatep *et al.* 2021). The samples were mixed thoroughly, and a 1 L subsample was collected and stored in an icebox for transport to the laboratory. All samples were analysed at Vison Labs in Hyderabad. COD was analysed according to standard methods for wastewater (method 5220D: closed reflux, colorimetric method; APHA 2017) and analysis of TS and VS followed the Indian standards for wastewater analysis (gravimetric method; Bureau of Indian Standards 1984). Samples were stored a maximum of 3 days following sample collection, if samples were not immediately analysed, they were stored in a refrigerator at 4 °C. For all parameters, 10% of the samples were analysed in duplicate, and the maximum deviation between duplicates was 8%.

Data analysis was done in Microsoft Excel 2010 and R software version 3.6.2. Due to the non-normal distribution of the data evident in the skewed distribution curves, median instead of mean values were considered for data analysis (Schmid & Huber 2014). Non-parametric tests were conducted to assess differences between categories of indicators at a 95% confidence level; Kruskal–Wallis test for indicators with multiple categories and Mann–Whitney *U*-test for indicators with two categories. During the analysis of the data, erroneous measurements and outliers were removed.

RESULTS AND DISCUSSION

Qualities (characteristics)

Summary statistics for TS, VS, and COD are presented in Table 1; in addition, the complete raw data set is available at https://doi.org/10.25678/0002VH. A wide range of values was observed, with standard deviations that were as high as mean values. This has similarly been reported in other studies in India, for example, reported COD values from faecal sludge of various origins ranging from 0.6 to 612.5 g/L (Shivendra *et al.* 2016; Sharma *et al.* 2020; Vijayan *et al.* 2020). In comparison, the COD concentrations in this study ranged from 0.2 to 220 g/L. The median TS concentration was higher for pit latrines than for septic tanks, which has also been observed in other studies in Kampala, Uganda, and in Lusaka, Zambia (Strande *et al.* 2018; Ward *et al.* 2021). As described in the methods, the samples for characteristics were collected during sludge discharge from trucks. Due to the limited availability of resources, it was not possible to compare qualities for both the truck and core sampler methods, as was done for quantities.

The median TS concentration was significantly lower ($p = 4.5 \times 10^{-8}$) for elliptical septic tanks (8.6 g/L) than for rectangular septic tanks (31.2 g/L) and circular pit latrines (36.4 g/L). The lower TS concentration in elliptical septic tanks could potentially be explained by their age, as 80% of the elliptical septic tanks were new (<3 years old). A positive trend was observed between the age of the containment and TS up until 20 years. The TS also suggests that the elliptical septic tanks in Sircilla perform differently than

Table 1 | Summary statistics for total solids, volatile solids, and COD concentrations for all samples in this study presented by mean, standard deviation, median, lower and upper quartile

Quality parameter	Mean	Standard deviation	Median	Lower quartile	Upper quartile
Total solids (g/L)					
All samples ($n = 164$)	31.4	26.8	26.8	9.1	45.0
Pit latrines ($n = 77$)	38.5	25.7	36.4	16.9	48.9
Septic tanks ($n = 87$)	25.2	26.3	16.7	5.3	38.3
Volatile solids (g/L)					
All samples ($n = 164$)	19.4	15.4	17.8	6.0	30.1
Pit latrines ($n = 77$)	24.5	14.6	24.1	10.9	32.3
Septic tanks ($n = 87$)	14.8	14.6	10.2	2.8	22.5
Chemical oxygen demand (g/L)					
All samples ($n = 163$)	41.6	37.0	32.0	11.5	63.0
Pit latrines ($n = 76$)	52.9	33.5	48.0	29.5	66.5
Septic tanks ($n = 87$)	31.7	37.2	18.0	5.7	45.0

conventional septic tanks and pit latrines, and the elliptical design does not seem to favour settling performance. The placement of the baffle in elliptical septic tanks could be interfering with the settling performance (USEPA 1980). It is, therefore, recommended that the government monitor and evaluate the performance and design of elliptical septic tanks prior to scaling up to other regions in India.

The concept of the Q&Q methodology presented in Strande *et al.* (2021) is that characteristics of faecal sludge could be statistically different among categories of demographic, environmental, and technical data. In Sircilla, the median COD concentration was significantly higher ($p = 0.017$) for households (39 g/L) than for commercial establishments (21.9 g/L). However, the median TS concentration for households (26.9 g/L) was not significantly different ($p = 0.91$) from commercial establishments (23.4 g/L). In contrast, in Kampala and Lusaka, both COD and TS were higher for households than for commercial establishments (Strande *et al.* 2018; Andriessen *et al.* in preparation; Ward *et al.* 2021). The difference is most likely a result of different usage patterns, but it is not clear in Sircilla why the difference was seen for COD but not TS. Other parameters with significant differences for TS, VS, and COD include containment type (concentrations were higher in pit latrines than septic tanks), containment shape (elliptical septic tanks had lower concentrations than circular pit latrines and rectangular septic tanks), and containment age (concentrations increased with age up to 20 years). Differences were not statistically significant for the number of users (no difference between categories), locality (no difference between slum and non-slum), and income level (no difference between low, middle, and high incomes).

As shown in Figure 3, in Sircilla, linear correlations were observed between TS and VS and TS and COD. Consistently observed correlations within a city allow projections to be made, in addition to observed differences by demographic data. These relationships can help reduce time and costs in future faecal sludge characterization studies, by reducing the required number of future laboratory analysis, and can aid in establishing more fundamental understanding of relationships between these parameters.

Quantities (accumulation rates)

As summarized in Figure 2, three methods were used for estimating accumulation rates on all septic tanks and pit latrines (FSAR-C, FSAR-T, and SBAR-C). The median values for each of the methods are presented by the category in Table 2. For all measurements taken in Sircilla, FSAR-C had a mean value of 118 L/cap·year, standard deviation of 162 L/cap·year, lower quartile of 21 L/cap·year, and upper quartile of 143 L/cap·year. FSAR-T had a mean of 161 L/cap·year, standard deviation of 184 L/cap·year, lower quartile of 47 L/cap·year, and upper quartile of 222 L/cap·year. SBAR-C had a mean of 26 L/cap·year, standard deviation of 34 L/cap·year, lower quartile of 8 L/cap·year, and upper quartile of 31 L/cap·year.

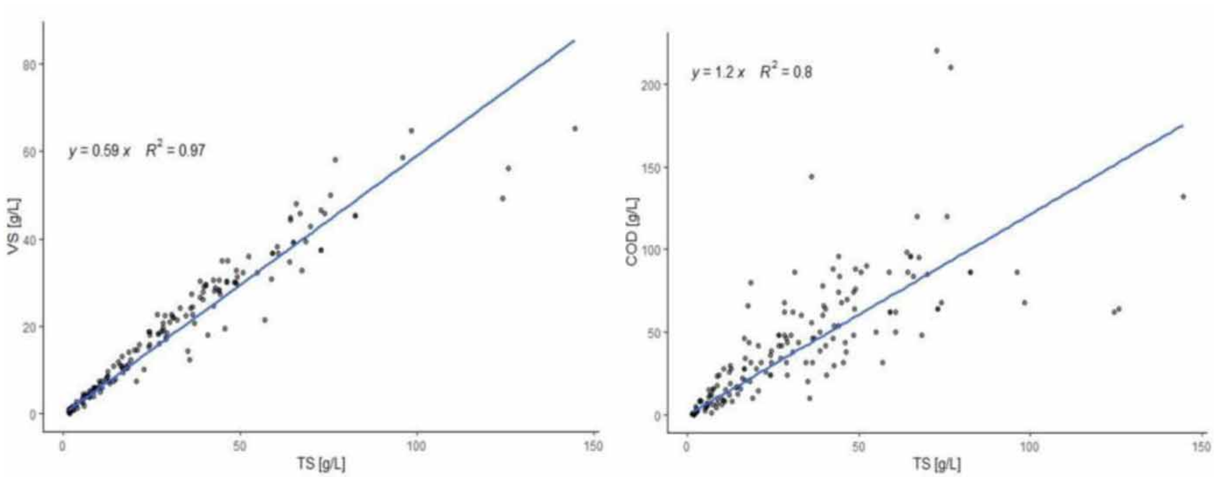


Figure 3 | Linear correlations between the concentrations of TS and VS (left) and TS and COD (right).

Table 2 | Median values of estimated faecal sludge accumulation rates based on the three different methods of data collection for total faecal sludge and sludge blanket accumulation rates, as summarized in Figure 2

	Faecal sludge accumulation rate (FSAR) (L/cap·year)		Sludge blanket accumulation rate (SBAR) (L/cap·year)
	FSAR-C ($n = 164$)	FSAR-T ($n = 118$)	SBAR-C ($n = 164$)
Sircilla (overall)	53 ($n = 164$)	96 ($n = 118$)	17 ($n = 164$)
Containment type			
Pit latrines	27 ($n = 77$)	63 ($n = 70$)	13 ($n = 77$)
Septic tanks	86 ($n = 87$)	167 ($n = 48$)	23 ($n = 87$)
Containment shape			
Circular pit latrines	26 ($n = 76$)	63 ($n = 69$)	12 ($n = 76$)
Rectangular septic tanks	64 ($n = 37$)	53 ($n = 15$)	19 ($n = 37$)
Elliptical septic tanks	177 ($n = 51$)	255 ($n = 34$)	27 ($n = 51$)
Origin			
Households	57 ($n = 134$)	97 ($n = 115$)	18 ($n = 134$)
Commercial	36 ($n = 30$)	90 ($n = 3$)	9 ($n = 30$)

Accumulation rates were also evaluated for differences between the categories of collected questionnaire data. All three types of accumulation rates were significantly higher for septic tanks as compared with pit latrines (FSAR-C ($p = 1.32 \times 10^{-6}$), FSAR-T ($p = 1.07 \times 10^{-4}$), and SBAR ($p = 3.92 \times 10^{-4}$); Figure 4). The relationship between the parameters used in the accumulation rate calculation (time, users, and sludge volume) was analysed to understand their influence on the results. Users and sludge volume were higher in septic tanks, though the time since last desludging was not significantly different when comparing septic tanks and pit latrines. Between types of septic tanks, elliptical septic tanks had higher accumulation rates than rectangular septic tanks for all three methods (Table 2). This is probably because the elliptical septic tanks are newer. The number of users could not explain this difference. No other significant differences within accumulation rates were observed between any of the other indicators collected in the questionnaire.

When making estimates on a city-wide scale, it is important to consider faecal sludge from commercial establishments, as it represents a significant portion of the total faecal sludge that accumulates. For example, in Sircilla, many people commute into the city on a daily basis to work in the textile industry and other commercial enterprises (Eawag & CDD 2019). Containments for toilets at commercial establishments often require frequent desludging due to higher volumes being produced.

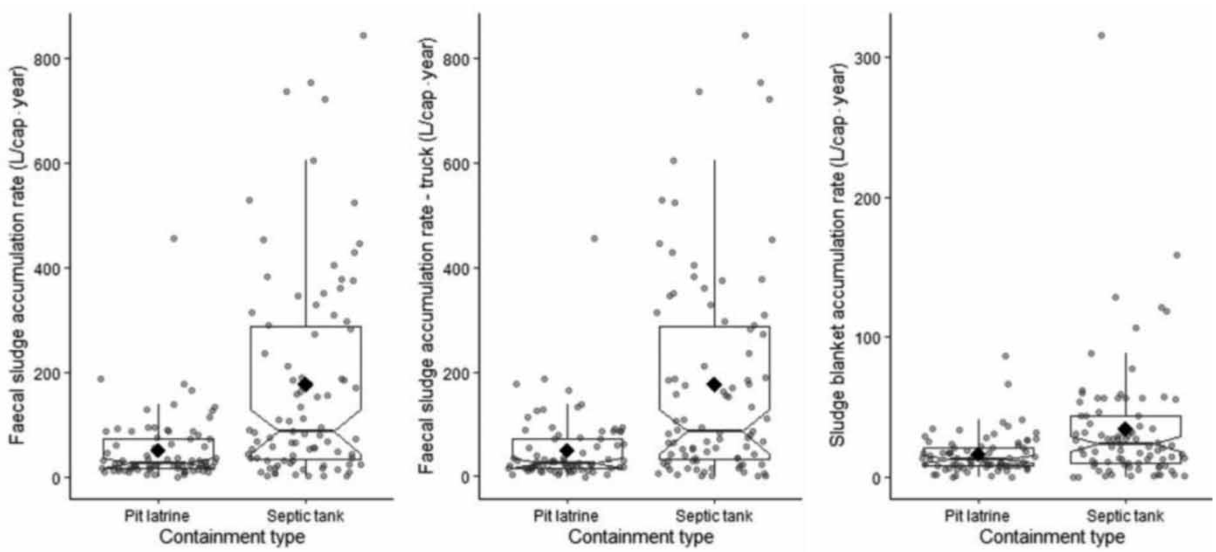


Figure 4 | Boxplots for faecal sludge accumulation rate measured using the core sampler (FSAR-C), the faecal sludge accumulation rate measured using truck volumes (FSAR-T), and the sludge blanket accumulation rate measured using the core sampler (SBAR-C) showing the difference between pit latrines and septic tanks, and the spread of the data. The diamonds represent mean values. Non-overlapping notches represent significant differences between categories.

To calculate accumulation rates, questionnaire data for 'time since last emptied' and 'number of users' is used. A sensitivity analysis was conducted to evaluate the impact of these assumptions. The maximum variability in the median was ±27 L/cap·year for FSAR-C, ±40 L/cap·year for FSAR-T, and ±4 L/cap·year for SBAR (calculation provided in Supplementary Table S1). To improve future estimates for accumulation rates, the concept of population equivalents for each onsite containment could be incorporated, rather than the total number of users. The number of users can be difficult to estimate as people typically use different toilets throughout the day (e.g. work, home, school, commercial establishments, etc.), toilet usage patterns are different from day to night, and from households to work. Population equivalents could factor in these different usage patterns (O'Brien *et al.* 2014).

In comparing the two methods for total faecal sludge accumulation (FSAR), values based on FSAR-T (truck) were higher than FSAR-C (core sampler), illustrating the large effect that methods can have on reported values, and the difficulty to compare results between different studies (Figure 2). It is not certain why the truck values were so much higher, but this has also been observed in other studies (Koottatep *et al.* 2021).

Theoretically, the total volume and height of faecal sludge in septic tanks are constant, while the sludge blanket should gradually increase over time as sludge settles out, as they are fully lined with an inlet and outlet allowing wastewater and supernatant to flow in and out in the same proportion. This is in contrast to pit latrines, which conventionally do not have an outlet, and so the total volume increases with time. This is why FSAR is conventionally measured for pit latrines, and SBAR for septic tanks. However, in this study for comparison, both FSAR and SBAR were measured for both pit latrines and septic tanks. Although faecal sludge volume in septic tanks should be constant, calculating FSAR with time since last emptied and number of users is useful, as including this unit of time in the equation is reflective of the accumulated amount of faecal sludge that is actually delivered to treatment plants (versus total amount produced prior to degradation/sludge accumulation, and septic tank effluent discharging to the environment). For example, if the entire septic tank contents are emptied and delivered to treatment, the emptying interval will have a large effect on the total amounts that are delivered to treatment.

Although SBAR has historically been considered the 'norm' for accumulation rates in septic tanks, very few studies report actual values of SBAR for septic tanks (Anh *et al.* 2014; Mills *et al.* 2014). The results of this study indicate that it is also possible to measure SBAR in pit latrines that have a more liquid consistency. Similarly, a study in Indonesia looking at the SBAR of septic tanks, pit latrines, and fibreglass tanks had a median value of 13 L/cap·year (Mills *et al.* 2014), compared with 17 L/cap·year in this study. Mills *et al.* (2014) also broke down the SBAR into containments with an outlet (mean 15 L/cap·year) and without an outlet (mean is 31 L/cap·year). Categories such as lined, partially lined, or unlined, and overflow or no overflow, are potentially more useful than 'septic tank' or 'pit latrine', as people use terminology differently around the world and they more accurately reflect the processes that are actually occurring inside the containment (Mills *et al.* 2014; Strande *et al.* 2021; Ward *et al.* 2021). In addition, septic tanks rarely follow design guidelines, many contractors resort to arbitrary sizing and design, and they are in general not being maintained as designed (Nnaji & Agunwamba 2012).

To evaluate the consistency of core sampler measurements, and how sludge blanket accumulates over shorter time periods, 28 of the elliptical septic tanks were measured six times over 8 months. Over this period of time, the height of the total faecal sludge in each of the tanks remained constant, other than the first measurement for the 5 that were emptied at the start of the study (Supplementary Material, Figure S4). However, no clear trend was observed for the height of the sludge blanket, in contrast to expectations (Supplementary Material, Figure S3). A possible explanation for this could be fluctuations of the sludge blanket based on daily usage patterns. For example, if sludge blanket height is measured during a period of heavy usage of toilets and water, perhaps it is not as settled as measurements taken after a period of inactivity, further illustrating that the understanding of what is occurring within containments is far from complete. Measurements for sludge blanket height should be taken over longer intervals, and consistently at the same time of day.

To illustrate why using accumulation rate (what actually accumulates with time in containment, accounting for losses due to infiltration and biological degradation) is more representative than using faecal sludge production rate (based on estimating what is entering the containment), production rates for households in Sircilla were calculated as a comparison (equations presented in Supplementary material). The median calculated production rate was 31,780 L/cap·year, which is 2–3 orders of magnitude higher than the accumulation rates shown in Table 2. This shows that using faecal sludge production can greatly overestimate the quantity of faecal sludge that needs to be managed. It is also not accurate to use historical design values for filling rates in rural areas, as usage patterns are much different in dense urban areas (e.g. 37 or 57 L/cap·year; Wagner & Lanoix 1958). How the filling rates put forth by the Bureau of Indian Standards were calculated is not clear, with the volume of digested sludge in septic tanks being 77 L/cap·year (Bureau of Indian Standards 1985). For pit latrines in rural areas, the guideline is 40 L/cap·year for dry pit latrines, and 35–95 L/cap·year for wet pit latrines specifically for desludging intervals between 2 and 6 years (Bureau of Indian Standards 1987). Although the rates in this study fall within this range, standardization and reporting of the methods used to estimate accumulation rates would make them more comparable worldwide.

CONCLUSIONS

This study compared three different methods for estimating accumulation rates that were each carried out on pit latrines and two types of septic tanks, and observed a wide range of values depending on the method. In previous studies, it was often not clear or fully reported how rates were estimated, or whether SBAR or FSAR was being measured. The variability of the results from the same systems when using the different methods in this study illustrates the importance of accurately defining and reporting terminology and methodology. The discourse surrounding containment type is also highly variable, and moving forward, providing more detailed containment classifications such as lined, partially lined, or unlined, together with overflow or no overflow will make results more comparable.

The differences in accumulation rates in this paper also raise the question, what is the 'true' accumulation rate? The selection of the most appropriate method for estimating Q&Q of faecal sludge will depend on the objective. For example, a scientific study into how faecal sludge accumulates in onsite containments, versus estimating loadings that are actually delivered to treatment for the design of a treatment plant, versus making future projections all require different values obtained with different sampling methods. However, each of the methods comes with its own set of uncertainties. The lack of standard methods for estimating Q&Q of faecal sludge, in addition to the parameters that estimates are based on sample collection, laboratory analysis, and measuring volumes of sludge, have made projections very uncertain and not comparable. As methods are being developed (Velkushanova *et al.* 2021), studies like this one, that evaluate and compare data obtained by various methods, will be important to aid in developing standard methods.

Most of the trends that were observed for qualities and quantities with demographic, environmental, and technical data are the same as in other regions of the world (e.g. Uganda, Indonesia). However, context-specific data is still necessary for the design of management solutions. Hopefully in the future, as the relation between trends in different regions is better understood, it will help us to understand more fundamental processes that govern faecal sludge accumulation in order to design optimal management practices.

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AUTHOR'S CONTRIBUTION

Prerna Prasad, Nienke Andriessen, and Linda Strande co-wrote the manuscript. Prerna Prasad, Nienke Andriessen, Anantha Moorthy, Amrita Das, and Kayla Coppens contributed to data collection and analysis. Rohini Pradeep, Nienke Andriessen, and Linda Strande co-managed the project, developed the concept for the study, and reviewed all the data. All authors read and approved the manuscript.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (https://doi.org/10.25678/0002VH).

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