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Low-cost onsite selection of suitable unplanted sand drying bed structure for faecal sludge treatment in less developed countries: A case study of Yaounde in Cameroon

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ABSTRACT

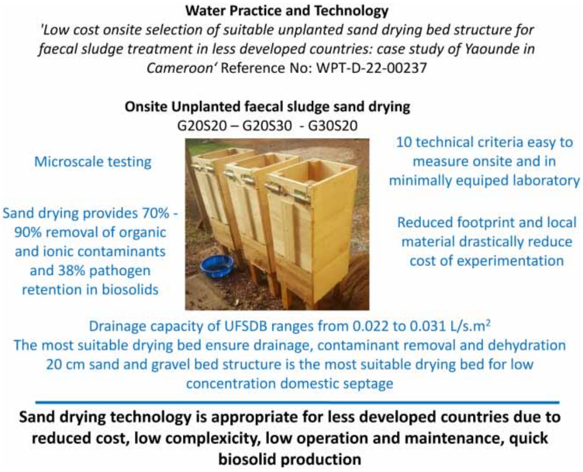
There are lots of drying bed structures in the literature that are planted or unplanted but few indicate reasons behind their choice. As this technology is widely spread in less developed countries, identification and analysis of selection criteria for appropriate unplanted faecal sludge drying beds are necessary. This article analyses a case study in Yaounde for domestic septage over three bed structures for which sludge and percolates parameters are analyzed and treatment performance assessed through 10 technical criteria using a low-cost infrastructure with a minimal footprint. These are related to mass and volume reduction, organic and mineral pollution, as well as drainage capacity. The bed structure used is constituted of gravel and sand with 20–30 cm thickness. These beds recorded more than 85% reduction in organic and suspended matter and a 70% reduction in nitrates and lead concentration with at least 38% of dissolved material and chemicals removed. Considering the suggested criteria, a bed with 20 cm of gravel and 20 cm of sand was found to be the most efficient for material and pathogens removal. This method provides an interesting selection option with low-cost infrastructure, material, and operation for popular selection of suitable faecal sludge treatment technology in less developed countries.

Key words: drying, faecal sludge, multicriteria, selection, treatment, Yaounde

HIGHLIGHTS

- Unplanted sand drying bed can remove 70–90% of organic and ion contaminants.
- Drainage capacity of UFSDB ranges from 0.022 to 0.031 L/s m^2.
- The most suitable drying bed ensures drainage, contaminant removal, and dehydration.
- 20-cm sand and gravel bed structure is the most suitable drying bed for low-concentration domestic septage.
- Low-cost modules can be used to test drying bed structures in less developed countries.

GRAPHICAL ABSTRACT



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'Low cost onsite selection of suitable unplanted sand drying bed structure for faecal sludge treatment in less developed countries: case study of Yaounde in Cameroon' Reference No: WPT-D-22-00237

Onsite Unplanted faecal sludge sand drying
G20S20 – G20S30 - G30S20

Microscale testing

Sand drying provides 70% - 90% removal of organic and ionic contaminants and 38% pathogen retention in biosolids

10 technical criteria easy to measure onsite and in minimally equiped laboratory

Reduced footprint and local material drastically reduce cost of experimentation

Drainage capacity of UFSDB ranges from 0.022 to 0.031 L/s.m^2
The most suitable drying bed ensure drainage, contaminant removal and dehydration
20 cm sand and gravel bed structure is the most suitable drying bed for low concentration domestic septage

Sand drying technology is appropriate for less developed countries due to reduced cost, low complexicity, low operation and maintenance, quick biosolid production

1. INTRODUCTION

As the world population is growing very fast, sanitation problems are becoming more and more critical, especially in towns of less developed countries. Worldwide, according to UNICEF-OMS (2015), more than 2.4 billion people do not have access to safe sanitation, and 90% of wastewater is rejected without proper treatment in nature, causing serious environmental and health challenges. This population is anticipated to increase to 5 billion by 2030 (Strande 2014), leading to a critical faecal pollution crisis. In urban centres the majority of houses are served by onsite sanitation systems such as septic tanks and pit toilets. The faecal sludges (FSs) collected from these systems are usually discharged untreated into urban and peri-urban environments, posing great risks to water resources and public health (Ingallinella *et al.* 2002). In fact, FS management is a growing challenge in urban areas due to rapid urbanization, population growth, and poor FS treatment facilities, especially in Africa (Manga *et al.* 2016). The cost of constructing and maintaining existing efficient technologies is also prohibitive.

In Cameroon, there is no complete wastewater management chain and some of the existing localised treatment plants which were built around 1970 (in Yaounde and Douala) are obsolete and many of them are no more used. Thus, nature is the main end point of all FS collected from septic tanks and pit latrines all around towns (MINEE 2011). In Yaounde sludge collected from domestic, hostels public toilets, and industries are all discharged in Nomayos, a peri-urban populated neighbourhood in Yaounde. Due to the high environmental and health risks, Cameroon Government with support from the World Bank through the Yaounde Sanitation project phase 2 (PADY II) constructed the first large sludge treatment plant in 2021 at Etoa Ahala in the Yaounde vicinity. This was inaugurated on September 4, 2021. This system includes a primary treatment with two sets of sand drying beds (30 cm thick) loaded with 300 L/m^2 septage. This plant receives close to 260 m^3/day septage. To align with the current loading rate in that plant, three bed structures were tested to assess the system's performance and select the suitable bed structure: (i) 20 cm of gravel and 20 cm of sand; (ii) 20 cm of gravel and 30 cm of sand, and (iii) 30 cm of gravel and 20 cm of sand. Despite many unplanted sand drying beds in the literature, no standard is set (Kouawa 2016) and little focus is placed on the sand filtering thickness. Most of the systems are designed to aim at enhancing nutrient recovery in the resulting dry solids, contaminant load removal in percolate, and shortening the dewatering time (Manga *et al.* 2016). Evaluating sand drying bed performance requires assessing several factors: dewatering time, contaminant load removal efficiency, solids generation rate, nutrient content, and helminth eggs viability in the dried sludge (Manga *et al.* 2016).

There are several parameters affecting the duration and efficiency of the dewatering process in sand drying beds. Bassan *et al.* (2014) indicate climate, properties of the sludge, loading rate, thickness of the sludge layer, and surface area of the drying bed. Besides, other advantages of using drying beds as a treatment technique are the low cost, low energy consumption, low chemical consumption, and low requirements of maintenance (Lindberg & Rost 2018). Indeed, onsite FS treatment plants generally include solid–liquid separation by settling/thickening processes, sludge dewatering and drying lagoons/beds, stabilization ponds, and co-

composting with refuse (Strauss *et al*. 1997). The selection of one of these methods depends on several technical, social, and economic criteria. This article focuses on ten technical criteria and the cost of the testing equipment.

2. METHODS

2.1. Location of the study site

The experimental study site was the city of Yaounde, Cameroon political capital precisely at '*Etoa Ahala* faecal *sludge treatment plant*' (coordinates 3°47′23.8″N; 11°28′18″E) in the southwest of the city (see Figure 1). The studied area has a tropical humid climate with Guinean type characterized by four seasons: a short rainy season (mid-March to end of June), a short dry season (early July to mid-August), a long rainy season (mid-August to mid-November), and a long dry season (mid-November to mid-March). The mean monthly temperature is between 22.4 and 25.7 °C with a mean annual rainfall of 1629 mm according to Kouam (2013), and sunshine hours between 1500 and 1750 h/year. Relative humidity in this area varies from 62% in February to 85% in July leading to evapotranspiration ranges of 82–113.2 mm (Kouam 2013).

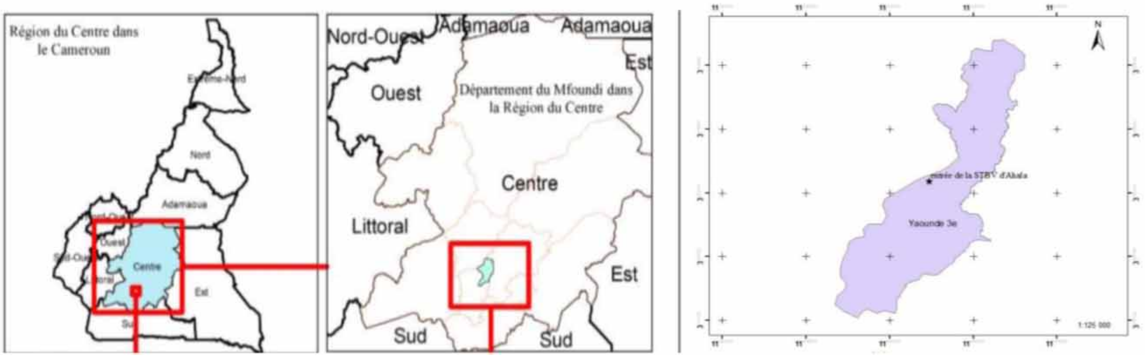

Figure 1 | Location of the Etoa Ahala sludge treatment plant in Yaounde.

2.2. Methodology

FS micro-modules were designed based on the planned dimensions of Etoa Ahala FS treatment plant (324.8 m^2) and the projected load for the drying tank (300 L/m^2). Experimental drying beds made of a wooden structure consisted mainly of gravel (Ø 5–15 mm) and sand (Ø 1–2 mm) with variable thicknesses according to three combinations: (i) 30 cm of gravel and 20 cm of sand (G30S20), (ii) 20 cm of gravel and 30 cm of sand (G20S30), and (iii) 20 cm of gravel and 20 cm of sand (G20S20). This structure was able to provide both drainage and filtration with free evaporation. The cost of constructing the micro-modules was 60 USD per module and took only 2 weeks in a local carpentry workshop. The sludge used for the test was from a household's septic tank of a slum district in Yaoundé. The sludge was allowed to settle for 72 h before it was poured into each module containing one of the three unplanted drying bed structures. Each module received 60 L of sludge (1054 kg/m^3 density and 18–21% dryness. The drying process took 14 days in humid conditions with global 8–10 sunshine hours per day from April 21 to May 5, 2021. Four samples were collected (Figure 2) and analyzed in the laboratory of hydrobiology at the University of Yaounde I: one for fresh sludge and one for each percolate drained from each drying bed. Eleven physico-chemical parameters were analysed (pH, conductivity, suspended matter, total dissolved solids, colour, turbidity, biological oxygen demand, chemical oxygen demand (COD), dissolved oxygen, nitrate, and lead). The drainage flow for each module was measured by counting the time required to collect 10 L and estimating the specific flow (L/s m^2). Performance evaluation was assessed towards the percentage reduction of physico-chemical parameters, drainage capacity, and log reduction for *Escherichia coli*. Trials were conducted into 0.15-m^2 hardwood micro-modules with a percolate collection ramp (Figure 3) charged with 30-cm sludge in accordance with the recommendation from Nielsen (2003) and commonly used range in sub-Saharan Africa experimental settings (Olufunke & Koné 2009; Tagba 2019).

Figure 2 | Percolate collection for laboratory analysis.

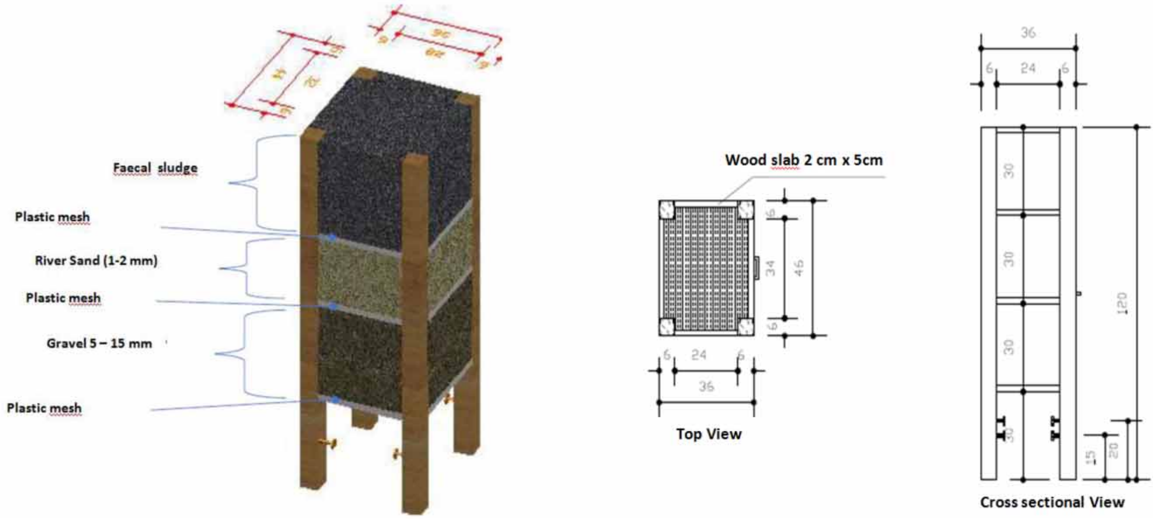

Figure 3 | Drying bed structure in experimental testing modules.

The selection of the suitable drying bed structure was based on 10 criteria providing higher organic, mineral, and bacteriological pollution removal, higher drainage capacity, and mass reduction (Table 1). This study focuses on parameters easy to determine in the context of less developed countries (see Table 1) where access to well-equipped laboratories, remoteness from experimental sites, and trained personnel are challenging. Indeed selection of adequate testing parameters depends on the end use of the results. This study considers only six out of 12 commonly tested parameters for physico-chemical WWTP performance (temperature, hydrogen potential (pH), COD, 5-day biochemical oxygen demand (BOD_5), total suspended solids (SS), phosphate, total nitrogen, total phosphorus, electrical conductivity (EC), nitrate, amonia nitrogen, orthophosphate) and two out of five parameters for microbiological analysis (*E. coli*, faecal coliform, faecal streptococci, helminth eggs, Ascaris eggs) according to several authors (Kuffour *et al.* 2009; Olufunke & Koné 2009; Hijosa-Valsero *et al.* 2012; Seck 2014; Defo *et al.* 2015; Kouawa 2016; Manga *et al.* 2016; Gnagne *et al.* 2019; Tagba 2019). As heavy metals can also be found in sludges (Al-Muzaini 2003), one out of 15 metallic elements which seem to be easily determined were tested: lead.

The study also considers drainage capacity in relation to the bed structure and bed material as it has been previously shown by Seck (2014) and Kuffour *et al.* (2009) that these have a significant influence on the drying bed drainage capacity.

Table 1 | Selection criteria for unplanted FS drying beds

No.	Selection criteria	Critical value (CV)	Score and range
1	Specific drainage flow (L/s.m^2)	0.025	1 = greater than CV 0 = less than CV
2	Concentration in NO_3^- (mg/L)	20	1 = less than CV 0 = greater than CV au
3	Concentration in Pb (μg/L)	100	1 = less than CV 0 = greater than CV
4	Percentage reduction (%) BOD_5	90	1 = greater than CV 0 = less than CV
5	Percentage reduction (%) COD	75	1 = greater than CV 0 = less than CV
6	Percentage reduction SS (%)	90	1 = greater than CV 0 = less than CV
7	Percentage reduction helminth eggs (%)	100	1 = equal to CV 0 = less than CV
8	Log reduction *Escherichia coli*	1	1 = greater than CV 0 = less than CV
9	Percentage reduction of mass (%)	80.	1 = greater than CV 0 = less than CV
10	Percentage reduction in volume (%)	65	1 = greatter than CV 0 = less than CV

Criteria thresholds were based on Benin and French treatment performance for suspended matter, turbidity, BOD_5, COD, helminth reduction, and *E. coli* reduction as indicated by Kerekou *et al.* (2001) and INERIS (2007). For nitrate and lead, Cameroon norms were used. Concerning other thresholds, they were defined after consultations with national experts in sludge treatment from academia and practitioners.

According to Heinss *et al.* (1998), filtration and drainage processes in sand drying reduce 50–80% of sludge initial volume and the siccity of pre-digested sludge in septic tanks from cities ranges between 18 and 70%. As siccity is more complex to determine on the field with generally limited access to adequate equipment, the mass reduction was chosen as the key selection criteria with a critical value of 80%.

3. RESULTS AND DISCUSSION

3.1. Physico-chemical and bacteriological characteristics of sludge and percolates

Fresh experimental FS was found to be low concentration sludge that does not fit Cameroon's norms for safe discharge in the natural environment. Besides, all percolates seem to comply with these norms for almost all standards apart from COD (Table 2). Percolates are of very low dissolved oxygen content which is bad for aquatic life since it would reduce available oxygen for life development. This is in line with conclusions from Olufunke & Koné (2009) who showed that percolates from sand drying are generally of high salinity and low oxygen.

These values of sludge concentration are close to values recorded in other African countries (Kouawa 2016). It is also observed from Figure 4 that this sludge contains up to 326 helminth eggs and 64 UFC/100 mL of *E. coli* which can be reduced to close to ¾ using unplanted sand drying beds. In fact, tested sand drying beds show a reduction of 70.3–79.7% of helminth eggs and 0.57–0.69 log reduction for *E. coli* UFC/100 mL. Values of helminth egg concentration for percolates are similar to those measured by Kengne (2006) ranging between 4 and 27 eggs/mL. *E. coli* reduction is half the performance registered by Latrach *et al.* (2014) with 200 L/m^2 over a bed constituted of sandy loam soil mixed to sawdust, metal iron, and charcoal at the ratio of 7.1.1 and 1 dry weight respectively, and gravel layers (3–5 mm). The difference can then be explained by the bed structure material difference (sawdust, iron, and charcoal added) which all contribute to developing an environment harmful to *E. coli*, resulting in a log reduction of 1.32.

G20S20 percolate presents higher performance for *E. coli* and the lowest for helminth eggs count, while G20S30 has the lowest for *E. coli*. The reduction performances are lower than those recorded by other authors

Table 2 | Physico-chemical parameters of household FS and percolates from sand drying beds in Yaounde

Parameters	**FS**	**Percolate** **G30S20**	 **G20S30**	 **G20S20**	**Discharge norms (MINEPDED 2016)**
pH	7.15	8.31	8.19	8.07	6–9
Conductivity (µS/cm)	1130	680	**460**	600	800
Suspended solids (mg/L)	490	47	41	**26**	50
Total dissolved solids (mg/L)	570	350	**230**	300	–
Colour (Pt.Co)	15,760	990	910	2,016	–
Turbidity (NTU)	4800	78	75	**48**	–
BOD (mgO_2/L)	1500	75	90	**75**	100
COD (mgO_2/L)	3230	480	510	**440**	200
Dissolved oxygen (mg/L)	0.23	0.48	0.43	0.57	-
Nitrates (mg/L)	16,384	22	**7**	18	20
Lead (µg/L)	247	74	81	**55**	100

Bolded values are beyond thresholds and indicate good characteristics of the bed structure.

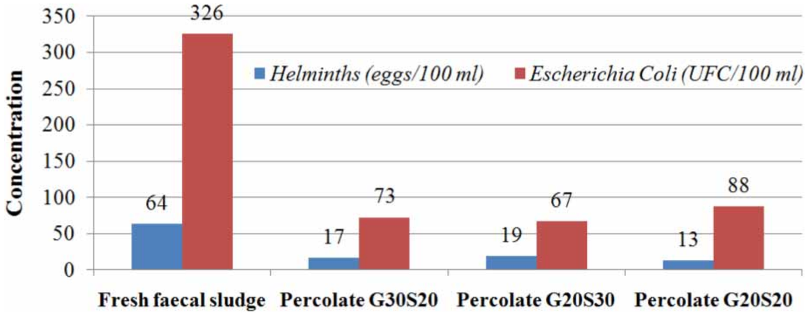

Figure 4 | Helminths and *Escherichia coli* concentration in sludge and percolates in Yaounde.

(Olufunke & Koné 2009; Tagba 2019) which ranges from 80 to 100%. This could be explained by the drying bed structure, which in those studies include a 10–30 cm thick additional gravel layer (5–10 mm).

The parasitic constitution of these sludges is of higher concentration compared to sludge tested by Tagba (2019) for helminth but very low for *E. coli.* Faecal coliform was not analysed in this study but general performances on sand drying bed range from 2 to 4 log reduction according to Tagba (2019) and Gnagne *et al.* (2019).

Table 2 shows that Cameroon norms cover most of the analysed physico-chemical parameters except dissolved oxygen, TDS, colour, and turbidity. Sludge studied shows characteristics close to those studied by Koné *et al.* (2016) for DCO, dissolved oxygen, SS, nitrates, and pH value.

It is observed that sand filtration reduces the acidity of percolates with a reduction of the organic content and it captures some acidic elements in the biosolid like lead. Indeed, filtration significantly reduces all parameters except dissolved oxygen which is increased, leading to basic low oxygen moderately saline discharge. As a consequence, it is recommended to always proceed to additional treatment before discharging them into water courses or ponds (Olufunke & Koné 2009).

3.2. Treatment performances of unplanted sand drying beds

3.2.1. Mass and volume reduction from sand drying bed

The drying process contributes to mass and volume reduction in proportions which vary with bed structure. The mass reduction recorded in Table 3 is between 79 and 82% while volume reduction ranges between 60 and 70%. The mass reduction is within the range of 80–82% for common dewatering techniques for digested sludge according to Stefanakis *et al.* (2014). In fact, regardless of the organic charge, dried sludge siccity is globally higher than 80% while using unplanted WWTP (Tagba 2019).

Table 3 | Performance evaluation of sand drying beds for physico-chemical parameters

Parameters	G30S20 (%)	G20S30 (%)	G20S20 (%)	MSL30 (%)	Norms France/Benin (%)
Percentage reduction of mass (%)	79.6	**81.9**	79	–	–
Percentage reduction of volume (%)	60	**70**	**66**	–	–
pH	−16.2	−14.5	−12.9		–
Conductivity (μS/cm)	39.8	59.3	46.9		–
Suspended Solids (mg/L)	90.4	91.6	94.7	***94***	***90***
Total Dissolved Solids (mg/L)	38.6	59.6	47.4		–
Colour (Pt.Co)	93.7	94.2	87.2		–
Turbidity (NTU)	98.4	98.4	99.0		***70***
BOD_5 (mgO_2/L)	95.0	94.0	95.0	***87***	***75***
COD (mgO_2/L)	85.1	84.2	86.4	***83***	***75***
Dissolved oxygen (mg/L)	−108.7	−87.0	−147.8		–
Nitrates (mg/L)	99.9	100.0	99.9		–
Lead (μg/L)	70.0	67.2	77.7		–

Bolded values are beyond thresholds and indicate good characteristics of the bed structure.

Volume reduction too is within the normal range indicated by Heinss *et al.* (1998) who reported that there is a change in volume of 50–80% using sand drying for sludge dewatering through filtration and drainage. According to Olufunke & Koné (2009), it can even rise up to 90%. Comparison between the different bed's structure for this study shows that the G20S30 bed has the greater mass and volume reduction, 82 and 70% respectively.

3.2.2. Drainage-specific flow

Drainage-specific flows recorded on experimental drying beds vary from 0.022 to 0.031 L/s m^2 (Figure 5). These are two to three times greater than 0.009 L/s m^2 found by Tagba (2019) in sokode (Togo) over 30 cm of gravel (5–10 mm), 40 cm of gravel (20–40 mm), and 10 cm of concrete slab. It is also close to the theoretical drainage capacity suggested by Nielsen (2003) on planted drying beds constituted of 15 cm of sand, 30–45 cm of gravel, and 10 cm of sandy loam soils. These values are better than drainage recorded by Nielsen (2003) for a continuous feeding mode (0.005–0.018 L/s m^2), thus reducing the gravel layer with finer porosity reduces drainage capacity, while reducing 10 cm of sand thickness leads to an increase of 41% of drainage capacity. Then the bed G20S20 has the highest drainage capacity while G20S30 has the lowest. As a consequence, reducing drying bed thickness increases drainage capacity as previously found by Manga *et al.* (2016) and Tchobanoglous *et al.* (2003).

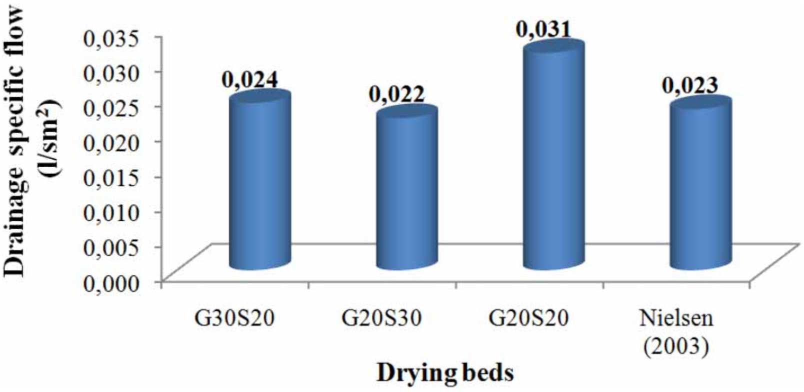

Figure 5 | Drainage-specific flow of experimental unplanted and planted drying beds.

3.2.3. Physico-chemical treatment performance

Considering the fact that Cameroon does not have clear standards on physico-chemical treatment performances for sludge, the study relied on Benin standards. According to Table 3, all drying beds reduce appearance and organic as well as ionic concentration by more than 80%, even though there is an increase in pH (12–16%) and dissolved oxygen (87–148%). Conductivity and lead reduction have lower values with the greatest values recorded for beds having 20 cm of gravel. As far as SS, COD and BOD_5 are concerned, all drying beds comply with Benin standards. Regarding overall performance, drying beds having 20 cm of gravel seems to be more efficient (G20S30 and G20S20).

Sand drying performances comply with Benin and French norms for SS, BOD_5, COD, and turbidity (70–90% removal required). Other performance parameters were not compared due to the absence of a clear performance standard.

3.3. Selection of the suitable FS unplanted drying bed

The selection is based on 10 criteria listed in Table 1 with scorecards determined based on literature review and expert consultation. Based on these criteria beds, G20S30 and G20S20 comply with seven of the 10 selection criteria (Table 4). These criteria do not consider other important parameters like arsenic, mercury, zinc, total solids, and organic matter which were analysed by Al-Muzaini (2003) for Jahra treatment plant since adequate laboratories are difficult to find and the cost of analysing samples are high.

Table 4 | Selection scoring for experimental unplanted FS drying beds

		G30S20		G20S30		G20S20		
No.	**Criteria**	**Value**	**Score**	**Value**	**Score**	**Value**	**Score**	**Threshold**
1	Specific drainage flow ($L/s.m^2$)	0.024	0	0.022	0	**0.031**	1	**0.025**
2	Concentration in $N0_3^-$ (mg/L)	22	0	**7**	1	**18**	1	**20**
3	Concentration in Pb (µg/L)	74	1	81	1	**55**	1	**100**
4	Percentage reduction BOD_5	***95.0***	**1**	***94.0***	1	***95.0***	1	**90**
5	Percentage reduction COD	85.1	1	84.2	1	**86.4**	1	**75**
6	Percentage reduction SS (%)	90.4	1	91.6	1	**94.7**	1	**90**
7	Percentage reduction helminth eggs (%)	73.4	0	70.3	0	**79.7**	0	**100**
8	LOG Reduction *Escherichia coli*	0.65	0	0.69	0	0.57	0	**1**
9	Percentage reduction of mass (%)	79.6	0	81.9	1	79	0	**80**
10	Percentage reduction in volume (%)	60	0	**70**	1	66	1	**65**
	TOTAL		**4**		**7**		**7**	

Bolded values are beyond thresholds and indicate good characteristics of the bed structure.

Despite relatively low performance on helminth and *E. coli* reduction, sand drying beds are suitable for predigested domestic FS treatment. Among tested sand gravel drying beds, according to the scoring G20S30 and G20S20 are better but the most suitable is then G20S20 with a higher specific drainage flow (41% greater than G20S30) and top values for seven out of 10 criteria. It is observed that G20S20 does perform within the threshold but is less performant than G20S30 and G30S20 for *E. coli* removal and volume reduction. Globally, these selected sand bed structures have comparable performance as 30 cm thick multi-soil layer (MSL30) tested by Latrach *et al.* (2014) the only difference lies in bacteriological performance which is higher for MSL30.

4. DISCUSSION

The performance registered within this experiment gives an idea of the practicability of the method and some indicative results. Further research with long-term testing, diverse wastewater sources, quality, and unloading would help to better appreciate the usefulness of both the approach and sand drying technology. According to Hijosa-Valsero *et al.* (2012), there is a significant decrease in unplanted wastewater treatment plant performance throughout time for all performance parameters. Thus, their performance, even if tested at the micro or mesoscale, should not rely only on the first month's efficiency.

Despite no replication being made to assess the influence of multiple charges or clogging dynamics these drying beds can be considered as appropriate passive technology for digested FS treatment in less developed countries. Indeed, treatment of low-concentration sludge with unplanted drying beds seems to significantly reduce acidity, conductivity, colour, turbidity, nitrates, BOD_5, and SS in proportions that are in accordance with discharge standards in force in Cameroon (Lako *et al.* 2021). However, further treatment is required if by-products (dry matter and percolates) are to be re-used for agriculture. Lavrnić & Mancini (2016) also concluded from an experiment in south Europe that in general, constructed wetlands like drying beds have trouble reaching the strictest standards, especially regarding microbiological parameters, but their effluents can still be suitable for reuse in areas that do not require water of the highest quality.

Despite this, constructed drying beds are still popular because of their reliability, ease of use, and low cost (Dharmappa *et al.* 1997). Latrach *et al.* (2014) even recommend a multi-soil-layering (MSL) system for decentralized sewage treatment in small communities.

Regarding the financial aspect, which is critical for adoption, a good indicator may be the cost per unit volume of sludge treated or the cost per unit area constructed. In this case, the tested drying bed cost 1 USD/L and 391 USD/m^2, which are affordable costs for onsite experiments. Indeed Gnagne *et al.* (2019) proved that results from the mesoscale (1–50 m^2) are still coherent with results from the micro-scale (less than 1 m^2). This is very interesting since the cost of testing appropriate bed structure and the material will drastically reduce when using micro-scale cheap prototypes.

From these, it is clear that the selection of appropriate low- to high-concentration FS drying bed structure for onsite experiments is possible using low footprint, low-cost prototypes with a simple test of several onsite and laboratory parameters. The evaluation frame proposed in this paper with these 10 criteria helps to decide on the most suitable bed structure based on drainage capacity, organic and ion pollution removal efficiency as well as bacteria removal efficiency for key indicators. Additional criteria could be identified and included in this methodology depending on the intended reuse of percolates or biosolids. For example, Manga *et al.* (2016) also considered dewatering time, solids generation rate, nutrient content, and helminth eggs' viability in the dried sludge. Whatever the goal, the focus should be the selection of a bed structure providing at least a 70% score. Since loading rates and sludge quality or origin could influence the result of tests it is recommended to consider loading rates between 200 and 400 L/m^2 day for such experiments.

5. CONCLUSION

This paper aimed at demonstrating a simple decision support method for the selection of a suitable unplanted FS drying bed based on 10 guiding technical criteria and simple field and laboratory tests. From this article, it is indicated that the drying bed structure (material and respective thickness) is very important to consider while designing testing schemes. The criteria proposed in this paper are easily determined from field measurements and experimentation is short (14 days for dewatering and 8 days for laboratory analysis). It seems then really practical with low-cost small units to rapidly test drying bed structures and identify the most suitable for the intended use.

Domestic pre-digested FS from households in Yaounde analysed as a case study to support decision on the drying bed structure helped to identify bed structures of 20 cm of gravel and 20–30 cm of sand as suitable for the reduction of most harmful parameters. So, the best structure is the one having the greatest drainage capacity, best organic and ionic contaminant load removal efficiency, and highest solid matter reduction performance. According to these criteria, G20S20 is preferred. Other criteria could be added to the selection grid depending on the end use of treatment by-products. For future studies, it is advisable to experiment sludge from other origins or concentrations and also conduct replications to analyse the change in performance and the clogging dynamics. Variable climate conditions could also be an interesting influential factor to assess.

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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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