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Characterization of Faecal Sludge in the Oueme Delta

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The One of the Sustainable Development Goals aims to: "Ensure access for all to sustainably managed water supply and sanitation services". To meet this challenge, several countries such as Benin have decided to take action to solve sanitation problems. Thus, the general objective of this study is to characterize the sludge in the Oueme Delta in order to know its identity and propose an adequate treatment. The Oueme Delta has a population of about 4,346,336 inhabitants. Based on the methods used for quantification, it results that nearly 64.96% of the sludge produced is found in nature, only 8.63% in the station to undergo treatment and of the remaining 26.41% a part is drained manually or mechanically and ends up in nature and another part always remains in the pits and will never be emptied. In addition, the analysis of the sewage sludge taken from three municipalities of the Delta de l'Oueme reveals that this sludge has a slightly alkaline pH and is highly saline. They are fresh, rich in organic pollutants, nutrients and pathogens given the results of

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the temperature associated with pH. With an average COD of 37570.93 mgO_2/L and an average BOD_5 of 5500.66 mgO_2/L, the sludge we analysed is poorly biodegradable. These results will be submitted to the stakeholders for assessment in order to reach consistent decisions for the sustainable management of this resource.

Keywords: Sludge; sanitation; oueme; organic pollutants.

1. INTRODUCTION

One of the major problems in developing countries is excreta management, due to the exponential growth in population and the lack of monitoring in the management of faecal sludge to ensure health and well-being in a sustainable manner. Benin's population has grown from 6,769,914 in 2002 to 10,008,749 in 2013, an annual growth rate of 3.5% [1]. With this population in the area of hygiene and basic sanitation, progress, albeit slow, is being made. The proportion of the population using an improved sanitation facility rose from 11.0% in 1990 to 30.0% in 2001 and to 44.4% in 2010 and 46.5% in 2011, with a strong disparity between urban and rural areas. Although appreciable, this progress, if maintained, will not allow the MDGs to be reached [2]. In the Oueme valley, the rivers and water bodies are threatened by the sanitary habits of the population. They still practise open defecation for the most part. As a result, the existing latrines are almost never emptied, and in times of flooding their contents are emptied into the lake. In addition to these two problems, there are mechanical emptying trucks in the Delta that take care of emptying the contents of the pits of faecal matter (Order N°069-1995). The emptied part can end up in nature or in the best case in a treatment plant. As far as treatment is concerned, stations have been built by the ministry in charge of the environment respectively in Takon for the municipality of Porto-Novo and in Wanserou for that of Parakou [2]. The only station still in operation is that of SIBEAU (Société Industrielle Béninoise d'Équipement et d'Assainissement Urbain), which is now overused [3]. In addition, unauthorised dumpers create informal dumping sites. These different situations have an impact on the health and well-being of the population, most of whom are unaware of the risks [4]. It should be noted that it is the population itself that creates this inconvenience, finding itself caught up fairly early on by health concerns and at the same time economic problems [5]. Improving public health requires good domestic sewage disposal, followed by good management of human excreta and the construction of latrines for those who do not have them. Excreta should be considered a hazardous material and handled with care [6]. However, the choice of sanitation method is influenced by, among other things, the typology of the habitat and the socio-economic conditions of the user and the environment that receives the sanitation facility [7,8]. Unsanitary disposal of infected human faeces leads on the one hand to contamination of soil and water supplies [9]. On the other hand, excreta may constitute a focus where certain species of flies proliferate and spread the infection by attracting domestic animals, rodents and vermin, thus creating an intolerable nuisance [10-13]. Excreta is an obvious source of disease, increasing the risk of diarrhoea, typhoid fever or dysentery [5]. Faecal sludge contaminates groundwater and water bodies, making their water unsafe. It is therefore imperative to know the quantities of sludge produced per year and their characteristics in order to treat them [14-19]. This study will focus on the characterisation of faecal sludge in order to propose an appropriate treatment for its reduction, elimination and/or valorisation in the Oueme Delta.

2. MATERIALS AND METHODS

2.1 Study Framework

The Oueme basin (about 50,000 km^2) comprises two geological units: an upper basin with an entirely Precambrian substratum and a pronounced relief; and a lower basin with a soft sedimentary substratum and a low relief that favours the spreading and divagation of rivers. The boundary between the two basins is located slightly north of the confluence of the Zou and Oueme rivers. The deltaic zone covers an area of 9,000 km^2 and extends for 90 km along the river to its outlet in the lagoon area of Porto Novo [20]. The communes concerned by this study are: Adjarra, Adjohoun, Aguegues, Akpro-Misserete, Avrankou, Bonou, Dangbo, Porto-Novo, Cotonou, Abomey-Calavi, Ouinhi, Ouidah, Toffo, Zangnanado, Ze, Cove, Zogbodomey, Seme-kpodji. The Oueme River enters the coastal sedimentary basin from the north-east of the Zangnanado plateau and receives its main tributary Zou at the latitude of Pobe and then flows along the Pobe-Porto-Novo plateau before flowing into the Porto-Novo lagoon [21]. The area thus crossed constitutes the Oueme Delta. The Oueme Delta is shaped like an elongated triangle and measures 90 km from north to south. The lagoon of Porto-Novo forms its southern façade. To the west, the vast deltaic plain is limited by the marshes of the Sô River and to the east by the Pobe-Porto-Novo plateau. Its surface area varies from about 1000 km² to 9000 km² according to Cookson and Stirk [22]. The Oueme Delta is subdivided into 3 main parts. The upper Delta, constituting its northern part, is an open corridor in the Cretaceous and Eocene clay formations over a distance of 20 to 30 km. It extends to the limit of Bonou where the Middle Delta begins. The Middle Delta is a plain about 50 km long that extends from Bonou to Azowlisse via Adjohoun. The width is relatively uniform in this area, hardly exceeding 10 km [23]. The lower Delta starts downstream of Azowlisse where the valley widens abruptly up to 20 km and ends at the south side where the river flows into the Porto-Novo lagoon. The middle and lower delta constitute the lower valley of the Oueme.

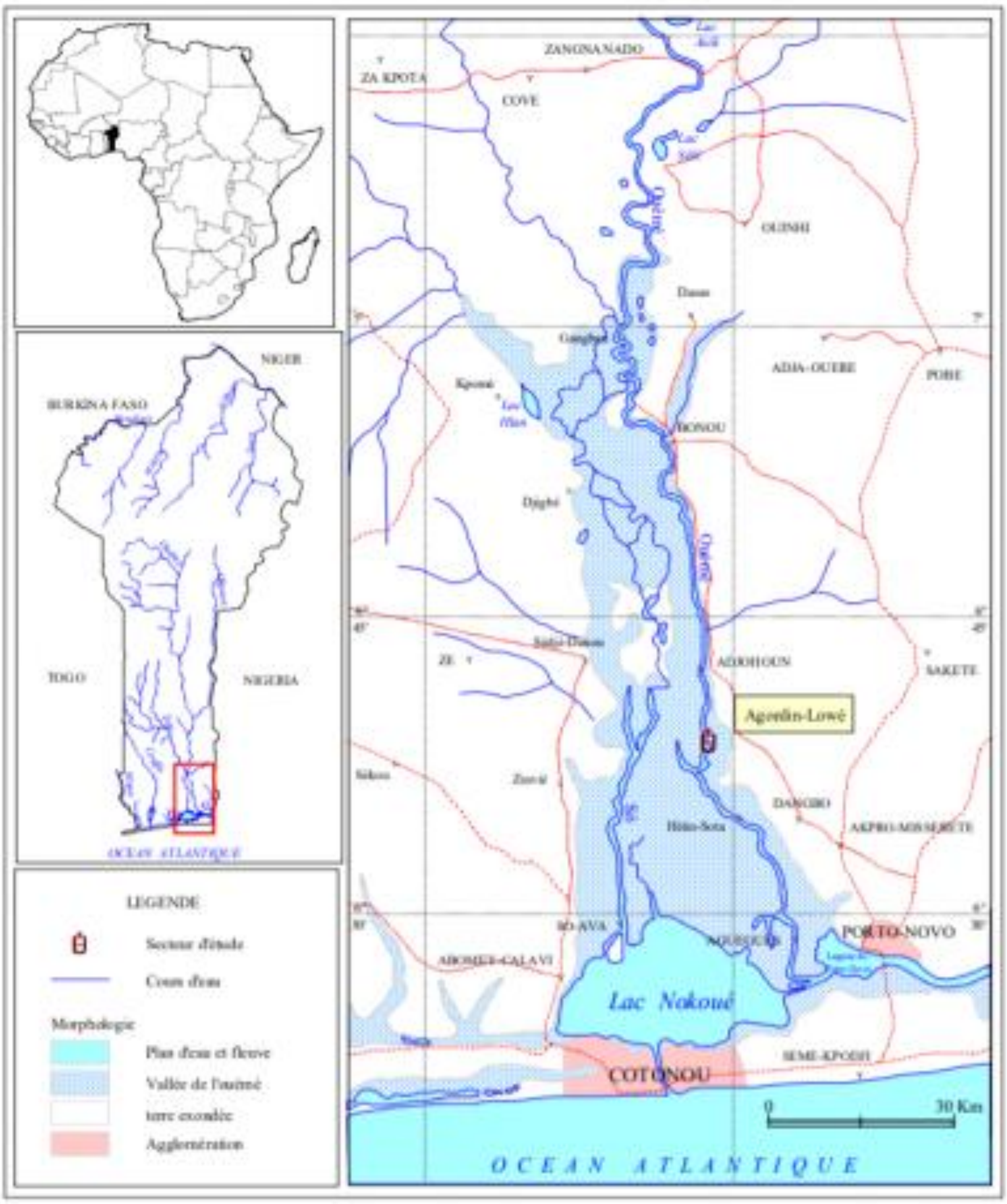

Fig. 1. Map showing the Oueme Delta

2.2 Data Analysis and Processing

In this measurement campaign, the products studied are septic tank sludge and latrine sludge. These products are studied from the contents of emptying trucks operating in the Oueme Delta. The objective is to characterise the faecal sludge that comes to the treatment plant, so the sample was taken at the plant during the unloading of the sludge by the faecal trucks. Three areas were selected. These are the areas where emptying is frequently done according to the survey of emptiers. In order to be as representative as possible, several samples are taken as the truck unloads the sludge, which are then mixed to form a composite sample. The samples are taken from different dumpers and from three different geographical sectors (Cotonou, Abomey-Calavi and Porto-Novo) that are within the geographical area. Ten (10) samples from each geographical sector were taken and studied. In the context of this measurement campaign, each sample of a product to be studied (septic tank sludge and sludge from latrines) is constituted as follows: sample A of at least 1 litre at the beginning of unloading on a truck, sample B of at least 1 litre in the middle of unloading on the same truck, sample C of at least 1 litre at the end of unloading on the same truck. A composite sample is reconstituted by mixing samples A + B + C in equal parts. Of this mixture, 1.5 litres will be retained for characterisation in the laboratory. The multi-parameter VWR MU 6100 H was used for direct in situ measurements of temperature, pH, oxidising power eH, salinity, conductivity and TDS. The value of suspended solids (SS) was obtained after membrane filtration of the sludge and drying at 105°C in an oven to constant mass according to the standard NFT 90-105-2, 1997. The dry matter was obtained after drying at 105°C in an oven by weighing to constant mass. Calcination of the sludge at 525°C in a kiln according to standard NF T 90-029, 2002 was necessary to obtain the value of Volatile Dry Matters (VDM). The multi-parameter VWR MU 6100 H was used for direct in situ measurements of temperature, pH, oxidising power eH, salinity, conductivity and TDS. The value of suspended solids (SS) was obtained after membrane filtration of the sludge and drying at 105°C in an oven to constant mass according to the standard NFT 90-105-2, 1997. The dry matter was obtained after drying at 105°C in an oven by weighing to constant mass. Calcination of the sludge at 525°C in a kiln according to standard NF T 90-029, 2002 was necessary to obtain the value of Volatile Dry Matters (VDM).

Total phosphorus was measured using a spectrophotometer (DR 2800) based on the standards NF EN 6878, 2005 and NF T 90-023, 1982. All nitrogen parameters (NO_3^-, NO_2^-, NH_4^+) were also determined using a spectrophotometer. For the determination of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand after 5 days of incubation (BOD_5) and Kjeldahl nitrogen (NTK) the volumetric and respirometric methods were used respectively according to AFNOR standards NFT 90-101, 2001, NF T 90-103, 1975; NF T 90-313, 1988; NF EN 25 663, 1994; NF T 90-110, 1981. The quantification of faecal sludge was based on available and accessible data. Indeed, there is only one dumping site for faecal sludge, SIBEAU, which covers our entire study area. Also, emptying is done very rarely because the existing autonomous sanitation system is based on dry latrines (not waterproof). In the case of this study, the data used comes from surveys and field observations. A survey questionnaire was drafted and sent to the emptiers. This survey allowed us to obtain information on the most emptied areas and to understand the functioning of the emptying market. Finally, the surveys allowed us to know the types of structures emptied, the profile of the clients, the dumping sites, the method of emptying and even the frequency of emptying per client. After analysing the samples in the laboratory and obtaining the data from the documentation, descriptive statistics were produced using Excel software, which allowed us to read the situation using graphs and to better interpret the results in order to obtain accurate information.

3. RESULTS AND DISCUSSION

The results of the characterisation of faecal sludge in the Cotonou commune reveal that the temperature of raw faecal sludge varies from 28.3° to 29.6°C with an average of 29°C for septic tanks and an average of 28.8°C for latrines (Table 1). The average pH is 7.4 for both types of facility. The faecal sludge is therefore slightly alkaline. In Porto-Novo, the average temperature is 33.5°C for septic tanks and 30.1°C for latrines and the pH varies between 7.2 and 7.9. In Abomey-Calavi, the average temperature of the sludge is between 32.5°C and 31.7°C and the pH is between 7.9 and 7.5.

Table 1. Physico-chemical parameters measured

			T(°C)	pH	eH	rH
Cotonou	Septic tanks	Average values	29,0	7,4	-48,1	14,7
		Average standard deviations	0,5	0,5	33,0	0,8
	Latrines	Average values	28,8	7,6	-68,5	15,0
		Average standard deviations	0,6	0,1	10,4	0,3
Porto-Novo	Septic tanks	Average values	33,5	7,2	-39,3	14,2
		Average standard deviations	2,0	0,2	11,7	0,3
	Latrines	Average values	30,1	7,9	-86,2	15,5
		Average standard deviations	0,9	0,1	9,2	0,2
Abomey-Calavi	Septic tanks	Average values	32,5	7,9	-81,2	15,5
		Average standard deviations	0,9	0,6	35,2	1,1
	Latrines	Average values	31,7	7,5	-59,8	14,9
		Average standard deviations	1,5	0,3	20,7	0,6
		Total average	30,93	7,58	-63,85	14,96

Table 2. Particulate pollution (SS, DM et VDM)

			SS (g/L)	DM (g/L)	VDM (%DM)
Cotonou	Septic tanks	Average values	4,3	9,5	63,8
		Average standard deviations	4,7	7,6	12,0
	Latrines	Average values	24,9	32,5	82,3
		Average standard deviations	8,8	8,9	8,6
Porto-Novo	Septic tanks	Average values	17,2	23,2	85,0
		Average standard deviations	15,7	19,8	12,4
	Latrines	Average values	7,7	22,6	62,1
		Average	1,9	3,7	6,4

			SS (g/L)	DM (g/L)	VDM (%DM)
		standard deviations			
Abomey-Calavi	Septic tanks	Average values	7,9	10,4	51,6
		Average standard deviations	9,4	9,4	17,8
	Latrines	Average values	25,2	28,5	62,9
		Average standard deviations	16,3	12,3	7,1
		Total average	14,53	21,11	67,95

Table 3. Salinity assessment parameters

			Cond (mS/cm)	TDS (g/L)	TDS calculated (g/L)	Salinity (g/L)	Cl^- (mg/L)
Cotonou	Septic tanks	Average values	9,1	4,6	5,2	4,8	957,7
		Average standard deviations	5,1	2,5	3,4	2,8	757,8
	Latrines	Average values	19,5	9,7	12,6	11,0	2318,3
		Average standard deviations	11,3	5,7	4,8	6,7	1312,2
	Septic tanks	Average values	2,5	1,3	6,0	1,1	188,5
Porto-Novo		Average standard deviations	1,1	0,5	5,8	0,5	42,5
	Latrines	Average values	26,8	13,6	14,9	14,8	2728,5
		Average standard deviations	2,0	0,8	2,5	1,5	373,2
	Septic tanks	Average values	4,3	2,3	2,5	2,0	405,2
Abomey-Calavi		Average standard deviations	1,4	0,9	0,9	0,7	289,9
	Latrines	Average values	13,9	6,9	8,3	7,1	2420,0
		Average standard deviations	3,3	1,6	0,4	1,8	130,0
		Total average	12,68	6,4	-	6,8	1503,03

Table 4. Summary of global pollution parameters

Average values	COD (mgO_2/L)	BOD_5 (mgO_2/L)	TKN (mg/L)	$N\text{-}NH_4^+$ (mg/L)	$N\text{-}NO_3^-$ (mg/L)	GLN (mg/L)	$N\text{-}NO_2^-$ (mg/L)	TP (mg/L)
Cotonou	38041,7	5625	597,98	481,80	1,13	648	62,32	113,44
Porto-Novo	37707,2	5622	556,28	393	1,12	580,25	22,82	88,08
Abomey-Calavi	36963,9	5255	406,47	407,05	0,13	421,25	20,96	152,92
Total average	37570,93	5500,66	520,24	427,28	0,79	550,06	35,37	118,14

Table 5. Comparison of sludge characteristics

Parameters	Oueme Delta (Benin)	Abomey-Calavi (Benin)	Abidjan, Ivory Coast [19](Appiah et al.)	Dakar, Senegal [32](Lo et al.)	Ouagadougou, Burkina-Faso [29] (Bako et al.)
pH	7,59	7,73	7, 31	7, 30	8,28
Cond (mS /cm)	12,68	10,748	3,75	-	2,05
SS (mg/L)	14,53	63636	21115	2130	5492
DM (mg/L)	21,11	34137	981	3488	8608
COD (mg/L)	37570,93	16709	19398	3853	6930
BOD_5 (mg/L)	5500,66	1507,5	9465	-	-
NH_4^+ (mg/L)	427,28	148,49	367,5	-	-
TP (mg/L)	118,14	-	-	-	-
PO_4^{3-} (mg/L)	-	170,72	94,52	-	-
Faecal coliforms (UFC/100 ml)	-	2 ,26.106	672,37.105	-	-
E. coli (UFC/100 ml)	-	8,14.105	-	-	-

These values are compatible with the development of the bacteria that purify the sludge. These bacteria generally develop at pH levels between 5 and 9 [24]. Indeed, temperature and pH represent a limiting factor for the development of purifying bacteria and thus impact the efficiency of the treatment (Degremont, [25]. The parameters eH and rH allow the evaluation of the aerobic, anoxic or anaerobic character of the environment. All the rH values measured make it possible to affirm that the environment was anoxic in the different pits and latrines from which the samples came. The analysis of these results shows a uniformity of temperature and pH values with small standard deviations. It should be noted that the pH values measured are generally higher than 7. The values of these temperatures reflect the biological activity in the sampled environments. The environments from which the sludge originates are anoxic environments.

Cotonou sludge has average TSS values between 4.3 g/L for septic tanks and 24.9 g/L for latrines (Table 2). For Porto-Novo sludge, the average values are between 17.2 g/L and 7.7 g/L. In Abomey-Calavi, the average values are between 7.9 g/L and 25.2 g/L. The MS measurement gives for Cotonou an average value of 9.5 g/L for septic tanks and 32.5 g/L for latrines. In Porto-Novo, values between 23.2 g/L and 22.6 g/L were obtained. And in Abomey-Calavi we have averages between 10.4 g/L and 28.5 g/L. Overall, the analysis of these results shows that latrines are more loaded than septic tanks, as one would expect. It should be noted that the particularity observed in Porto-Novo, where the average values measured on septic tanks are higher than those of latrines, is due to a large overflow observed on the first tank.

This already draws attention to the fact that the residence time of the sludge in the pits to be emptied has a significant influence on the sludge load recovered. The average dry matter (DM) values measured do not indicate rapid clogging when the sludge is spread on a drying bed. It should be pointed out that the emptiers are also used to diluting the sludge during emptying. Furthermore, the SVD data allow us to conclude that there is a high presence of organic fraction in the measured sludge (characteristic values of faecal sludge). These VDM values ensure the perfect implementation of a biological process by planted filter. Nevertheless, attention must be paid to the loading phase (see salinity values).

The analysis in Table 3 shows that the sludge from latrines has very high salinity values compared to that from septic tanks. This indicates a very high mineralization of the sludge. The calculated TDS values are of the same order of magnitude as the measured TDS values, and allow for a gradual increase in load, with lag times to allow adaptation by the plants before continuing the increase in load. The high chloride concentration values indicate that this ion is a significant contributor to conductivity, however there is no link between the geographical location of the latrines/ septic tanks and salinity. The measured salinity values are related to anthropogenic activities.

The chemical and organic parameters of the sludge (Table 4) correspond to carbonaceous pollution and are represented by average COD and BOD_5 values of 37570.93 mg O_2/L and 5500.66 mg O_2/L respectively. The high COD value could be explained by a significant presence of oxidisable organic matter. The COD/BOD_5 ratio is higher than 5, which reveals the presence of a large proportion of organic matter that is difficult to biodegrade in these sludges [26]. This poorly biodegradable character corroborates with previous studies conducted by (Bassan et al. [27] shown in Table 5) on faecal sludge in Benin and Burkina Faso. However, the quality of sludge in Côte d'Ivoire, Guinea and Senegal shows a biodegradable character. These results are explained by the presence of a large amount of detergent and other chemicals used by households.

The mineral chemical characteristics of the sludge evaluated show that the sludge is rich in ammonium (NH_4^+) with an average content of 427.28 mg/L. Nitrite and nitrate have average concentrations of 0.79 mg/L and 35.37 mg/L respectively. These high levels in the faecal sludge can be explained by the quasi-continuous organic decomposition activity in the pits and during the transport of the sludge from the households to the disposal site. The higher nitrate value compared to nitrite shows that the sludge arriving at the site is partially decomposed, however, it is still fresh due to the ammonium value. In the presence of oxygen, bacteria convert ammonium to nitrite and then to nitrate through the process of nitrification. The pH and storage time contribute strongly to this process. The total nitrogen concentration is 550.06 mg/L and the total phosphorus concentration is 118.14 mg/L.

Faecal sludge is therefore very rich in nutrients and is of interest for agriculture. The BOD_5, COD, TN and TP values show that carbonaceous pollution dominates over nitrogenous and phosphorusous pollution. The analysis of the measured values shows that the COD values are very high compared to the BOD_5, which leads us to deduce that we are not in the presence of fresh sludge. This corroborates with the rH values indicating an anoxic environment. The concentrations of nitrogen and phosphorus compounds, in dry masses determined, show that the faecal sludge is highly loaded and rich in nutrients. The COD, BOD_5 and dissolved TKN data (on the supernatant) give a predictive view of the maximum values to be expected normally at the drying bed outlet and are good indicators for the sizing of the lagoons for the treatment of water from the drying beds.

Table 5 compares the results of our study with those of previous studies in Abidjan [28], Ouagadougou [29] and Dakar [30].

carried out in Abidjan [28], Ouagadougou [29] and Dakar [30-32] and we also considered results from more recent studies on the city of Abomey-Calavi in Benin only. The results of this comparative study show that the pH values are higher than 7 and are between 7 and 9, the conductivity values in Benin are higher than those in Abidjan and Ouagadougou. Those of the Delta are higher than those of Abomey-Calavi. The COD of the Delta is higher than that of Abidjan, Abomey-Calavi, Ouagadougou and Dakar in that order. Consequently, the BOD_5 of the Delta is higher than that of Abomey-Calavi and that of Abidjan is higher than that of the Delta. With these COD and BOD_5 values, the COD/BOD_5 ratio proves that Abidjan sludge is biodegradable and Benin sludge is poorly biodegradable. For SS and DM, the values obtained in Abomey-Calavi are higher than in the Delta, Abidjan, Ouagadougou and Dakar. These results can be explained by different factors, notably the period when the samples were taken (dry season, rainy season), the types of structures emptied, the residence time, the age of the structures and the method of taking sludge samples. In addition to all the physicochemical parameters studied on the Delta sludge, the study on the Abomey-Calavi sludge presents us with values concerning microbiology and by analogy we can say that the probability of finding faecal coliforms and Escherichia coli in our Delta samples is very high.

4. CONCLUSION

This study focuses on the characterisation of faecal sludge in the Oueme Delta. The results of the sludge analysis show that the sludge has a slightly alkaline pH and is highly saline. The pH and temperature show the high biological activity of the environment. The sludge comes from an anoxic environment. The biodegradability test shows that the sludge is poorly biodegradable (COD/BOD_5 ratio >5). The values obtained after the nitrogen pollution analysis prove that the sludge is rich in nutrients and is partially decomposed on arrival at the treatment site. The residence time in the sewage treatment plant is long, which allows the ammonium to be gradually transformed into nitrite and then nitrate through the nitrification process. The slow evolution of the nitrification process is due to the fact that the environment is anoxic. Moreover, this richness in nutrients presents an interest for soil improvement (agriculture) and a risk for water courses and plants due to the phenomenon of eutrophication through their uncontrolled discharge into the environment.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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