

Assessment of Heavy Metals Contamination in Sediments of Bra Kanon Lake (Daloa, Côte d'Ivoire) Using Pollution Indices

Seiny Roger N'dri¹, Amadou Kouyaté^{2,*}, Issiaka Sanou³, N'guessan Jean Louis Kouakou²,
Kouakou Séraphin Konan², Nina Lydie Amon⁴, Leygnima Yaya Ouattara⁵,
Mougo André Tigori², Ali Sanou^{1,5}, Brou Dibi²

¹Laboratoire des Sciences Physiques Fondamentales et Appliquées (LSPFA), Ecole Normale Supérieure (ENS),
08 BP 10 Abidjan, Côte d'Ivoire

²Laboratoire des Sciences et Technologies de l'Environnement (LSTE), Université Jean Lorougnon Guédé,
UFR Environnement, BP 150 Daloa, Côte d'Ivoire

³Laboratoire de Chimie et Energies Renouvelables (LaCER), Unité de Formation et de Recherche en Sciences
Exactes et Appliquées (UFR/SEA), Université Nazi BONI, Bobo-Dioulasso, B.P. 1091 Bobo 01, Burkina Faso.

⁴Département de l'Environnement et de la Santé, Université Institut Pasteur de Côte d'Ivoire (IPCI),
01 BP 490 Abidjan 01, Côte d'Ivoire

⁵Laboratoire des Procédés Industriels de Synthèses, de l'Environnement et des Energies Nouvelles (LAPISEN),
Institut National Polytechnique Félix Houphouët-Boigny (INP-HB), BP 1313 Yamoussoukro, Côte d'Ivoire

*Corresponding author: amadoukyte@yahoo.fr

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Abstract The objective of this study is to evaluate the level of metal contamination in the sediments of Lake Bra Kanon (Daloa, West-Central Côte d'Ivoire) by applying pollution indices. Sediment samples were collected and transported to the laboratory for analysis. A total of ten (10) heavy metals, namely Aluminum, Arsenic, Cadmium, Chromium, Copper, Iron, Manganese, Nickel, Lead and Zinc, were measured using an argon plasma ionizing source mass spectrometer (ICP-MS). The recorded values were compared to those of the upper continental crust. The results obtained showed that the sediments are contaminated by cadmium (4.69 – 6.92 mg/kg), copper (53.4– 65.2 mg/kg), and manganese. (751.8 – 985 mg/kg). Furthermore, the order of accumulation of the metal charge in the sediments is: D1 > D3 > D2. Environmental assessment of sediment pollution by heavy metals was carried out using contamination factor (CF), degree of contamination (DC), modified degree of contamination (mDC), index of metal pollution (MPI) and pollution load index (PLI). The results of CF ($CF_{Cd} = 46.9 - 69.2$; $CF_{Cu} = 3.73 - 4.56$; $CF_{Mn} = 1.42 - 1.87$), DC (54.73 – 77.63), mDC (5.473 – 7.763) and MPI (5.81 – 8.55) showed that the sediments were polluted. The pollution load index ($PLI < 1$) indicated that the lake sediments were weakly affected by anthropogenic sources. However, the results reveal signs of the lake's vulnerability. Hence the need to develop strategies for the protection of this aquatic ecosystem.

Keywords: Daloa, lake Bra Kanon, sediments, heavy metals, metal pollution indices

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1. Introduction

In recent years, environmental contamination by metals has raised ecological and public health problems [1,2]. Indeed, the rampant increase in anthropogenic activities contributes enormously to high levels of metals in water and especially in sediments [3]. Aquatic ecosystems are among the environments most subject to heavy metal contamination [4]. Aquatic systems are often the source of

these metals which represent a real danger for humans, animals and the environment [5,6]. Furthermore, these heavy metals have adverse effects on aquatic organisms when their concentrations are very high in aquatic ecosystems. Thus, metal contamination of aquatic ecosystems remains an increasingly worrying environmental problem [7].

These metals are present in all compartments of the aquatic ecosystem, namely fauna, flora, water and sediments [7]. Sediments can also behave as endogenous sources of contamination by resuspension or by evolution

of the speciation of heavy metals, which will affect their bioavailability [8]. Therefore, they are considered the most important reservoirs [9], sources of heavy metal contamination [10] and constitute an essential study matrix for aquatic systems [11]. The trapping of heavy metals in sediments could pose an ecotoxicological problem for aquatic life [12]. Indeed, the contamination of sediments by heavy metals constitutes a real danger for water, living species and for human health [13] because all metals are toxic when they are present at a level above the tolerance limit [14].

In Côte d'Ivoire, studies recently carried out in various aquatic environments have revealed the presence of heavy metals in sediments at often very high concentrations [8,15,16,17,18,19,20]. However, these concentrations of heavy metals in sediments do not provide sufficient information on the level of sediment contamination. It is therefore necessary to evaluate the level of contamination of metals in sediments and their toxicity by applying pollution indices to preserve life in the aquatic environment.

Several pollution indices have been used to assess the level of metal contamination in soils and sediments [21,22,23,24,25,26]. Indeed, environmental quality indices are a powerful tool for developing, evaluating and converging raw environmental information towards decision-makers, managers or the public [27]. The objective of the present study is to evaluate the level of metal contamination in the sediments of Lake Bra Kanon by applying pollution indices.

2. Materials and Methods

2.1. Presentation of the Study Area

Lake Bra Kanon (Figure 1) is located in Daloa, between 6°30' and 8° North latitude and between 5° and 8° West longitude [28], precisely in the Evêché district with an area of 84551 m². It is a reservoir created by the first Mayor of the city of Daloa. Lake Bra Kanon does not receive any other effluent except in the event of rain when the rainwater runs off to flow into the reservoir. However, potential sources of lake pollution have been identified. Three sampling sites were chosen to carry out lake sediment sampling. A downstream site (D1), a middle site (D2) and an upstream site (D3) of the lake (Figure 1). The GPS coordinates of the different sampling sites are recorded in Table 1.

2.2. Collection and Preservation of Sediment Samples

Sediment samples were taken in December 2020. The sediment samples were taken using a Van Veen stainless steel grab with a surface area of 250 cm² and a mass of 5 kg. The bucket is steered using a rope into the water. When it hits the bottom of the water, the throw of the messenger triggers the jaws to close and the rope is pulled to raise the bucket to the surface. The sediment samples are removed from the bin, packaged in new plastic packaging and stored in coolers containing ice to keep them at a low temperature of 4°C to avoid any degradation

before their analysis in the laboratory [29]. Once in the laboratory, the sediment samples packaged in the packages are stored in a freezer at -20°C [30].

Before use, the samples are dried in an oven at 50°C for 24 hours. Subsequently, they undergo pre-sieving on a 1 mm mesh sieve in order to eliminate rock debris, branches, leaves and organic debris before being sieved to < 63 µm. In order to obtain a constant mass, the fine fraction (< 63 µm) is retained and newly dried in an oven at 60°C for one hour. It is stored individually in polyethylene bags indelibly labeled and numbered, in accordance with the numbers of the different sampling sites.

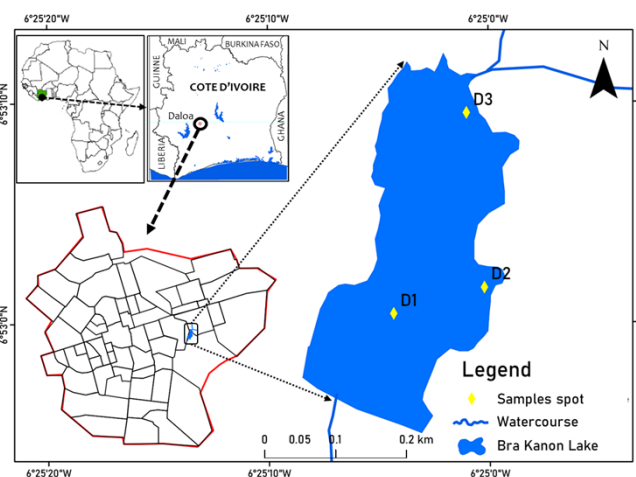


Figure 1. Presentation of sediment sampling sites in Lake Bra Kanon

Table 1. GPS coordinates of the different sediment samples collection sites

Sampling sites	Geographical positions	
	X	Y
D1	785353	761636
D2	785377	761639
D3	785454	761916

2.3. Heavy Metal Analysis

Heavy metal analysis was carried out using an argon plasma ionizing source mass spectrometer (ICP-MS), according to EPA methods (200.8, 3050, 6020) [31] and Standard Method for the Evaluation of Water and Wastewater [32]. The sample is driven into an argon plasma via a peristaltic pump and a nebulizer. The metals contained in the sample are atomized and ionized in the plasma. The produced ions are introduced into the mass spectrometer chamber where they are directed through a series of charged metal plates, separated by a quadrupole, to finally be captured by a detector. The concentration of an element at a specific mass is determined by comparison between the quantities of ions captured between the sample and standard solutions.

2.4. Assessment of the Level of Metallic Contamination of Sediments

2.4.1. Metal Load

The metal loading (ML) of a sample is the arithmetic sum of the concentration of all the metals measured in this

sample [33]. The metal load (mg/kg) for each sediment sample was calculated with the mathematical formula given by equation 1 [33,34]:

$$ML = \sum_{i=1}^n C_i \quad (1)$$

Where C_i is the concentration of metal i in the sediment sample.

2.4.2. Metal Pollution Index (MPI)

The metal pollution index (MPI) is a reliable and accurate method for monitoring metal pollution [35]. It makes it possible to compare the total heavy metal content between different study sites [8,33,36]. This index is defined as the n th root of the multiplication of concentrations. MPI was calculated with the equation proposed by Usero [37]:

$$MPI = (C_1 \times C_2 \times \dots \times C_n)^{1/n} \quad (2)$$

Where C represents the concentration of the metal in the sample and n the total number of metals measured in the sediment sample.

2.4.3. Contamination Factor

The contamination factor (CF) is obtained by dividing the concentration of each element in the sediment sample by the background concentration (UCC) [25,38]. CF is given by the formula [39]:

$$CF = \frac{C_M}{C_R} \quad (3)$$

With C_M the concentration of the metal in the sediment and C_R the reference value of the metal. The reference values taken are the crustal concentrations (UCC : Upper Continental Crust) of the different metals studied (mg/kg) (Table 2). The contamination factor contains four (4) classes which are given in Table 3.

Table 2. Heavy metals concentrations of the upper continental crust [40]

Heavy metals	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
UC	774	20	0.	35.	14.	308	52	18.	17.	52.
C	40	.0	10	00	30	90	7	60	00	00

Table 3. Classes of the contamination factor [39,41]

Class	Value	Contamination
1	$CF \leq 1$	Weak
2	$1 < CF \leq 3$	Moderate
3	$3 < CF \leq 6$	Considerable
4	$CF \geq 6$	Very strong

2.4.4. Degree of Contamination

The degree of contamination of a sediment is the sum of all the contamination factors. This index assesses sediment contamination by giving an indication of the degree of overall sediment contamination from a sampling site [42]. The degree of contamination is expressed as follows [39]:

$$DC = \sum_{i=1}^n CF_i \quad (4)$$

With CF_i the contamination factor of metal i and n the number of heavy metals measured in the sample.

The values of this index determine four classes of contamination [39,43] which are given in Table 4.

Table 4. Classes of the degree of contamination [39,43]

Class	Value	Degree of contamination
1	$DC < 6$	Low
2	$6 \leq DC < 12$	Moderate
3	$12 \leq DC < 24$	Considerable
4	$DC \geq 24$	Very High

2.4.5. Modified Degree of Contamination

The modified degree of contamination (mDC) is an index proposed by Abraham and Parker [44]. The modified degree of contamination (mDC) makes it possible to generalize the degree of contamination (DC) by defining it as the sum of all the contamination factors (CF) for a given set of pollutants divided by the number of pollutants analyzed in the sample [44]. The mDC index therefore allows an overall assessment of the pollution present in sediment samples [25,38].

The modified degree of contamination is defined as follows [44]:

$$mDC = \frac{1}{n} \sum_{i=1}^n CF_i \quad (5)$$

With CF_i the contamination factor of metal i and n the number of heavy metals measured in the sample.

The mDC consists of seven classes [25,38] which are presented in Table 5.

Table 5. Modified degree of contamination classes [25,38]

Class	Value	Degree of contamination
1	$mDC < 1.5$	Very low
2	$1.5 < mDC < 2$	Low
3	$2 < mDC < 4$	Moderate
4	$4 < mDC < 8$	High degree
5	$8 < mDC < 16$	Very high
6	$16 < mDC < 32$	Extremely high
7	$mDC \geq 32$	Ultra high

2.4.6. Pollution Load Index

The pollution load index is a powerful tool for assessing heavy metal pollution [24,45,46]. The pollution load index represents the number of times the metal content in the sediment exceeds the background concentration [8]. It provides comprehensive information on the toxicity of metals in a sample [42].

The pollution load index is evaluated using the following mathematical relationship [47]:

$$PLI = (CF_1 \times CF_2 \times \dots \times CF_n)^{1/n} \quad (6)$$

With CF the contamination factor and n the number of heavy metals measured in the sample.

The PLI value < 1 indicates the absence of pollution, while the PLI value $= 1$ indicates a reference pollution level and the PLI value > 1 indicates pollution [24,48].

2.5. Statistical Analysis

In the majority of environmental studies, the results lead to a complex data set. Statistical tests have the advantage of identifying the existence or not of the effects of one parameter on another and also of quantifying these effects by giving them a degree of significance [49].

In this study, principal component analysis (PCA) and the Bravais–Pearson linear correlation coefficient r were used to determine the relationship between the variables and measure the intensity of this link. The correlation coefficient varies from -1 to +1. The value -1 indicates a perfect negative correlation and the value +1 represents a perfect positive correlation while the value 0 shows an absence of correlation between the variables. Indeed, the closer the value of r is to -1 or +1, the stronger the linear relationship. The closer the value of r is to 0, the weaker the linear relationship is [50,51]. Statistical analysis of the data was carried out with STATISTICA 7.1 software.

3. Results and Discussion

Sediments are important sinks for heavy metals and play an important role in the enrichment and remobilization of metals in aquatic systems [52]. The analysis of sediments should therefore be included in environmental studies because they are the result of the integration of all processes (biological, physical and chemical) that occur in an aquatic ecosystem, influencing the metabolism of the entire system [53,54].

3.1. Concentrations of the Studied Heavy Metals and Metal Load in Sediments

Table 6 shows the heavy metals contents in the sediment samples as well as the metal loading values. The present study reveals the presence of all heavy metals studied in the sediments of Lake Bra Kanon. This presence indicates contamination of the sediments by these metals. Indeed, sediments are the most important reservoirs of metals and other pollutants in the aquatic environment [18,55].

The values recorded for all metals at the different sampling sites were compared to those of the upper continental crust (UCC). It appears from this comparison that the contents of aluminum, arsenic, chromium, iron and nickel in the sediments are lower than the concentrations in the upper continental crust which are 77440 mg/kg for Al, 2 mg/kg for As, 35 mg/kg for Cr, 30890 mg/kg for Fe and 18.6 mg/kg for Ni (Table 6). These low concentrations of heavy metals observed in the sediments could be explained by the diffusion of each metal in the dissolved phase due to physicochemical conditions such as pH, redox potential and organic matter, certainly by the dilution phenomena which take place

through a supply of less or slightly contaminated sediments [4].

On the other hand, the concentrations of the metals Cd, Cu and Mn are higher than the values of the continental upper crust which are 0.10 mg/kg for Cd; 14.3 mg/kg for Cu and 527 mg/kg for Mn (Table 6). These high contents obtained can be explained by adsorption phenomena due to environmental and physicochemical conditions. Indeed, it is known that the high pH in the dry season promotes the fixation of heavy metals in sediments [4]. Furthermore, these high concentrations suggest that the sediments are polluted by cadmium, copper and manganese at all sites. Furthermore, lead has a higher value than the crustal standard (17 mg/kg) at site D1 while zinc has concentrations higher than the crustal level (52 mg/kg) at sites D1 and D3. These data reflect localized pollution of lead and zinc. These large quantities of heavy metals accumulated in sediments constitute a danger for the aquatic environment [56] because high concentrations of metals in aquatic systems are known to harm aquatic organisms through the phenomenon of bioaccumulation [18]. Metals bound to sediments are likely to be released into the water column, during changes in environmental conditions such as redox potential, pH, desorption, thus affecting aquatic biota [4].

The study reveals that site D1 recorded 50% heavy metals whose concentrations are lower than those in the upper continental crust while site D2 recorded 70% metals and site D3 recorded 60%. The order of accumulation of metals in sediments is: D1 > D3 > D2. This order of accumulation of metals in the sediments suggests that site D1 located upstream is more seriously polluted by heavy metals than the other two sites and would be due to the fact that site D1 located upstream of the lake and closer to possible sources of pollution (domestic discharges, swimming, agricultural activities) receives more metals than the other two sites.

The metal load reflects the total quantity of heavy metals measured in a given sample [33]. The metal load is higher in site D1 (1464.513 mg/kg) and lower in site D2 (1104.401 mg/kg). The order of accumulation of the metal load in the sediments of Lake Bra Kanon is: D1 > D3 > D2. The metal load is very high in all sampled sites. This high metal load could harm aquatic organisms. Indeed, in aquatic ecosystems, metals tend to accumulate in sediments and biomagnify along aquatic food chains [57]. The high loads are believed to be due to high levels of copper, iron, manganese, lead and zinc in the sediments. However, these heavy metal contents in the sediments do not provide sufficient information on the level of sediment contamination. In order to therefore evaluate the degree of contamination of the sediments of Lake Bra Kanon, the contamination indices were calculated.

Table 6. Concentrations of heavy metals in sediments

	Heavy Metals (mg/kg)										ML (mg/kg)
	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn	
D1	0.064	0.324	6.5	8.45	53.4	331.7	985	0.075	26.6	52.4	1464.513
D2	0.137	0.095	4.69	6.12	61.2	213.5	751.8	0.059	15.9	50.9	1104.401
D3	0.034	0.089	6.92	5.98	65.2	110.5	855	0.062	16.7	54.6	1115.085
UCC	77440	2	0.10	35	14.3	30890	527	18.6	17	52	

3.2. Level of Sediment Contamination

3.2.1. Metal Pollution Index

The metal pollution index (MPI) makes it possible to compare the overall content of heavy metals in different samples [8,36]. The recorded values indicate overall contamination in the following descending order: D1 (8.55) > D2 (6.67) > D3 (5.81) (Table 7). This could be attributed to the high concentrations of Cu, Fe and Mn recorded during the sampling period. However, these values are all greater than 1 (MPI > 1) for all sampled sites; thus reflecting that all the metals contained in the sediments are not safe for aquatic organisms [36,58].

Table 7. MPI values of sediments from Lake Bra Kanon

Sites	MPI
D1	8.55
D2	6.67
D3	5.81

3.2.2. Contamination Factors

The contamination factor (CF) helps determine the relative level of contamination for each item, thus providing a measure of the extent of contamination [38]. The values of the heavy metal contamination factors in

sediments are presented in Table 8. The contamination factor made it possible to observe different levels of contamination depending on the metal. For cadmium, the CF values are 46.9; 65 and 69.2 respectively for D2, D1 and D3. These values are well above 6 (CF > 6), thus indicating strong cadmium contamination of the sediments at the three sites [39,46]. For copper, the CF values recorded are 3.73 for D1, 4.28 for D2 and 4.56 for D3. These values being between 3 and 6 ($3 < CF \leq 6$), they reflect considerable copper contamination of the sediments [39,48]. For manganese, the CF values are respectively 1.42; 1.62 and 1.87 for site D2, site D1 and site D3. These values show moderate contamination of sediments by this metal. Moderate sediment contamination is also observed for lead at site D1 (1.56), for zinc at site D1 (1.00) and at site D3 (1.05) [39,42]. Concerning aluminum (0.0000004 – 0.000001), arsenic (0.0445 – 0.162), chromium (0.17 – 0.24), iron (0.0035 – 0.01), nickel (0.003 – 0.004), lead at sites D2 (0.93), D3 (0.98) and zinc at site D2 (0.98), the CF values are less than 1 (CF < 1). These values reflect the absence of contamination of sediments with these metals [24,39]. Generally speaking, the CF values of heavy metals are in the following descending order: $CF_{Cd} > CF_{Cu} > CF_{Mn} > CF_{Zn} > CF_{Pb} > CF_{Cr} > CF_{As} > CF_{Fe} > CF_{Ni} > CF_{Al}$.

Table 8. CF values of sediments for the studied metals

	Contamination Factors									
	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
D1	0.0000008	0.162	65	0.24	3.73	0.01	1.87	0.004	1.56	1.00
D2	0.0000001	0.0475	46.9	0.17	4.28	0.0069	1.42	0.003	0.93	0.98
D3	0.0000004	0.0445	69.2	0.17	4.56	0.0035	1.62	0.003	0.98	1.05

3.2.3. Degree of Contamination, Modified Degree of Contamination and Pollution Load Index

Degree of contamination (DC), modified degree of contamination (mDC) and pollution loading index (PLI) have been widely used in the assessment of sediment pollution by heavy metals [24,42,46,48,59]. In this study, the degree of contamination and the modified degree of contamination were used to assess the overall contamination of sediments by heavy metals [44]. The values of the degree of contamination and the modified degree of contamination of the sediments are presented in Table 9. These degree of contamination values were between 54.75 and 77.63 and all above 24 (DC > 24); indicating a very high degree of contamination of the sediments of lake Bra Kanon [24,39,42,43]. These very high degrees of contamination (DC > 24) observed could indicate serious anthropogenic pollution of the lake [42]. Furthermore, the modified degree of contamination (mDC) values of the sediments were between 4 and 8 ($4 < mDC < 8$) thus showing a high degree of sediment contamination [25,46].

To assess the impact of anthropogenic activities on the sediment quality of Lake Bra Kanon, the pollution load index (PLI) was calculated (Table 9). The values obtained ranged between 0.083 at site D3 and 0.124 at site D1. The recorded values are all less than 1 (PLI < 1), thus indicating an absence of anthropogenic pollution [46,60]. Furthermore, these PLI values are designated as no to low pollution and also do not indicate any considerable

anthropogenic activity [42]. Therefore, the PLI results do not support those of DC and mDC. However, the results of the present study could indicate that the contamination of Lake Bra Kanon sediments by heavy metals would be the result of both natural and anthropogenic sources. It should be noted that PLI makes it possible to know the quality of the environment [61] and to assess the impact of anthropogenic activities on the quality of sediments. Indeed, PLI values greater than 1 (PLI > 1) indicate a contribution from anthropogenic sources; thus highlighting a progressive deterioration of sediment quality [8,58].

Table 9. Values of DC, mDC and PLI of sediments from Lake Bra Kanon

	DC	mDC	PLI
D1	73.57	7.357	0.124
D2	54.73	5.473	0.092
D3	77.63	7.763	0.083

3.2.4. Relationship Between the Heavy Metals

Correlations between the metals measured in the different samples are established using principal component analysis (PCA) and the Bravais–Pearson correlation matrix. These methods are widely used to characterize and evaluate existing relationships between variables [17,18,38] [50,51,62,63] [64,65,66].

In the factorial plan F1 X F2, the eigenvalues of the two components F1 and F2 and their contribution to the total

inertia are given in Table 10 and Figure 2. The two axes taken into consideration to describe the correlations between the measured parameters hold the total information alone, i.e. 100% with 66.44% for axis 1 and 33.56% for axis 2. These factorial axes are therefore representative of the variance of all the data and essentially reflect the total inertia.

Principal component analysis (PCA) made it possible to illustrate different correlations between heavy metals in sediments from the correlation circle [66]. The correlation circle (Figure 3) represents the projection of the initial variables on a two-dimensional plane constituted by the first two factors F1 (66.44%) and F2 (33.56%). In the correlation circle, the F1 axis is defined on the positive side by copper (Cu). On the negative side, it is defined by manganese (Mn), nickel (Ni), lead (Pb), arsenic (As), chromium (Cr) and iron (Fe). The second axis is defined

by cadmium (Cd) and zinc (Zn) on the positive side. On the negative side, it is defined by aluminum (Al). According to Kouakou et al., parameters defined on the same side of an axis are positively correlated with each other while those defined on different sides of the same axis are negatively correlated with each other [66]. The results obtained therefore indicate a correlation between the different parameters and could reflect an influence between the parameters [65].

Table 10. Eigenvalues and percentages expressed for axes F1 and F2

	F1	F2
Eigenvalueur	6.64	3.36
Variability (%)	66.44	33.56
Cumulative percentage (%)	66.44	100.00

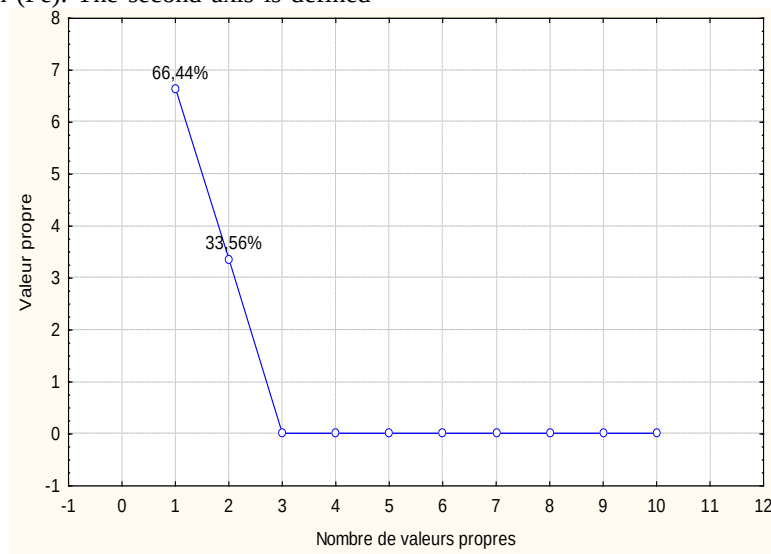


Figure 2. Distribution of inertia between the axis of eigenvalues and the axis of the number of eigenvalues

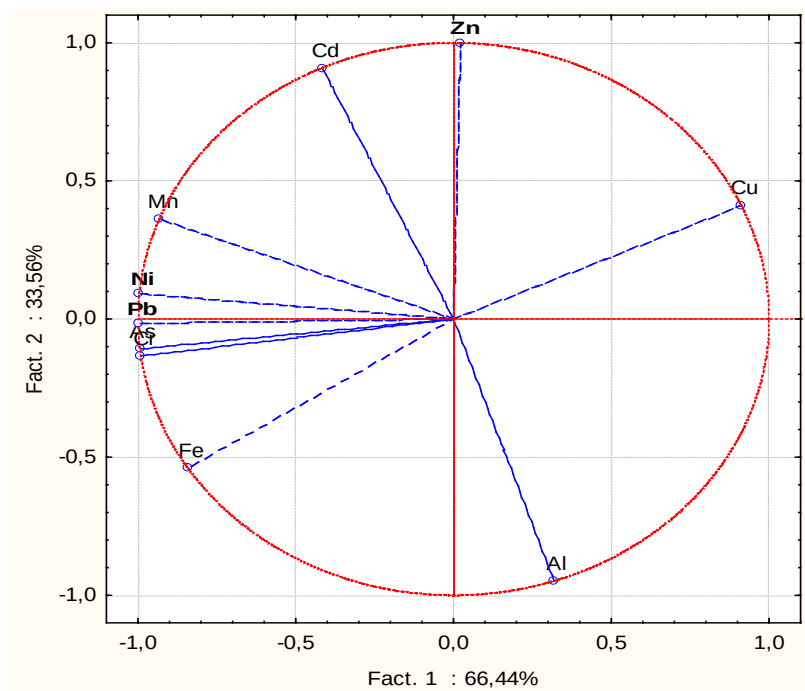


Figure 3. Projection of variables onto the factorial plan F1 and F2

Table 11. Bravais–Pearson correlation coefficients between variables

	Al	As	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Al	1									
As	-0.21	1								
Cd	-0.99	0.32	1							
Cr	-0.18	1.00	0.29	1						
Cu	-0.10	-0.95	-0.01	-0.96	1					
Fe	0.24	0.90	-0.14	0.91	-0.99	1				
Mn	-0.64	0.89	0.72	0.87	-0.70	0.59	1			
Ni	-0.40	0.98	0.50	0.97	-0.87	0.79	0.96	1		
Pb	-0.30	1.00	0.40	0.99	-0.92	0.85	0.92	0.99	1	
Zn	-0.94	-0.13	0.90	-0.16	0.43	-0.56	0.34	0.07	-0.04	1

The Bravais–Pearson linear correlation matrix was carried out to elucidate the relationships between the variables measured in the different samples. The correlation coefficients are presented in Table 11. Coefficients in bold are significant at $P < 0.05$. Examination of the matrix indicates the existence of positive and significant correlations between the metals: As - Cr ($r = 1.00$), As - Fe ($r = 0.90$), As - Mn ($r = 0.89$), As - Ni ($r = 0.98$), As - Pb ($r = 1.00$), Cd - Mn ($r = 0.72$), Cd - Ni ($r = 0.50$), Cd - Zn ($r = 0.90$), Cr - Fe ($r = 0.91$), Cr - Mn ($r = 0.87$), Cr - Ni ($r = 0.97$), Cr - Pb ($r = 0.99$), Fe - Mn ($r = 0.59$), Fe - Ni ($r = 0.79$), Fe - Pb ($r = 0.85$), Mn - Ni ($r = 0.96$), Mn - Pb ($r = 0.92$) and Ni - Pb ($r = 0.99$). These significant and positive correlations observed between metals indicate their mutual dependence and a common source of pollution [17,66]. Furthermore, the good correlations observed between these metals suggest similar geochemical characteristics and a common origin for these elements. [25,38,67]. However, significantly negative correlations were found between Al - Cd ($r = -0.99$), Al - Mn ($r = -0.64$), Al - Zn ($r = -0.94$), As - Cu ($r = -0.95$), Cr - Cu ($r = -0.96$), Cu - Fe ($r = -0.99$), Cu - Mn ($r = -0.70$), Cu - Ni ($r = -0.87$), Cu - Pb ($r = -0.92$) and Fe - Zn ($r = -0.56$). These results show an inverse dependence between these metals, thus reflecting a decrease in one of the parameters with the increase in the other [50,66]. Non-significant correlations ($r < 0.5$) were observed between certain variables. These low correlations indicate that the presence or absence of one of these parameters has little effect on the content of the other [33,68].

4. Conclusion

This study aimed at evaluating the level of contamination of aluminum, arsenic, cadmium, chromium, copper, iron, manganese, nickel, lead and zinc in the sediments of Lake Bra Kanon in Daloa in the Center-West of Côte d'Ivoire by the application of some pollution indices. The results showed that the contents of cadmium, copper and zinc in the sediments were higher than their concentrations in the upper continental crust (UCC). This accumulation of heavy metals in the sediments is believed to be due to anthropogenic activities (agricultural practices, artisanal fishing, animal watering) near the lake and to the input of wastewater from surrounding households. The order of accumulation of heavy metals in the sediments was at site D1: Mn > Fe > Cu > Zn > Pb > Cr > Cd > As > Ni > Al; at site D2: Mn > Fe > Cu > Zn > Pb > Cr > Cd > Al > As > Ni and D3: Mn > Fe > Cu > Zn > Pb > Cd > Cr

> As > Ni > Al. The study has also revealed that only 50% of heavy metals assayed had lower concentrations than the upper continental crust at site D1 while site D2 recorded 70% metals and site D3 recorded 60%. The metal load (ML) and metal pollution index (MPI) showed that the sediments are contaminated with higher contamination at site D1. The contamination factor (CF) showed that the sediments were polluted by cadmium, copper, lead and zinc and virtually unpolluted by aluminum, arsenic, chromium, iron and nickel. The degree of contamination (DC) and modified degree of contamination (mDC) indicated that the lake sediments were highly contaminated. However, manganese, iron, copper, zinc and lead would be the main contributors to this high contamination. The pollution load index ($PLI < 1$) indicated an absence of anthropogenic pollution of the sediments. The principal component analysis and the correlation matrix highlighted the different correlations that exist between the heavy metals present in the sediments. These results showed that the sediments are contaminated and present a risk for aquatic organisms and humans, thus justifying the need for monitoring the environmental quality of the sediments of Lake Bra Kanon. Anything that will reduce contamination and pollution of the lake, thus promoting the protection of the aquatic ecosystem and the health of the population.

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