Physicochemical characterization of soils in receiving environments polluted by effluents from agrifood industries in Cameroon

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Abstract

The objective of this study was to characterize soil samples collected in different receiving environments. The impact of effluent discharges from agrifood industries was assessed by analysing seven physicochemical parameters in ten receiving environments at a depth of 100 cm randomly upstream and downstream of the discharge area depending on the seasons. Data processing and analysis were carried out using Excel and XLSAT software. The results in the rainy season upstream showed lead concentrations between 11.05 mg/kg and 18.81 mg/kg. Downstream, these are between 2.35 mg/kg and 11.98 mg/kg. In the dry season upstream, lead values are between 15.75 mg/kg and 22.47 mg/kg. Downstream, these are between 12.49 mg/kg and 19.81 mg/kg. Cadmium concentrations in upstream and downstream seasons ranged from 1.62 mg/kg to 9.98 mg/kg. Only cadmium had values above the WHO recommended limits (Cd < 2 mg/kg; Pb < 100 mg/kg). Soil samples from FERME H&F, the Yaounde slaughterhouse and Douala showed good mineralization for a C/N ratio between 4 and 12 downstream during the rainy season. A high C/N ratio (>15) reflecting the richness in organic matter in the soils of the receiving environments was observed upstream during the rainy season in soil samples from Nodiscam, FERMENCAM, SOSUCAM Mbandjock and Nkoteng.

Keywords: effluents, agrifood industries, pollution, receiving environments.

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1. Introduction

The agro-food industries in the world in general and in Cameroon in particular use and consume large quantities of potable water for the manufacture of their products (Fusto et al., 2025). However, during the various production activities, large volumes of liquid effluents are generated. These effluents are wastewater that is sometimes untreated and dumped in an uncontrolled manner into natural ecosystems, causing degradation of the environments which receive various sources of pollutants depending on the type of agro-food sector (Sravya et al., 2025). More than 6,000 agro-food companies are counted in the cities of Douala and Yaoundé (INS, 2013). This sector represents 11% of the gross domestic product (GDP), 6% of exports and 33% of industrial production. The consequences of this evolution focused on economic growth are now acutely evident. Effluents discharged into natural ecosystems contribute to the modification of abiotic factors as well as the degradation of soil, groundwater and surface water quality (Emakpor et al., 2025; Priso et al., 2017; WWAP, 2017). Food industry effluent receiving environments show rapid responses to variations in environmental constraints (Noukeu et al., 2019). Environmental pollution is a major global concern, and Cameroon is no exception.The characteristics of discharged food industry effluents vary greatly from one industry to another. The work of Noukeu et al., 2016 showed that food industry effluents contain extremely high levels of suspended solids (SS), chemical oxygen demand (COD), biochemical oxygen demand (BOD5), nitrate and phosphate. These values are mostly above the limits prescribed by the WHO. These suggest that these effluents cannot be discharged into natural ecosystems without treatment. In this study, the hypothesis that the discharge of effluents from the food industry could modify the characteristics of soil samples in receiving environments will be verified. Few studies have been conducted on the analyses of soils in receiving environments for industrial effluents in general and for effluents from the food industry in particular. Hence, the interest of this study, which will allow a good assessment of the level of pollution of soils, exposed to industrial discharges.

2. Materials and methods

2.1. Collection of soil samples

Soil samples were taken from the receiving environments close to the effluent discharge source of the agro-food industries depending on the sector. Samples were taken from 2 distilleries, 2 sugar refineries, 2 breweries, 2 slaughterhouses, an oil mill and a chicken farm. These sampling sites are distributed in the Littoral and Center regions of the country. A total of ten receiving environments were chosen for this study and soil samples were taken depending on the seasons on the one hand and on the upstream and downstream on the other hand. The different receiving environments are presented in Table 1. These are: FERMENCAM, GUINNESS, FERME H&F, SCR MAYA, SOSUCAM Mbandjock, SOSUCAM Nkoteng, Douala Slaughterhouse, Yaounde Slaughterhouse, Nodiscam and SOFAVINC. The collected soil samples were sun-dried before being stored in labeled bags and transported to the soil laboratory of the International Institute of Tropical Agriculture (IIAT) in Nkolbisson, Yaounde. Particle size analysis of the soils was carried out using the hydrometer method described by Bouyoucos (1962). Total phosphorus was determined using the ammonium phosphomolybdate method described by Murphy and Riley (1962). Organic carbon was determined by chromic acid digestion followed by spectrophotometer measurement in accordance with the procedures described by Heanes (1984). Total nitrogen was determined by wet acid digestion as described by Bremner, 1965 and Buondonno et al., 1995; followed by colorimetric titration in accordance with the procedure described by Anderson and Ingram (1993).

Table 1. The receiving environments inventoried and their geographical coordinates

Receiving environments	Geographic coordinates
SOSUCAM (Mbandjock) Candy	N:04.44383° E: 011.90853°
SOSUCAM (Nkoteng) Sugar Factory	N:04.28331° E:012.06019°
NODISCAM (Mbandjock) Distillery	N:04.44641° E: 011.89167°
FERMENCAM (Douala) Distillery	N:04.06451° E:009.37180°
Douala Slaughterhouse (SODEPA)	N:04.11097° E:009.64572°
Yaoundé Slaughterhouse (SODEPA)	N:03.92336° E: 011.53264°
SOFAVINC (Yaoundé) Brewery	N:03.81464° E:011.51001°
SCR. MAYA (Douala) Oil Mill	N:04.09846° E: 00963154°
GUINNESS (Douala) Brewery	N:04.05057° E:009.74431°
FERME H&F (Yaoundé) Breeding	N:03.84495° E: 011.45468°

2.2. Data processing and statistical analyses

Microsoft Excel software and XLSTAT version 2024 software were used to perform various statistical analyses and present them in the form of tables and graphs. Descriptive statistics was used to obtain essential information such as the mean and standard deviation. The Principal Component Analysis (PCA) performed is one of the most widely used multivariate data analysis methods when we have a table of quantitative data in which our observations (of individuals) are described by p variables (descriptors, measurements) (Jolliffe, 2002). The use of PCA in this work favoured the study and visualization of correlations between variables. Correlation matrix tables were also produced.

3. Results

3.1. Granulometric characteristics of soil samples

The percentage of each fraction of solid particles analyzed in the different soil samples of the receiving environments as presented in Table 2 indicates that all soil samples are rich in sand.

Table 2. Granulometric characteristics of soil samples from receiving environments

3.2. Physicochemical characteristics of soil samples in the upstream rainy season

	Douala Slaughterhouse	Yaounde Slaughterhouse	ADIC	FERMENCAM	GUINNESS	FERME H & F	SCR Maya	SOSUCAM Mbandjock	SOSUCAM Nkoteng	SOFAVINC
% Sand	84.32±0.017	94.87±2.89	85.05±1.46	91.77±1.52	89.79±2.22	90.94±0.41	88.79±1.79	65.22±1.02	97.61±0.07	80.01±0.96
% Clay	6.56±0.59	1.08±3.37	6.22±3.37	4.17±0.02	6.01±1.47	1.57±1.01	8.02±1.41	19.68±1.54	0.57±0.04	12.36±0.53
% Silt	9.08±0.57	4.62±2.14	9.65±1.54	2.44±0.064	4.89±1.08	3.96±1.56	4.08±0.50	14.60±0.66	1.73±0.155	8.15±0.44

The values of the physicochemical parameters measured upstream during the rainy season in the soil samples of the different receiving environments were noted (Table 3). The pH ranges from 4.10 to 7.29. The soils of SOFAVINC, the Douala slaughterhouse and Yaounde have an acidic pH; the soils of FERMENCAM and GUINNESS are neutral. The electrical conductivity ranges from 130.23 µS/cm for SOSUCAM Nkoteng to 5430 µS/cm for FERME H&F. Total phosphorus (TP) expressed in mg/kg is high at GUINNESS (2380 mg/kg) and at the Douala slaughterhouse (1530 mg/kg). Low values were observed at FERMENCAM (30 mg/kg), SOSUCAM Mbandjock (40 mg/kg), SOFAVINC (60 mg/kg) and the Yaounde slaughterhouse (97 mg/kg). The organic carbon values (OC) and total nitrogen (TN) are expressed as a percentage (%).

Table 3. Physicochemical characteristics of soil samples measured during the rainy season upstream of the discharge of effluents from the agro-food industries

	Douala Slaughterhouse	Yaounde Slaughterhouse	Nodiscam	FERMENCAM	GUINNESS	FERME H & F	SCR MAYA	SOSUCAM Mbandjock	SOSUCAM Nkoteng	SOFAVINC
pH	5.06±0.15	5.21±0.18	6.57±0.23	7.29±0.17	7.21±0.026	6.06±0.11	6.76±0.05	6.43±0.04	6.52±0.27	4.10±0.06
EC	1349±38.22	1913±11.54	642.33±60.79	1935±55.58	637.33±63	5430±1281.6	468.33±26.5	236±3.21	130.23±1.8	325.33±7.6
TP	1530 ±70	97±10	120±20	30±0.8	2380±130	440±30	120±10	40±3	180±50	60±3
OC	6.3±0.01	9.37±0.040	2.07±0.24	6.4±0.01	5.77±0.24	13.49±0.09	1.34±0.21	5.47±0.23	1.02±0.22	3.13±0.11
TN	0.64±0.05	1.03±0.06	0.16±0.02	0.32±0.006	0.45±0.05	2.23±0.009	0.076±0.01	0.30±0.02	0.06±0.03	0.22±0.003
C/N	9.92±0.92	9.11±0.45	13.04±1.16	19.96±0.31	13.03±091	6.05±0.07	17.65±1.31	18.02±0.47	20.16±9.83	13.98±0.26
Cd+	5.84±0.05	4.88±0.02	5.96±0.035	5.82±0.08	7.65±0.55	6.05±1.03	6.27±0.01	6.34±0.57	6.74±0.81	5.55±0.58
Pb^{2+}	15.02±0.02	11.05±0.03	13.16±0.57	12.68±0.56	18.81±1.42	13.45±1.50	14.04±1.50	16.11±1.09	16.05±0.99	17.64±0.56

3.3. Physicochemical characteristics of soil samples in the rainy season downstream

Soil samples collected downstream during the rainy season show low lead and cadmium values compared to upstream; however, total phosphorus levels remain high (Table 4). Organic carbon values are high in soil samples from FERME H&F (12.81%); and the Yaoundé slaughterhouse (8.37%). Total nitrogen levels are low in soil samples from SOFAVINC, Nodiscam, FERMENCAM and GUINNESS. All soil samples show good conductivity. pH values show a trend towards alkalinity compared to upstream.

Table 4. Physicochemical characteristics of soil samples taken during the rainy season downstream of the discharge of effluents from the agri-food industries

	Douala Slaughterhouse	Yaounde Slaughterhouse	Nodiscam	FERMENCAM	GUINNESS	FERME H & F	SCR Maya	SOSUCAM Mbandjock	SOSUCAM Nkoteng	SOFAVINC
pH	7.53±0.35	7.9±1.05	6.94±0.58	7.73±0.67	7.56±0.36	6.87±0.32	7.15±0.48	6.48±0.09	6.71±0.62	6.01±1.48
EC	1391±2.65	1964.66±32.9	783.33±1.5	1944.33±2.08	663±58.65	5719.33±1112	500.66±79	328±78.08	143±12.12	371±29.71
TP	1190 ± 90	80 ± 30	110 ± 10	20 ± 6	2280 ± 60	370 ± 60	110 ± 10	30 ± 5	170 ± 40	50 ± 3
OC	5.63±1.59	8.37±0.040	1.70±0.31	5.4±0.01	5.53±0.27	12.81±0.52	7.01±0.04	4.8±0.18	1.43±0.60	3.12±1.10
TN	0.40±0.06	0.96±0.11	0.11±0.005	0.15±0.06	0.35±0.05	1.23±0.009	0.68±0.08	1.30±0.02	0.66±0.35	0.21±0.003
C/N	14.16±0.06	8.77±0.86	14.72±3.17	38.44±12.49	16.21±2.08	10.44±0.38	10.30±0.015	3.68±0.49	2.16±0.52	14.61±4.93
Cd^+	2.50±0.57	2.55±0.60	1.62±0.55	2.48±0.51	3.32±1.19	2.38±0.55	2.94±0.57	2.34±0.57	1.74±0.81	1.52±0.58
Pb^{2+}	4.05±0.99	2.35±0.56	6.01±0.98	4.49±0.04	8.47±1.004	7.78±1.005	8.38±1.01	10.11±0.01	10.05±0.98	11.98±0.03

3.4. Physicochemical characteristics of soil samples in the dry season upstream

For the upstream dry season samples, all the parameters measured in the soil samples show higher values than those of the rainy season (Table 5). Total phosphorus is very high in the soil samples of FERMENCAM (3050 mg/kg), at the Douala slaughterhouse (2530 mg/kg) and at the Yaounde slaughterhouse (1450 mg/kg). The values of organic carbon and total nitrogen are very low in the soil samples of SOFAVIN and SOSUCAM Mbandjock and Nkoteng. Cadmium has very high values in soil samples from FERMENCAM (9.98 mg/kg). The C/N ratio is very high in soil samples from SOSUCAM Mbandjock (16.57) and Nkoteng (15.55).

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Table 5. Physicochemical characteristics of soil samples taken during the dry season upstream of effluent discharges

	Douala Slaughterhouse	Yaounde Slaughterhouse	ADIC	FERMENCAM	GUINNESS	Ferme H & F	SCR MAYA	SOSUCAM Mbandjock	SOSUCAM Nkoteng	SOFAVINC
pH	4.93±0.12	5.1±0.20	7±0.23	7.13±0.11	6±0.006	6.67±0.15	6.43±0.06	6.46±0.25	4.06±0.11	4.07±0.12
EC	1075.7±2.52	1646.7±162	1862±51.1	624±58.10	4596.67±1.05	415±4.36	2213.33±8.9	110.23±8.2	274.33±0.24	285.13±0.66
TP	2530 ± 70	1450 ± 390	1030 ± 20	3050 ± 530	144 ± 35	1120 ± 10	1060 ± 10	1220 ± 80	430 ± 46	940 ± 30
OC	7.3±0.15	10.37±0.40	8.07±0.59	6.77±0.79	15.49±0.02	2.34±0.21	6.46±0.23	2.02±0.22	2.79±1.09	2.79±1.09
TN	1.64±0.05	2.03±0.06	1.32±0.005	1.45±0.048	3.23±0.009	0.17±0.01	0.77±0.48	0.59±0.47	0.22±0.10	0.22±0.10
C/N	4.46±0.39	5.11±0.18	6.11±0.42	4.70±0.70	4.80±0.04	13.29±0.51	10.56±5.47	6.77±6.83	16.57±14.68	15.35±12.62
Cd^{+}	6.17±0.53	6.22±1.15	7.82±0.08	9.98±0.034	8.05±0.03	7.61±1.16	8.66±0.007	8.41±0.35	8.28±0.006	8.29±0.01
Pb^{2+}	19.35±0.56	15.71±0.55	17.68±0.59	22.47±0.42	19.11±0.60	17.71±1.13	19±0.015	18.87±0.32	18.98±1.02	18.31±0.60

3.5. Physicochemical characteristics of soil samples in the dry season downstream

Soil samples collected downstream during the dry season show low values for trace metal elements (TME). However, total phosphorus, organic carbon, and total nitrogen values remain high in soil samples from the Douala slaughterhouse and FERME H&F Farm. These soils have less acidic pH downstream (Table 6).

Table 6. Physicochemical characteristics of soil samples taken during the dry season downstream of effluent discharges

	Douala Slaughterhouse	Yaounde Slaughterhouse	ADIC	FERMENCAM	GUINNESS	FARM M&F	SCR MAYA	SOSUCAM Mbandjock	SOSUCAM Nkoteng	SOFAVINC
pH	6.5±0.35	7.57±0.67	7.27±0.59	7.40±1.05	6.56±0.36	5.86±0.32	7.48±0.68	5.48±0.09	5.71±0.62	5.35±0.40
EC	1317±28.99	2121.33±329	710±36.06	1844.33±40	627.33±60	4886±1689.9	410.67±33.4	251.67±45.4	119.67±17.6	307.67±2.52
TP	1770 ±300	880 ± 30	795 ± 110	910 ± 50	1387 ± 62	1000 ± 30	920 ± 90	870 ± 10	342 ± 50	680 ± 60
OC	6.33±0.70	9.04±0.52	2.00±0.08	6.73±0.59	6.53±0.27	11.48±0.98	2.51±0.45	5.6±0.57	2.77±0.07	2.13±1.10
TP	0.94±0.006	1.30±0.53	0.91±0.004	0.92±0.06	0.93±0.005	1.92±0.001	0.10±0.008	1.05±0.20	0.71±0.35	0.11±0.003
C/N	7.05±0.72	7.57±2.21	2.19±0.1	7.35±0.59	6.99±0.27	5.97±0.51	25.72±4.80	5.43±0.89	4.45±1.71	10.60±9.5
Cd^{+}	4.5±0.57	5.02±1.01	5.62±0.55	5.48±0.51	6.32±0.54	4.71±0.56	5.60±0.57	6±0.58	6.07±0.50	5.28±0.99
Pb^{2+}	14.02±0.02	13.05±0.03	12.49±0.04	15.35±0.56	19.81±0.99	14.78±0.98	14.04±3.23	14.44±0.58	14.38±1.49	15.64±2.29

3.6. Correlation between physicochemical parameters measured upstream and downstream in the soil samples taken in the rainy season

In each receiving environment, correlations between the physicochemical parameters measured in the soil samples during the rainy season were observed (Figure.1). Thus, during the rainy season; upstream; the soil samples from the Douala slaughterhouse show a positive and significant correlation between total nitrogen and total phosphorus with r= 0.99 and P= 0.045; a negative and significant correlation between total nitrogen and electrical conductivity with r= -1 and P= 0.004; while a negative and non-significant correlation is observed between total phosphorus and electrical conductivity with r= -0.99 and P= 0.05. The Yaounde slaughterhouse shows that there is a positive and significant correlation between total nitrogen and total phosphorus with r= 0.99 and P= 0.005. The NODISCAM sample shows a positive and significant correlation between organic carbon and electrical conductivity with r= 0.99 and P= 0.016. In the FERMENCAM soil samples, a negative and significant correlation is observed between total nitrogen and the C/N ratio with r= -1 and P=0.006. In the SCR Maya company soil samples, a positive and significant correlation is observed between total nitrogen and total phosphorus (r= 0.99; P= 0.025); while in SOSUCAM Mbandjock, there is a positive correlation between total nitrogen and organic carbon (r= 0.99; P= 0.032); a negative correlation between total nitrogen and the C/N ratio (r= -0.99; P= 0.033).

In the SOSUCAM Nkoteng soil samples, positive and significant correlations are observed between lead and electrical conductivity (r= 0.98; P= 0.024) on the one hand and between total phosphorus and total nitrogen (r= 0.99; P= 0.022) on the other hand.

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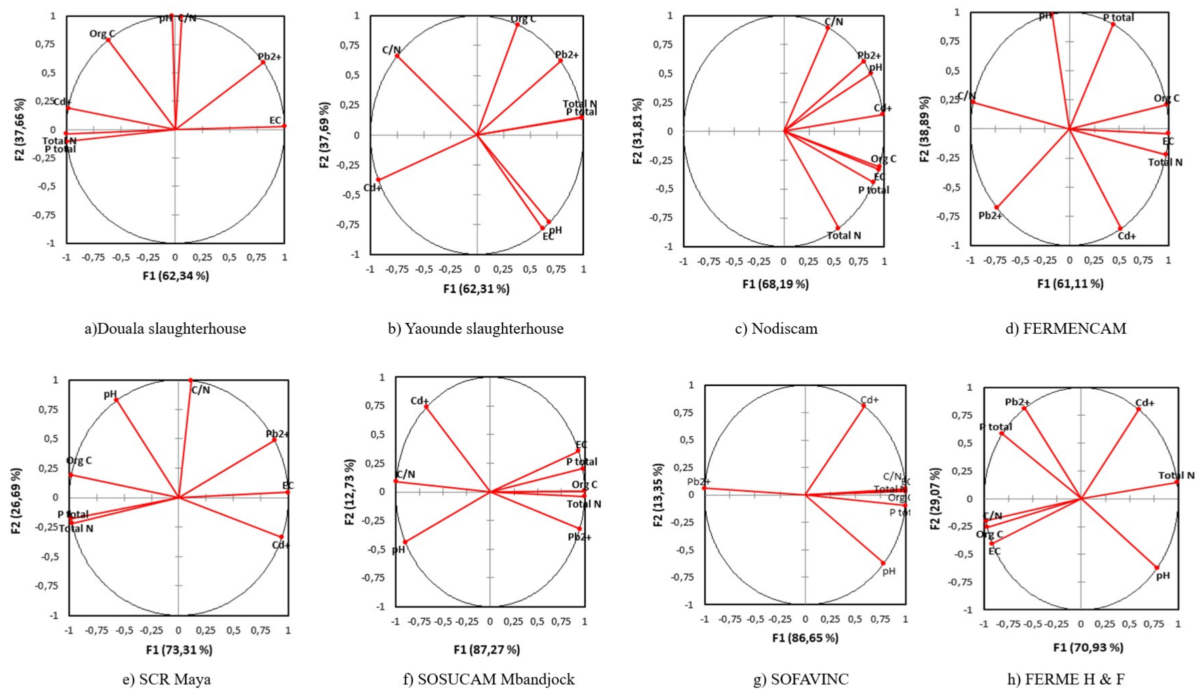


Figure 1. Correlation circle of physicochemical parameters measured in upstream soil samples during the rainy season.

There is a negative and significant correlation between organic carbon and conductivity (r = -0.98; P = 0.011). Correlations exist between the physicochemical parameters measured in the SOFAVINC soil samples (Table 7) and in the FERME H & F soil samples (Table 8). Upstream of the GUINNESS company, the soil samples collected show a single positive and significant correlation between lead and electrical conductivity (r = 0.99 and P = 0.05).

Table 7. Correlation test between physicochemical parameters measured upstream in soil samples at SOFAVINC during the rainy season.

Correlation matrix (Pearson)								
Variables	pH	EC	Total P	C Org	N Total	C/N	CD+	Pb2+
pH	1							
EC	0.759	1						
Total P	0.838	0.991	1					
Org C	0.755	1,000**	0.990	1				
Total N	0.744	1,000*	0.988	1,000*	1			
C/N	0.757	1,000**	0.991	1,000**	1,000*	1		
Cd^{+}	-0.049	0.613	0.504	0.618	0.631	0.615	1	
Pb^{2+}	-0.819	-0.995	-0.999*	-0.995	-0.993	-0.995	-0.533	1

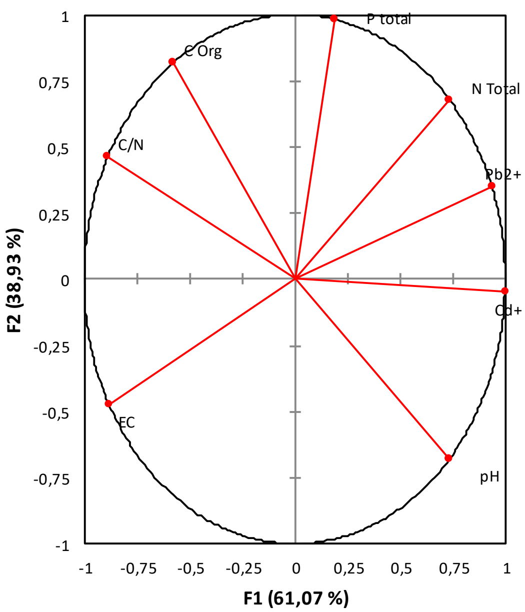
* p<0.05; **p<0.005; ***p<0.0005

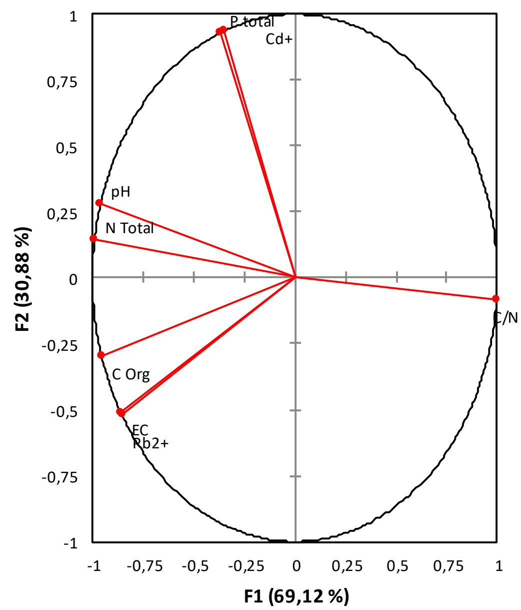
Table 8. Correlation test between physicochemical parameters measured upstream in soil samples from the FERME H&F in the rainy season

Correlation matrix (Pearson)								
Variables	pH	EC	Total P	C Org	N Total	C/N	CD+	Pb2+
pH	1							
EC	-0.466	1						
Total P	-0.999*	0.507	1					
Org C	-0.600	0.988	0.636	1				
Total N	0.681	-0.965	-0.715	-0.994	1			
C/N	-0.643	0.977	0.679	0.998*	-0.999*	1		
Cd^{+}	-0.036	-0.868	-0.011	-0.779	0.708	-0.742	1	
Pb^{2+}	-0.962	0.205	0.948	0.357	-0.454	0.409	0.308	1

* p<0.05; **p<0.005; ***p<0.0005

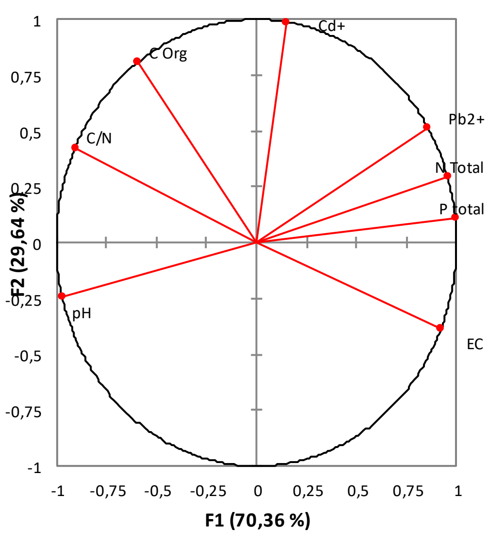
The physicochemical parameters measured downstream in soil samples from the receiving environments of the Douala slaughterhouse, the SCR MAYA company and FERME H&F do not show any correlation. However, in soil samples from the Yaoundé slaughterhouse, a negative and significant correlation was observed between the C/N ratio and total phosphorus (r= -0.99; P= 0.041); a negative and significant correlation between cadmium and total nitrogen (r= -1; P= 0.003). Soil samples downstream from the NODISCAM company show a negative but significant correlation between organic carbon and total phosphorus (r= -0.99; P= 0.028); between cadmium and total phosphorus (r= -0.99; P= 0.025). Two positive and significant correlations were obtained in soil samples collected downstream during the rainy season at FERMENCAM between total phosphorus and cadmium (r= 1; P= 0.018); between lead and electrical conductivity (r= 1; P= 0.006); a positive and significant correlation between total nitrogen and the C/N ratio (r= 0.99; P= 0.039). In soil samples from GUINNESS, only one positive but significant correlation was observed between lead and electrical conductivity (r= 0.99; P= 0.036). Soil samples collected downstream of SOSUCAM Mbandjock and Nkoteng show a negative and significant correlation between organic carbon and lead (r= -1; P= 0.009) on the one hand, a positive and significant correlation between total nitrogen and pH (r=0.99; P= 0.032), between electrical conductivity and the C/N ratio (r=0.99; P= 0.028) on the other hand. In soil samples collected downstream of the SOFAVINC company, correlations between pH and organic carbon (r= 0.99; P= 0.024); between the C/N ratio and pH (r= 0.99; P= 0.038); between total nitrogen and electrical conductivity (r= 1; P= 0.013); and between organic carbon and C/N ratio (r= 1; P= 0.014) were observed (Figure. 2).

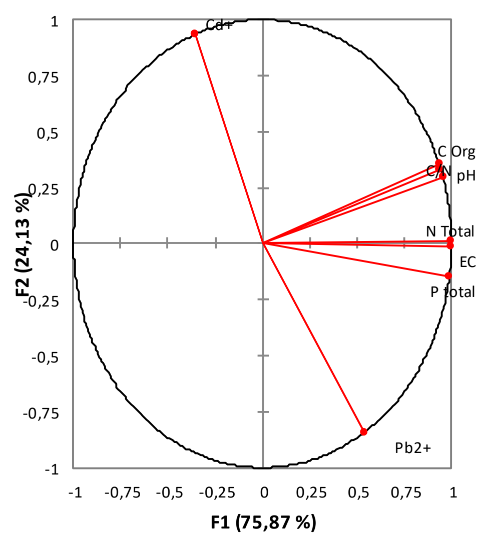




a) Douala slaughterhouse

b) FERMENCAM





c) SOSUCAM Nkoteng

d) SOFAVINC

Figure. 2. Correlation circles of physicochemical parameters measured downstream in soil samples during the rainy season.

3.7. Correlation between physicochemical parameters measured upstream and downstream in the soil samples taken in the dry season

Analysis of soil samples from the Douala slaughterhouse during the dry season, upstream, (Table 9) shows negative and significant correlations between pH and conductivity (r=-1; P= 0.003); pH and Pb^{2+} (r=-1; P=0.011); Pb^{2+} and conductivity (r=-1; P=0.003); pH and Pb^{2+} (0.03).

A positive and significant correlation between total phosphorus and Cd^{+} (r= 0.99; P= 0.014). At the Yaoundé slaughterhouse, soil samples show a negative and significant correlation between total phosphorus and organic carbon (r= -0.99; P= 0.041); also between total nitrogen and lead (r= -0.99; P= 0.023). Soil samples taken upstream of the NODISCAM company show two significant correlations, one between pH and Pb^{2+} (r= 1; P= 0.012); the other between organic carbon and the C/N ratio (r= 0.99; P= 0.038). In the FERMENCAM soil samples, seven correlations are observed between the physicochemical parameters (Table 10).

Table 9. Correlation test between physicochemical parameters measured upstream in soil samples from the Douala slaughterhouse during the dry season

Correlation matrix (Pearson)								
Variables	pH	EC	Total P	C Org	N Total	C/N	CD+	Pb2+
pH	1							
EC	-1.00**	1						
Total P	-0.564	0.567	1					
Org C	0.471	-0.467	0.463	1				
Total N	-0.437	0.440	0.989	0.588	1			
C/N	0.687	-0.684	0.213	0.965	0.354	1		
Cd^{+}	0.524	-0.528	-0.999*	-0.504	-0.995	-0.259	1	
Pb^{2+}	-1,000*	1,000*	0.549	-0.487	0.421	-0.700	-0.509	1

* p<0.05; **p<0.005; ***p<0.0005

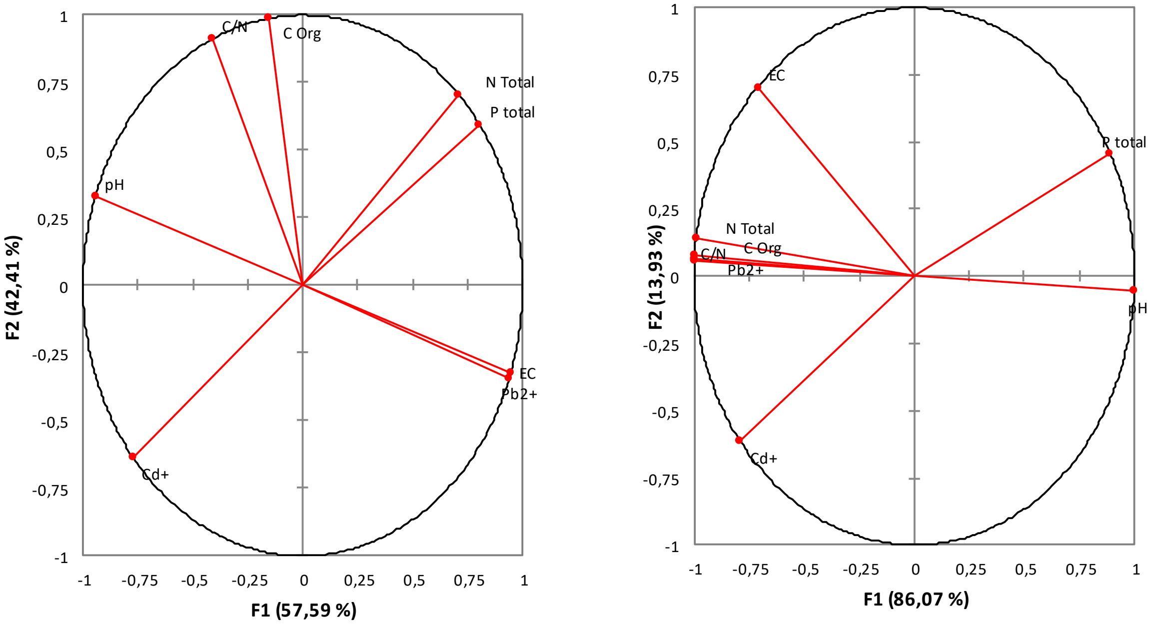
Table 10. Correlation test between physico-chemical parameters measured upstream in FERMENCAM soil samples in the dry season

Correlation matrix (Pearson)								
Variables	pH	EC	Total P	C Org	N Total	C/N	CD+	Pb2+
pH	1							
EC	-0.746	1						
Total P	0.866	-0.313	1					
Org C	-1.00**	0.752	-0.862	1				
Total N	-0.996	0.804	-0.817	0.997	1			
C/N	-1.00**	0.748	-0.864	1.00**	0.996	1		
Cd^{+}	-0.756	0.128	-0.982	0.750	0.693	0.754	1	
Pb^{2+}	-1,000*	0.763	-0.853	1,000*	0.998*	1,000*	0.739	1

* p<0.05; **p<0.005; ***p<0.0005

In the GUINNESS soil samples, only one significant positive correlation was observed between organic carbon and the C/N ratio (r = 0.99; P = 0.045). At FERME H&F , soil samples showed a significant positive correlation between organic carbon and the C/N ratio (r = 0.99; P = 0.022); a significant negative correlation between the C/N ratio and total nitrogen (r = -0.99; P = 0.046).

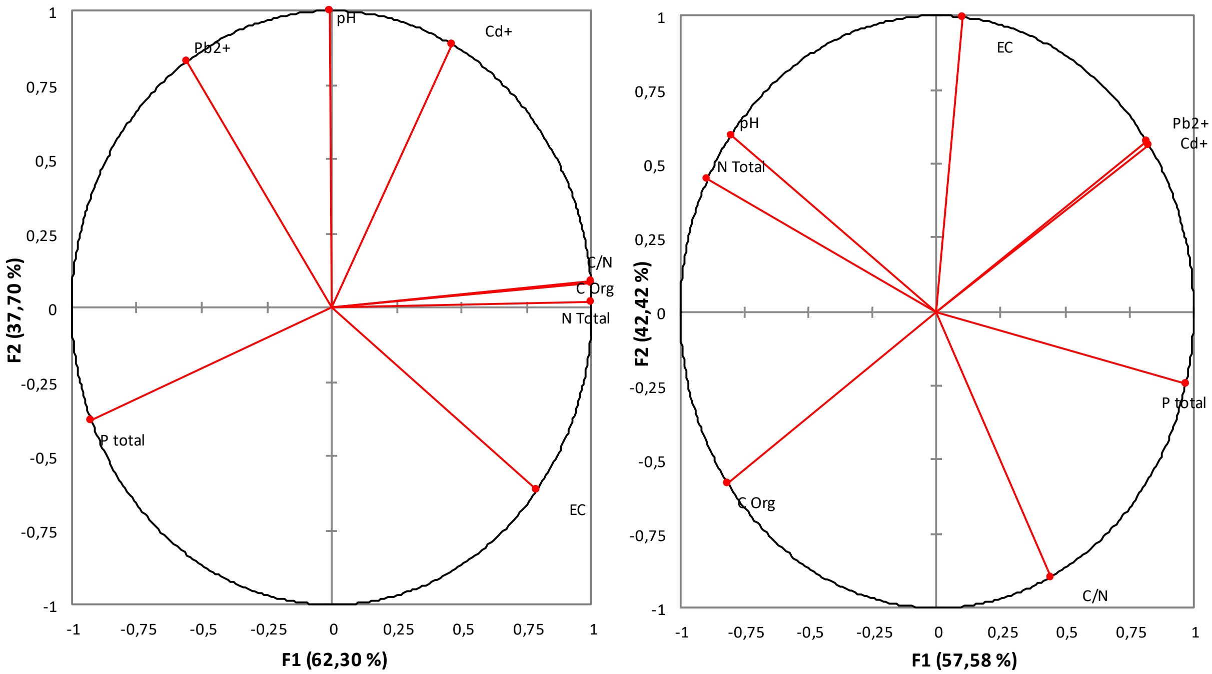
In the soil samples analysed upstream of the SCR MAYA company, three significant correlations are observed; two negative ones between total nitrogen and cadmium on the one hand (r= -0.99 and P= 0.028); total nitrogen and lead on the other hand (r= 0.99; P= 0.034); a positive correlation between lead and cadmium (r= 0.99; P= 0.006). However, at SOSUCAM Mbandjock, a negative and significant correlation between conductivity and pH is observed (r= -0.99; P= 0.036). In the soil samples from SOSUCAM Nkoteng, a negative and significant correlation between total phosphorus and the C/N ratio (r= -0.99; P= 0.022) is observed; whereas in the SOFAVINC soil samples there was a positive and significant correlation between pH and lead (r = 0.99; P = 0.021).



a) Douala slaughterhouse b) FERMENCAM

Figure. 3. Correlation circles of physicochemical parameters measured upstream in dry season soil samples.

The physicochemical parameters measured downstream in the soil samples of the receiving environments show a single positive and significant correlation at the Douala slaughterhouse between the C/N ratio and organic carbon (r= 0.99; P= 0.034), at the Nodiscam company, between total phosphorus and total nitrogen (r= 0.99; P= 0.009), at FERME H&F between organic carbon and the C/N ratio (r= 0.99; P= 0.004) and at SOSUCAM Nkoteng, a negative correlation between pH and the C/N ratio (r= -0.99; P= 0.011). The soil samples from the Yaoundé slaughterhouse show a negative and significant correlation between pH and electrical conductivity (r= -0.99; P= 0.003); a negative and significant correlation between the C/N ratio and total nitrogen (r= -0.99; P= 0.045). FERMENCAM has three positive and significant correlations observed between total nitrogen and organic carbon (r= 0.98; P= 0.042); between the C/N ratio and organic carbon (r= 1; P= 0.003) and between the C/N ratio and total nitrogen (r= 0.99; P= 0.045). In the GUINNESS soil samples, a negative and significant correlation between pH and the C/N ratio (r=-1; P= 0.018) is observed as well as a positive and significant correlation between cadmium and lead (r= 0.99; P= 0.045). Soil samples located downstream of SOSUCAM Mbandjock show three significant correlations, two negative between organic carbon and cadmium (r= -1; P= 0.017); between organic carbon and lead (r= -1; P= 0.006) on the one hand, a positive correlation between cadmium and lead (r= 1; P= 0.011) on the other hand (Figure.4).



a) FERMENCAM b) SOSUCAM Mbandjock

Figure. 4. Correlation circles of physicochemical parameters measured downstream in dry season soil samples.

In soil samples collected downstream of SOFAVINC, a negative correlation between organic carbon and conductivity (r= -0.99; P= 0.05) is observed; similarly, a positive correlation between organic carbon and the C/N ratio (r= 0.99; P= 0.021) and a negative and significant correlation between total phosphorus and pH (r= -1; P= 0.001). Soil samples collected downstream of SCR MAYA show two correlations, a negative and significant one between lead and electrical conductivity (r= -0.99; P= 0.034) and a positive and significant one between organic carbon and the C/N ratio (r= 0.99; P= 0.025).

4. Discussion

Compared with the physicochemical characteristics of the analyzed effluents (Noukeu et al., 2016), soil samples from the SOSUCAM Mbandjock and SOSUCAM Nkoteng receiving environments show acidic pH values between 6.43 and 6.71 upstream and downstream of the rainy season. In the dry season, these values are between 4.06 and 5.71. These acidic pH values were also observed in sugar effluents (Singh et al., 2025). Kumar (2014), after irrigation with sugar mill effluents, noted changes in the physicochemical characteristics of the soil in the dry and rainy seasons. He found basic pH values between 8.63 and 8.72 in soils irrigated at different concentrations of sugar effluent; while the results obtained by Sagar and Prakash (2013) corroborate those found in the SOSUCAM soil samples. They found acidic pH values ranging from 5.7 to 6.8; they noted that the pH values range from acidic to basic as the analysed soils are further away from the sugar refinery plant i.e. downstream.

In all the soil samples analyzed in this study, the pH is acidic upstream and a trend towards neutrality or alkalinity downstream is observed. Soil pH plays an important role in the mobility of heavy metals and is an important factor influencing the solubility of the metal and therefore its toxicity (Mireles et al., 2004). Thus, the cadmium and lead concentrations in the soil samples studied are very high. The increase in soil pH of the receiving environments is due to the presence of soluble salts contained in agro-food effluents (Hlaibi and Mechnou, 2025). Soil acidity can influence the mineral nutrition of plants. The values of electrical conductivity upstream and downstream during the rainy season are high in the soil samples from the FERME H&F site, the Yaounde slaughterhouse and FERMENCAM. The results obtained in this study are in agreement with those reported by Rulli et al. (2025) who also observed an increase in electrical conductivity following the addition of vinasse from a distillery such as FERMENCAM. The measurement of electrical conductivity (EC) makes it possible to estimate the salinity of the soil and to have an estimate of the concentration of soluble salts present there. These salts mainly contain the cations Ca^{2+}, Na^{+}, Mg^{2+} and the anions Cl^{-}, $SO4^{2-}$, HCO_3^{-}. They are also found at high concentrations in the effluents of FERMENCAM and FERME H&F (Noukeu et al., 2016). This high conductivity also depends on the loads of endogenous and exogenous organic matter generating salts after decomposition and mineralization and also with the phenomenon of evaporation which concentrates these salts in the soil (Aminot and Kerouel, 2004). The organic matter concentration of the soil samples in this study is justified by the carbon, nitrogen contents and the C/N ratio values. In the rainy season, in the soil samples taken upstream, the values of 9.37%, 13.49% and 6.4% of organic carbon were observed in soils from the Yaoundé slaughterhouse, FERME H&F and FERMENCAM respectively. The total nitrogen contents range from 0.06% in the soil samples from SOSUCAM Nkoteng to 2.23% in the soil samples from FERME H&F. In the soils taken downstream, a reduction in these parameters was observed. Furthermore, in the dry season, upstream, very high contents of these parameters are observed. On the other hand, downstream a decrease in concentration is observed. The C/N ratio, which reflects the rate of mineralization of carbon and nitrogen and consequently the degree of decomposition of organic matter in the soil, showed good mineralization with values between 4 and 12 in the rainy season in soil samples from FERME H&F, the Yaoundé slaughterhouse and Douala. Low values of this ratio were observed in the dry season. A high C/N ratio (15 to 20) was observed in the rainy season and the dry season in the soils of NODISCAM, FERMENCAM, SOSUCAM Mbandjock and Nkoteng. These high values of the C/N ratio can be justified by the high organic matter content of the agro-food effluents (high BOD_5, COD and MES) studied which feed the receiving environments. These soils show a reduction in biological activity and a difficulty in the process of mineralization of organic matter, which can cause the immobilization of nitrogen in the soil by microorganisms with the consequence of very eutrophic soils (Stevenson, 1994; Girard, 2011). Kumar and Chopra (2012) who found high values of organic matter in soils irrigated by distillery effluents confirm this result. Thus, Knoth et al. (2007) report that vinasse can contain up to 16546 mg/L of dissolved organic carbon. According to Mouni et al. (2009), the concentration of organic matter increases with the addition of suspended matter, which shows the organic nature of the suspended matter in the effluents discharged in this study. The total phosphorus values measured in soil samples from the Douala slaughterhouse, GUINNESS, FERME H&F, NODISCAM, SCR MAYA, FERMENCAM, SOSUCAM Nkoteng and SOSUCAM Mbandjock are high during the rainy season and the dry season upstream and downstream. These significant amounts of phosphorus in the studied soils can be transported to watercourses in particulate form or in dissolved form in runoff water. Given the major role of phosphorus in the eutrophication process, Kumar and Chopra (2014) justify this presence in the soil by the irrigation of soils with agro-food effluents rich in phosphorus. They found lower phosphorus values (142.86 mg/kg) in the irrigated soils during the rainy season than those obtained in the soils of this study (3050 mg/kg in the FERMENCAM soils during the dry season upstream). The trace metal elements (TME) measured in the soil samples show higher lead concentrations than cadmium concentrations and it is the soils of GUINNESS, the Douala slaughterhouse and SOFAVINC that have lead values between 15.02 mg/kg and 18.81 mg/kg; cadmium values are between 4.88 mg/kg and 7.66 mg/kg upstream of the rainy season, while downstream these values decrease slightly. In the dry season, the concentrations of both TMEs are higher. Compared with the phytotoxicity threshold (lead 500 mg/kg; cadmium 1 mg/kg) defined by Tremel-Schaub and Feix (2005) to authorize the agronomic use of a soil, as well as the values of normal TME in soils (0.06 mg/kg for cadmium and 10 mg/kg for lead) established by Fagot (1993); only cadmium contents showed higher values.

The accumulation of heavy metals in soil is related to their concentration in wastewater (Al-Nakshabandi et al., 1997; Madyiwa et al., 2002; Luo et al., 2006). However, long-term irrigation of the studied effluents could cause a progressive accumulation in the soil, as well as the transfer of a fraction of these substances to plants and, subsequently, could cause toxicity phenomena in humans (Aleem and Malik, 2003; Singh et al., 2004; Gonzalez and Gonzalez, 2006). Numerous studies confirm a significant accumulation of such substances in soils irrigated for a prolonged period with wastewater (Huerta et al., 2002; Wong et al., 2002; Yadav et al., 2002; Mireles et al., 2004; Dère et al., 2006). Both cadmium and lead are non-essential TMEs. However, cadmium is mobile in the soil and more easily absorbed by plants than most heavy metals (Baize and Paquereau, 1997; Vick and Poe, 2011). Cadmium and lead are toxic even in small amounts to plants, animals, and humans. They accumulate in the soil due to their long biological half-lives (Goethberg et al., 2002). The level of soil contamination by TMEs depends on its physico-chemical properties (texture, percentage of clay, pH, cation exchange capacity (CEC), organic matter content), the concentration and type of TME present in the effluents and finally the duration during which the soil has been subjected to irrigation (Biswas, 1987; Remon et al., 2005; Tankari et al., 2013; Priso et al., 2017).

According to Madyiwa et al. (2002), there is a strong correlation between the storage of TMEs in the soil, the concentration of organic matter and the CEC. When these last two parameters are high, the vertical distribution of exogenous metals is limited to the first 10-20 cm of the soil where the majority of organic matter is found. In this study, at more than 50 cm from the soil, the presence of high cadmium concentrations was observed. Studies have shown that heavy metals can be absorbed and immobilized by clay minerals or also be complexed by soil organic matter, thus forming an organometallic complex (Lamy et al., 2005). The richer a soil is in organic matter, the more it is able to immobilize heavy metals and prevent their leaching into groundwater. In this study, soil samples with a high C/N ratio have cadmium concentrations above the standards. In addition, some correlations can be observed between heavy metals measured in soil samples and other physicochemical parameters of the soil. The granulometric composition of the soil could also play a role in the rapid infiltration of discharged effluents. The granulometric analysis showed a dominance of the coarse fraction in all soils and low proportions of fine particles (clays and silts). This granulometry gives the soil good porosity allowing air and water to circulate, and roots to develop well.

Conclusion

Agro-food industries discharge their untreated effluents into natural environments. As a result, many pollutants end up in receiving environments without their effect on these environments being truly known. This study made it possible to characterize the soils of the receiving environments, to make a comparison between the soils collected upstream and downstream of the pollution source on the one hand, and to see the impact of the rainy season and the dry season on the physicochemical characteristics of the soils. Analysis of the soil in the receiving environments showed their richness in sand, facilitating the infiltration of effluents. All the soils studied have acidic pH upstream and a tendency towards neutrality or alkalinity downstream regardless of the season. The richness in organic matter is marked by high values in total phosphorus and organic carbon. The values of the C/N ratio showed good mineralization in the rainy season compared to the dry season. The high values of this ratio are justified by the richness in organic matter of the agro-food effluents studied which punctually feed the receiving environments. In the soils, the concentrations of lead are higher than those of cadmium. However, only the cadmium values obtained in all the soils are above the standards set for heavy metals.

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