

Assessment of the Flow of Chemical Pollution Emitted by Faecal Sludge from the Attidjin Site, Lomé-Togo

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Abstract The lack of sites for the treatment and hygienic disposal of fecal sludge in cities in developing countries contributes to the pollution of the urban environment and the spread of fecal diseases. Thus, the study examined the effect of metal and organic pollutants from faecal sludge released at the Attidjin site near homes. Indeed, this site is open air and receives the fecal sludge collected from the city of Lomé. The calculation of the COD/BOD₅, BOD₅/COD and TSS/BOD₅ ratios shows that the faecal sludge discharged at the Attidjin site is biodegradable and contains organic pollutants. The NH₄⁺ and NO₂⁻ levels of these sludge are also measured and reveal that these faecal sludges contain nitrogen pollutants. The assessment of inorganic pollution was also assessed by the measurements of Cu, Ni, Zn and Mn. The Mohlman index was also measured and the results showed that these sludge are in the mineralization phase because their MI < 80 mL/g. The degree and sources of contamination were determined by calculating metal and organic pollution indices: contamination factor (CF), geoaccumulation index (Igeo), global pollution index (PI) and organic pollution index (OPI). The organic pollution index is equal to 0.75; this corresponds to very high organic pollution of the site with a high contamination factor (FC > 6). The Igeo values were Class 2 for Cu and Class 3 for Zn. These values show that the site is highly contaminated with Cu and Zn with a contamination factor of 0 < FC < 1. The pollution load index PLI = 1 indicates the presence of these metal pollutants at the site level. The biological treatment of these faecal sludge will be the solution to mitigate the effects of this pollution flow.

Keywords: Attidjin site, faecal sludge, organic pollution, metal pollution, contamination

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1. Introduction

Pollution is a real environmental problem because of the untreated faecal sludge discharged into the undeveloped areas, which are the main source of organic and metallic pollution of water, soil and air.

Faecal sludge (FAE) is a mixture of human excreta, consisting of water, organic and inorganic matter, including nutrients, while faecal sludge management is a set of scientific practices that provide collection, transport, treatment and disposal of fecal sludge collected on site at an appropriate site without polluting the environment [1-4]. The choice of disposal site for these collected faecal sludge depends primarily on the soil condition and the hydrogeological condition of the area. However, faecal sludge is a high pathogenic hazardous material [5], their release to undeveloped sites creates a huge burden on public and environmental health [3,6]. Indeed, lack of hygienic disposal of faecal sludge is a source of oro-fecal diseases [7]. These diseases spread from

person to person through various pathways, unwashed hands, flies, surface water, soiled food, direct contact with faecal sludge, etc. Ensuring hygienic, functional and sustainable sanitation is a global challenge, especially in developing countries. In fact, in the city of Lomé, the emptying and transport of fecal sludge is carried out by dump trucks and the space reserved for the deposit of these sludge is an old quarry for the removal of silty sand which has not been developed. The site is open-air and is located in Attidjin, a north-eastern suburb of Lomé, about 25 km from the city center. However, most of the faecal sludge collected from autonomous sanitation systems in the city of Lomé is discharged into the Attidjin site. Faced with this practice and the problems of environmental pollution and the health risks incurred by the residents of the site, our work aims to characterize the physico-chemical parameters of pollution and make inventories of the pollution streams that could be emitted by this uncontrolled release of faecal sludge. Strategies to mitigate these pollution effects on the entire ecosystem will be considered.

2. Materials and Methods

2.1. Framework of Study

The site covers an area of approximately 5 hectares and is located in the following geographic coordinates: 6°14'7.44" North Latitude and 1°5'16" East Longitude. The site is a former quarry for silty sand. For this reason, it has a rather complex configuration consisting essentially of adjoining basins interspersed with earthen mounds. Some of these ponds have been used to discharge effluent. These basins have low points where effluent overflows during rainy periods. These points significantly reduce pool capacity (Figure 1).

2.2. Sampling

The samples were taken when the dump trucks were unloaded at the site. The sludge was removed from a container at the beginning of unloading, when the tank is half empty and just before the end of unloading. The sludge collected in the container is then thoroughly mixed before being stored, at room temperature, in plastic bottles (not hermetically sealed). Thirty (30) samples were collected, including 10 pit latrine (PL) sludge samples (numbered A1 to A10); 10 public septic tank (PST) sludge samples (numbered B1 to B10) and 10 domestic septic tank (DST) sludge samples (numbered C1 to C10). In the laboratory, the samples were processed and analyzed for the desired parameters.

2.3. Chemical Pollution from Faecal Sludge

Chemical pollution was assessed by determining levels of organic and inorganic pollutants. Also, the degree and sources of contamination were determined by calculating metal and organic pollution indices. The ammonium

(NH_4^+) and nitrite (NO_2^-) ions were determined by molecular absorption spectrophotometry [8]. Kjeldhal nitrogen (KjN) is quantified by selenium mineralization and soda alkalization [9]. COD was determined by the titration method [10]. Tintometer Oxidirect (Lovibond) was used to measure BOD_5 . The measurement of UV absorbance (Abs) at 254 nm showed the aromatic character of the organic matter. The method is based on the property of certain organic molecules to be absorbed in UV through their conjugated bonds [11]. The determination of metallic trace elements in the minerisats is carried out by flame mode atomic absorption spectrometry [12]. Organic matter was determined by the fire loss method [13] (Equation 1).

$$\%OM = \frac{m_1 - m_2}{m_1 - m_0} \times 100 \quad (1)$$

OM : organic matter (%);

m_0 : empty crucible mass (g);

m_1 : final mass (g);

m_2 : mass of the crucible containing the ash (g).

The determination of suspended matter (SM) was made by filtration [14]. The Mohlman Index (MI) indicates the quality of the sludge and the values were determined by Equation 2.

$$MI \text{ (mL / g)} = \frac{DM}{SDM} \quad (2)$$

- DM (mL/L): volume of decantable material in 30 minutes from sludge emptying;
- SDM (mg/L): Suspended dry matter content at 105°C

For the processing of data relating to the monitoring of organic pollution parameters, the organic pollution index (OPI) is useful [15]. OPI is dependent on levels of ammonium, nitrite, orthophosphate and BOD_5 in faecal sludge [16]. The organic parameters of faecal sludge are classified according to five classes (Table 1).

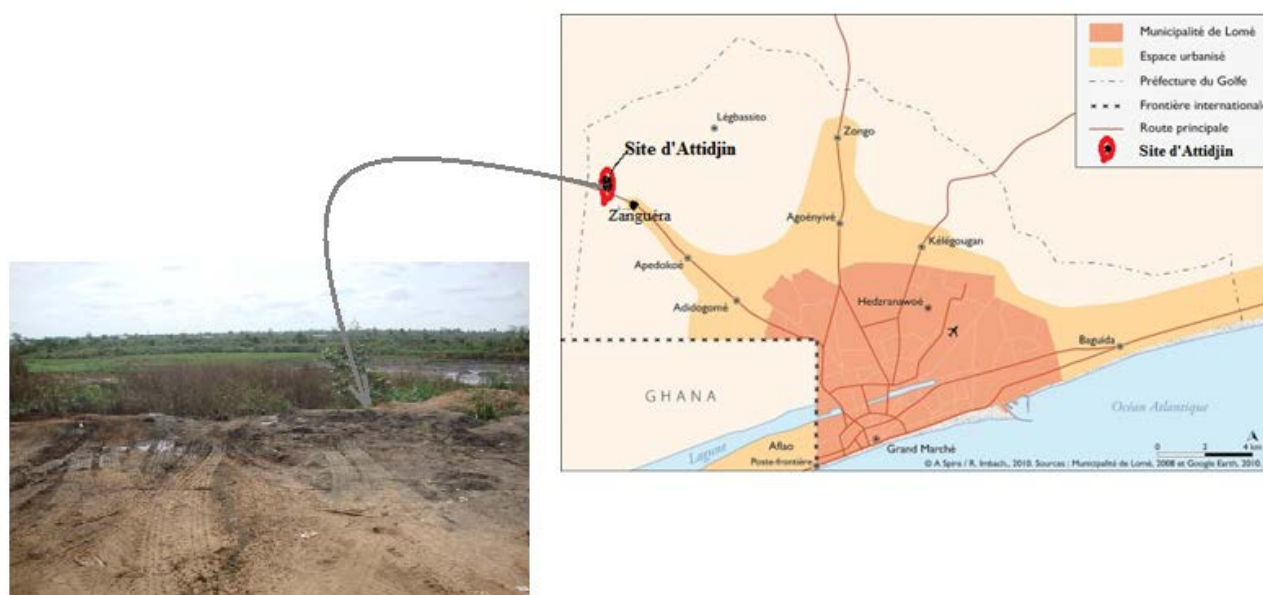


Figure 1. Attidjin site

Table 1. Classes of organic pollution parameters

Parameters → Class ↓	OBD ₅ mg O ₂ /L	NH ₄ ⁺ mg N/L	NO ₂ ⁻ µg N/L	PO ₄ ³⁻ µg P/L
5	< 2	< 0.1	5	15
4	2 – 5	0.1 – 0.9	6 – 10	16 – 75
3	5.1 – 10	– 2.4	11 – 50	76 – 250
2	10.1 – 15	2.5 – 6.0	51 – 150	251 – 900
1	> 15	> 6	> 150	> 900

OPI = average class numbers of the 4 parameters (at best):

= 5.0 – 4.6 : zero organic pollution

= 4.5 – 4.0 : low organic pollution

= 3.9 – 3.0 : moderate organic pollution

= 2.9 – 2.0 : organic pollution

= 1.9 – 1.0 : very high organic pollution.

The contamination index (CI) is a calculated adimensional number for each sample (j) and for each element (i) (Equation 3).

$$CI_{ij} = \frac{C_m}{C_r} \quad (3)$$

C_m ; measured metal concentration and C_r reference concentration.

The classification of faecal sludge on the basis of the CI value is done according to 4 classes: CI < 1 low contamination factor, 1 < CI < 3 moderate contamination factor, 3 < CI < 6 considerable contamination factor, CI > 6 high contamination factor.

The Pollution Load Index (PLI) Estimates the overall level of contamination based on the total concentration of all metals studied. The PLI was calculated using Equation 4 [17].

$$PLI = \sqrt[n]{CI_1 \times CI_2 \times CI_3 \times \dots \times CI_n} \quad (4)$$

CI_i: metal contamination factor i.

The metal pollution index gives cumulative information on the metal pollution of the site. For PLI = 0, there is no deterioration; for PLI = 1, only pollutant reference levels are present, and the value of PLI > 1 indicates progressive deterioration of the site.

The Metal Geoaccumulation Index (Igeo) provides information on the level of metal accumulation in the site. It is evaluated from equation 5.

$$I_{geo} = \log_2 \left(\frac{C_m}{1.5 \times B_n} \right) \quad (5)$$

C_m : Concentration of the measured element in the sample; B_n : Element concentration in a geochemical background; 1.5: Consistency taking into account natural fluctuations in the content of a given substance in an environment as well as anthropogenic fluctuations.

Table 2. Different Classes

Class	Values	Level of contamination
0	Igeo < 0	uncontaminated
1	0 < Igeo < 1	From uncontaminated to moderately contaminated
2	1 < Igeo < 2	Moderately contaminated
3	2 < Igeo < 3	Moderately to severely contaminated
4	3 < Igeo < 4	Severely contaminated
5	4 < Igeo < 5	From severely contaminated to extremely contaminated
6	5 < Igeo	Extremely contaminated

The Igeo values allow to define seven classes of contamination level gathered in Table 2 [15,17].

The geochemical background value B_n taken is taken from the global average shale value (mg.kg⁻¹) of the metals determined in the study. The values are Zn = 95, Cu = 45, Ni = 68, Mn = 850 [15].

3. Results and Discussions

3.1. Mohlman Index

The ability to settle sludge is assessed by the Mohlman index (MI). The determination of MI led to the results in Table 3.

Table 3. Determination of the Mohlman Index

	PL	DST	PST
MI (mL/g)	94.18 ± 3.63	22.26 ± 0.82	19.43 ± 0.85

PL: faecal sludge of pit latrine; DST: faecal sludge of domestic septic tank; PST: faecal sludge of public septic tank.

Analysis of the results obtained shows that the faecal sludge of DST and PST have their MI < 80 mL/g, which means that these sludge are in the mineralization phase and in addition to this phase we can observe the physical phenomenon in the case of dephosphation or septic tanks receiving water loaded with silt [18]. The presence of silt increases the mass of the sludge resulting in greater decantability and consequently a change in the weight/volume ratio. For the faecal sludge of PL, their MI is in the range of 80 mL/g < MI < 150 mL/g, which means that the sludge is less diluted and more significantly in the degradation phase.

3.2. Assessment of Organic Pollution

COD/BOD₅, BOD₅/COD, SM/DBO₅ and Oxidizable Matter (OxM) ratios (Table 4) appreciate the origin and present important interests of faecal sludge. The use of these ratios is a good way to give an image of the degree of pollution of faecal sludge and also to optimize the physical-chemical parameters of these faecal sludge in order to propose a suitable treatment method [19] (Table 4).

The COD/BOD₅ ratio gives an indication of the biodegradability of faecal sludge. For a ratio of less than 3, faecal sludge is easily biodegradable; beyond 5, it is

difficult to biodegrade. This report also allows us to infer whether faecal sludge released directly to this undeveloped site has characteristics of domestic liquid effluents [10,19]. Thus, for the Attidjin faecal sludge removal site, the COD/BOD₅ ratio is equal to 1.28 ± 0.15 for the faecal sludge of LP. And for faecal sludge of DST and PST the values of this ratio are respectively 1.44 ± 0.23 and 1.41 ± 0.13 . Although faecal sludge has a high organic load, it is easily biodegradable because the COD/BOD₅ ratio values are less than 3. Thus, with the biodegradable character of these fecal sludge a biological treatment seems quite suitable.

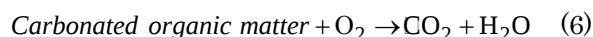
Table 4. Organic parameter ratio values

	PL	DST	PST
COD/BOD ₅	1.28 ± 0.15	1.44 ± 0.23	1.41 ± 0.13
BOD ₅ / COD	0.67 ± 0.07	0.71 ± 0.10	0.72 ± 0.07
SM/BOD ₅	3.14 ± 0.18	34.44 ± 5.11	4.73 ± 0.44
OxM (mg/L)	1188.16 ± 39.92	450.83 ± 41.53	3723.57 ± 217.23

PL: faecal sludge of pit latrine; DST: faecal sludge of domestic septic tank; PST: faecal sludge of public septic tank.

The BOD₅/COD report gives very interesting indications on the origin of fecal sludge pollution and its treatment possibilities [20]. This ratio is generally correlated with the age of the effluents and thus the degree of progress of the stabilization of the massif [21]. For our study, these ratios are 0.67 ± 0.07 for the faecal sludge of PL, 0.71 ± 0.10 for DST faecal sludge effluents and relatively high, in the order of 0.72 ± 0.07 for the faecal sludge of PST (Table 4). This is the general case for discharges charged with organic matter. This organic load makes the faecal sludge quite unstable, that is to say they will evolve quickly to digested forms with the risk of release of odors. Indeed, faecal sludge from pit latrines and septic tanks are predominantly organic.

The measurement of oxidizable materials (OxM) is particularly used to determine the quantities of organic matter present in an effluent. Their concentration is assessed using global parameters: SM, COD, BOD. In an oxygenated environment, these organic materials can be oxidized by water-purifying microorganisms according to equation 6.



But, the BOD₅/COD ratios of the faecal sludge are high, confirming that these faecal sludge are heavily laden with organic matter. This result is confirmed by the estimate of oxidizable matter, with contents of 1188.17 ± 39.92 mg/L for the faecal sludge of PL, 450.83 ± 41.53 mg/L for the faecal sludge of DST and a high level of 3723.57 ± 217.23 mg/L for the faecal sludge of PST. However, the SM/BOD₅ ratio is 3.14 ± 0.18 for the fecal sludge of PL and 34.44 ± 5.11 for DST. This ratio is 4.73 ± 0.44 for sludge of PST and relatively high. In addition, the COD/BOD₅ ratio is less than 3, which allows us to deduce that the organic matter load in the faecal sludge of the PL, DST and PST are easily biodegradable [22].

There is also a highly significant correlation between the COD and BOD₅ levels of the different types of faecal sludge discharged at the Attidjin site (Figure 2).

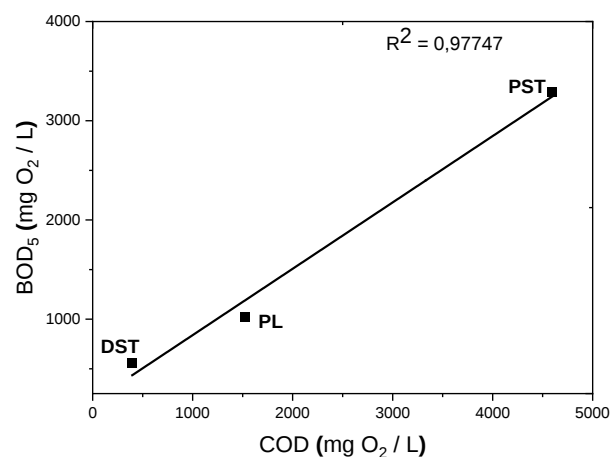


Figure 2. Correlation between BOD₅ and COD levels in Attidjin faecal sludge types

Pollution by organic matter, whether degradable or not, is mainly due to the discharge of urban populations whose sanitation systems are autonomous.

In general, SM are involved in the composition of faecal sludge by their effect of ion exchange or absorption on both trace chemical elements and microorganisms. However, the results of our work show perfect parallelism between these different couples (COD, SM) and (BOD₅, SM) (Figure 3 and Figure 4). This means that biodegradable or not biodegradable faecal sludge pollution is in particulate form.

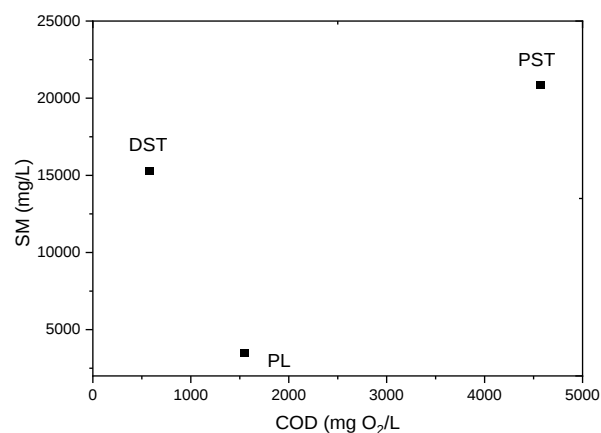


Figure 3. SM content as a function of COD

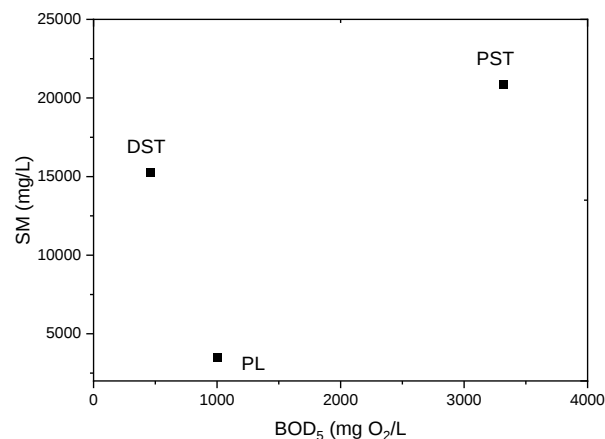


Figure 4. SM content as a function of BOD₅

These correlations also suggest that the degradation processes of SM, COD and BOD₅ organic matter are influenced by the environmental parameters of septic tanks, including pH, dissolved oxygen and temperature. These correlations confirm that, the MSS represent the mineral and organic particles; they then cause the turbidity of the sludge emptying and they are also, sources of COD and BOD with a mechanical action of siltation [20].

The results of the work show that faecal sludge contains a significant amount of organic matter, the evolution of the characteristics of this organic matter allows to understand the state of chemical degradation from which it is derived. Thus, the chemically oxidizable organic matter contained in sludge is also determined by calculating the characteristic ratio such as COD/OxM. This ratio is also used to characterize the organic charge and chemical degradation of faecal sludge [22]. As part of this work, the calculation of the COD/OxM ratio of PL, DST and PST sludge yields respectively 1.28 ± 0.08 , 1.25 ± 0.11 and 1.26 ± 0.12 . These values are very similar and less than 4. This confirms that the faecal sludge at the Attidjin site is difficult to degrade chemically [22].

The Abs/OxM ratio provides information on the origin of organic matter in faecal sludge. It is also an indicator of the reactivity of faecal sludge organic matter to chemical oxidation. Thus, these values are in line with the changes in the other parameters since they reflect a more advanced state of degradation for PL and DST sludge whose Abs/OxM ratio values correspond to more aromatic and less biodegradable organic compounds faecal sludge, but also differences in the ability of these organic materials to be chemically oxidized with potentially important consequences both in terms of treatment and in the choice of dosage indicators. Thus, the ratio Abs/OxM calculated on the sludge of PST gives 8.29 ± 1.23 mgC/L. This value less than 10 mgC/L actually translates sludge called «young» and a state of low humification of the Organic Matter [23]. The Organic Matter present in sludge of PST at this stage of degradation is composed of organic substances low humified and mostly hydrophilic rich in volatile fatty acid. But as for the Abs/OxM ratio values of the LF and FSD sludge, they are respectively 20.80 ± 0.58 mgC/L and 22.09 ± 0.30 mgC/L. These values greater than 10 show that PL and DST sludge are slightly more degraded than PST sludge.

These values are in line with the changes in the other parameters since they reflect a more advanced state of degradation for PL and DST sludge whose Abs/OxM ratio values correspond to more aromatic and less biodegradable organic compounds [24].

In order to estimate the biodegradability of faecal sludge, it is interesting to analyse the NH_4^+/KjN ratio.

Indeed, the calculation of this ratio gives 1.04 ± 0.26 and 1.14 ± 0.28 respectively for the sludge of PL and DST, then 0.8 ± 0.13 for the sludge of PST. These values confirm that the organic matter mineralization phase is very advanced for the sludge of PL and DST because the nitrogen supplied by these types of sludge is mainly in mineral form ($\text{NH}_4^+/\text{KjN} > 1$), whereas that brought by the PST sludge is in organic form. These results show once again that PSF sludge is very young and that its degradation phase has barely begun.

3.3. Assessment of Organic Pollution and Contamination Indices

Based on the results obtained, we observed that the three types of faecal sludge that are released at the Attidjin site are in class 1 and their organic pollution index (OPI) is equal to 0.75, which corresponds to very high organic pollution. With respect to CI values for all organic parameters, faecal sludge from public septic tanks and pit latrines have $\text{CI} > 6$, which is a high contamination factor. However, the faecal sludge with a domestic septic tank released showed a considerable contamination factor because its index is $3 < \text{CI} < 6$.

3.4. Assessment of Metal Pollution

The results of the work showed that the faecal sludge at the Attidjin site contained copper (Cu), nickel (Ni), zinc (Zn) and manganese (Mn) (Table 5). The presence of these metallic trace elements (MTE) in the sludge can also be linked to the permanent uses of detergents for the maintenance of toilets, toilet waters and papers and anal cleaning waters.

For these 4 trace metal elements sought in the 3 types of faecal sludge, their contamination factor is $\text{CI} < 1$; which reveals that the site of Attidjin is weakly contaminated by these 4 trace elements. However, the calculation of the PLI pollution load index gives 0.51; 0.37, 0.54 and 0.29 respectively for Cu, Ni Zn and Mn. These PLI values show that these metal elements can cause progressive deterioration of the site. And if fecal sludge continues to be discharged into this area, it could further impact surface and groundwater quality.

For the geo-accumulation index (Igeo) of trace metal elements, the values are given in Table 6. The Igeo values calculated for zinc are in class 3 for the different types of sludge, indicating that the site is severely contaminated. But for copper, Igeo values are in class 2 for sludge from domestic and public septic tanks, which shows that the site is moderately contaminated [25].

Table 5. Teneurs en Cu, Ni, Zn et Mn des BV d'Attidjin, matière sèche

MTE (mg/kg DM)	PL	DST	PST	Limit values*
Cu	113,13 $\pm$ 32,08	144,41 $\pm$ 50,52	142,56 $\pm$ 35,18	500
Ni	14,56 $\pm$ 2,31	14,93 $\pm$ 2,89	13,02 $\pm$ 1,91	100
Zn	875,98 $\pm$ 165,10	974,06 $\pm$ 132,35	846,52 $\pm$ 237,66	3000
Mn	279,55 $\pm$ 56,45	283,95 $\pm$ 41,39	296 $\pm$ 82,11	1500

* Limit values set by the standard Afnor U 44-041; DM: dry matter.

Table 6. Geo-accumulation index (Igeo) for different types of faecal sludge

MTE	Contamination factor		
	PL	DST	PST
Cu	0.74	1.09	1.07
Ni	-2.81	-2.77	-2.97
Zn	2.62	2.77	2.57
Mn	-2.19	-2.16	-2.11

However, the calculation of the Igeo values of nickel (Ni) and manganese (Mn) gave values below zero, which shows that we are in class 0. Thus, Ni and Mn contaminate less the site of Attidjin.

4. Conclusion

The quality of any environment at the waste dump site is very important to humans. Thus, the assessment of chemical pollution fluxes emitted by faecal sludge from the Attidjin site was carried out during this study. The quality of faecal sludge received by this site was assessed by calculating the Mohlman index. The results showed that the sludge is in the mineralization phase with IM < 80 mL/g. For organic pollution, calculations of COD/BOD₅, BOD₅/COD and SM/BOD₅ ratios show that the faecal sludge discharged at the Attidjin site contains organic pollutants. The sludge is class 1 and its IOP is equal to 1, which corresponds to very high organic pollution of the site with a very high contamination factor (CI > 6). However, the assessment of inorganic pollution was also assessed by the measurements of Cu, Ni, Zn and Mn contents of faecal sludge. The calculation of their contamination factor (CI < 1) showed that the site is weakly contaminated by these 4 trace elements. But, these metal elements Cu, Ni Zn and Mn can cause progressive deterioration of the site with their PLI pollution load index equal 0.51; 0.37, 0.54 and 0.29 respectively. However, the site is severely contaminated in Zn with a geo-accumulation index (Igeo) which is class 3.

The Attidjin site is a public hazard due to its potential to retain chemical pollutants and its emissions of unpleasant odours. Our next work will concern the assessment of the chemical quality of well water and drilling in the immediate vicinity of the site.

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Conflict of Interests

The authors declare that they have no conflict of interest.

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