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ARTICLE

Characterization and Management of Sewage Sludge in Abomey-Calavi: Pathways to Sustainable Treatment Solutions

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ABSTRACT

In the Republic of Benin, as in many other West African countries, urban areas have experienced rapid population growth in recent years. This situation has led to an increasing demand for sanitation facilities, necessitating regular emptying of these systems. In a bid to reduce health risks and protect the surrounding natural environment, the management of the by-products from these systems has become a significant concern for decision-makers at various levels. This study aims to characterize fecal sludge at the Abomey-Calavi treatment station and suggest a mixed biological treatment approach. Fifteen sewage sludge samples were collected in 1,500 ml plastic bottles from Adjagbo's Sewage Treatment Station, operated by SGDS-SA, a Waste Management and Sanitation company. Physico-chemical parameters were determined using spectrophotometric analysis. Colonies were enumerated using membrane filtration and inoculation. Correlation analysis was performed on sewage sludge samples. The main results indicate an alkaline character (pH > 7) and a high organic pollutant load in the fecal sludge, with average concentrations of Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand over 5 days (BOD_5) at 18,730 mg $O_2.L^{-1}$ and 6,612 mg $O_2.L^{-1}$, respectively. The COD/BOD_5 ratio of 2.83 suggests that the material is partially biodegradable. Furthermore, the nutrients exhibited high concentrations of nitrates, with an average value of 4,786 mg.L^{-1}, while nitrites, ammoniacal nitrogen, and orthophosphates had average concentrations of 22.48 mg.L^{-1}, 119.74 mg.L^{-1}, and 239.0 mg.L^{-1}, respectively. This study characterized fecal sludge at the Abomey-Calavi treatment station and suggests a mixed biological treatment approach.

Keywords: Characterization; Fecal Sludge; Treatment; Benin

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1. Introduction

The issue of wastewater and fecal sludge management has become increasingly pressing for policymakers in developing countries. In urban areas of these nations, particularly in Benin, in the absence of collective sanitation facilities, households primarily depend on individual sanitation systems, although access rates remain low [1,2]. These sanitation systems generate significant quantities of fecal sludge, evacuation, transportation to appropriate treatment facilities, and valorization which are crucial for minimizing health risks and protecting the immediate environment. This challenge is a major concern for both households and the authorities overseeing fecal sludge management at various levels [3,4].

Furthermore, open defecation and uncontrolled dumping of sludge from sanitation systems into the environment persist in certain regions of sub-Saharan Africa, particularly in the absence of suitable disposal sites and adequate disposal systems [5–7]. Such deplorable practices are responsible for numerous public health issues, including aesthetic and olfactory nuisances, as well as the increasingly detected contamination of groundwater, thereby highlighting the vulnerability of aquifers to pollution [2,8,9]. Moreover, according to the final results of the fourth general population and housing census (RGPH4), approximately 7,000 individuals, including 4,300 children, die each year from diarrhea [10]. These fatalities are attributed to 90% of cases arising from contaminated water sources (both surface and groundwater) and inadequate sanitation and hygiene facilities [9,10]. The most critical challenge is the lack of urban infrastructure and functional sanitation systems, compounded by rampant population growth [11,12]. Consequently, it is imperative and urgent to establish a well-supported modern policy for the management of fecal sludge.

In Benin, following the implementation of the Government Action Program for 2021–2026, two treatment stations have been established and made operational to receive and treat fecal sludge from the autonomous sanitation systems in the cities of Cotonou, Abomey-Calavi, Porto-Novo, and surrounding regions. One of these stations, located in the municipality of Abomey-Calavi, can receive up to 600 m³ of fecal sludge per day, while the other, situated in Sèmè-Podji, has a capacity of 506 m³/day, expandable to 755 m³/day [13]. A third station is currently under construction in the city of Parakou.

For sustainable management and effective treatment of fecal sludge, it is essential to establish a robust and reliable database to evaluate the quantity of sludge generated and monitor its evolution. This will facilitate the planning and definition of future strategies, assess their valorization potential, optimize treatment methods, predict environmental emissions, and ultimately work towards mitigating their impact. Therefore, the characterization of fecal sludge becomes a necessary tool for reporting on the quality and quantity of the material to be managed [14]. However, establishing a safe and effective management system for fecal sludge is not straightforward. A significant obstacle remains the availability of characterization and quantification data, which continues to pose a persistent challenge.

It is for these reasons that the present study aims to conduct a physicochemical and microbiological characterization of the fecal sludge discharged at the Kanssoukpa site in Abomey-Calavi, Benin.

2. Materials and Methods

2.1. Study Area

The commune of Abomey-Calavi is located in southern region of Benin, within the Atlantic province. It is bordered to the north by the commune of Zè, to the south by the Atlantic Ocean, to the east by the communes of Sô-Ava and Cotonou, and to the west by the communes of Tori-Bossito and Ouidah (**Figure 1**). This commune is the largest in the province, occupying over 20% of its area. It spans 539 km², which represents 0.48% of the national territory of Benin, and exhibits the highest average population density in the Atlantic province, with 1,218 inhabitants per km². It comprises 145,510 households and a total population of 656,358 [15].

The climate is characterised by distinct rainy and dry seasons. The long rainy season extends from April to July, while the short rainy season occurs from October to November. Regarding the dry seasons, the short dry season lasts from August to September, and the long dry season runs from December to March.

There are three aquifers in the area: the Continental

Terminal aquifer, which is approximately 120 metres deep; the Paleocene aquifer, located at a depth of 320 metres; and the Maastrichtian aquifer, which reaches depths of 1500 metres. The drinking water for the municipality of Abomey-Calavi is sourced by drilling into the Continental Terminal aquifer Terminal [16,17]. According to reports, the Continental Terminal begins with a sandy clay marine layer containing glauconite, followed by continental deposits that consist of sand, sandy clay, clay, and sandstone, becoming progressively more detrital and coarser [17,18]. The layers are discontinuous and irregular, exhibiting lenticular forms.

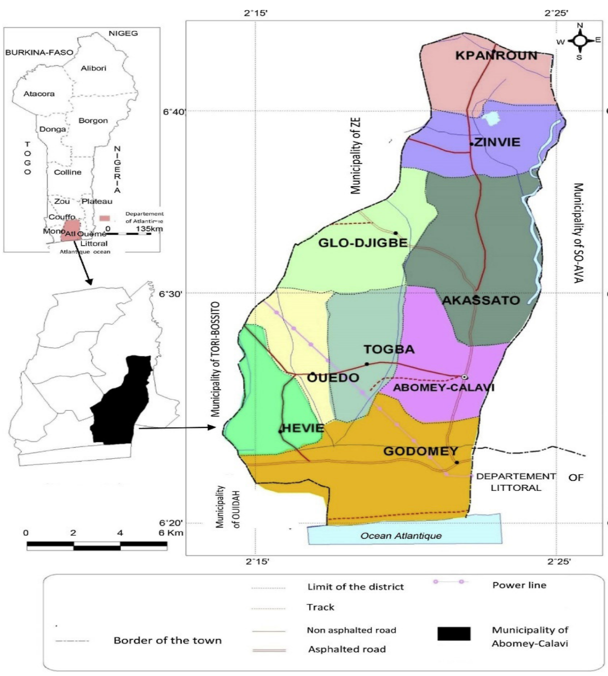

Figure 1. Location of the Study Area.

2.2. Sludge Sampling Site

Samples of sewage sludge were collected from the Sewage Treatment Station (STS) located at Adjagbo, which is operated and maintained by the Waste Management and Sanitation Company (SGDS-SA). The Adjagbo STS has a treatment capacity of 600 m³ per day. The treatment process employed is lagooning, utilizing a technology of planted drying beds (with macrophytes in primary treatment) and lagoons in secondary treatment. This is a natural treatment system that requires no chemical inputs and has very low electrical energy consumption.

Specifically, this process includes screening of sludge deposited by trucks; a stirred buffer basin with a volume of 1,200 m³; primary treatment using macrophyte-planted drying beds (20 beds with a total surface area of 36,500 m²); secondary treatment through a series of lagoons (three lagoons with areas of 4,680 m², 3,100 m², and 3,100 m²); a rock filter of 1,400 m² to improve the quality of the effluent from secondary treatment and final treatment using two series of lagoons, each measuring 2,000 m².

2.3. Sampling and Conditioning of Sludge

Five sewage sludge samples were collected per month for three months in 1,500 ml plastic bottles. These bottles were thoroughly washed with detergent and rinsed extensively with distilled water before being left to dry before sampling. To ensure a sufficiently representative sample, collections were made during the discharge of sludge by vacuum trucks, following three phases at proportions of 1/3 each: one at the beginning, one after half of the tanker's contents had been discharged, and a final collection at the end. Thus, five samples were obtained, each consisting of a mixture of sludge from septic tanks and latrines. This sampling campaign was repeated once a month for three months. These samples were kept cool and transported promptly to the laboratory. For ease of handling, each sample was labelled according to the order of collection.

2.4. Methods

The pH of the samples was measured in situ using a HACH model HQ4300 pH meter. The dry matter content was determined by drying a precise mass of sewage sludge in an oven at 105 °C until a constant mass was achieved. Sludge samples were centrifuged at approximately 4,500 rpm for about 20 minutes to collect the sediment mass. This sediment, dried at 105 °C and weighed, allowed for the determination of suspended solids according to the NF T 90-105-2 standard.

Organic matter and organic carbon were quantified through the incineration of pre-dried sludge in an electric furnace at 400°C, following the NF EN 15935 standard. Parameters such as nitrites, nitrates, ammoniacal nitrogen, and phosphates were determined using molecular absorption spectrometry method (UV-VIS T65) in accordance with the NFT EN 26777, ISO 7890-3, AFNOR NF T90-

015-2, and NF EN ISO 6878 standards, respectively. Total nitrogen was assessed following the oxidation of bound nitrogen to nitrogen oxides at high temperatures, in accordance with the NF EN 12260 (T 90-060) standard. Chemical Oxygen Demand (COD) was determined using the reflux method in an open system, as per NF T 90-101. This method involves oxidizing all oxidizable material contained in a known quantity of the sample using an excess dichromate solution in the presence of a silver catalyst (silver sulfate) in a strongly acidified medium with sulfuric acid. The excess dichromate was then titrated with a ferrous ammonium sulfate solution in the presence of a ferroïne indicator. Biochemical Oxygen Demand over five days (BOD_5) was measured using the respirometric method, as outlined in AFNOR NF EN 1899-2 (T90-103-2) [19].

The enumeration of colonies through membrane filtration and inoculation into appropriate culture media, as well as liquid media, followed the NF EN ISO 9308-1 standard and allowed for the determination of fecal coliforms and Escherichia coli. Chromo cult Agar was employed, followed by incubation at 44°C for 24 hours.

Data Processing

To analyse the varying strength and direction of the relationships between two or more variables assessed on sewage sludge samples, a correlation matrix was established. To ensure that the correlations between the variables are sufficiently strong for the application of dimension reduction techniques, such as principal component analysis (PCA), Bartlett's test of sphericity was employed. A significant result at the 5% level allows us to reject the null hypothesis that all correlations are equal to zero, indicating homogeneity among the variables.

To determine whether the correlation matrix is "singular", we calculated the "determinant" of the matrix. This determinant should not equal 1 in order to reject the null hypothesis. Both the determinant and Bartlett's test of sphericity assist in verifying whether a correlation matrix possesses the necessary properties for conducting a PCA. **Table 1** presents the results of the determinant of the correlation matrix alongside those of Bartlett's test.

Correlation analysis is a statistical technique that provides insights into the relationships between variables. The Pearson correlation coefficient(p) can be expressed as a percentage. Thus, the closer the coefficient p is to the extreme values of −100 or 100, the stronger the linear relationship between the variables. PCA was employed to assess the relationships among the various variables measured and their structure for potential grouping by zone.

Table 1. Determinant and Bartlett Correlation Test.

Correlation Matrix Determinant	**2.418643e−19**		
Bartlett correlation test	Chisq	P-value	Df
	3,856,704	1,02e−04	120

The software R software, version 4.4.1 along with its RStudio interface (2024.09.0–375) was used to process the data.

3. Results and Discussion

3.1. Physicochemical Characterization of Sewage Sludge

Table 2 displays the descriptive statistics of the physicochemical parameters analyzed. The analysis of **Table 2** reveals that the temperature and electrical conductivity range from 26.6 to 28.3 °C and from 18.78 to 22.32 mS cm^{-1}, with average values of 27.56 °C and 21.33 mS cm^{-1}, respectively (**Table 2**).

These values for electrical conductivity are significantly higher than those reported by previous studies [7,20–22]. This suggests a pronounced mineralization reaction of the nutrients.

The temperature values are slightly lower than those reported by Kone (31.82 °C) and Irotori (30.93 °C). These temperature and electrical conductivity values, along with pH, indicate a medium conducive to the activity of mineralizing microorganisms, primarily psychrophilic bacteria ($T < 30$ °C). It is noteworthy that biological activity is more pronounced during warmer periods than in winter, as it plays a crucial role in the kinetics of reactions.

The pH of the sewage sludge varies between 7.33 and 8.53, with a mean value of 8.224 and a median of 8.37, coinciding with the first quartile. Generally, a pH value above 7 suggests a basic nature of the sample. The analyzed sewages sludge's are predominantly basic, exhibiting a tendency towards neutrality. These results are consistent with from the study conducted on the sludge of septic tanks and latrines in the Ouémé Delta basin in Benin (**Table 2**) [20]. Similar approximate results were observed in the municipality of Abidjan in Côte d'Ivoire [22], indicating values very close to the neutral zone (pH = 7). The same outcome was recorded in the sewage sludge of the city of Aného in Togo and in that deposited on the drying beds of Zagtouli in Ouagadougou [7,21]. This pH range (5–9) is highly favorable for developing a wide range of microorganisms responsible for the purification of sludge. For instance, Nitrosomonas, a bacterium involved in nitritation, has an optimal pH range between 7.4 and 9, while those engaged in nitration thrive between 8.5 and 9.1 (**Table 2**) [21].

Table 2. Physicochemical Parameters of Sewage Sludge.

Parameters	***Units***	***Min.***	***1st Qu.***	***Median***	***Mean***	***3rd Qu.***	***Max.***
Temperature	°C	26.60	27.30	27.50	27.56	28.10	28.30
Electric Cond.	*mS.cm^{-1}*	18.78	21.67	21.80	21.33	22.10	22.32
pH		7.330	8.370	8.370	8.224	8.520	8.530
NO_2^-		8.60	20.17	21.61	22.48	28.71	33.31
NO_3^-		3,556	3,893	3,946	4786	4,817	7,716
NH_4^+		3.95	100.58	115.33	119.74	170.81	208.03
TN	*mg.L^{-1}*	4,840	4,940	5,460	5,390	5,780	5,930
PO_4^{2-}		30.6	118.8	194.4	239.0	284.8	566.4
OC		170.4	200.0	340.0	382.1	540.0	660.0
OM		306.3	360.0	612.0	687.7	972.0	1,188.0
SM		400.7	404.0	1,010.0	998.9	1580.0	600.0
MES		30,000	32,000	59,000	49,570	61,850	65,000
COD		2,449	17,760	22,560	18,730	23,520	27,360
BOD_5	*mg O_2.L^{-1}*	1,281	4,394	6,654	6,612	7824	12,906

Furthermore, such a high pH value contributes to reducing certain pathogenic bacteria. This is particularly true for fecal coliforms, which decline in number as the pH increases, reducing their prevalence in the environment.

Orthophosphates are present in concentrations ranging from 30.6 mg L^{-1} to 566.4 mg L^{-1}, with a mean value of 239.0 mg L^{-1}. Similarly, nitrates (NO_3^-) are found in substantial quantities in the sewage sludge, ranging from 3556 mg L^{-1} to 7716 mg L^{-1}, with an average of 4786 mg L^{-1}. These values significantly exceed those reported by [7,20,21]. This substantial variation in nitrate levels in the sewage sludge may be attributed to the highly favorable pH for the microbial activity of nitrifying bacteria in the nitrogen cycle. Additionally, the electrical conductivity supports the mineralization of nutrients, particularly organic nitrogen. In nitrates, nitrogen is in its highest oxidation state (+V), thus representing a strong oxidant in the nitrogen transformation chain.

The elevated concentration of this mineral form of nitrogen could be due to the duration of sewage sludge retention in the tanks, the frequency of septic tank emptying, and the various cleaning products used in latrines. In contrast, nitrites and ammonium present lower values, ranging from 8.6 to 33.31 mg L^{-1} and from 3.95 to 208.03 mg L^{-1}, respectively. These low values, when compared to those recorded nitrates, can be explained by the fact that ammonium, the acidic form of ammonia, would more readily convert to ammonia in a slightly alkaline medium, following the reaction equation (1):

$$NH_4^+ + OH^- \longrightarrow NH_3 + H_2O \quad (1)$$

Thus, ammonia, through nitrification, initially converts to nitrites according to the following equation (2):

$$NH_3 + O_2 \xrightarrow{Enzyms} NO_2^- + 3H^+ + 2e^- \quad (2)$$

Nitrites are generally unstable and are converted more rapidly into nitrates through an oxidation reaction catalyzed by enzymatic activities within the nitrogen cycle, as indicated by the following reaction (3):

$$NO_2^- + H_2O \xrightarrow{Enzyms} NO_3^- + 2H^+ + 2e^- \quad (3)$$

The duration of the sludge in the pits would justify the time required for the occurrence of each of these chemical and biological reactions within the sewage sludge. However, these values are below those reported by Irotori et al., (2022) and significantly higher than the values of nitrites and ammonium obtained by Kone et al., (2017). Furthermore, our results indicate a higher concentration of nitrates compared to nitrites in the sewage sludge. These findings are in agreement with the result of contrast with those of other authors (**Table 3**) [20].

This variation may once again be explained by the types of sludge sampled (latrine, VIP, septic tank, or a mixture of all), as well as the duration of the sludge in the pits, which varies from household to household.

Total nitrogen (TN), organic carbon (OC), and organic matter (OM) concentrations range respectively from 4840 to 5930 $mg.L^{-1}$, 170.4 to 660.0 $mg.L^{-1}$, and 306.3 to 1188.0 $mg.L^{-1}$, with mean values of 5390 $mg.L^{-1}$, 382.1 $mg.L^{-1}$, and 687.7 $mg.L^{-1}$. These values indicate the presence of biodegradable materials within the sewage sludge. Additionally, the carbon to nitrogen ratio is equal to 0.07. This very low value does not support the selection of a biological treatment for the analyzed sludge, which requires an optimal C/N ratio between 20 and 30 [23,24]. Moreover, the chemical oxygen demand (COD) and biochemical oxygen demand over five days (BOD_5) exhibit mean values of 18730 $mgO_2.L^{-1}$ and 6612 $mgO_2.L^{-1}$, respectively. The COD/BOD_5 ratio of 2.83 further confirms the presence of a significant proportion of biodegradable materials [25]. Similar results have been reported in Abidjan, Ouagadougou, and Togo [7,21,22]. Therefore, biological treatment may not be favorable for the sewage sludge, as over time, the settleable organic matter undergoes biological transformation in the pit through anaerobic processes (liquefaction, acidogenesis, methanogenesis) [26]. In contrast, higher COD/BOD_5 ratios have been recorded in Benin by Irotori et al., (2022) in the sludge of the Ouémé Delta. Factors such as sampling method, season, and duration of sludge storage in the pits could account for this variability in results.

Dry matter (DM) and suspended solids (SS) concentrations range from 400.7 $mg.L^{-1}$ to 1600.0 $mg.L^{-1}$ and from 30000 $mg.L^{-1}$ to 65000 $mg.L^{-1}$, with mean values of 998.9 $mg.L^{-1}$ for dry matter and 49570 $mg.L^{-1}$ for suspended solids. The high concentration of suspended solids obtained in the sewage sludge accounts for the COD value, as a significant proportion of the latter is in particulate form [26]. According to Koné et al. (2011), suspended solids (both particulate and colloidal) consist of organic matter, micropollutants (both organic and inorganic), microorganisms (bacteria, viruses, etc.), and mineral salts. They can, therefore, be a source of organic clogging of filters due to obstruction [27].

Table 3. Comparison of the Measured Parameter Concentrations with Those Reported by Other Authors.

	Units	Ab-Calavi Bénin	Soro et al., (2020) Abidjan	Kone et al., (2017) Ouagadougou	Poromna et al., (2020) Togo	Irotori et al., (2022) Bénin
Temp.	**°C**	27.56	-	31.82	-	30.93
Cond.E	**$mS.cm^{-1}$**	21.33	3.75	3392	9.10^{-3}	12.68
pH		8.22	7.31	7.58	7.41	7.58
NO_2^-	**$mg.L^{-1}$**	22.48	-	0.50	-	35.37
NO_3^-		4.786	-	23.7	71.33	0.79
NH_4^+		119.74	367.50	557	371.88	427.28
NT		5.39	-	-	-	520.24
CO		382.1	-	-	-	-
MO		687.7	-	-	-	-
MS		998.9	981	-	144.000	-
MES		49.57	21.12	1125	-	-
PO_4^{2-}		239.0	-	39.5	102.67	-
COD	**$mgO_2.L^{-1}$**	18.730	19.400	1.950	13.140	37,570.93
BOD_5		6.612	9.465	785	6.201	5500.66
Coli. Fec	**UFC/100 ml**	60.060	672.370	320.000	7.78E+08	-
E.Coli		30.840	-	-	2.20E+08	-

3.2. Microbiological Characterization of Sewage Sludge

Table 4 displays the descriptive statistics of fecal coliforms and Escherichia coli in the sewage sludge. The analysis of **Table 4** shows that several fecal coliforms and Escherichia coli range from 44,601 to 75,000 CFU/100 ml and from 7,800 to 47,000 CFU/100 ml, with mean values of 60,060 and 36,000 CFU/100 ml, respectively. Higher values have been reported in similar studies [7,21,22]. This may be attributed to the variability in the characteristics of sewage sludge from one environment to another, as well as the methods of sampling, storage duration, and the characteristics of different seasons. Furthermore, these lower values are influenced by the alkaline nature of our samples. According to Chedad and Assobhei (2007), a basic pH significantly reduces the growth rate of coliforms. They indicate that the T90 values for fecal coliforms at pH 5, 7, and 8.3 are 75 hours, 25 hours, and 20 hours, respectively.

Table 4. Microbiological Characterization of Sewage Sludge.

	unit	*Min.*	*1st Qu.*	*Median*	*Mean*	*3rd Qu.*	*Max.*
Feacal Coliform	***UFC/100 mL***	44,601	53,300	60,300	60,060	67,100	75,000
E.Coli		7,800	20,400	36,000	30,840	43,000	47,000

3.3. Statistical Analysis of Data (PCA)

3.3.1. Correlation Matrix

Figure 2 presents the results of the correlation analysis among all the parameters measured in the studied sewage sludge samples.

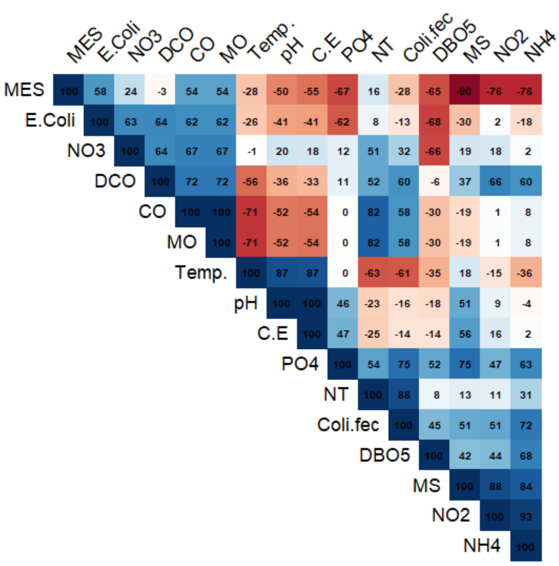

Figure 2. Correlation Analysis Among Parameters Measured in the Studied Sewage Sludge Samples.

The correlation matrix shows a significant correlation among the analyzed parameters, with positive correlations observed among parameters like MES, E. coli, nitrates, COD, organic carbon, organic matter, orthophosphates, pH, electrical conductivity, total nitrogen, fecal coliforms, BOD_5, total solids, nitrites, and ammonium ion. Positive correlations were observed with temperature, pH, and electrical conductivity, while negative correlations were found with fecal coliforms, BOD_5, total solids, nitrites, and ammonium ion. The strong correlation of COD with E. coli, nitrates, organic matter, total nitrogen, fecal coliforms, nitrites, and ammoniacal nitrogen suggests a close link between organic pollution and fecal-origin bacteria (**Figure 2**).

The correlation matrix shows a strong correlation between phosphates, total nitrogen, fecal coliforms, BOD_5, total solids, and ammoniacal nitrogen, suggesting potential for nutrient recovery from sewage sludge. However, it also warns of potential coliform contamination of water during sludge application to agricultural land, requiring careful management.

3.3.2. Principal Component Analysis (PCA)

Figure 3 displays the Principal Component Analysis (PCA) of the sludge physicochemical parameters. The analysis of **Figure 3** shows that the first and second factors account for 72.50% of the explained variance in sewage sludge. Factor1 (F1) is positively correlated with Suspended Solids (MES), organic matter, Chemical Oxygen Demand (COD), total nitrogen, fecal coliforms, Escherichia coli, and nitrates, while negatively correlated with electrical conductivity, pH, and temperature. Factor 2 (F2) is strongly correlated with dry matter, ammoniacal nitrogen, and MES, indicating high nutrient content and contamination by fecal-origin bacteria. Two primary categories of sewage sludge are identified by this analysis, taking into consideration the contribution of the examined factors for characterizing sewage sludge:

Class 1: Sewage sludge that is rich in nutrients and has low levels of organic contaminants and high amounts of fecal bacteria. Fecal-origin bacteria will be more prevalent and the sewage sludge will contain less organic pollutants if it is nutrient-rich.

Class 2: Sewage sludge that is extremely low in nutrients, low in microorganisms, and high in organic contaminants. Fecal-origin bacteria will be more prevalent and the sewage sludge's nutritional content will be lower if it contains more organic contaminants.

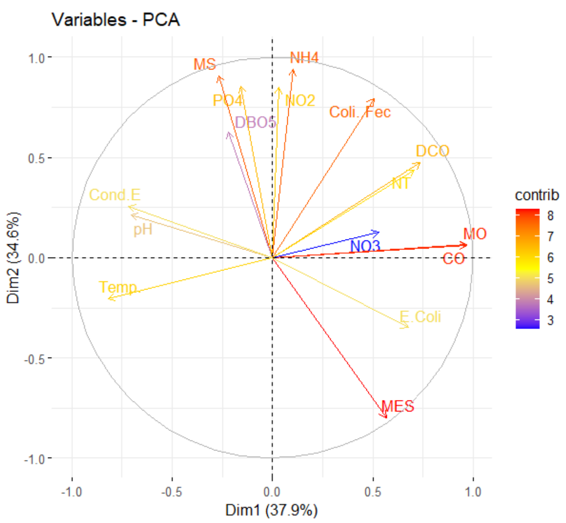

Figure 3. Principal Component Analysis of the Sludge Physicochemical Parameters.

4. Conclusion

In light of the findings, this study provides a comprehensive database on the characterization of sewage sludge in Benin. The mean BOD5/COD ratio of 2.83 indicates a significant presence of biodegradable organic matter, suggesting that the sludge contains substantial organic material suitable for treatment. However, the C/N ratio of 0.07 is markedly low compared to the optimal range of 20 to 30, which severely limits the potential for biological treatment methods.

These findings underscore the necessity for a mixed treatment approach that incorporates both biological and chemical processes. Given the high levels of biodegradable organic matter, integrating biological treatment options with supplementary measures, such as chemical dosing or aerobic treatment, could enhance the overall efficiency of the treatment process. Therefore, we recommend that future treatment strategies for faecal sludge focus on addressing the low C/N ratio while capitalising on the high biodegradable content. This approach could significantly improve the sustainability and effectiveness of sludge management practices in Benin.

Author Contributions

Conceptualization, N.T.; methodology, N.T.; validation, N.T. and B.A.; formal analysis, G.J.G.; investigation, B.A.; data curation, B.A.; writing—original draft preparation, B.A.; writing—review and editing, G.J.G., F.P.T. and J.F.; supervision, N.T., F.P.T. and J.F.; project administration, N.T.; All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of the University of Abomey-Calavi.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study and written informed consent has been obtained from the patient(s) to publish this paper.

Data Availability Statement

Data are available at the Laboratory of Study and Research in Applied Chemistry, Polytechnic School of Abomey-Calavi, University of Abomey-Calavi. You should contact the corresponding author for the data request.

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Conflicts of Interest

Blaise Agbatchi reports financial support from the University of Abomey-Calavi (UAC. Agbatchi is affiliated with the Polytechnic School of Abomey-Calavi, University of Abomey-Calavi. A patent is pending under Agbatchi's name; further details are not applicable. The other authors declare no conflict of interest.

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