

Research Article

Characterization and Quantification of Fecal Sludge in a Developing Urban Center: The Case Study of Bafoussam, West Region of Cameroon

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Abstract

This study aimed to quantify and characterize fecal sludge (FS) from on-site sanitation systems and make it available to public services. This study employed two methods: one based on the demand for mechanical emptying, and the other based on a count of the number of trucks deposited on the site. The sludge samples were then taken from the pits, followed by physicochemical, bacteriological and parasitic analyses. The results showed that all 660 households surveyed had a commode, with 73% traditional latrines, 21% modern toilets with a septic tank, 4% flush toilets, 1% VIP latrines and 1% pipe latrines. The annual volume of FS discharged at the treatment plant is estimated at 2,880 m³/year using the truck count and 40,310 m³/year based on mechanical emptying demand. In addition, the FS characteristics showed great variability, with average values of pH (6.6), Salinity (2.7 ‰), Conductivity (4.7 mS/cm), Total Dissolved Solids (TDS: 0.555 g/L), Ammonium ion (1.914 g/L), Biochemical Oxygen Demand (BOD₅: 2.858 g/L), Total volatile solids (TVS: 78.1%) and Dry Matter (DM: 12.4%). The analyses also revealed high bacterial and parasitic load with fecal coliforms concentration of $8.5 \times 10^6 \pm 0.6 \times 10^6$ CFU/100mL, fecal streptococci concentration of $3 \times 10^6 \pm 1.7 \times 10^6$ CFU/100 mL and 6767 ± 1782 helminth eggs. The findings from this study will provide the scientific basis for improving the feasibility of establishing a FS treatment plant in Bafoussam.

Keywords

Fecal Sludge Management, Fecal Sludge Quantification, Fecal Sludge Characterization, On-site Sanitation System, Treatment Plants

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1. Introduction

Rapid urbanization, particularly in developing countries, has exacerbated sanitation challenges for over 2.7 billion people worldwide, projected to reach 5 billion by 2030 [1]. An estimated population of 2.5 billion lack access to improved sanitation facilities, with 892 million resorting to open defecation [2]. This urban expansion strains already inadequate sanitation infrastructures, compelling cities to urgently address these issues to align with sustainable development goals for 2030 [3]. This sustainable development program aims to improve working conditions in the sanitation sector, thereby contributing to four of the seventeen Sustainable Development Goals: eradicate poverty in all its forms everywhere in the world (SDG 1) by providing disadvantaged populations with improved access to basic services; enable everyone to live in good health and promote well-being for all at all ages (SDG 3); guarantee access to water and sanitation and ensure sustainable management of water resources (SDG 6); and promote decent work for all (SDG 8). The SDG framework provides an opportunity to reverse and improve the situation of sanitation workers [4].

The heart of this problem is fecal sludge management (FSM), increasingly recognized as essential for urban cleanliness and health [5, 6]. Yet, in many low-income countries, including Cameroon, there is a conspicuous absence of proper FSM systems, leading to indiscriminate discharge of untreated sludge into water bodies and land, posing significant

public health and environmental risks [7-9].

Continuous progress in sludge treatment processes is essential for treatment operations and the healthy development of the wastewater treatment industry. The last 30 years have seen a worldwide diversification of sludge management, treatment, and purification technologies. Although the three main disposal routes for treated sludge remain dominant (i.e., land application, landfill, and storage), new approaches are emerging that cover the use of sludge for resource recovery (hydrogen, biochar, nutrients, etc.) [10].

In "latrine cities" like Bafoussam in Cameroon, the FSM chain encounters a critical bottleneck post-collection due to the absence of treatment facilities [11]. The consequences are dire, with untreated sludge often dumped near urban areas or left untreated in the environment, exacerbating health hazards [12, 13].

Recognizing the imperative for comprehensive FSM services to safeguard public health, there is a growing demand for FS infrastructures and services [14]. However, the design and planning of treatment facilities hinge on precise data regarding FS characteristics and quantities, a crucial yet scarce resource in Cameroon and specifically in Bafoussam [15].

Therefore, this study aims to fill this critical gap by quantifying and characterizing FS from Bafoussam on-site sanitation systems, laying the groundwork for the implementation of appropriate treatment methods.

2. Material and Methods

2.1. Study Area

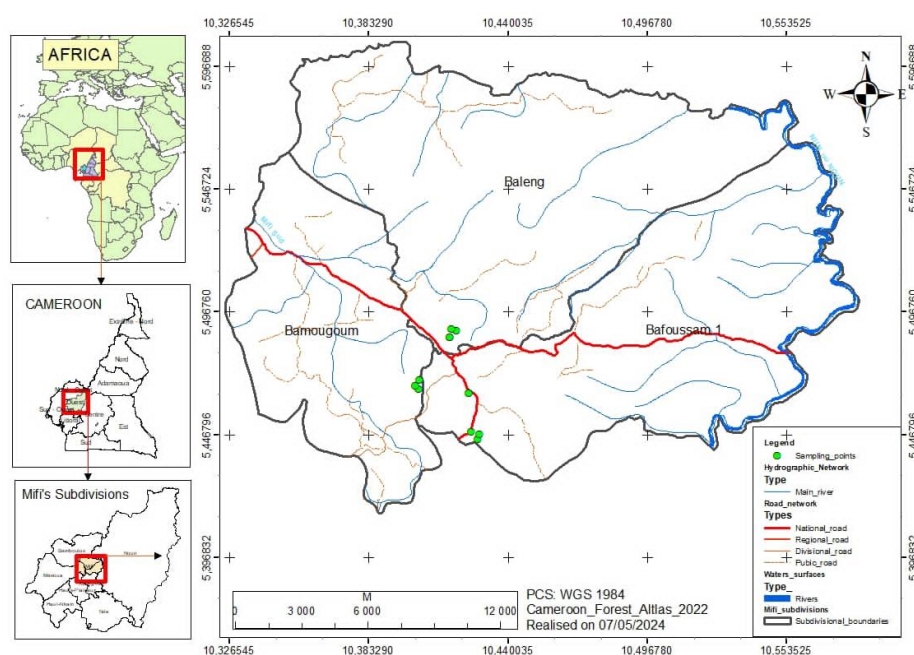


Figure 1. Thematic map showing the localization of the city of Bafoussam as well as the FS sampling points.

The present research was carried out in the town of Bafoussam, the capital of the West region of Cameroon. Bafoussam is in the Western Cameroon Highlands, with a surface area of 2,600 hectares and a population of 437,000 in 2020 [1]. The climate is mild and cool, with a dry season from mid-November to mid-March and a rainy season from mid-March to mid-November. Annual rainfall is 1,800 mm [16]. The relief is made up of a succession of hills with steep slopes. Geologically, the town is built on plateau basalt derived from ancient volcanism [17]. From a pedological point of view, Tsalefack [18] has shown that the city's soil is part of the great highland complexes of West Cameroon, made up of ferrallitic soils, and hydromorphic soils (Figure 1).

2.2. Surveys and Observations

Field surveys based on questionnaires and observations made it possible to know the existing emptying methods, the types of pits used, the emptying frequencies, the number of users, and the number of trucks.

2.2.1. Diagnosis of Sanitation Facilities in the Town of Bafoussam

The diagnosis of sanitation facilities in the town of Bafoussam was carried out using a household survey questionnaire and an interview guide sent to other structures producing FS (hotels and markets). Direct observations and meetings with stakeholders aimed to analyze the players in the sector and to investigate practices, perceptions, and problems encountered in the FSM.

2.2.2. Field Survey

To obtain a good estimate of FS production, a socio-economic survey was conducted to gather information on households and establishments that produce FS. The household survey itself consisted of asking a series of questions based on a direct administration of questionnaires to households in the study area. In all, 660 forms were administered. The information on the survey form relating to the current state of FSM was supplemented by interviews, which consisted of direct discussions with FS operators on the one hand, and employees of the major structures producing FS on the other.

2.3. Quantification Methods of FS

In this study, two approaches were used to quantify FS. The FS was quantification based on the mechanical emptying demand and counting the number of trucks dumping on the site at the treatment plant.

2.3.1. Method 1: Mechanical Emptying Demand

It is based on evaluating the production of mechanically emptied sludge. It corresponds to a collection rate and is linked to the

installed operational capacity of the emptying operators.

The production of sludge in mechanically drained structures, Q [m^3/year] is given by the relationship:

$$Q = \frac{P \cdot N}{f} * v * \eta \quad (1)$$

N : total number of sanitation facilities in Bafoussam and surrounding area;

P [%]: proportion of structures emptied mechanically;

f [year]: frequency of mechanical emptying;

v [$\text{m}^3/\text{rotation}$]: average volume of sludge emptied per facility;

η [rotations/work]: average number of rotations required to empty a wastewater facility.

2.3.2. Method 2: Counting the Number of Trucks Dumping on the Site at the Treatment Plant

This quantification method enables the investigators, over a given period, to count the number of trucks dumping their sludge at the Kouekong dumping site in Bafoussam. Interviews with the emptying operators and the site operator revealed the volume of each of the two trucks currently operating in the town, as well as the frequency with which they dumped their sludge.

2.4. Characterization of Fecal Sludge

2.4.1. FS Sampling

The FS was collected from traditional pit latrines and septic tanks, which are the main excreta collection systems in the town of Bafoussam. The adapted sampling device used consisted of an assembly comprising a metal bar one meter (1 m) long, 3 cm in diameter and weighing 10 kg. It also consisted of a hollow metal box 10 cm in diameter and 20 cm high [19]. This box is welded to the lower end of the metal bar and is used to collect excreta when the device is introduced into the pits. The upper end is connected to a graduated string measuring more than 15 m (Figure 2).



Figure 2. Fecal sludge sampling device (a: string; b: metal bar; c: graduated string).

The sampling device was inserted into the pits through the orifice. The equipment was introduced through the hole in the latrine slab, and the area was vigorously shaken. A fraction of the sample (approximately 0.628 l) was extracted, and it was transferred to 1.5-litre leak-proof polyethylene jars for easy transport. Ten (10) FS samples were taken throughout the town.

2.4.2. Physicochemical and Bacteriological Analysis

The parameters used to determine the physicochemical, bacteriological and parasitic quality of the sludge analyzed are, in particular, pH, electrical conductivity (EC), Total Dissolved Solids (TDS), salinity (Sal), biochemical oxygen demand (BOD₅), Total solids (TS), Total volatile solids (TVS), ammonium ions (NH₄⁺), fecal coliforms, fecal streptococci and helminth eggs. These parameters were determined using standard wastewater analysis protocols [20, 21].

The pH, EC, TDS and Salinity were measured in situ with the Multi Hach (HQ14d) parameters equipped with the different probes, following the same protocol by simply changing probes according to the measured gravimetrically by drying in an oven at 105 °C for 24 hours. TVS was measured using an oven at 550 °C for 2 hours. The five-day oxygen biochemical demand (BOD₅) was determined by the five-day incubation method in the dark and at 20 °C temperature using an OxiDirect (Lovibond). At the end of this incubation period, the value of BOD₅ was read directly on a BOD₅ scale on the bottle. Ammonium (NH₄⁺) was determined by using the colorimetric method with a Hach DR3900 spectrophotometer reading at adequate wavelengths. For parameter to be measured and the reading is done after stabilizing the display. TS was fecal coliforms and streptococci, these parameters were determined by membrane filtration and enumerated following the standard protocol described by Rodier et al. [21]. The culture media used were BEA medium for fecal streptococci, and TTC and Tergitol 7 medium for fecal coliforms. The parasitrap method was used to determine helminth eggs. Helminth eggs were observed, and imaging was performed using a light microscope, model Olympus CH-2.

3. Results

3.1. Diagnosis of Sanitation Systems in the City of Bafoussam

3.1.1. Socio-demographic and Residential Characteristics of Respondents

The socio-demographic and residential characteristics of the 660 households surveyed in the city's three divisions are presented in Table 1. In this survey, 61% of respondents were men and 39% were women.

The housing occupancy status revealed that the different respondents to the survey were owners (73%) and tenants

(27%). The majority of households surveyed in Bafoussam live in urban areas (74%), 51% of the households had at least secondary education, while 30% had only primary education and 10% had higher education. Overall, the households surveyed were located at mid-slope (63%), followed by those on the ridge (23%) and in the lowlands (14%). The majority of respondents were women in the household (42%), followed by heads of household (33%) and children in the household (24%). Overall, the size of households was between 5 and 10 people (59%), regardless of the commune concerned. Non-collective sanitation is predominant in the town of Bafoussam and most of the households surveyed use traditional full-flush latrines.

Concrete/cement blocks/bricks are used in the majority of cases (68%), followed by sheet metal (13%), rammed earth (6%), mats/leaves/plastic paper (5%), and planks/carpets (4%) for the superstructure walls. Concrete (92%) is the main material used to build the slab of the sanitation facilities in the households surveyed. The majority of households in the town of Bafoussam have latrines with depths of between 5 and 10 m (30%) and between 10 and 15 m (22%). Nearly 59% of respondents said they did not use water to flush excreta, whereas 41% did.

Table 1. Socio-demographic and residential characteristics.

Characteristics	Frequency	Percentage
Housing occupancy status		
Owners	481.8	73 %
Tenants	178.2	27 %
Place of residence		
Urban area	488.4	74 %
Rural area	171.6	26 %
Topographical position		
Mid-slope	415.8	63 %
Above the ridges	151.8	23 %
In the shallows	92.4	14%
Home building materials		
Semi-solid without barrier	323.4	49 %
Batted earth	178.4	27 %
Solid or semi-solid with barrier	158.4	24 %
Respondent's household status		
Household women	277.2	42 %
Household managers	217.8	33 %
Household children	158.4	24 %
Other	6.6	1 %

Characteristics	Frequency	Percentage
Level of education of head of household		
High school level	336.6	51 %
Primary education	198	30 %
Top level	66	10 %
No level	33	5 %
Not known	26.4	4%
Household size (person)		
[1-5]	198	30 %
[5-10]	389.4	59 %
[10-15]	52.8	8 %
[15-+∞]	19.8	3 %
Types of household excreta collection systems		
Traditional latrines	481.8	73 %
Modern toilet with septic tank	138.6	21 %
Manual flush latrines	26.4	4 %
VIP latrines	6.6	1 %
Cannon latrines	6.6	1 %
Level of sanitation facilities		
Medium-sized devices	396	60 %
Characteristics	Frequency	Percentage
Well-designed features	145.2	22 %
Undeveloped devices	118.2	18 %
Construction materials for superstructure walls		
Concrete/brick/baked brick	448.8	68 %
Metal Sheet	85.8	13 %
Batted earth	39.6	6 %
Mats/leaves/plastic paper	33	5 %
Planks/carabot	26.4	4 %
Others	26.4	4 %
Slab construction materials and pit depths		
Concrete	607.2	92%
Wood	39.9	6%
Stones	6.6	1%
Others	6.6	1%
Depth of pits (m)		
Between 5 and 10 m	198	30 %
Depth < 5 m	26.4	4 %
Between 10 and 15 m	145.2	22 %
More than 15 m	46.2	7 %

Characteristics	Frequency	Percentage
No information	244.2	37 %
Latrine operation		
Households not using water to flush excreta	389.6	59 %
Households using water to flush excreta	270.6	41 %

3.1.2. Fecal Sludge Management (FSM) in the City of Bafoussam

The Fecal Sludge Management (FSM) profile and socio-economic characteristics of the 660 households surveyed within the city's three divisions are detailed in Table 2.

Table 2. Fecal sludge (FS) management and socio-economic characteristics.

Solutions envisaged if the latrines are full	Frequency	Percentage
Traditional and VIP latrines		
Construction of a new latrine	429	65 %
Emptying	231	35 %
Modern flush toilets and septic tanks		
Construction of a new latrine	211.2	32 %
Emptying	448.8	68 %
Criteria for choosing an emptying service		
Quality of service	323.4	49%
Accessibility	237.6	36%
Cost	66	10 %
Other	33	5 %
Responsible for manual emptying of latrines		
Mechanical emptying when filling pits	633.6	96 %
Manual emptying when filling pits	26.4	4 %
Emptying frequency (4% _n)		
One oil change	21.648	82 %
Two oil changes	1.848	7 %
Several oil changes (between 3 and 5 times)	1.06	4%
Other	1.848	7 %
Periodicity of draining		
Emptying 3 years ago	303.6	46 %
Emptying 2 years ago	46.2	7 %
Emptying 1 year ago	191.4	29 %

Solutions envisaged if the latrines are full	Frequency	Percentage
Emptying 6 months ago	118.8	18 %
Cost to households of emptying their excreta disposal system		
<10000	59.4	9%
[10000-20000]	59.4	9 %
[20000-50000]	118.8	18 %
>50000	422.4	64 %
Reuse potential		
Types of organic fertilizer used by farmers		
Poultry manure	460	70 %
Beef Bursaries	6.6	1 %
Household waste compost	26.4	3 %
Sanitary sewage sludge	6.6	1 %
People's readiness to use treated FS in agriculture		
Favourable opinion on the use of fertilizers from FS	508.2	77 %
Unfavourable opinion on the use of fertilizers from FS	151.8	23 %
Amounts that could be disbursed for the purchase of 50 kg of fertilizer from FS (XAF)		
[1000-2000]	283.8	43 %
> 2000	85.8	13 %
[500-1000]	171.6	26 %
<500	66	10 %
Other	52.8	8 %

Among users of traditional latrines or VIP latrines, 65% thought they would build a new facility, compared with 35% who thought they would empty the pit. Among users of

modern toilets with septic tanks, 32% thought they would build a new facility, compared with 68% who thought they would empty the pit. The vast majority of households consider the quality of the service (49%) and accessibility (36%) to be the main criteria for choosing to have their tanks emptied. Of the 4% of households that use manual emptying when the sanitation system is full, 50% use a manual emptier and 42% is emptied by a family member. Of the 4% of households that have already emptied their system, 82% have done so once, 7% twice and 4% 3 to 5 times. Overall, respondents mentioned that they had emptied their sanitation facilities several times. In fact, 46% had done so more than 3 years ago, 29% a year ago, 18% less than 6 months ago and 7% 2 years ago. The majority of households surveyed (82%) felt that they had emptied their toilet only once more than a year ago.

In terms of emptying costs, most households surveyed (64%) estimate having paid more than 79.59 USD for emptying services. Emptying prices depend mainly on the type of installation, its accessibility, the volume of the pit and the distance travelled. Up to 77% of farming households were in favor of using fertilizers made from sanitary sewage sludge. This would appear to be due to the fact that these people are aware of the richness of these fertilizers in terms of plant nutrients. The majority of people surveyed (62%) thought that the cost of fertilizers produced from FS was the same as that of the organic fertilizers generally used. For those households in favor of this use (77%), 43% wanted a 50 kg bag of this fertilizer to cost between 1.59 and 3.18 USD, 26% between 0.80 and 1.59 USD, 10% wanted it to cost less than 0.80 USD and 12% wanted it to cost more than 3.18 USD.

3.2. Quantification of Fecal Sludge

3.2.1. Demand for Mechanical Drainage

Based on the parameters established above and setting a rate of one turn for each facility emptied, the quantity of sludge emptied annually is estimated at 40,310 m³ using the mechanical emptying demand approach (Table 3).

Table 3. Estimated quantity of FS produced based on the demand for mechanical emptying.

Parameters	Dry toilets	Water based toilets	Total
Number of on-site wastewater treatment facilities (N)	51,787	18,195	69,983
Frequency of emptying (%)	35.0	68.0	/
Average frequency between two emptying operations (year)	10	8	/
Volume of works (m ³)	10	10	/
η (rotation/work)	1	1	/
Quantity of sludge emptied annually (m ³)	21,751	18,559	40,310

3.2.2. Count of Trucks Discharging at the Site

Based on the parameters established above, and assuming three weekly truck rotations at the dumping site, the quantity of sludge emptied annually would be 2880 m³ or approximately 3000 m³ (Table 4).

Table 4. Quantity of FS produced in Bafoussam based on the number of lorries dropping off at the site.

Parameter	Value
Number of trucks	2
Volume of trucks (m ³)	10
Number of weekly dumping/trucks	3
Weekly volume (m ³)	60

Parameter	Value
Monthly volume (m ³)	240
Annual volume (m ³)	2,880

Estimation of the Quantity of Biosolids that will be Obtained after the Treatment of FS at the Nkouekong Station

Accurately estimating the quantity of biosolids is essential for effective agricultural utilization, as it provides critical information regarding the volume of organic fertilizer produced following sewage sludge treatment. This, in turn, facilitates the accurate prediction of the land area required for crop cultivation. Table 5 shows the estimated quantity of biosolids that will be obtained after the treatment of FS based on the two quantification methods.

Table 5. Estimated quantity of biosolids obtained after treatment of FS.

Methods	Parameters		Estimation (m ³)
	TS (%)	quantity of sludge (m ³)	
Demand for mechanical drainage	12.4	3,000	372
Count of trucks discharging at the site	12.4	40,310	4,998.44

3.2.3. Physicochemical and Bacteriological Characteristics of the FS

According to Table 6, the average pH value of the sludge analyzed was 6.6, with a variance of 0.5. From these values, it should be noted that the pH is slightly acidic. These pH values range from 5.7 to 7.8. About conductivity, very high values

were recorded for sludge from certain sanitation facilities.

A disparity was also observed in the BOD₅ values of the FS from the independent sanitation facilities analyzed, the average value recorded being 2.858 g/L. Ammoniacal nitrogen, nitrate ion, and phosphate ions levels followed the same trend as the other parameters mentioned above.

Table 6. Characteristics of raw FS produced in the commune of Bafoussam.

Parameters	Number of samples	Mean	Variances	Max	Min
pH	10	6.6	0.5	7.8	5.7
Sal (‰)	10	2.7	1.1	4.4	1.2
Electrical conductivity (mS/cm)	10	4.7	3.2	8.0	2.3
TDS (g/L)	10	0.555	0.803	2.192	0.003
NH ₄ ⁺ (g/L)	10	1.914	0.227	5.25	0.362
PO ₄ ³⁻ (g/L)	10	0.029	0.028	0.036	0.024
NO ₃ ⁻ (g/L)	10	0.436	0.112	0.558	0.3
COD (gO ₂ /L)	10	10.545	1.066	15.025	7.34

Parameters	Number of samples	Mean	Variances	Max	Min
BOD ₅ (gO ₂ /L)	10	2.858	0.408	3.720	1.5
TVS (%)	10	78.1	10.8	88.4	55.1
TS (%)	10	12.4	9.1	17.3	7.2
Fecal coliform (CFU/100 mL)	10	8.5*10 ⁶	0.4*10 ⁶	12 x 10 ⁶	1 x 10 ⁶
Fecal streptococci (CFU/100 mL)	10	3*10 ⁶	3*10 ⁶	7 x 10 ⁶	1 x 10 ⁵

3.2.4. Parasitic Characteristics of Fecal Sludge

The levels of parasites (Table 7), particularly helminth eggs, in the sewage sludge analyzed are high. The concentrations thus obtained are comparable to those of sludge from tropical countries, and therefore much higher than those of wastewater,

in which parasitic germ levels are generally of the order of 30 - 2000 germs/L [22]. Figure 3 shows some images of helminth eggs in the fecal sludge sample observed in the laboratory under the microscope.

Table 7. Mean parasitic characteristics of FS produced in Bafoussam. (n=10).

Parasite names	Mean number per liter	Standard deviation
<i>Tenia</i> sp.	3,000.1	1,964.6
<i>Ascaris lumbricoides</i>	2,301.4	581.3
<i>Strongyloides stercularis</i>	1,150.4	774.3
<i>Hymenolepis nana</i>	38.4	83.2
<i>Trichuris trichiura</i>	225.7	214.7
<i>Trichostrongylus ovum</i>	51.4	83.2
TOTAL	6,767.4	1,781.6

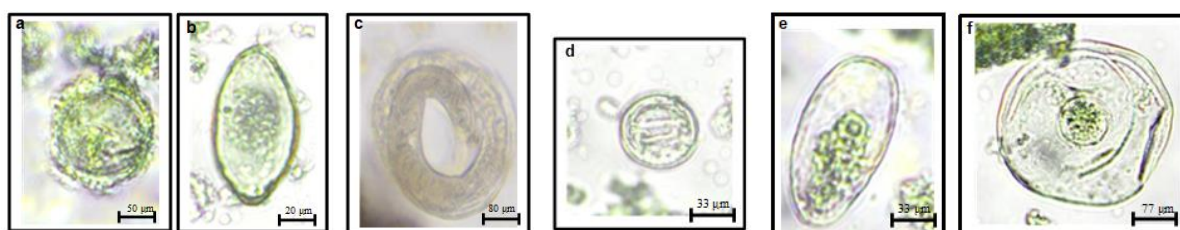


Figure 3. Images of helminth eggs contained in FS in Bafoussam.

(a: *Ascaris lumbricoides*., b: *Trichuris trichiura*, c: larvae of *Strongyloides stercularis*, d: *Tenia* sp., e: *Strongyloides stercularis*, f: *Hymenolepis nana*).

3.2.5. Characteristics of Raw FS Produced in the City of Bafoussam Compared with FS Produced in Other Cities

A comparison of the FS produced in the different towns shows variability (Table 8). Unlike household wastewater, FS is highly variable. It is 10 to 100 times more concentrated than

domestic wastewater. FS from the urban community of Bafoussam has low levels of physicochemical parameters, with the exception of ammoniacal nitrogen, which is much higher than the levels found in FS from Yaounde.

Geographical factors such as climate and topography can influence the composition of sewage and sludge. Bafoussam and Bangkok may experience environmental conditions that

favor the accumulation of solids in the sewage system, resulting in higher concentrations of solids (TS and TVS) in the sludge. Bafoussam has relatively high BOD₅ values compared to the other locations, suggesting a higher organic and inorganic pollutant load in the sewage or sludge. Yaounde stands out with exceptionally high BOD₅ values, indicating significant pollution levels in its wastewater. This could be ex-

plained by the fact that Yaounde being the capital city of Cameroon, likely has a higher population density and industrial activity compared to other locations in the study. Increased human activity and industrial discharge can contribute significantly to the organic and inorganic pollutant load in wastewater.

Table 8. Characteristics of FS in Bafoussam compared with those produced in other towns.

Parameters	Bafoussam	Bangkok [22, 23]	Accra [22, 24]	Domestic wastewater [25]	Yaounde [26]	Bangangte [27]
pH	6.6	7.7	7.6	7.904	7.7	7.23
Conductivity (mS/cm)	4.7	/	/	1589		3.96
Salinity (‰)	2.7	/	/	0.798		/
TDS (g/L)	0.555	/	/	1.017		/
MES (g/L)	8.74					
DBO ₅ (g/L)	2.858	2.8	0.6 – 1.5	0.666	15.135	2.392
TS (%)	124	16	11	1	15	10.5
TVS (%)	78.1	69	60	/	/	66.45
PO ₄ ³⁻ (g/L)	0.029			0.127		
NO ₃ ⁻ (g/L)	0.436			0.081		
NH ₄ ⁺ (g/L)	1.914	/	/	0.03-0.07	0.61	1.935

4. Discussion

4.1. Diagnosis of Sanitation Systems in the City of Bafoussam

4.1.1. Socio-Demographic and Residential Characteristics of Respondents

The majority of households surveyed in Bafoussam live in urban areas (74%), 51% of the households had at least secondary education, while 30% had only primary education and 10% had higher education. Level of education may play a role in the respondent's ability to understand issues related to FSM of on-site sanitation systems [26].

Regarding topographical position, the preponderance of latrines on mid-slopes in the households surveyed can be explained by the nature of the rugged terrain in the town of Bafoussam, which is made up of valleys, plateaus and hills. This type of terrain most often determines the occupation of building areas according to the topography and generally does not allow the entire surface area to be occupied. These results are almost similar to that of Wanda et al. [27] in the city of

Bangangte, which offers only 70% of its surface area for urbanization. The low prevalence of latrines investigated at the ridge level (23%) can be explained by the rocky soil structure, which is constantly subject to erosion and landslides [28]. This is also the case in Bangangte where households were located at crests (22.2 %); mid-slope (70%) and dregs (7.8%) [22]. The topographical layout of households is also linked to socio-economic and cultural habits.

The variability in household size within the study area can be explained by the ethnic diversity of the populations, which has an influence on family planning [29]. Letah et al. [26] obtained a different result with households dominated by men (77.7%), mostly with secondary education and with a household size varying between one (1) and six (6) people.

Non-collective sanitation is predominant in the town of Bafoussam and most of the households surveyed use traditional full-flush latrines. Different results were obtained in Maputo city, 9% of population is covered by sewerage systems, 35% uses septic tanks, 55% uses pit latrines and 1% has no facilities or practicing open defecation [30]. The full bottom type of structure is the most widespread in Sub-Saharan Africa [31-33]. The main disadvantages of this type of latrine are odors and the proliferation of flies, and it is subject to high health and environmental risks.

Concrete/cement blocks/bricks are used in the majority of cases (68%). The use of this material for the construction of toilet superstructures in the majority of households would depend on the socio-economic conditions of the populations. In addition, Jenkins et al. [34], working on the characterization of sanitation structures in Tanzania, mentioned that around 80% of latrines have a superstructure.

Concrete (92%) is the main material used to build the slab of the sanitation facilities in the households surveyed. The superstructures of these latrines are generally made of concrete/baked brick. The use of concrete as the construction material for the latrine slab can be explained by the desire to make the latrine watertight in order to limit the spread of excrement, a highly pathogenic product. These results are similar to those of Letah et al. [26] working on assessment of the FSM practices in households of a sub-Saharan Africa that showed that 93.25% of sanitation facilities were built in concrete.

The majority of households in the town of Bafoussam have latrines with depths of between 5 and 10 m (30%) and between 10 and 15 m (22%). Indeed, Jenkins et al. [34], working on the importance of using adequate sanitation systems, have shown that one of the keys to preserving the health and hygiene of populations in developing countries is the use of an appropriate excreta storage system. The depths of the pits vary, which may be due to the uneven relief of the study area. They are deeper on the ridges and shallower in the shallows.

The low rate of water use for flushing excreta in latrine operation is likely due to the majority of these latrines being dry and not connected to the water supply network. Non-collective sanitation technologies can be wet or dry. In addition, the work of Mpakam et al. [35] in the town of Bafoussam shows that people living in precarious neighbourhoods have very low incomes and are therefore unable to afford a connection to the drinking water supply network and adequate sanitation facilities.

4.1.2. Fecal Sludge Management in the City of Bafoussam

The majority of users of traditional latrines or VIP latrines, thought they would build a new facility. The vast majority of households consider the quality of the service and accessibility to be the main criteria for choosing to have their tanks emptied. This result can be explained by the inadequacy and absence of service roads in good condition to enable the emptying service to reach these dwellings, the availability of land for new construction and the high cost of emptying. These results are close to those of Mbang et al. [36], who quantified of FS from autonomous sanitation systems in the city of Yaounde, where 80% of people reported never having emptied their pits, and only 15% reported doing so. However, the difference observed in the current study can be attributed to the fact that in Yaounde, most households use large pits, which are less frequently emptied due to their capacity. However, it was noted that

people living in urban areas were more likely to ask for their systems to be emptied if they were full. This result confirms those of Deffo et al. [11] in the same city.

Respondents mentioned that they had emptied their sanitation facilities several times. This could be because, these pits are very deep, approximately more than 15 m deep. In contrary to our findings, Letah et al. [26] obtained 74.10% of respondents mentioned the emptying of their pits, 21.10% mentioned the addition of chemical substances and only 4.80% mention the construction of another latrine, and 50.99% have empty their latrine pit within a time limit not less than twice/year, 12.39% empty their latrines twice a year, 18.31% with a period of three times/year, 10.77% of respondents empty their latrines four times/year, and 7.54% more than four times/year.

The prices thus declared seem relatively high and far from the costs practiced in Yaounde, between 56.51 USD and 134.50 USD on average [36]. In Bhaluka in Bangladesh it was reported that mechanical emptying (13 USD) costs more than manual emptying (5 USD). Higher cost is also attributed to high operation and maintenance costs such as the cost of discharging FS at treatment plants or legal disposal sites [37]. The prices thus declared seem relatively high and are close to the costs charged in Yaounde, 127.34 USD on average [38]. However, these costs are far higher than those in Bafoussam (39.79-63.67 USD). This being the case, analysis of the emptying prices declared by the emptier seems relatively stable and does not show any major distortion compared with the prices mentioned in other similar studies [38]. However, Faye et al. [39] point out that the price of emptying waste is not often determined according to objective criteria and is often part of a commercial logic in which the service provider tries to make as much profit as possible. Similar results were obtained when characterising the mechanical emptying activity in the city of Yaounde [29].

77% of farming households were in favour of using fertilisers made from sanitary sewage sludge. The majority of people surveyed (62%) thought that the cost of fertilizers produced from FS was the same as that of the organic fertilizers generally used. These results were in line with the work of Kingel et al. [40], who showed that the use of FS is highly economically advantageous. Overall, FS is a very heterogeneous product containing significant quantities of nutrients, carbonaceous matter, biodegradable compounds, and bacteria. Its recovery must take into account the concentrations of its various components, particularly biodegradable compounds, and also the possibility of draining the product formed [41].

4.2. Quantification of Fecal Sludge

4.2.1. Demand for Mechanical Drainage

Based on demand for mechanical drainage, the quantity of sludge emptied annually is estimated at 40,310 m³. The work of kodom et al [42] on sludge quantification in Kara gave

similar results with 41347.2 m³/year. These quantities of sludge produced are much higher than those produced in the municipality of Bangangte (10,479 m³/year) [27].

4.2.2. Count of Trucks Discharging at the Site

The quantity of sludge emptied annually would be approximately 3000 m³. These quantities of sludge produced are much lower than those produced at the Nomayos site in Yaounde (51,247.56 m³/year) and the Bois des Singes site in Douala (151,000 m³) [15, 42]. This wide disparity could be justified by the intensity of the emptying activity in each of these towns. In Bafoussam, only two trucks are used for emptying, while in Douala, the emptying fleet comprises forty-one trucks (151,000 m³). In Yaounde this fleet has around forty emptying trucks [43].

4.3. Physicochemical and Bacteriological Characteristics of the Sludge Analyzed

The variation of pH is undoubtedly due to the Construction materials of the devices. This result is similar to that of Pegui et al. [15] working on the quantification and characterization of FS in the city of Douala with an average pH of 6.6 and different from that of Ato et al. [43] working on the chemical characterization of FS in the metropolis of Kumasi, Ghana with an average pH of 7.87.

The average conductivity was 4.7 ms/cm, with a variance of 3.2 ms/cm. It appears that these facilities are characterized by the high electrical conductivity of the sludge produced. This value is higher than that obtained by Wanda et al. [27] in septic tanks (1.18 mS/cm and 0.56 mS/cm, respectively). This difference can be explained by the typology of autonomous sanitation devices. However, some samples recorded very low electrical conductivity values. Indeed, Moussa [44] has shown that there is a relationship between conductivity and mineralization so that a conductivity of >1000 µS/cm indicates excessive mineralization of the effluent.

Organic matter (BOD₅ and COD) contents in samples were high, contrasting those obtained by Kengne et al. [45] in the city Yaounde, Wanda et al. [27] with the highest values of BOD₅ and COD recorded in pit latrines (4.640 gO₂/L and 10,951 gO₂/L respectively). However, values recorded by Bassan et al. [46] are generally of the same range with those obtained in this study. These characterized sludge BOD₅ values are greater than 1485.7 mg/L, and well below the 11,835 and 24,600 mg/L reported by Pegui et al. [15], Appiah-Effah & Nyark [47] and Gudda et al. [48] respectively. This observed variance could be due to differences in diet and user habits, as these studies were conducted in different geographical areas associated with different diets and management practices [49]. The samples reported by Pegui et al. [15], however, were from mixed sludge collected from trucks, unlike the upper-layer sludge used in this study, which was sampled directly from on-site sewage systems.

The average NH₄⁺ content was 1913.9 mg/L. The quantity of TS and TVS varied greatly depending on the treatment works investigated. TVS levels varied between 55.1% and 88.4%, with an average of 78.1%. Variability was also observed in changes in TS, with values ranging from 7.2% to 17.3%, with an average of 12.4%. These dry matter values reflect the high-water content and pollutant load of FS in the town of Bafoussam. These results corroborate those of Bigumandondera [50] working on non-collective sanitation in sub-Saharan Africa: application to the city of Bujumbura, shows a variation in the rate of TS and TVS, indicating that FS still contains a significant proportion of organic matter that should be recycled. However, this data also serves as a warning of the health and environmental consequences of dumping FS in the natural environment without prior treatment.

The concentrations of fecal coliforms and fecal streptococci, which are indicators of fecal contamination, although high, are within the range of concentrations commonly found in excreta.

4.4. Parasitic Characteristics of Fecal Sludge

The presence of these parasitic germs in FS thus indicates a greater likelihood of gastrointestinal diseases and viral infections in the population of the town of Bafoussam. Nzoubet et al. [51] working on the treatment of FS in a pilot-scale artificial vertical flow wetland for the removal of helminth eggs obtained the lowest quantities with an average value of 62.51 helminth eggs/g DM, this may be because the majority of its FS came from public toilets and that They were therefore more stable than ours.

5. Conclusion

With an annual volume of approximately 41.000 m³ disposed of at Nkouekong through mechanical emptying and an additional 3.000 m³ by trucks count, it is evident that a substantial amount of sludge is generated from various subdivisions. Moreover, the high concentration of microbes and parasites in the sludge emphasizes the urgency of establishing a treatment plant and promoting awareness regarding proper handling and transportation of FS. This is crucial not only for safeguarding public health but also for addressing broader challenges such as energy security, job creation, and sustainable resource utilization. Despite being a significant issue in sub-Saharan African countries like Cameroon, FSM often receives insufficient attention in sanitation programs and projects, particularly regarding on-site sanitation facilities. Recognizing the potential of FS as a valuable resource underscores the importance of integrating comprehensive management strategies into sanitation initiatives, thereby unlocking its potential for beneficial reuse and contributing to sustainable development goals.

Abbreviations

BEA Medium	Bile Esculin Agar Medium
BOD ₅	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
FS	Fecal Sludge
FSM	Fecal Sludge Management
Sal	Salinity
SDG	Sustainable Development Goals
TDS	Total Dissolved Solids
TS	Total Solids
TTC Medium	2,3,5-triphenyltetrazolium Chloride Medium
TVS	Total Volatile Solids

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Declarations

Ethics approval and consent to participate Consent for publication.

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Conflicts of Interest

The authors declare no conflicts of interest.

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