Assessing Septic Tank Desludging in Urban Areas for Safely Managed Sanitation

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ABSTRACT

Regular and well-planned desludging is crucial for maintaining septic tanks, which are widely used in low- and middle-income countries, to ensure that they function correctly and prevent sludge buildup. This study aimed to identify potential areas for intervention to improve safe sanitation access in the city by examining the relationship between sociodemographic factors and residents' awareness, willingness to engage in desludging practices, and on containment ownership. The study analyzed data on various sociodemographic factors, willingness to participate in desludging services, knowledge of emptying practices, and containment ownership, using descriptive and non-parametric correlation methods. Of the 443 records, 343 met the inclusion criteria for statistical analysis, and a review of 17 documents on domestic wastewater management in Indonesia was also conducted. This study found that most Semarang City residents have toilet and containment facilities, indicating that the city has a well-established transporting septage as part of safely managed sanitation services. However, regular desludging is not practiced as a standard, which suggests that the sanitation chain may not be safely managed. Only 24.2% of households performed desludging regularly, while 70.8% never did. The study also found that age played a significant role in determining people's decisions to desludge practices for their septic tanks. Most sociodemographic factors showed weak correlations with desludging knowledge and practices, except for age, which demonstrated a moderate association. This approach can help identify the most effective strategies for engaging residents in desludging practices and improving the overall state of sanitation in the city. These findings highlight the urgent need for targeted awareness campaigns and affordable desludging services.

Keywords: Desludging practices; on-site sanitation system; safely managed sanitation; septic tanks; sociodemographic factors.

1. Introduction

1.1. Background

Safely managed sanitation (SMS) is defined by WHO and UNICEF (2014) as "the use of improved facilities that are not shared with other households and where excreta are safely disposed of *in situ* or transported and treated offsite." A sanitation service chain (SSC) is safely managed when service extends beyond access to include safe emptying, transport, treatment, and disposal (Odagiri *et al.,* 2021). SSC, collectively known as fecal sludge management (FSM), consists of excreta capture and storage in a containment facility, emptying the containment, transporting the contents, sludge treatment, and the end of use or disposal (Medland *et al.,* 2016). Therefore, proper excreta capture and storage are critical for achieving SMS in the SSC (Winkler *et al*., 2017). The emptying of containment facilities, also known as desludging, is an essential step in SSC because it removes the accumulated sludge from the containment facilities and transports it to a treatment plant for further processing (McConville *et al*., 2019).

It is essential to plan and manage the desludging process carefully to ensure safety and effectiveness (Greene *et al*., 2021). In Indonesia, as in many other low- and middle-income countries (LMICs), onsite sanitation systems such as septic tanks are used by households for their sanitation systems. The term "septic tank" is often used generically for household containment, even when systems are not technically septic (Odagiri *et al*., 2021). This may be because the construction of septic tanks does not comply with the standards (Septarini *et al*., 2021). A septic tank is a watertight containment facility that allows the supernatant of human excreta to leave through a pipe (Peal *et al*., 2020). The tanks are constructed using concrete or prefabricated septic tanks to prevent the leakage of liquid effluents (Naser *et al*., 2019; Saxena and Den, 2021). The tank requires regular emptying of accumulated settled solids to maintain its function. Mehta *et al*. (2019) reported that the desludging activity should be done regularly, at least once in 2 – 5 years (y), so that the tank will not overload due to the excessive sludge and can ensure the biological process performed properly. Some containments can operate for up to 20 years without emptying; however, such systems do not function

as true septic systems (Foster *et al*., 2021). Therefore, old-unemptied septic tanks will have solidified sludge that is difficult to pump out and must be removed manually (Jaiswal *et al*., 2022).

Greene *et al*. (2021) stated that Indonesia has 79 percent (%) onsite sanitation density, the third highest onsite facility compared to other countries in the world. Therefore, on-site sanitation management is critical for improving the sanitation conditions in Indonesia. According to the National Medium-Term Development Plan (NMTDP/*Rencana Pembangunan Jangka Menengah Nasional* (RPJMN)) 2020 – 2024 of Indonesia, the national target for basic sanitation service (BSS) access is 90% and SMS access is 15% at the end of 2024. Therefore, many local governments are promoting BSS and SMS access in their areas to achieve national targets (Odagiri *et al*., 2020). For instance, the Semarang City Government issued an action plan to achieve 100% BSS access by the end of 2022, which is contained in Semarang City Mayor Regulation Number 92/2018. The Statistical Agency of Semarang City also reported that BSS access in 2021 in Semarang City has already reached 93.67%. However, SMS data are limited, making the effects of government interventions difficult to measure. Identifying factors that may influence the decision of citizens to participate in emptying containment facilities is an effort to achieve the national target of the SMS (Cookey *et al*., 2020). However, there has been limited research on this topic.

1.2. Theoretical Framework

Inadequate desludging practices continue to challenge the effectiveness of urban onsite sanitation systems in many LMICs, including Indonesia, where septic tanks are widely used but seldom regularly emptied (Odagiri et al., 2021). Multiple studies have demonstrated that desludging behavior is influenced by a complex interplay of sociodemographic, technical, institutional, and financial factors. Sociodemographic attributes, such as age, education, and household size, shape perceptions of sanitation risk and influence compliance behavior, with older and more educated individuals showing greater adherence to safe sanitation practices (Alemu et al., 2018; Malima et al., 2022, Ma et al., 2025).

As reported by Seleman *et al.* (2020), the sociodemographic background (age and sex) of the citizen, topography, accessibility, toilet types, and toilet category influence willingness to desludge. Willetts *et al.* (2022) mentioned that other factors, such as budget support from the government, clear institutional responsibilities, and flexible management services, can increase sanitation resilience. Devitt *et al*. (2016) informed that financial concerns and knowledge affect sanitation behaviors. Odagiri *et al*. (2021) found that household socioeconomic status, septic tank age, size of household, and size of the tanks may influence the decision of desludging. A clear understanding of the factors relevant to emptying containment facilities can be used to develop appropriate actions and suggestions, leading to a higher SMS rate.

Technically, poor infrastructure and limited access to desludging services, particularly in informal or densely populated areas, pose significant barriers to regular maintenance (Baye, 2025). From an institutional perspective, fragmented governance, unclear desludging mandates, and the absence of household-level registries contribute to low uptake despite national policies promoting SMS (Sinharoy et al., 2019). Wang et al. (2025) proposed a coupled coordination framework integrating ecological, economic, and social subsystems to enhance urban environmental performance, which is highly relevant for long-term sanitation strategies. The perceived high cost of desludging often deters households from performing regular emptying, particularly when subsidies or equitable cost-sharing mechanisms are not in place (Mashiane and Odeku, 2024).

Recent studies have highlighted the importance of integrating sustainable bioremediation strategies and local innovations into sanitation planning. For instance, the use of local fungal strains for wastewater treatment shows promising removal efficiencies for various pharmaceutical pollutants (Sayed et al., 2024b). Similarly, biodegradation approaches utilizing indigenous bacteria and agro-waste-based biostimulants have demonstrated cost-effective pollutant breakdown, suitable for developing regions (Sayed et al., 2021; 2022). Inadequate management of fecal sludge and wastewater not only threatens groundwater and surface water but also increases the risk of contaminant transfer into the food chain, as observed in recent studies on pharmaceutical uptake in

crops irrigated with untreated wastewater (Sayed et al., 2024a). These complementary environmental technologies, while not a direct substitute for desludging, support overall sanitation ecosystem improvements and underscore the need for multipronged interventions.

The sociodemographic properties, accessibility of containment tanks, willingness and knowledge to empty containment facilities, and desludging practices were also analyzed using correlation analysis. Strategic actions for improving SMS services are also recommended at the end of the discussion. While studies such as Odagiri et al. (2021) have provided national-level insights into sanitation coverage, this study focuses on behavior and decision-making at the household level, particularly on the upstream SSC. Such a detailed analysis is uncommon in Indonesia and is intended to support national-level studies by adding local, household-level perspectives. This is among the first studies in Indonesia to correlate household demographics and containment characteristics with desludging behavior at the city scale.

This study is expected to fill the knowledge gaps, especially upstream of SSC, to determine various sociodemographic factors with the emptying practices of containment facilities. The Semarang City government is going to improve its sanitation services, this study provides a baseline for policy recommendations at the city level. This study aims to identify the current situation of SMS access relying on emptying practices in Semarang City by conducting a descriptive analysis based on a field questionnaire study. The study was conducted between March and May 2023 in Semarang City as a representative case study of LMICs (Fig. 1). This study addresses three questions: (i) what are current household desludging practices and knowledge levels; (ii) how do sociodemographic and containment factors relate to willingness and behavior; and (iii) which city-level strategies could improve SMS?

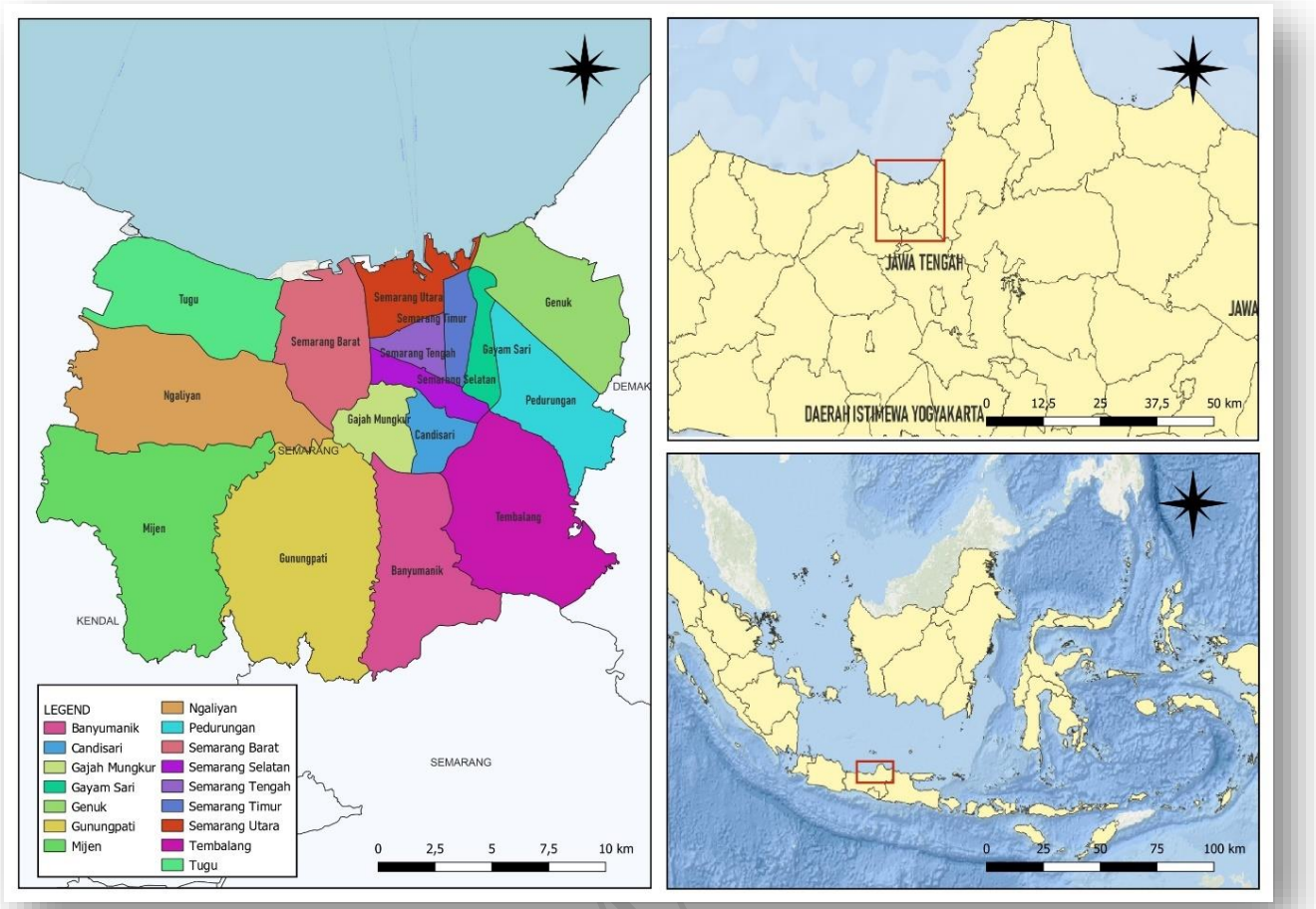

Figure 1. Geographic location of the study area in Semarang City, Indonesia

2. Materials and Methods

The methods used in this study were divided into two sections: data collection and analysis. Data collection is presented to explain the data gathered during the field survey, and data analysis is used to explain how the data were analyzed using both descriptive and quantitative analyses.

2.1. The study area and data collection

A field survey was conducted to collect data on the availability of sanitation facilities in each sub-district area. This survey provides valuable insights into the current state of sanitation in Semarang City and can help identify areas for improvement. Surveyors collected data from 443 households randomly distributed across the city about their willingness to participate and their knowledge of SMS

151 access. Interviews were administered face-to-face by a team of trained enumerators under the
152 supervision of the research team, following a standardized questionnaire to ensure consistency. The
153 refusal rate was ~19.5% or 107 respondents refused to participate in the survey. A stratified random
154 sampling approach was used to ensure city-wide representativeness. The city was divided into 16
155 administrative districts and samples were proportionally drawn from each district based on the latest
156 household registry. Data collection occurred during daytime hours, which may have contributed to
157 the higher proportion of female respondents (63.6%), many of whom were female respondents present
158 at home during working hours. This gender distribution has been acknowledged as a limitation in
159 terms of the potential bias in representation. Several data related to the containment, such as the
160 number of containments in each household, construction, material, base floor, shape, age, placement
161 of containment, and the distances to shallow wells, groundwater, and the road were also gathered to
162 understand the characteristics of the containment tanks. Sociodemographic data of the respondents,
163 such as gender, age, occupation, income, education level, the status of the respondent in the family,
164 and the ownership status of the house, were gathered to understand any potential correlations between
165 those data with the knowledge, willingness to empty their septic tanks, and containment ownership.
166 This analysis helps identify potential barriers and opportunities for SMS access and guide strategies
167 for improving sanitation services in Semarang City. The survey also collected data on the emptying
168 practices of fecal sludge from the containment tanks. This included information about desludging
169 behavior, last time to desludge, accessibility to desludge, and satisfaction with toilet quality.
170 Regarding the data for desludging behavior, the surveyor asked the respondents whether their
171 containment tanks were emptied regularly. Containment tanks need to be emptied periodically to
172 prevent overflow and maintain their functionality (Odagiri *et al.,* 2021). Satisfaction with toilet
173 quality was related to information about dissatisfaction with the facilities, such as lack of lighting and
174 ventilation, overflowing toilets, and poor cleanliness. The study also collected data on respondents'
175 desires to improve their toilet facilities, including their perceptions of toilet emptying services from
176 the local government.

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178

179 *2.1. Data analysis*

180 In this study, a descriptive analysis was conducted on the collected data on various sociodemographic
181 characteristics, willingness to participate in emptying services, knowledge of emptying practices, and
182 containment ownership. A normality test was performed to check the distribution of data. As the data
183 did not follow a normal distribution, the Spearman rank, a non-parametric calculation, was used to
184 analyze the correlation between the data. First, a total of 443 datasets were checked and screened
185 using several inclusion criteria: people who have containment tanks, live in their own house, and
186 intend to use the desludging facilities. All currency values were converted from Indonesian Rupiah
187 (IDR) to United States Dollar (USD) at 1 USD = 16,300 IDR. A total of 343 records met the inclusion
188 criteria for statistical analysis. In addition to the household survey, a qualitative component was
189 included through a critical desk review and content analysis of 17 documents related to on-site
190 domestic wastewater management in Indonesia. These documents were used to identify institutional,
191 social, and technical barriers and to develop strategies for improving safely managed sanitation
192 (SMS) services in Semarang City.

193

194 **3. Results and Discussion**

195 *3.1. Sociodemographic characteristics of the respondents*

196 It is necessary to gather and analyze information about respondents to understand their socio-
197 demographics, knowledge, and behavior. By grouping respondents based on sex, age range, and
198 occupation, it was possible to identify trends and patterns within the population (Supplementary
199 Materials). Women also dominated the respondents, accounting for 63.6% of the total respondents.
200 It appears that most respondents are women who are housewives of middle age (40-60 y accounting
201 for 51.3% of the total respondents). The second largest number of respondents were self-employed
202 or shop owners (17.5%) and not working or retired people (11.7%). Since the survey was conducted

on weekdays and working hours, the respondents mostly came from these groups. Additionally, collecting information on monthly income and education level can provide insights into the economic and educational backgrounds of the respondents. The respondents came from low- and middle-income households. The minimum wage in Semarang City is USD 187.75 in 2023. Half of the respondents, 179 (52.2%), had a lower expenditure than the minimum wage of Semarang City. The head of the family accounted for 25.7% of the total respondents, which may have influenced the decision regarding desludging practice. The highest educational level of the respondents came from a senior high school degree, accounting for 39.4% of the total respondents, followed by a bachelor's degree (21.0%), junior high school (13.7%), and elementary school (11.1%). However, in the family of each respondent, the highest education level is mostly coming from university (50.7%), followed by senior high school (39.4%), and diploma 3 (7.9%),

3.2. Current situation of SMS access in Semarang City

According to the data presented by the Statistical Agency of Semarang City, in 2021, the overall access to SMS was 93.67%. All respondents revealed that they have 1-2 toilets per household, so they do not need communal toilets as many rural areas do. Therefore, most containment tanks were installed and connected to their toilets (92.3%), while the rest were channelled and connected to a communal wastewater treatment plant (WTP) through a piped network. This prevents them from having such a containment tank in their homes. Each household had one containment tank (86.3%), but a few respondents said that they have 2-5 containment tanks in their house. The containment tank was mostly made of concrete (58%) and plastered brick (33.5%) as walls, and the base floor was constructed using compacted soil (40.2%) and concrete (30.3%). Many of the containment tanks were self-modified (86.9%), whereas the rest were prefabricated (9.0%). More than half of the respondents said that containment tanks were built more than 10 y ago (58.9 %). Cubes or prism containment tanks dominated the containment type, accounting for 65.0%. Information regarding the containment characteristics in Semarang City based on a field survey as shown in Fig. 2.

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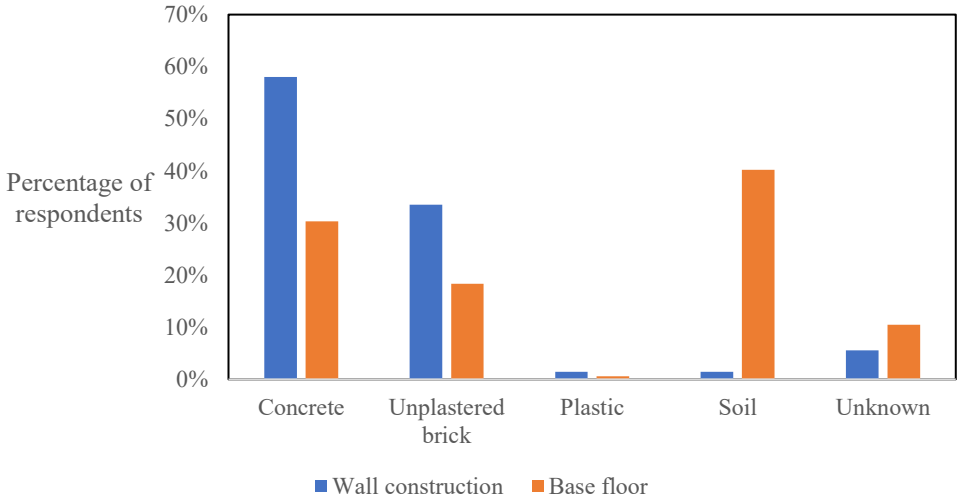

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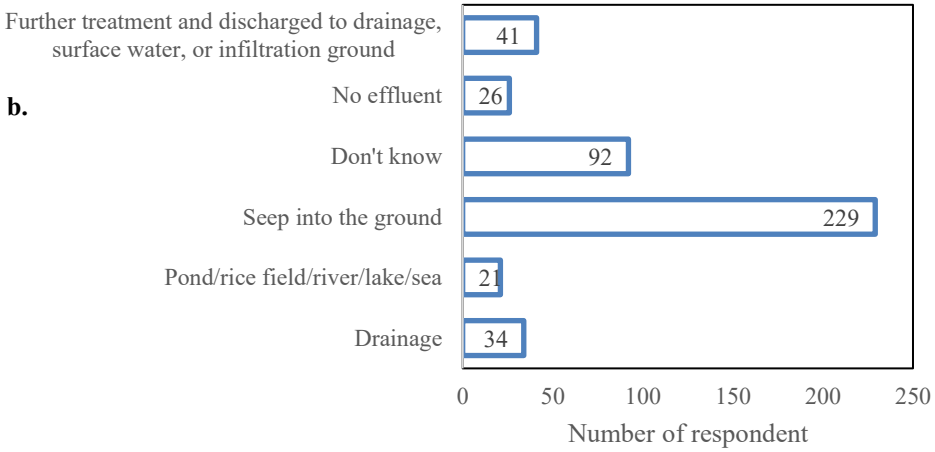

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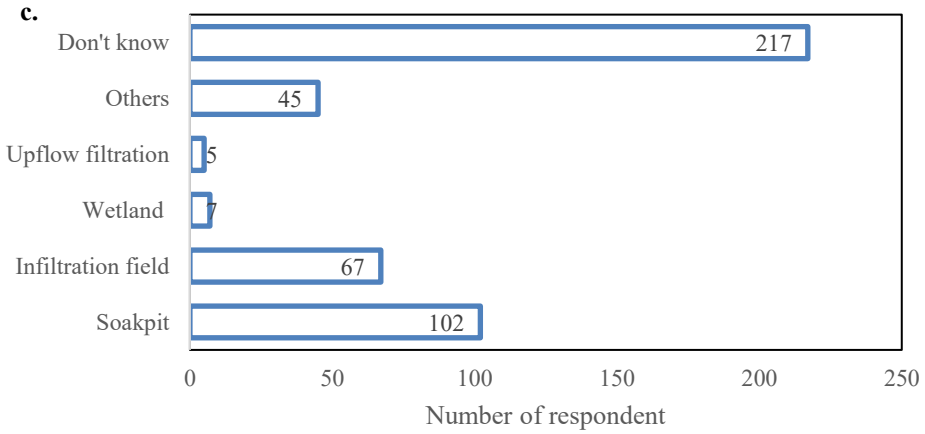

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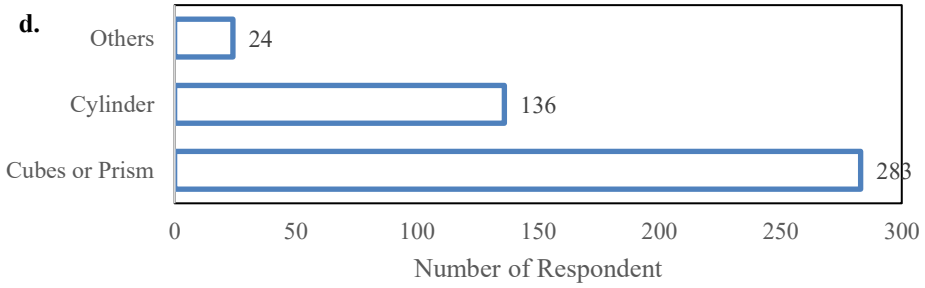

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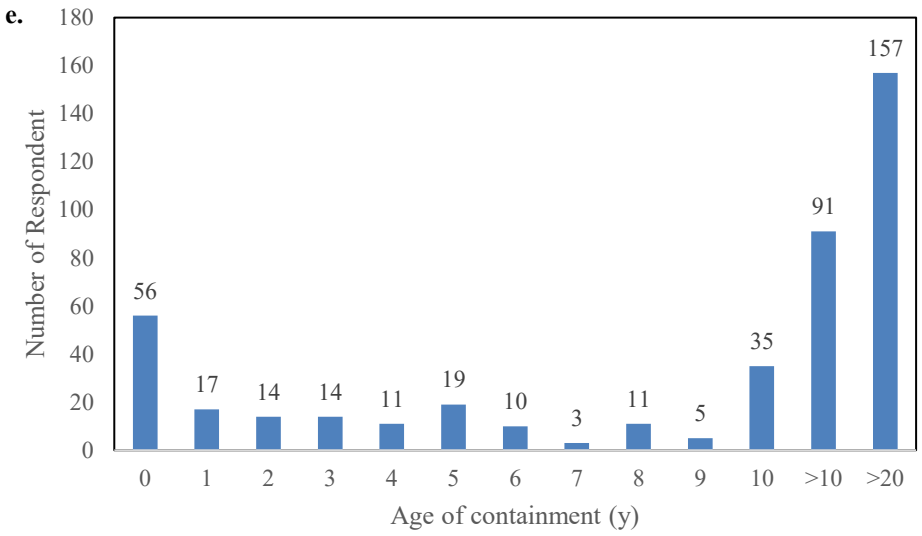

Figure 2. Several characteristics of containment tanks in Semarang City: (a) construction; (b) overflow; (c) further treatment; (d) shape of containment tank; and (e) age (n=443)

The containment was placed mostly under the building (60.1%) and backyard (38.2%). The containment tanks were accessible because most of them had roads of more than 15 meters (m) (73.8%) and were located less than 25 m from the road (76.7%). The distance of the containment tanks to the shallow well or river was generally less than or equal to 10 m (31.8%). However, regarding this information, many respondents could not describe the distance of the waterways or supply water sources to the containment tanks (37.0%). The effluent from most of the containment tanks installed in Semarang City seeps through the soil (54.2%), while a few are discharged into drainage (7.0%) and waterways (2.3%). However, many respondents also did not know (46.6%) about further treatment of the water overflowing from the containment tanks, probably because the majority of the respondents were female respondents. Therefore, others said that overflow water seeped into infiltration wells (23.3%). Detailed data regarding the accessibility of the containment tanks are provided in Table 1.

Table 1. Accessibility of containment tanks

Criteria	Frequency	%
Placement of containment		
Under the building	206	60.1%
Outside of the building (backyard)	131	38.2%
Some under buildings and outside houses	4	1.2%
Unknown	2	0.6%
Road width		
Accessible by pedestrians only	23	6.7%

Criteria	Frequency	%
The width of the road is less than 1.5 m	67	19.5%
The width of the road is more than 1.5 m	253	73.8%
Distance from containment to the road		
≤25 m	263	76.7%
≥25 – 50 m	52	15.2%
≥50 – 100 m	19	5.5%
≥100 m	9	2.6%
Desludging access		
Access pipe	130	37.9%
Manhole	213	62.1%

In the field survey, 70.8% of the 343 households said that they never performed regular desludging, and 58.6% did not know when their containment tanks were empty (58.6%). As reported by Mehta *et al.* (2019), the ideal time for desludging is 2 – 5 y, whereas in this study, only 24.2% of the respondents performed the desludging activity regularly, as shown in Fig. 3. This is likely due to high toilet satisfaction. More than 50% of the respondents were satisfied with the condition of the toilet facilities in their homes (70.5%). Only a small portion of the respondents (8.2%) felt that they were not satisfied with the toilet quality because of the cleanliness of the toilet, the building not permanently constructed, and some problems with the containment facility.

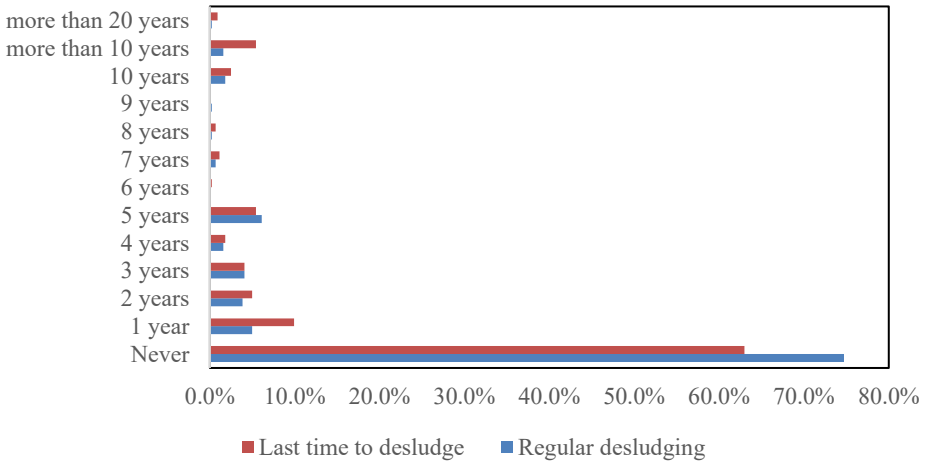

Figure 3. Desludging practices of the respondents (n=443)

According to the respondents' knowledge of desludging practices, as shown in Fig. 4, many people still think that they do not need to empty their containment tanks. A septic tank can be used for a long

time, and emptying is not necessary if the containment is not full (Peal *et al*., 2020). Consequently, 54% of respondents think that emptying practices are not necessary, while the urgency of the septic tank to be emptied is high, accounting for 97% of the total respondents. Interestingly, 74% of the respondents confirmed that the desludging activity needs to be conducted regularly once every 3 – 5 y, even though it is not yet full. Almost all respondents (96%) agreed that desludging activity should be conducted to prevent environmental contamination. Regarding their knowledge of the Semarang City Government desludging service, many respondents did not know about it. Therefore, promoting the service may be necessary to improve respondents' knowledge.

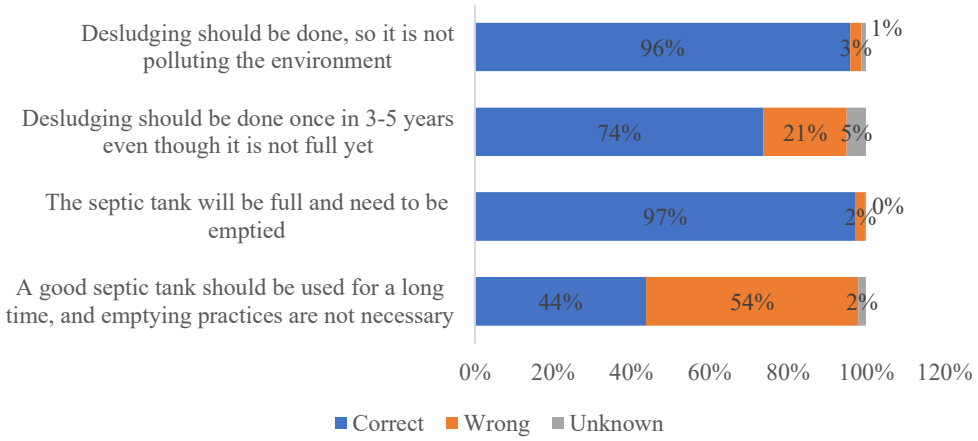

Figure 4. Knowledge of the respondents related to the desludging practices (n=443)

Among the respondents who were willing to perform desludging activities, 27.1% were willing to empty their containment in the next 2 y. However, many of them, accounting for 55.7%, were also confused and unsure about the desludging time. The biggest reason why they want to empty their containment is if it is full (91.5%), and there is a blockage or other related problem in the containment tanks (71.7%). Several people also gave other reasons, such as the possible contamination of groundwater sources (15.5%), the smoothness of wastewater discharge (15.7%), joining government programs (10.8%), or something to do with containment tanks (13.1%). Therefore, respondents also gave some consideration as to why they decided to empty their containment, such as prices for desludging services (41.4%), difficulties in finding desludging services (15.7%), lack of knowledge on how to open the septic tank (7.9%), and not knowing the location of septic tanks (1.5%). Since

287 price becomes one of the limiting factors affecting the willingness to engage in desludging activities,
288 determining the willingness to pay becomes critical to further study. In this study, the willingness to
289 pay was not calculated in the questionnaire survey; however, there is a survey related to the cost of
290 performing emptying practices. In this study, most respondents (52.9%) ever paid 6.13 – 18.41 United
291 States Dollar per cubic meter (USD/m^3) to empty their containment tanks. Desludging practices
292 should be conducted regularly because of the possibility of system clogging, which may result in
293 system failure and other unpleasant conditions. Thus, desludging is essential to protect public health
294 and the environment (Vidal *et al*. 2019). If it is not treated and emptied regularly, the sewer pipe can
295 be blocked by sludge, which prevents the proper operation of the toilet (Zewde *et al*. 2021). Therefore,
296 desludging in many developing countries is challenging because of people's limited awareness of the
297 practice, inadequate infrastructure, and resources (Capone *et al*., 2020). Despite these challenges, the
298 desludging infrastructure in Semarang City is adequate and reliable. Desludging is performed using
299 vacuum trucks to remove solids from the containment. The private sector provides these services,
300 whereas the local government owns and operates a septage treatment plant.
301
302 *3.3. Factors affecting willingness, knowledge, and practices of desludging*
303 It is essential to consider the sociodemographic characteristics of the respondents when studying the
304 factors that affect desludging practices. As can be seen in Table 2, the Spearman Rank correlation
305 between sociodemographic factors and accessibility to the tanks to the desludging practices,
306 willingness, and knowledge of desludging activity is presented. The results showed that most factors
307 did not correlate significantly or were less correlated with the factors. For instance, expenditure,
308 occupation, and level of education in the family appear to have a weak relationship with desludging
309 practices. Age has a moderate relationship (has a value between 0.25 – 0.50) with desludging
310 practices, whereas other factors such as education and expenditure showed weaker associations. In
311 addition, no single factor was correlated with willingness to desludge. Knowledge of desludging had
312 a weak relationship with age and education level. There was also no relationship between knowledge

313 of desludging and desludging practices (0.029) and willingness to desludge (0.087). These results
314 suggest that knowledge alone does not motivate action; other factors (e.g., age, cost, and access)
315 likely play a greater role. There was a weak relationship between desludging practices and willingness
316 to desludge (0.159). These results indicate that age may influence people's decision to perform
317 desludging practices because they have more knowledge. Therefore, desludging practices may be
318 influenced by willingness to desludge. Given the small correlations, additional factors likely influence
319 households' decisions to desludge. Leong *et al.* (2022) reveal that technical factors such as service
320 years, volumetric accumulation rate, and adequate working volume can influence the desludging
321 frequency. In that study, 4 y (ranging from 3.82 to 6.32 y) of desludging frequency was suitable for
322 residential areas in Malaysia. Bao *et al.* (2020) stated that desludging programs in Indonesia should
323 be performed periodically for to 3-5 y as stated in the Ministry of Public Work and Housing Number
324 4/2017. Therefore, it is necessary to maintain the function of the septic tank and the microbiological
325 treatment inside the containment. Other technical considerations, such as environmental factors,
326 microbial activities, and the size of containment facilities, should be considered as optimum
327 desludging practices (Leong *et al.,* 2022). Even though it is known that desludging practices are
328 needed and provide environmental benefits, many of them are not willing to adopt regular practices.
329 A lack of knowledge or awareness of the importance of emptying may contribute to the low rate of
330 emptying practices. Access to desludging services is not a limiting factor in many big cities
331 (McConville *et al*., 2019). Therefore, sociodemographic factors, accessibility, and construction of
332 containment may hinder people from emptying their containment tanks.
333 As found in the statistical calculations, desludging frequency is also determined by the
334 sociodemographic characteristics of the affected area. Therefore, desludging practices and knowledge
335 of desludging can be influenced by several factors such as age, expenditure, and education level.
336 Peletz *et al.* (2020) stated that low-income households have low willingness to pay for desludging
337 services. The price for desludging activity may be expensive and this practice is not their basic need,
338 so they will spend their money on other reasons such as food, housing, and energy, higher than their

living standards, so they cannot pay for emptying. Therefore, desludging services that offer a lower price may increase the willingness to participate in the campaign (Burt *et al*., 2019). Willetts *et al.* (2020) mentioned that the higher the household knowledge and education level, the higher the encouragement and willingness to participate in SMS services. The willingness to pay for sanitation activities may also be higher when they do not have a higher education level. A lower education level also reflects lower environmental awareness, affecting engagement, preparedness, and response to the SMS (Willetts *et al.,* 2022).

Table 2. Spearman rank correlations results

Factors	Age	Gender	Expenditure	Occupation	Education level	Highest education level in family	Accessibility to the tanks
Desludging practices	0.271”	-0.004	0.176”	0.161”	-0.034	0.115’	-0.080
Willingness to desludge	0.019	0.081	-0.056	0.040	0.019	-0.077	0.000
Knowledge of desludging	0.144”	-0.071	0.001	0.019	0.137’	0.013	-0.012

“Correlation is significant at the 0.01 level
‘Correlation is significant at the 0.05 level

The positive correlation between age and desludging behavior may be attributed to multiple factors. Older individuals may have a greater awareness of sanitation risks, more direct experience with septic overflows or repairs, and longer tenure in their residences. This aligns with the findings of Devitt et al. (2016), who suggest that sanitation behavior improves with age due to increasing risk aversion and concern for family health. Elderly people are the vulnerable group with the highest risk for sanitation facilities, including toilets and septic tanks. Elderly, sick, and disabled people may need better toilet flushing than the onsite treatment system. They are much more aware of desludging practices (Devitt *et al.,* 2016; Tsinda *et al.,* 2013). The observed influence of age on desludging practices may be attributed to higher health awareness, prior experience with sanitation issues, or greater concern for household and environmental conditions among older adults. Therefore, this finding may be essential to make a priority cluster in Semarang City, especially for those interested

in participating in the desludging campaign. Understanding social characteristics will make the engagement process easier.

3.4. Strategies to improve SMS services

Beyond individual-level factors, technical and institutional barriers may significantly influence desludging behavior. For example, the absence of a centralized registry or tracking system for septic tank locations and desludging schedules makes it difficult to enforce or promote timely emptying. Many households are also unaware of government-operated desludging services, resulting in underutilization of available infrastructure. These barriers reflect a gap in communication and coordination between service providers and residents, highlighting the need for improved digital platforms, data management, and public outreach.

Developing and maintaining adequate sewer collection and treatment infrastructure can be a significant financial challenge for developing countries because of the high construction and operation costs. However, according to the findings of this study, several sociodemographic factors have a weak relationship with desludging practices and knowledge. As age has a moderate relationship, clustering people based on their age when promoting, educating, and supporting the importance of desludging practices may be appropriate for increasing the knowledge and willingness of desludging practice. Other factors such as expenditure and education level should also be considered.

Periodic desludging activities should be promoted to maintain efficient containment through household outreach and other incentives. Basamykina *et al.* (2021) mentioned that the addition of biological additives can improve the rate of microbiological activity inside the containment tanks, thus, reduce the frequency of desludging practices. This practice can help reduce the overall cost of desludging. Specific actions, such as subsidized desludging for low-income families, implementation of an SMS certification program for compliant households, and integration with digital service booking platforms, could be introduced to increase access and participation in desludging services.

Further action should also consider appropriate equipment to safely and efficiently remove sludge from containment facilities. This aligns with broader evidence that insufficient treatment and oversight of wastewater streams can result in pollutant accumulation in food crops, reinforcing the urgency of ensuring safe desludging and disposal pathways (Sayed et al., 2024a). The local government should also provide training and protective equipment for workers and establish clear guidelines and regulations for the safe handling of fecal sludge during desludging activities (Lerebours *et al.,* 2021).

Table 3. Intervention planning

Timeframe	Intervention	Objective	Responsible Stakeholder(s)
Short-term	- Public awareness campaigns targeting age clusters (e.g., elderly, household heads)	Increase knowledge and willingness to desludge	Health Office (G), Environmental Office (G), Community Leaders (C)
	- Promotion of biological additives for containment tanks	Reduce desludging frequency and cost	Environmental Office (G), Private Sector (P)
	- Mapping and data collection of containment tanks	Build a sanitation baseline for planning	Local Government (G), Urban Planning Agency (G)
Mid-term	- Subsidized desludging program for low-income families	Improve equity in access to desludging services	Local Government (G), Public Works Agency (G)
	- SMS household certification program	Incentivize regular desludging and system compliance	City Government (G), Neighborhood Associations (C)
	- Public-private collaboration with digital service platforms for desludging requests	Streamline service delivery and accessibility	Local Government (G), Tech Startups (P), Private Desludgers (P)
Long-term	- Institutionalization of regular desludging schedules (e.g., every 3–5 y)	Ensure consistent desludging and reduce environmental risks	Environmental Office (G)
	- Expansion of mobile desludging units to underserved or narrow-road areas	Improve access in hard-to-reach neighborhoods	Environmental Officers (G), Operators (G)
	- Monitoring and evaluation system for desludging activities and SMS progress	Track progress and inform policy updates	City Planning and Evaluation Department (G)

Notes: C = community/household; G = government; P = private sector

4. Conclusion

This study found that while sanitation access in Semarang City is generally well established, there is still room for improvement in achieving the goal of SMS. In 2021, 93.67% of Semarang City households had BSS, with most having to 1 – 2 toilets connected to individual containment tanks rather than communal systems. The containment tanks were mainly made of concrete or plastered brick, mostly self-modified, over a decade old, and often located under buildings or backyards. These tanks are generally near roads and shallow wells, with effluent usually seeping into the soil. However, many respondents did not know the exact distances or details of the further water treatment. Containment tank accessibility was generally high, but many respondents, particularly housewives, were unaware of the specific aspects of water overflow management from containment tanks. The survey found that a significant majority of respondents (70.8%) did not regularly desludge their containment tanks and 58.6% were unaware of when their tanks were last emptied, although many were satisfied with their toilet facilities. A common misconception among respondents was that desludging was not needed unless the tank was full, although 96% acknowledged that regular desludging was crucial to prevent environmental contamination. The factors motivating desludging included full tanks, blockages, and groundwater contamination, with 27.1% of the respondents planning to desludge within the next 2 y. Cost was a major deterrent, with most respondents paying 6.13 – 18.40 USD/m^3 for desludging; this practice is vital for preventing system failures and maintaining public health, despite limited awareness and infrastructure challenges. The high level of intention among residents to engage in desludging activities in the next few years is a positive sign for the city's progress towards this goal.

The study also identified several sociodemographic factors that influence people's consideration of their desludging activities. In general, age appeared to be the most influential factor, with higher levels leading to an increased likelihood of desludging practices and knowledge of desludging. Elderly individuals who are more knowledgeable about desludging and require better sanitation facilities should be the focus of desludging efforts. However, other factors such as expenditure and education level should also be considered when designing interventions to increase the uptake of

sanitation services in the city. Offering lower-cost desludging services can boost participation, and households with higher education levels tend to be more willing to engage in sanitation maintenance. As these factors have a weak to moderate relationship, there are other possible factors that influence the decision of people to empty their containment tanks. Enhancing SMS services requires regular desludging. The use of biological additives can help to reduce the frequency of desludging. In addition, it is important to provide appropriate equipment and train workers and address financial constraints, particularly in developing countries.

Semarang, as a second-tier city with moderate income diversity, high reliance on onsite sanitation (over 79%), and relatively advanced sanitation policy planning, represents a useful urban case within Indonesia. While the results may not directly apply to rural or peri-urban areas, cities with similar characteristics, such as Surabaya, Yogyakarta, or regional capital in Southeast Asia, may experience comparable behavioral and infrastructure constraints. This reinforces the potential applicability of the findings in LMIC contexts where urban onsite sanitation is dominant. These findings can guide other urban municipalities in Indonesia and similar LMICs to advance SMS targets or outcomes. Further actions by the local government based on the strategies and findings from this study are needed to improve SSC and SMS access in Semarang City. Future work should focus on behavioral interventions and digital tracking systems to further strengthen sanitation management in similar urban contexts.

Acknowledgements

The authors would like to express their gratitude to all field surveyors who contributed to the data collection.

448 **References**

449 Alemu, F., Kumie, A., Medhin, G., Gasana, J. (2018). The role of psychological factors in predicting
450 latrine ownership and consistent latrine use in rural Ethiopia: A cross-sectional study. *BMC*
451 *Public Health*, **18**(1): 229.

452 Bao, P.N., Abfertiawan, M.S., Kumar, P., Hakim, M.F., (2020). Challenges and opportunities for
453 septage management in the urban areas of Indonesia – Case study in Bandung City. *Journal of*
454 *Engineering Science and Technology*, **52**(4): 481.

455 Basamykina, A., Kharlamova, M., Burka, M., Lukanin, A., Savenkova, E., (2021). The efficiency
456 improvement of faecal sludge management with rate increase of biodegradation in septic tanks
457 and pit latrines. *IOP Conference Series: Earth & Environmental Science,* **689**(1): 012013.

458 Baye, F. (2025). Exploring urban infrastructure challenges in informal peri-urban Woldia: barriers,
459 implications, and informal strategies. *Frontiers in Sustainable Resource Management*, **4**,
460 1555564

461 Burt, Z., Sklar, R., Murray, A., (2019). Costs and willingness to pay for pit latrine emptying services
462 in Kigali, Rwanda. *International Journal of Environmental Research and Public Health,* **16**(23):
463 4738.

464 Capone, D., Buxton, H., Cumming, O., Dreibelbis, R., Knee, J., Nalá, R., Ross, I., Brown, J., (2020).
465 Impact of an intervention to improve pit latrine emptying practices in low income urban
466 neighborhoods of Maputo, Mozambique. *International Journal of Hygiene and Environmental*
467 *Health,* **226**: 113480.

468 Cookey, P.E., Kugedera, Z., Alamgir, M., Brdjanovic, D., (2020). Perception management of non-
469 sewered sanitation systems towards scheduled faecal sludge emptying behaviour change
470 intervention. *Humanities and Social Sciences Communications*, **7**(1): 1-20.

471 Daniel, D., Djohan, D., Machairas, I., Pande, S., Arifin, A., Al Djono, T.P., Rietveld, L., (2021).
472 Financial, institutional, environmental, technical, and social (FIETS) aspects of water, sanitation,
473 and hygiene conditions in indigenous - rural Indonesia. *BMC Public Health* **21**(1).

Devitt, C., O'Neill, E., Waldron, R., (2016). Drivers and barriers among householders to managing domestic wastewater treatment systems in the Republic of Ireland; implications for risk prevention behaviour. *Journal of Hydrology,* **535**: 534–546.

Foster, T., Falletta, J., Amin, N., Rahman, M., Liu, P., Raj, S., Mills, F., Petterson, S., Norman, G., Moe, C., Willetts, J., (2021). Modelling faecal pathogen flows and health risks in urban Bangladesh: implications for sanitation decision making. *International Journal of Hygiene and Environmental Health,* **233**: 113669.

Greene, N., Hennessy, S., Rogers, T.W., Tsai, J., Francis, (2021). The role of emptying services in provision of safely managed sanitation: A classification and quantification of the needs of LMICs. *Journal of Environmental Management,* **290**: 112612–112612.

Jaiswal, J., Mehta, D., Mehta, M., (2022). Impacts of scheduled desludging on quality of water and wastewater in Wai city, India. *Environment and Planning B: Urban Analytics and City Science,* **49**(8): 2216-2229.

Leong, W.K., Ngo, A.L.K., Wong, A.C.H., Ling, J.H., Sia, H.T., (2022). The mandatory 4 years desludging frequency of underground septic tanks in residential areas: A case study in Sibu Sarawak, East Malaysia. *Journal of the Civil Engineering Forum,* **8**(2): 147–156.

Lerebours, A., Scott, R., Sansom, K., (2021). Private emptiers' perspectives on the regulation of faecal sludge emptying services in Sub-Saharan Africa. *Journal of Water, Sanitation and Hygiene for Development,* **11**(5): 785–793.

Ma, S., Liu, H., Li, S., Lyu, S., & Zeng, H. (2025). Quantifying the relative contributions of climate change and human activities to vegetation recovery in Shandong Province of China. *Global NEST Journal*, **27**(5): 07160.

Malima, G., Mshida, H., Machunda, R., Moyo, F., Banzi, J., Gautam, O. P., Mbeguere, M., Smith, K., Caimcross, S., Njau, K. N. (2022). What influences individuals to invest in improved sanitation services and hygiene behaviours in a small town? A formative research study in Babati, Tanzania. *Plos One*, **17**(7), e0270688.

500 Mashiane, K., & Odeku, K. O. (2024). Sustainable solid waste management practices in South Africa:
501 A comparative legal analysis. *Journal of Comparative Law in Africa*, **11**(2): 1-42.
502 McConville, J.R., Kvarnström, E., Maiteki, J.M., Niwagaba, C.B., (2019). Infrastructure investments
503 and operating costs for fecal sludge and sewage treatment systems in Kampala, Uganda. *Urban*
504 *Water Journal,* **16**(8): 584–593.
505 Medland, L.S., Scott, R.E., Cotton, A.P., (2016). Achieving sustainable sanitation chains through
506 better informed and more systematic improvements: lessons from multi-city research in Sub-
507 Saharan Africa. *Environmental Science: Water Research & Technology,* **2**(3): 492–501.
508 Mehta, M., Mehta, D., Yadav, U., (2019). Citywide Inclusive Sanitation Through Scheduled
509 Desludging Services: Emerging Experience From India. *Frontiers in Environmental Science,* **7**:
510 188.
511 Naser, A.M., Doza, S., Rahman, M., Ahmed, K.M., Gazi, M.S., Alam, G.R., Karim, M.R., Khan,
512 G.K., Uddin, M.N., Mahmud, M.I., Ercumen, A., Rosenbaum, J., Annis, J., Luby, S.P., Unicomb,
513 L., Clasen, T.F., (2019). Sand barriers around latrine pits reduce fecal bacterial leaching into
514 shallow groundwater: A randomized controlled trial in Coastal Bangladesh. *Environmental*
515 *Science & Technology,* **53**(4): 2105–2113.
516 Odagiri, M., Thomas, A., Listyasari, M., Mills, F., Bain, R.E.S., Muhammad, Z., Slaymaker, T.,
517 Mardikanto, A., Gultom, A., Indiyani, A., Rangkuti, H., Willetts, J. (2021). Safely managed on-
518 site sanitation: A national assessment of sanitation services and potential fecal exposure in
519 Indonesia. *International Journal of Environmental Research and Public Health.* **18**(15): 8204.
520 Odagiri, M., Cronin, A.A., Thomas, A., Kurniawan, M.A., Zainal, M., Setiabudi, W., Gnilo, M.E.,
521 Badloe, C., Virgiyanti, T.D., Nurali, I.A., Wahanudin, L., Mardikanto, A., Pronyk, P., (2020).
522 Achieving the Sustainable Development Goals for water and sanitation in Indonesia–Results
523 from a five-year (2013–2017) large-scale effectiveness evaluation. *International Journal of*
524 *Hygiene and Environmental Health.* **230**: 113584.

525 Peal, A., Evans, B., Ahilan, S., Ban, R., Blackett, I., Hawkins, P., Schoebitz, L., Scott, R., Sleigh, A.,
526 Strande, L., Veses, O., (2020). Estimating safely managed sanitation in urban areas; lessons
527 learned from a global implementation of excreta-flow diagrams. *Frontiers in Environmental*
528 *Science,* **8**: 1.
529 Peletz, R., MacLeod, C., Kones, J., Samuel, E., Easthope-Frazer, A., Delaire, C., Khush, R., (2020).
530 When pits fill up: Supply and demand for safe pit-emptying services in Kisumu, Kenya. *PLOS*
531 *One.* **15**(9): e0238003.
532 Saxena, S., Den, W. (2021). In situ treatment technologies for pit latrines to mitigate groundwater
533 contamination by fecal pathogens: a review of recent technical advances. *Journal of Water,*
534 *Sanitation and Hygiene for Development,* **12**(1): 102.
535 Sayed, K., Baloo, L., Kutty, S.R.B., Makba, F. (2021). Potential biodegradation of Tapis Light Crude
536 Petroleum Oil, using palm oil mill effluent final discharge as biostimulant for isolated
537 halotolerant Bacillus strains. *Marine Pollution Bulletin*, **172**: 112863.
538 Sayed, K., Baloo, L., Kutty, S.R.B., Al Madhoun, W., Kankia, M.U., Jagaba, A.H., Singa, P.K.
539 (2022). Optimization of palm oil mill effluent final discharge as biostimulant for biodegradation
540 of tapis light crude petroleum oil in seawater. *Journal of Sea Research*, **188**: 102268.
541 Sayed, K., Wan-Mohtar, W. H. M., Hanafiah, Z. M., Bithi, A. S., Md Isa, N., Abd Manan, T. S. B.
542 (2024a). Occurrence of pharmaceuticals in rice (Oryza sativa L.) plant through wastewater
543 irrigation. *Environmental Toxicology and Pharmacology*, 104, 104475.
544 Sayed, K., Mohtar, W.W., Hanafiah, Z.M., Bithia, A.S., Imad, W.A.A.Q. (2024b). Removal of
545 pharmaceuticals from municipal wastewater using Malaysian Ganoderma Lucidum Fungal
546 Strain. *Jurnal Kejuruteraan*, **36**(4): 1467-1476.
547 Seleman, A., Gabrielsson, S., Mbwette, T.S.A., Kimwaga, R., (2020). Drivers of unhygienic
548 desludging practices in unplanned settlements of Dar es Salaam, Tanzania. *Journal of Water,*
549 *Sanitation and Hygiene for Development,* **10**(3): 512–526.

Septarini, A., Islami, B.B., Putri, G.L., Pratama, M.A., Foster, T., Willetts, J., Priadi, C.R., (2021). Sanitation inspection of household fecal containment in Bekasi, Indonesia. *IOP Conference Series: Earth & Environmental Science,* **776**(1): 012004–012004.

Sinharoy, S. S., Pittluck, R., & Clasen, T. (2019). Review of drivers and barriers of water and sanitation policies for urban informal settlements in low-income and middle-income countries. *Utilities Policy*, **60**: 100957.

Tsinda, A., Abbott, P., Pedley, S., Charles, K., Adogo, J., Okurut, K., Chenoweth, J., (2013). Challenges to achieving sustainable sanitation in informal settlements of Kigali, Rwanda. *International Journal of Environmental Research and Public Health.* **10**(12): 6939–6954.

Vidal, B., Hedström, A., Barraud, S., Kärrman, E., Herrmann, I., (2019). Assessing the sustainability of on-site sanitation systems using multi-criteria analysis. *Environmental Science: Water Research & Technology,* **5**(9): 1599–1615.

Wang, Z., Wang, F., Ma, S. (2025). Research on the Coupled and Coordinated Relationship Between Ecological Environment and Economic Development in China and its Evolution in Time and Space. *Polish Journal of Environmental Studies*, **34**(3): 3333–3342.

Willetts, J., Mills, F., Al'Afghani, M., (2020). Sustaining community-scale sanitation services: co-management by local government and low-income communities in Indonesia. *Frontiers in Environmental Science,* **8**.

Willetts, J., Priadi, C., Ombasta, O., Wulandari, D., Imtiyaz, I., Sudhiastiningsih, N.N.S.N.S., Kohlitz, J., Mills, F., Listyasari, M., (2022). Co-developing evidence-informed adaptation actions for resilient citywide sanitation: Local government response to climate change in Indonesia. *Environment and Planning B: Urban Analytics and City Science,* **49**(8): 2129–2150.

Winkler, M., Jackson, D., Sutherland, D., Payden; Lim, J.M.U., Srikantaiah, V., Fuhrimann, S., Medlicott, K., (2017). Sanitation safety planning as a tool for achieving safely managed sanitation systems and safe use of wastewater. *WHO South-East Asia Journal of Public health,* **6**(2): 34.

WHO and UNICEF, (2014). Progress on sanitation and drinking water: 2014 update. *World Health Organization and United Nations Children's Fund.*

Zewde, A.A., Li, Z., Xiaoqin, Z., (2021). Improved and promising fecal sludge sanitizing methods: treatment of fecal sludge using resource recovery technologies. *Journal of Water, Sanitation and Hygiene for Development,* **11**(3): 335-349.