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Research Paper

Septic tank usage and its faecal sludge management in Cuenca, Ecuador

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ABSTRACT

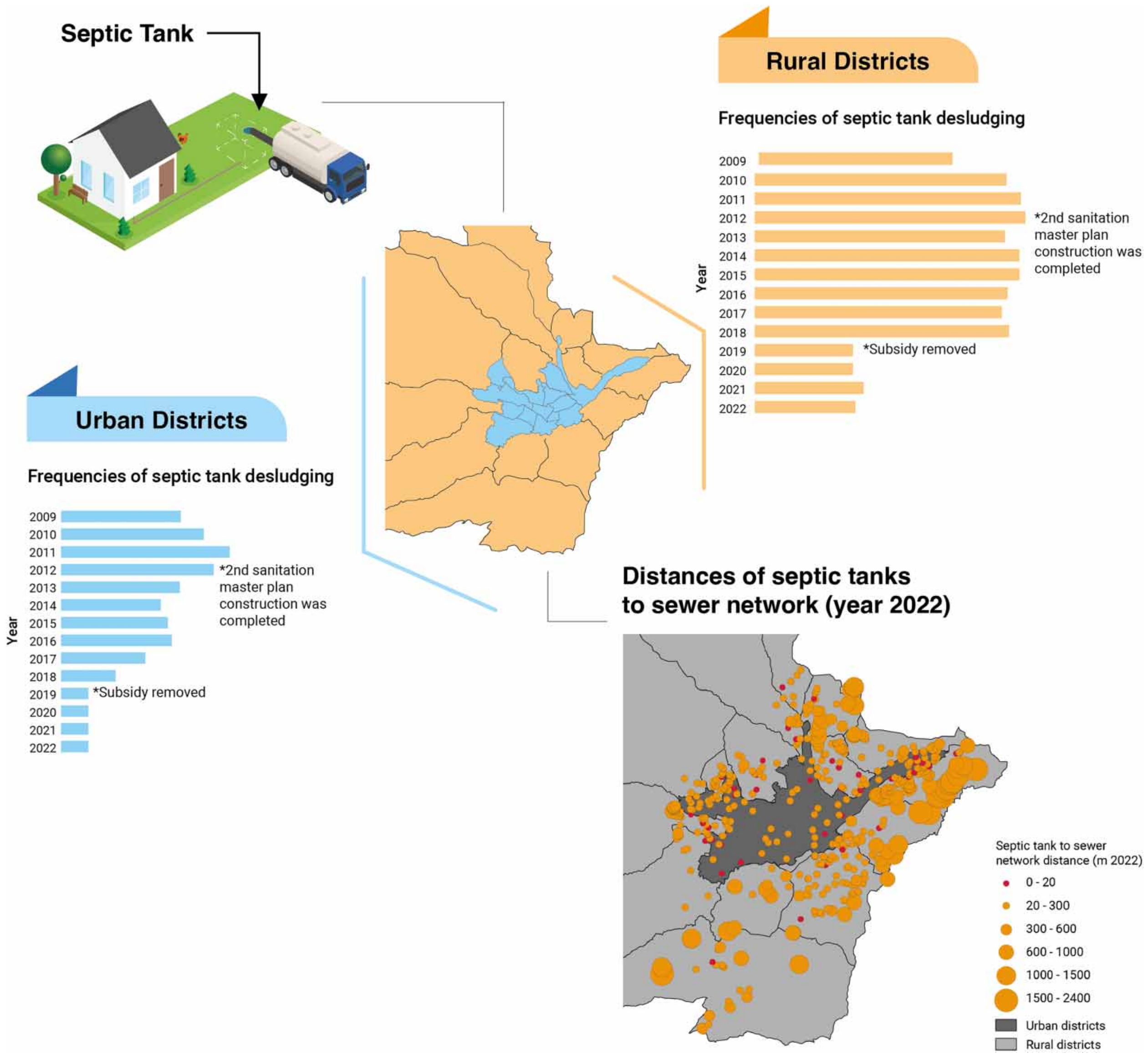
On-site sanitation systems such as septic tanks are widely used for treating domestic wastewater in urban and rural areas which lack sewage systems. However, a large portion of these systems do not properly treat human excreta. A main challenge to improve this is the absence of comprehensive data regarding the usage, emptying and maintenance. In this study, records of septic tank desludging frequency during 2009–2022 and the sewerage coverage updated to 2022 were used to investigate their spatial and temporal utilisation, and the persistence of septic tank usage in areas with sewer networks and uncover the current state of Faecal Sludge Management in Cuenca, Ecuador. The spatial behaviour revealed that OSSs are still in use besides the presence of a sewer network. In 2022, there were 109 septic tanks in urban areas with 14.7% in sectors with sewerage service. In rural areas, 469 septic tanks were recorded with 7.8% situated in areas with sewer networks. Although there is no specialised infrastructure in place for the treatment and disposal of faecal sludge, the city has effectively managed it with the existing sanitation facilities. This assessment contributes to the formulation of a secure framework for a safely managed sanitation.

Key words: faecal sludge management, on-site sanitation, septic tank, sewer coverage, temporal evolution

HIGHLIGHTS

- Septic tanks are still in use in places where there is a sewage system (14.7% in urban areas and 7.8% in rural areas).
- Urban districts, that are located close to the rural ones, have a septic tank/inhabitants ratio comparable to the rural districts.
- A successful measure that promoted the end-user connection to the sewage system was the removal of the septic tank desludging subsidy.

GRAPHICAL ABSTRACT



INTRODUCTION

The framework of the 2030 Agenda for SDG, and particularly SDG 6 'Clean water and sanitation', promotes ensuring safe sanitation for all (UN-Water 2021). However, around 2.8 billion individuals in low- and middle-income countries still rely on their sewage disposal on sanitation systems known as on-site, with nearly half of those on-site sanitation systems (OSSs) failing to adequately process human excreta (Jakariya *et al.* 2023). Specifically in Latin America only one-third of the faecal sludge (FS) of OSSs are securely managed (UNICEF/WHO 2021). Thus, it is essential to improve the secure and effective operation of OSSs, by regularly emptying and transporting the accumulated FS to an external treatment facility before the final disposal (Conaway *et al.* 2023).

OSSs are predominantly employed in rural and peri-urban areas, particularly where conventional sewage infrastructure is absent or where challenging topography hinders its implementation. Septic tanks are the prevailing choice for on-site treatment and disposal of domestic FS (Richards *et al.* 2016). FS refers to the mixture of undigested and partially digested slurry or solids that arise from the storage or treatment of blackwater or excreta (Peal *et al.* 2014). For FS, the US Environmental Protection Agency (2023) recommends to empty the septic tanks every 3–5 years or when biosolids exceed 25% of their volume. The mechanical method used for emptying septic tanks involves the use of a vacuum truck or tanker. The same truck serves both as an emptying device and a transportation vehicle for FS (Conaway *et al.* 2023). Additionally, solid–liquid separation is vital in FS treatment. Plants are designed for efficient settling and dewatering before further processing of liquid and solid components (Ward *et al.* 2021).

Removing FS from households is a matter of personal interest, however, the whole FS management chain is a public interest (Strande *et al.* 2014). Therefore, the entire service chain, i.e. collection, transportation and treatment unit sizing (Shukla *et al.* 2023), needs to be accounted for effective management of FS. Nevertheless, one of the main obstacles to safely and effectively managing sanitation is the lack of data about the existing infrastructure, i.e., sewer networks and OSSs (Nasim *et al.* 2022). Then, quantifying the amount of FS produced, which is the initial step in developing an infrastructure (Shukla *et al.* 2023), as well as the emptying requirements is of the most relevance.

In Ecuador, which is a low-income country located in the northern Andean region of South America, sanitation and FS management are critical. Only around 68% of the Ecuadorian population have sewer connections (UNICEF/WHO 2022). Of the total population, 68.1% live in urban areas and 31.9% in rural areas. Among the population living in urban areas, 16.3% of households lacked a connection to the sewerage system, meanwhile, in rural areas, this figure increased to 75.8% (Viteri & Pozo 2019). This shows a significant contrast in sanitation infrastructure between urban and rural areas. The disparity arises due to the rural areas being designated for agriculture and ecosystem conservation, making them less consolidated and challenging to implement a sewerage system. To close disparities in access to enhanced sanitation, substantial financial investments and the implementation of sustainable technological solutions tailored to the specific context of each region, alongside political commitment, are indispensable (Adugna 2023).

The data provided by Viteri & Pozo (2019) evidenced that in Ecuador a considerable segment of the population requires an alternative approach to managing their wastewater. Among the various OSSs in use, septic tanks are a recognised secure alternative to centralised sanitation, especially in peri-urban and rural regions because of their simplicity for maintenance and construction. In fact, 24.3% of Ecuadorian households, without access to a centralised sewerage system, resort to discharging their wastewater into septic tanks. Furthermore, for those households using septic tanks, the majority (92.2%) do not empty their tanks but infiltrate the leachate into the soil, followed by those who report discharging it anywhere in the open (6.9%) (Pozo *et al.* 2016).

Ecuadorian regulation establishes that the local government should provide the sewerage service, while the households need to take responsibility for the end-user connection. Therefore, based on qualitative data collection, the local governments frequently assume that merely having sewerage coverage suffices as sanitation, leaving behind the end-user connections and the OSSs that are in use. A previous study by Córdova *et al.* (2023) examined that local governments showed efforts to address OSS, potentially linked to low levels of sewerage coverage. In the absence of strict regulations, there might be some households that besides being inside the sewer coverage area, are not yet connected to the network. This low connectivity to the sewerage system could carry out negative implications related to (1) unmaterialised health and environmental benefits of sewer infrastructure investments; (2) failure of the financial sustainability of the sewer system which depends on the user's contribution; (3) reduction in treatment plant's efficiency because of the low wastewater volume entering the plant; and (4) clogging of the sewer networks with sediments when very low volumes of wastewater enter the system (Sturzenegger *et al.* 2020).

In order to avoid these negative implications, a global understanding of the OSSs problem is essential. In Ecuador there is limited high-quality and representative data about OSSs usage, the end-user sewer connections and subsequent FS management. Therefore, research on OSSs and the assessment of the historical and current situation of FS management are imperative. This study is the first attempt to explore the temporal and spatial distribution of the use of OSSs in urban and rural areas, specifically septic tanks. Its objective is also to investigate whether there remain septic tanks in places where a sewer network is available and reveal the posterior FS management situation. As a study case, a middle-sized city in Ecuador, Cuenca was selected. The reason is that this city has implemented at least some level of FS management, although it may not be optimal and it has an extended sewer network with a wastewater treatment plant. However, it still highly relies on septic tanks.

METHODS

Study area

The study was conducted in the urban and rural areas of Cuenca, Ecuador (Figure 1). Cuenca is a middle-sized canton located in the south of Ecuador, covering approximately 3,190.54 km^2. The urban districts (called Cuenca City) represent about 3% of

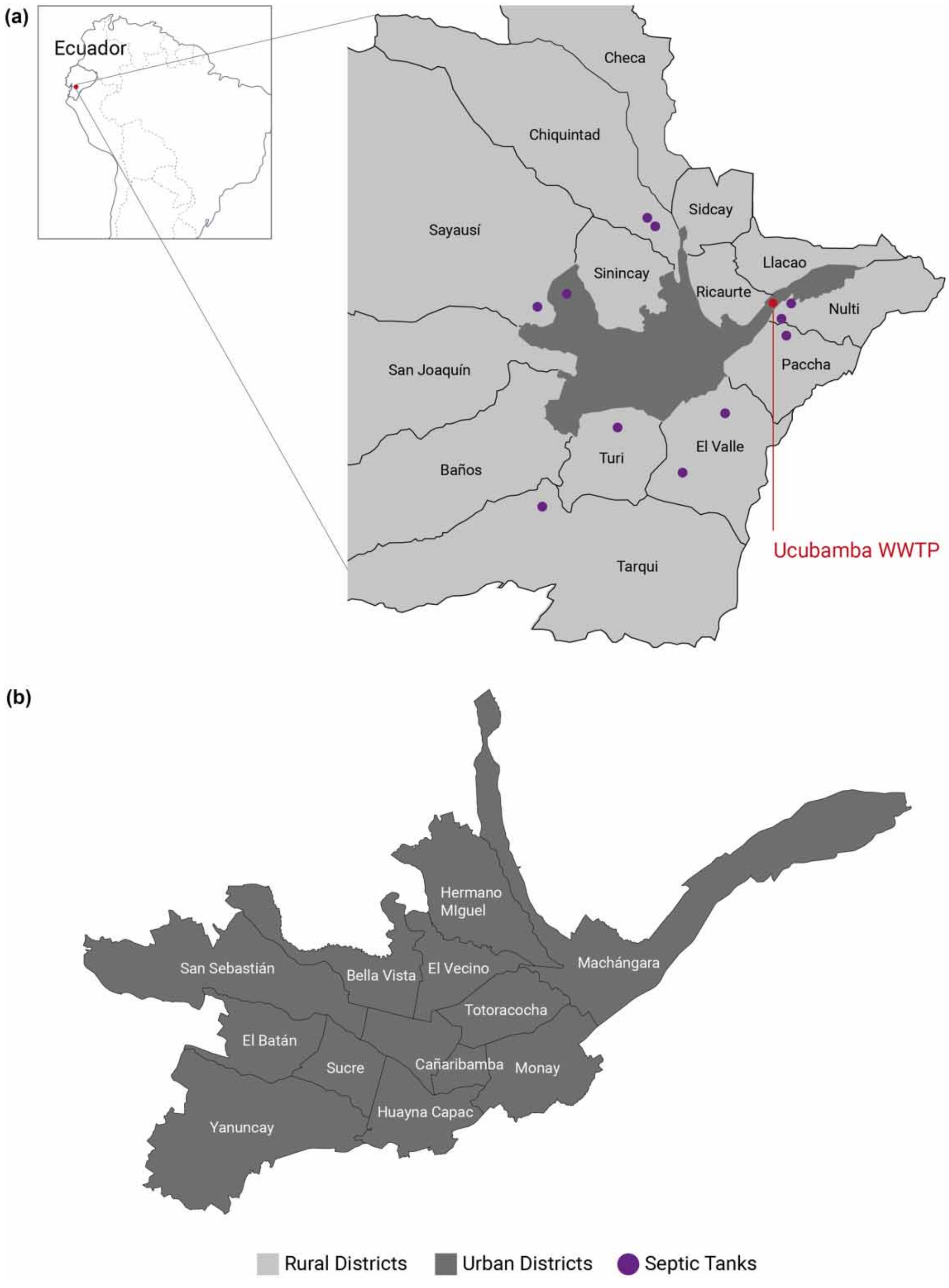


Figure 1 | Study area in Cuenca, Ecuador: (a) location of rural districts with the selected 12 septic tanks and Ucubamba WWTP and (b) location of urban districts.

the total area. From the 97% of the rural area, 75.5% is intended for protection, 1% for urban expansion and 23.5% for production. Cuenca has around 636,996 inhabitants (INEC 2020).

Cuenca canton is divided into 36 districts, 21 in the rural area (light gray in Figure 1) and 15 in the urban area (dark gray in Figure 1). For the rural sector, the closest districts to the urban area that had a significant number of septic tanks were highlighted: Baños, Llacao, Nulti, Paccha, Checa, Chiquintad, Sidcay, Ricaurte, San Joaquín, Sinincay, Sayausí, Tarqui, Turi, and El Valle for deeper analysis.

Cuenca has a centralised wastewater treatment plant (WWTP) located at the west of the city (2°52′15.1″S, 78°56′30.8″ W) (Figure 1). It treats mainly urban wastewater through two waste stabilisation pond treatment lines. Each line includes an aerated, a facultative and a maturation pond. The system also has a sludge treatment unit that extracts and dehydrates sludge from the aerated and facultative ponds. The dehydrated sludge is finally disposed of in a landfill.

Data preparation

Three types of data were used for this research. First, records of septic tank desludging frequency; second, sewer network; and third, field visits with a household questionnaire. Specific data preparation was performed for each of them.

Frequency of septic tank desludging

The frequency of septic tank desludging by vacuum trucks in the rural and urban districts of Cuenca was collected from 2009 to 2022. The data were obtained from the official records of ETAPA EP. For that, users in need of emptying a septic tank (based on their own perception of the service needed) contacted ETAPA EP. Subsequently, ETAPA EP processed this request based on the two available vacuum trucks to perform the cleaning at the designated location. During the study period, 19,731 service requests were recorded with an ID, cadastral code, geographical location and empty date.

The collected data were systematised, geographically mapped and classified according to their location in urban and rural districts. Throughout the analysed timeframe, a total of 5,636 operational septic tanks were documented as having been emptied. A septic tank was operational (receiving the wastewater from a household) when the owners required the emptying service regularly. Some septic tanks were emptied more than once during the study period. Recognising inactive units is crucial when assessing total septic tanks. Therefore, for temporal trends, we used desludging frequency, and for septic tank locations, we considered only 2022 data, ensuring the inclusion of exclusively active units.

The desludging frequency to district population ratio was calculated to assess population influence. For the urban average ratio, Machángara was omitted due to its distinct rural behaviour, preventing distortion of the urban average. Similarly, in establishing the rural average, Baños, Checa, and Turi were excluded for exhibiting urban-like characteristics.

Sewer network

The sewer networks had information regarding material, diameter, type of sewerage and year of construction. In this case, the sewer network from 2022 was used. The spatial coverage of the whole network and the length (km) for each district were calculated. Furthermore, the sewer network was contrasted with the active septic tanks in 2022. The shorter distance between the tanks and the network was obtained. The distance of 20 m was accounted for under the assumption that if the residence was within a 20 m distance, there was potential for a sewer network connection.

Field visits with household questionnaire

For the third data type, 12 septic tanks (purple dots in Figure 1) were randomly selected from nine districts of Cuenca. Field visits and household questionnaires were applied to the selected 12 septic tanks during July 2020. The questionnaire had 10 questions related to socioeconomic information and septic tank characteristics and maintenance, i.e, volume of the tank, number of inhabitants in the corresponding household and time since the last empty.

Furthermore, in order to quantify the height of the accumulated sludge in the septic tank, a white towel test was performed (Mara 1996). With these data, the per-capita sludge accumulation was estimated. Finally, technical field visits were conducted to gather data about the FS disposal location which is the Ucubamba WWTP.

Using the FS heights, the number of inhabitants, and FS age (defined as the time since the last emptying was done), the per-capita sludge accumulation rate was determined. This was achieved by dividing the volume of sludge found in each of the analysed septic tanks by the number of users and the duration of sludge accumulation, as detailed in the following expression:

$$Per\ capita\ sludge\ accumulation = \frac{Sludge\ volume}{\#inh.*t}\left(\frac{L}{person*year}\right) \quad (1)$$

RESULTS AND DISCUSSION

Spatial distribution of septic tank desludging frequency and sewer network

Septic tanks and sewer networks from 2009 to 2022 are shown in Figure 2. It illustrates the spatial distribution and frequency of cleaning activities of septic tanks (red colour), as well as the layout of sewer networks (blue colour) with their pipeline lengths in kilometers.

Figure 2(a) showcases the spatial coverage of septic tank desludging frequency throughout the specified time frame, highlighting their presence in both urban and rural areas. Figure 2(b) displays the extent and coverage of the sewer networks in the year 2022. Similarly, as the septic tank desludging frequency coverage, the network had a presence in urban and rural districts. While the urban ones showed full coverage, the rural ones depicted a less extended coverage than the septic tank desludging frequency.

Furthermore, Figures 2(c) and 2(d) show the frequency of septic tank desludging and sewer pipeline length for the rural districts, and Figures 2(e) and 2(f) for the urban ones. By seeing the figures, patterns emerge in the utilisation and maintenance of septic tanks, revealing the trends in emptying frequency and geographic concentration. Rural districts showed a higher frequency of septic tank desludging and shorter lengths of sewer pipelines, demonstrating the increased necessity of FSM from OSSs in rural areas compared to urban ones. As the sewerage network will not reach the most remote areas, OSSs will continue to be used. Although, when considering the length of sewer pipelines, the area of each district must be noted. Smaller districts (central ones) presented fewer kilometers of sewerage but coverage of 100%.

The observed emptying patterns could be influenced by the district's population. Therefore, the ratio of septic tank desludging per inhabitant (ST/Inh) has been analysed as a comparative factor (Table 1). The urban sector exhibited the lowest ratio, while rural districts like Baños, Checa and Turi displayed similar ratios. Interestingly, Machángara, an urban district, demonstrated an ST/Inh ratio that was comparable to the average ratio observed in rural areas. This observation highlights that the urban/rural classification based on sanitation services does not always accurately reflect the situation of some districts.

It is important to note the lack of available data regarding septic tank emptying in the more remote areas of rural districts. Therefore, this study does not consider the operation of OSSs in those locations, however we expect they exist. Besides this limitation, understanding the evolving sanitation landscape in Cuenca offers insights into the coexistence of septic tanks and centralised sewer systems within the regiońs sanitation framework.

Temporal evolution in septic tank desludging

As observed in Figure 3, the total emptying frequency changed its tendency over the last 14 years, with the highest peaks in 2011 and 2012 and the lowest values after 2018. In 2012, the completion of the second sanitation master plan in Cuenca included the expansion of collection networks by 67 km. This expansion is evident in the decrease of desludging numbers particularly in the urban sector after 2012. However, the decline in 2012 was not as drastic as the one in 2019. Between 2013 and 2018, an average of 1,565 septic tanks per year were desludged, while in the last four years (2019–2022), the average frequency of septic tank desludging was 581 per year. It was expected that the desludging frequency, and thus the septic tank use, would decrease remarkably after the increase in the sewer system coverage, but this was not quite the behaviour until the years 2018–2019. A similar behaviour was observed in India, where the dependence on OSS stayed near constant at 60% although a national urban infrastructure plan provided support for sewerage development (Dasgupta *et al.* 2021).

The pronounced decline in 2019 for urban and rural areas can be attributed to the removal of the subsidy that resulted in a more than 200% increase in the desludging cost (the hourly desludging rate increased from approximately 40 USD to around 105 USD), thereby making the service more expensive. With the new costs, users had the option to connect to the sewer network (if the sewer network were available and at an affordable cost), retain the FS in their septic tanks for an extended period or resort to illegal dumping or improper disposal practices. These choices impact public health and environmental sanitation since less desludging can result in overflowing septic tanks, contaminating groundwater and surface water and increasing the risk of diseases spread through faecal matter. Therefore, in urban areas with sewer infrastructure, it is recommended not to provide subsidies. Instead, policies should focus on encouraging sewer connections to improve sanitation effectively.

Prior to the removal of the subsidy, septic tank desludging was more cost-effective than connecting to the sewer network. Additionally, due to the lower cost before 2019, it is likely that users sought the service more frequently, even before the septic tank reached full capacity. In a research conducted in Dakar, Senegal, Dodane *et al.* (2012) discovered that the expenses per person per year associated with managing FS which includes the collection, transportation, and treatment of sludge from

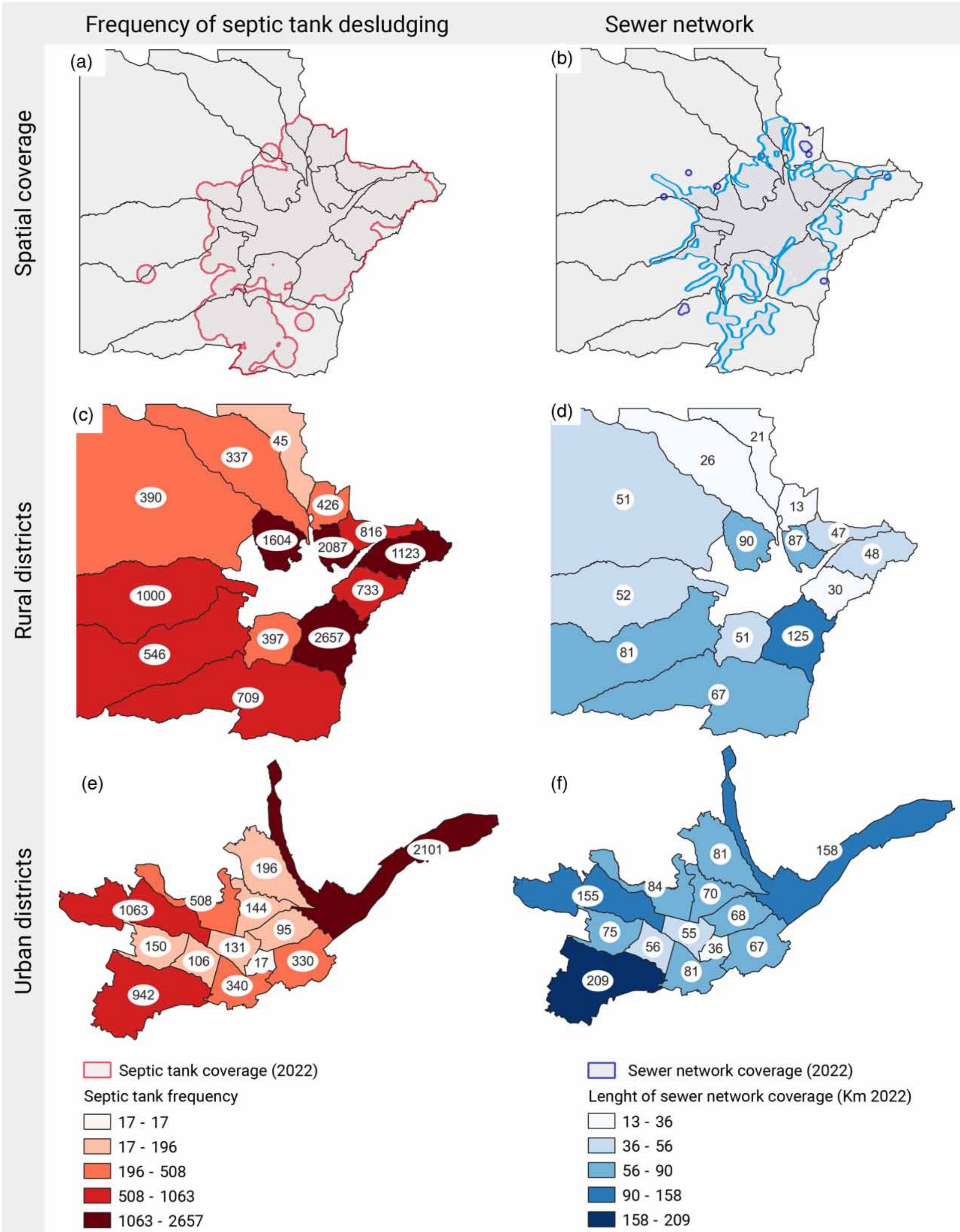


Figure 2 | Spatial coverage of (a) frequency of septic tank desludging in 2022, (b) sewer network in 2022. Septic tank desludging frequency from 2009 to 2022 in (c) rural districts, (e) urban districts. Length of sewer network in km in 2022 in (d) rural districts and (f) urban districts.

OSSs were notably lower compared to the costs of a conventional sewerage system. On the other hand, the capacity of septic tanks often correlates with the financial capabilities of households. Smaller tanks tend to fill up more frequently, requiring greater maintenance investment, conversely, larger tanks run the risk of collapsing if their structure is weak (Rojas 2012).

It is important to differentiate the temporal evolution between the urban and rural areas because even if the majority of septic tanks are located in the rural sector, the urban counties also make use of septic tank emptying. Figure 4(a) shows

Table 1 | Average septic tank desludging (ST)/inhabitants (Inh) ratio for each of the sectors during 2009–2022

Sector	ST/Inh ratio (SD[a])
Urban[b]	0.003 (0.001)
Machángara	0.022
Rural[c]	0.032 (0.02)
Baños	0.002
Checa	0.004
Turi	0.003

[a]Standard deviation.
[b]Urban districts, excepting Machángara district.
[c]Rural districts, excepting Baños, Checa, and Turi districts.

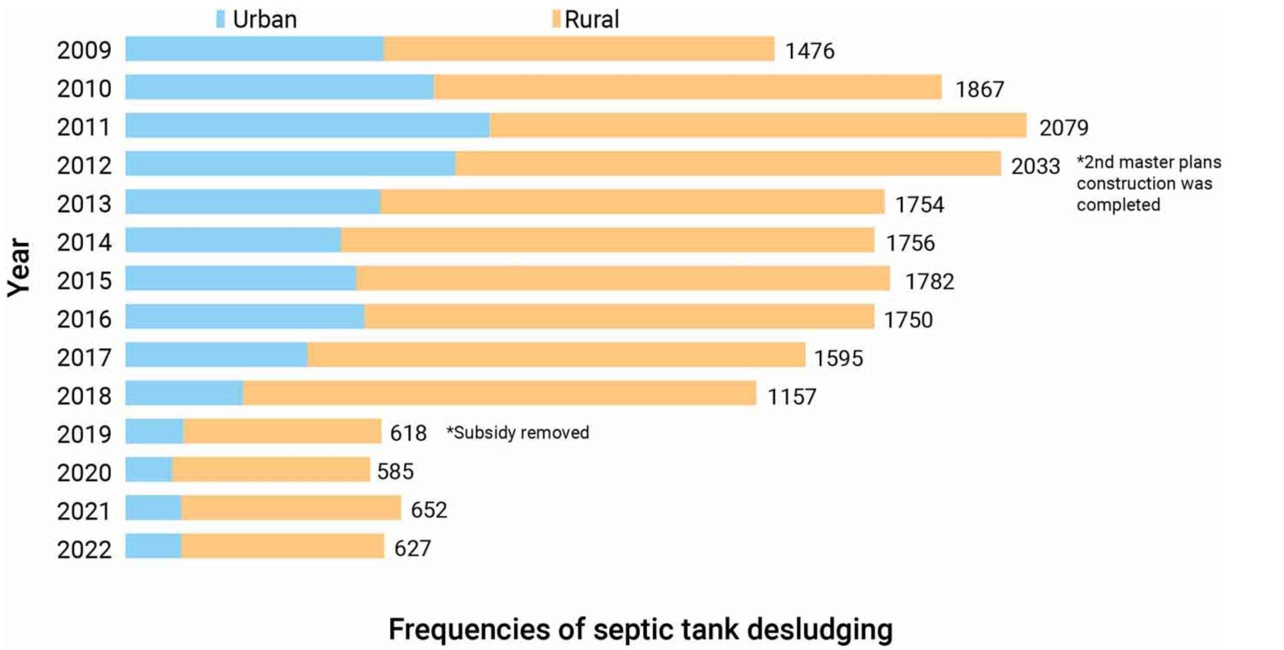


Figure 3 | Frequencies of septic tank desludging by year in the study area for rural districts in blue and urban in orange.

the desludging frequencies in urban areas throughout the study period. Five out of eight urban districts exhibited lower emptying frequencies when compared to their rural counterparts; however, all districts experienced at least one septic tank emptying event over the last 14 years. The lower frequencies observed in these districts can be attributed to the presence of urban sanitation infrastructure, making it easier and cheaper for people to connect to nearby sewer systems. Districts such as Machángara, San Sebastián and Yanuncay (Figure 4(a)) showed similar desludging frequency as the rural ones (Figure 4(b)). The outskirts of these three districts are located closer to the rural area than to the urban center, which may influence their behaviour as such. Further, downtown districts which are located in areas with 100% sewer coverage still had active septic tanks as well. One of the reasons for the observed urban behaviour might be the required financial investments because households are responsible for the end-user connection to the sewer network. However, Daudey (2018) mentioned that the cost ratio between conventional sewage systems and septic tanks is not always significant (ranges from 1 to 4.7). Similar to related literature (Sturzenegger *et al.* 2020), this study identifies another factor influencing the household delay in connecting to the network or the decision to abstain from the connection, which is the legal and regulatory framework.

In Ecuador, there is no national law requiring households to connect to the sewerage system upon its construction. Each local government has its own legislation. In Cuenca, a regulation (Registro Oficial No. 222 1993) outlines the connection

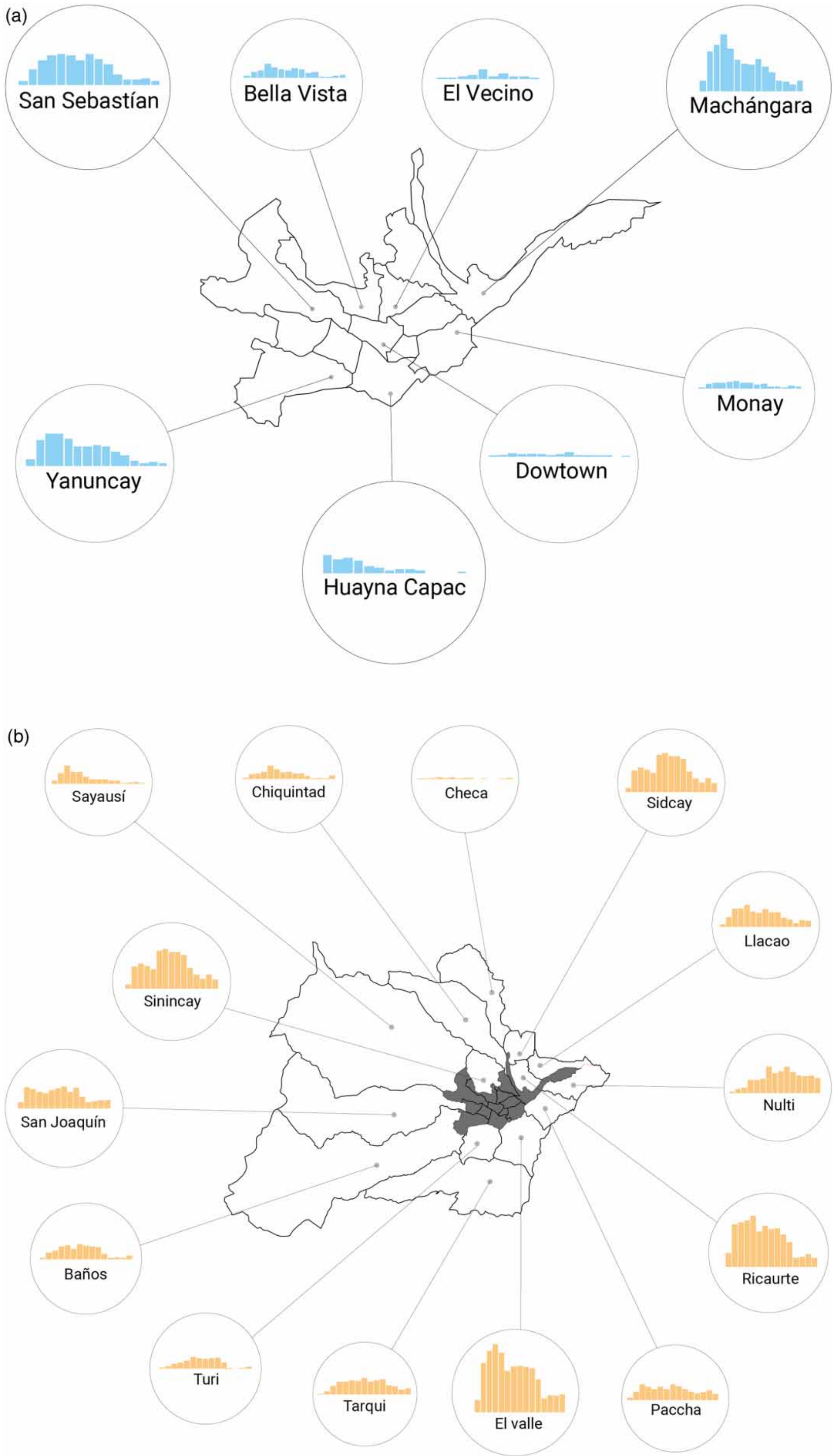


Figure 4 | Frequencies of septic tank desludging in (a) urban districts and (b) rural districts.

procedure to the sewerage system and the types of wastewater allowable to discharge into the system. The authority can prohibit connections to the sewerage. However, the regulation does not oblige households to close their OSSs and connect to the sewerage in areas where it exists. Thus, the absence of a regulatory structure poses enormous challenges for local governments to enforce end-user connections. This absence undermines sustainable FSM efforts and hinders progress towards achieving Sustainable Development Goals (SDGs) related to water, sanitation, and health.

The temporal evolution in rural districts (Figure 4(b)) is different than in the urban ones (Figure 4(a)). Most of the people who live in rural areas rely on septic tanks because they lack a sewer network nearby. Specifically, in El Valle, Ricaurte, Sidcay and Sinincay districts are suffering a rapid expansion of informal settlements which makes it more difficult to provide sewer service. However, there also was a reduction in emptying frequency as well for most rural districts during the last four years – 2019 to 2022 (Figure 4(b), also observed in Figure 3). Even if in rural areas there was an effort to build wastewater decentralised systems, this effort did not have a significant consequence in reducing septic tank emptying. This phenomenon may be attributed to the persistently low coverage of decentralised systems, stemming from the non-consolidated nature of rural areas in the region. Furthermore, funding is scarce and cultural preferences for traditional sanitation practices may have contributed to this scenario. The local administration built rural wastewater treatment plants in Tarqui (3), El Valle (1), Ricaurte (1) and San Joaquín (1). However, in 2019, one of the plants in Tarqui was shut down due to the implementation of a sewer network, directing the wastewater to the centralised WWTP in Cuenca. Nevertheless, in some other districts such as Nulti and Paccha, the frequency of septic tank desludging did not show any significant reduction in the last years. In those rural districts, the sewer network has not undergone expansion and the absence of other decentralised wastewater systems made the use of septic tanks the only and simplest sanitation option in these areas.

Comparison of sewer network and septic tank locations

Every year, the sewer system coverage increases in Cuenca, in urban and rural areas. With this increase, a decrease in septic tank use is expected, as was analysed in the last section. Here, we contrast the placement of sewer networks and active septic tanks for urban and rural areas in the year 2022 within a maximum distance of 2.4 km.

Figure 5 shows the distances of septic tanks to the closest sewer network pipeline in urban and rural areas. In total, there were 578 active septic tanks in 2022, with 109 located in the urban and 469 in the rural areas. In the urban ones, there were

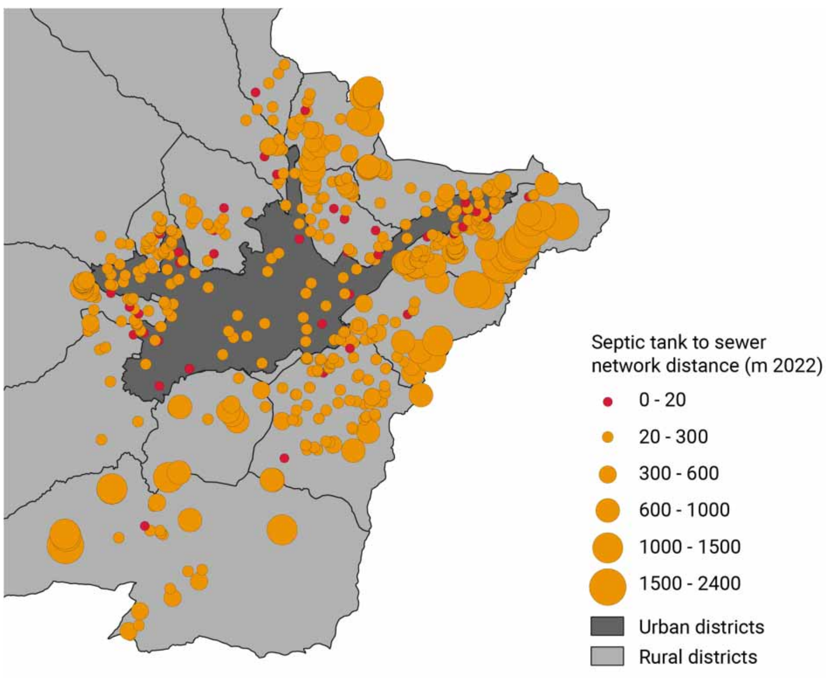


Figure 5 | Distances of septic tanks to sewer network for urban and rural districts.

still septic tanks in use with distances less than 20 m to the sewer network, even in areas with full access to a sewage system (red points in Figure 5). Of the 109 septic tanks in use inside the urban area, 14.6% were located closer than 20 m to the sewer network. In the rural area, of the 469 operating tanks 7.8% were located within the 20 m distance. This shows the challenge of end-user connection between dwellings and sewage pipelines that the water and sanitation utilities need to face. In addition to financial barriers that hinder connectivity, factors such as lack of education, interest, motivation, and information may contribute to this observed behaviour. The lack of education/information contributes to a limited understanding of the benefits and importance of connecting to a sewer network. Households may not fully grasp the long-term advantages to both their well-being and the broader community. Motivational factors can also stem from a perception that the immediate benefits of sewer connectivity may not outweigh the associated costs. Individuals might prioritise other needs or perceive the current sanitation solution as adequate, diminishing the motivation to transition. They prefer to maintain the septic tank rather than adopt a new solution like a sewer network. Improving access to relevant information is crucial for empowering households to make well-informed choices. When comparing similar urban behaviours in Latin America, it has been reported that time constraints and lack of information were identified as the primary barriers in 59% of households in Bolivia. Conversely, in Brazil and the Metropolitan Area of Buenos Aires, Argentina less than half of the households indicated that financial constraints were the main factor (Sturzenegger *et al.* 2020).

Moreover, 381 septic tanks were situated within the proximity of 20–300 m from the sewer network, while 73 were located between 300 and 600 m, 40 between 600 and 1,000 m, five within the range of 1,000–15,000 m, and 16 between 15,000 and 24,000 m (Figure 5). These distance categories highlight areas where the challenge is not the end-user connection but rather the effective management of FS or the incorporation of decentralised wastewater systems.

FS management

Quantification of FS produced is the initial and crucial step in establishing an effective management system which includes infrastructure for collection, transportation, and appropriately sized treatment units (Shukla *et al.* 2023). Thus, the accumulation rates were individually calculated for each surveyed septic tank obtaining a median value of 142 L/person/yr (0.39 L/person/d) with an Interquartile Range (IQR) of 252 L/person/yr. This value was higher than the one reported by Englund *et al.* (2020) for Hanoi city (32 L/person/yr) and Méndez Novelo *et al.* (2007) for Mérida México (20 L/person/yr), but in the range of the ones reported for China (350 g/person/d), Kenya (520 g/person/d) and Thailand (120–400 g/person/d) (assuming a density of 1 g/cm^3) (Strande *et al.* 2014). It is worth noticing that, due to significant variation in desludging frequency for each septic tank (i.e service is required based on households' perception), the gathered data exhibited also a large standard deviation (525.82 L/person/yr). The significant dispersion included extreme values extending up to 1,600 L/person/yr. Caution is advised in the application of these values for FSM purposes.

For the collection and transport of FS, ETAPA EP has two emptying trucks. According to Taweesan *et al.* (2015), a city should have at least one vacuum truck per 1,000 households to achieve an FS collection with more than 80% efficiency. But in the case of Cuenca (5,636 active septic tanks during the study period), the collection efficiency is below that number. Despite this deficiency, Cuenca is the only city in the country that reports this service for the entire urban and rural area.

Each septic tank owner bears the responsibility of requesting the emptying service when it is perceived as necessary. The time it takes for a septic tank to fill up depends on the size, lining type, soil type, rainfall and groundwater level (Sharada Prasad & Ray 2019). Thus, it could take from one month to years for a septic tank to fill up and consequently be emptied. ETAPA EP receives the requests, organises them based on location and dispatches vacuum trucks capable of collecting 8 m^3 each. To reach that volume, the trucks often collect FS from multiple septic tanks resulting in septage with highly variable quality and varying degrees of stabilisation. This is especially important in order to propose an adequate treatment for the FS. Technologies that support an enormous variety of solids and hydraulic loads would be needed.

The truck operators carry the septage to the centralised WWTP of Cuenca. The FS is dumped into the second aeration pond, which is filled with the inert and organic solids that come in the FS (Figure 6). The pond was not originally designed for this purpose, but it is the best alternative in the absence of proper FS treatment measures. Utilising the WWTP for FS disposal helps mitigate environmental pollution and potential health impacts that would arise from disposing of the FS elsewhere. The organic fraction of FS in the aeration pond undergoes treatment in the sludge facility, concluding the FSM cycle at the landfill.

In Ecuador, as in other developing countries, there is a lack of policies regarding the FSM. A robust and comprehensive policy is urgently needed in this regard. In Cuenca, as outlined earlier, there is a management plan in place, but it lacks

Figure 6 | (a) FS discharge into the aeration pond in the WWTP and (b) accumulation of material in the aeration pond in Ucubamba WWTP.

specific policies. The findings of this study suggest the formulation of effective policies in two critical directions. First, policies should motivate and, if required, mandate the connection of households where sewer systems already exist, and emphasising education and proper information dissemination regarding environmental and public health benefits. Second, FSM policies should prioritise decentralisation, particularly in rural areas, and should incorporate suitable technologies to support this objective, given the ongoing and expected use of OSSs. Then, a substantial investment in infrastructure and efficient collection systems will also be required to ensure proper FS extraction. A holistic, policy-driven approach is needed for a sustainable FSM, encompassing the entire process from extraction to treatment.

CONCLUSIONS

This study explored the temporal and spatial use of OSSs represented by septic tanks in urban and rural areas. It also revealed remaining septic tanks in places where there is an available sewer network and the FS management situation. As a study case, it was performed in Cuenca, Ecuador.

The study showed that some urban districts have a septic tank/inhabitants ratio comparable to the rural districts. This observation exhibited that the urban/rural classification based on sanitation services does not always accurately reflect the actual situation of some districts. Furthermore, of the 109 active septic tanks in the urban area, still, 14.6% of them were located within distances closer than 20 m from the sewer network. In the rural area, of the 469 operating tanks, 7.8% were located within the 20 m. Finally, 381 septic tanks were located between 20 and 300 m of the sewer network. This shows the challenge of end-user connection between dwellings and sewage pipelines. Governments need to address these connectivity challenges in a particular context, first by generating and collecting high-quality data to understand the magnitude and causes of the connectivity problem; and then by testing the effectiveness of different interventions. According to this study, a measure that effectively reduced the use of OSS in the urban area was the removal of the septic tank empty subsidy, showing that unfortunately, the economic factor is the only effective one in many cases. There are numerous reasons for promoting the end-user connection when there is sewage system coverage. There are important health and environmental benefits, as well as financial operability of the systems.

It results evident that the rapid population growth and informal human settlements, both in urban and rural areas, hinder the progress of centralised sewer system coverage from meeting the increasing year-to-year demand. The use of OSSs will continue to be a necessity. In our context, septic tanks stand as the most prevalent system in areas without access to sewer networks. Therefore, more extensive studies are required to quantify and characterise the FS from these systems, which is crucial for effective operation and consequent FSM.

Cuenca lacks a dedicated system solely for the treatment and final disposal of septic tank sludge. However, using the wastewater treatment plant for treatment purposes does contribute to some form of FSM, preventing it from causing environmental contamination. Knowing that the FS is highly variable, appropriate technologies should be studied. These technologies must be capable of handling the high hydraulic and solid loads associated with FS.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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