



Research article

Assessment of traces metals in sediment from Ebolowa Municipal Lake basin (central-africa): potential risk and provenance

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ABSTRACT

This study focused on assessing contamination levels of heavy metal elements (Cr, Co, Ni, Zn, Cu, Mo, Cd, and Pb) in surface sediments for the Ebolowa Municipal Lake (EML) basin in Southern Cameroon and identifying possible pollution sources. Twenty-one samples from the EML and its tributaries (Mfoumou and Bengo'o) were subjected to geochemical analysis by inductively coupled plasma-mass spectrometry (ICP-MS). The results obtained from these analyses allowed us to calculate the Contamination factor (CF), enrichment factor (EF), geo-accumulation index (Igeo), Potential Ecological Risk Factor (Er), Pollution Load Index (PLI), and Potential Ecological Risk Index (RI). Multivariate statistics completed these analyses. The concentrations in mg/kg are as follows: Cr (96.46) > Zn (55.94) > Cu(34.01) > Ni(30.77) > Co(16.14) > Pb(10.58) > Mo (0.61) > Cd (0.14). However, these concentrations are higher in the sites subjected to the most anthropogenic pressure (EML and Mfoumou). The pollution indexes are between: $0.29 \leq CF \leq 2.76$, $-28.10 \leq I_{geo} \leq 0.13$, $0.14 \leq EF \leq 2.19$. PLI values < 1 in all sites. Er has high values for Cd (21.43–42.85) and low values for the other elements. RI < 100 values for all elements and on all sites. Pearson's correlation matrix and the Hierarchical Classification Ascending (HCA) illustrate two sources of inputs. The spatial distribution of TME seems to be impacted by autochthonous inputs of domestic effluents and parameters such as particle size and organic matter content. The pollution index values illustrate low to moderate contamination and pollution in Cr, Ni, Co, Cd, and Cu. The Er values illustrate a moderate ecological risk for Cd. The RI values indicate a low ecological risk for all sites. High values are mainly associated with poor domestic waste management, non-compliant automotive buildings and agricultural activities.

1. Introduction

To ensure their survival and comfort, humans have always shown little concern for their natural environment. The results today are drastic, in particular for aquatic ecosystems. Pollutants that reach them constitute an environmental problem. Indeed, most of these contaminants can be found in very high proportions, thus becoming dangerous for aquatic life, both in the water column and in the bottom sediments. Urban lakes, especially those in Cameroon, remain receptacles for effluents from the urban areas within their catchment areas.

Due to their toxic effects at more or less variable concentrations, their persistence and bioaccumulation in several environmental compartments, trace metals (TME) are the subject of particular attention in environmental pollution studies (Choi et al., 2015; Ali

et al., 2016; Bing et al., 2016; Dai et al., 2018). Some of these elements, such as copper (Cu) and zinc (Zn), at low concentrations, are seen as essential because they favor the growth of animal and plant organisms, but others, such as lead (Pb), chromium (Cr) and cadmium (Cd), have harmful effects at the lowest concentrations (Muhammed and Ahmad, 2020). These are indeed responsible for several public health problems (Dai et al., 2018; Wang et al., 2019). According to Alloway (2013) and Muhammed and Ahmad (2021), TME comes from the geochemical background and from anthropogenic sources. In fact, they are associated with soil erosion, rock weathering, atmospheric fallout, or volcanic eruptions and mining, industrial effluents, fertilizer use in agriculture, waste treatment, and, increasingly, domestic activities (Dai et al., 2018; Wang et al., 2019; Varolet et al., 2020).

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Sediments constitute an important ecological compartment in aquatic environments. They are the assemblages of different constituents, including minerals, organic debris, and other species (Muhammed and Ahmad, 2020). TME are natural ingredients of minerals or may be attached to suspended load forming complex bonds with other compounds. Sediments play a vital role in the ecological balance of a body of water. Several studies (Dai et al., 2018; Bing et al., 2016; Wang et al., 2019; Varol et al., 2020) have shown that most of the pollutants that arrive in aquatic environments are stored in sediments. Based on the physicochemical parameters of the environment such as hydrogen potential (pH), redox potential (Eh), conductivity (Cs), and temperature (T), pollutants stored in sediments, in this case TME, can be returned to the water column (Arnason and Fletcher, 2003; Jafarabadi et al., 2017; Wang

et al., 2019; Varol et al., 2020). Thus, sediments represent a potential source of pollutants. That is why sediments are commonly used (Goher et al., 2014; Ji et al., 2015) in environmental assessment.

The assessment of TME pollution in aquatic environments has been the subject of several studies around the world. These include the studies of Dai et al. (2018) in China; Muhammed and Ahmad, 2020 in Pakistan; Tnoui et al. (2021) in Morocco; Ekengélé et al. (2012); and Ekoa et al. (2018) in Cameroon. However, the studies conducted in Cameroon have focused on the country's most important metropolises. These investigations are supported by the relatively simple approaches of concentration measurement and the calculation of pollution and ecological risk indices (CF, Igeo, EF, PLI, Er, RI, etc.). To these are added statistical methods (Pearson correlation matrix, Principal Component Analysis,

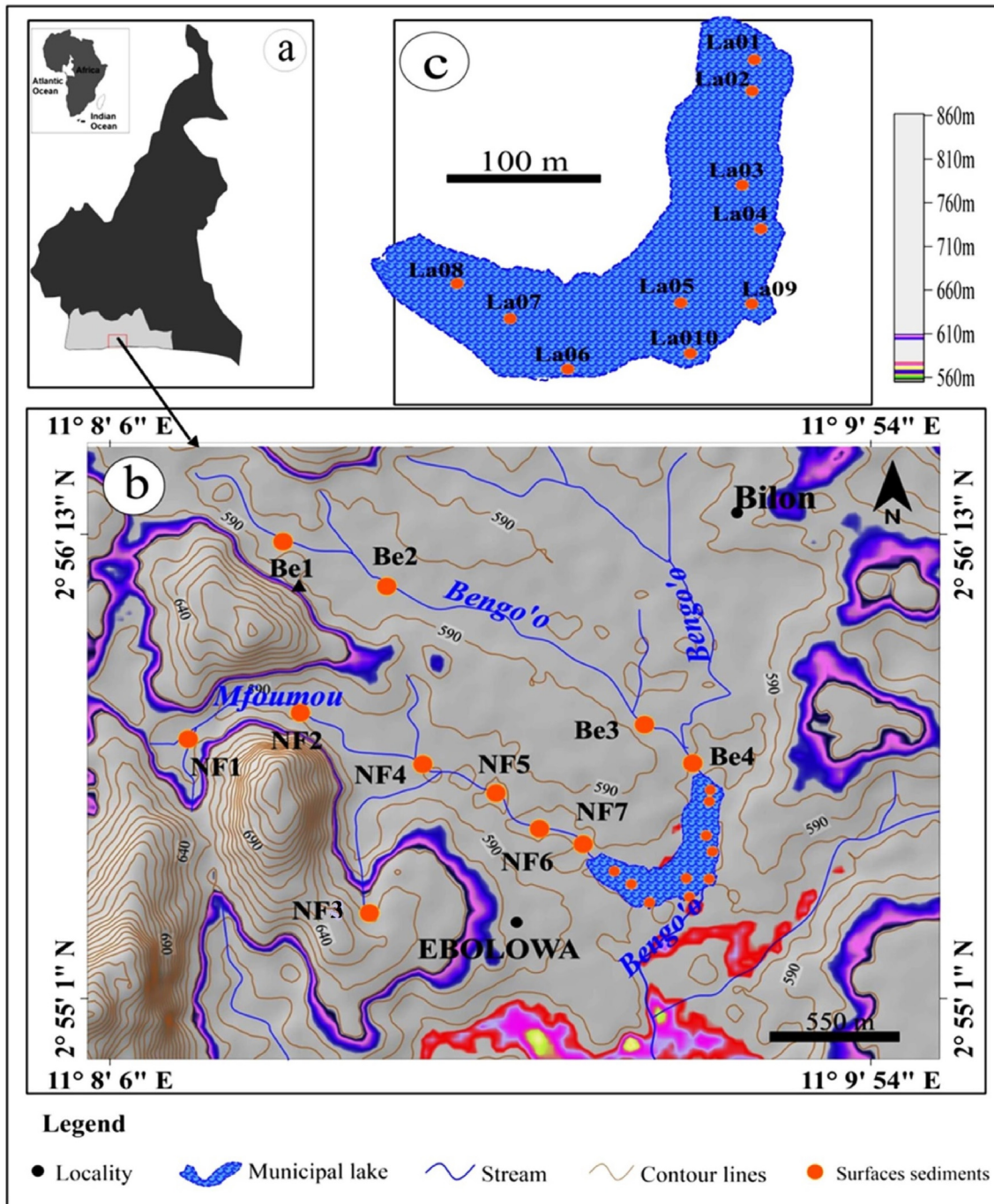


Figure 1. Location map of the study area (a) location of Cameroon and the Southern region; (b) EML and its tributaries Bengo'o and Mfoumou; (c) EML.

ascending hierarchical classification, etc.), and modeling (Buaiasha et al., 2020; Ćosić-Flajsig et al., 2020; Kumar Tripathy, 2020).

No such study has been carried out in the southern part of the country, particularly in Ebolowa city. The Ebolowa Municipal Lake (EML), which is located within it, is a recreation area but also an alternative to the supply of drinking water for the population. However, due to that position, it is the appropriate receptacle for waste from a large part of the town. Indeed, the city has no water treatment plant. The effluents from various activities migrate directly into the Bengo'o and Mfoumou streams, and then into the EML. Also, several activities and installations, notably commercial activities, fishing, laundries, and hospitals, are observed in and around the EML. This set of parameters makes the EML an environment vulnerable to pollution. This study assesses the sediment quality and identifies the possible sources of heavy metal (Al, Fe, Cr, Cu, Pb, Cd, Mn, Mo, Co, Ni, Cu) pollution in the surface sediment of the EML and its tributaries. Sediment quality was assessed by pollution and ecological risk indices; the Enrichment Factor, the Contamination Factor, the Geoaccumulation index (Igeo), the Pollution Load Index (PLI), the Ecological Risk Factor (RI), and the Ecological Risk Index (Er). The Pearson correlation matrix, principal component analysis, and cluster analysis were used to identify the main sources of metals in the samples.

2. Materials and methods

2.1. Description of sample site

The Ebolowa Municipal Lake (Figure 1) is located in Southern Cameroon (N03°06'13"-N03°43'11"; E11°00'27"-E11°32'07"). Its mean depth is 4 m. Its surface and perimeter are, respectively, 13.25ha and 2.13km, with a capacity of 980.5 m³ and a specific flow of 0.28 m³/s. Its water is slightly acidic (pH = 6.88) and warm, with the average temperature being around 24.69 °C (Madjiki et al., 2013). The region is characterized by an equatorial climate (Suchel, 1987) with high rainfall (1800 mm/year on average) and temperatures of 24.4 °C on average. These conditions favor the formation of yellow ferralitic and hydromorphic soils (Bekoa, 1994; Valerie, 1995). Geologically, the study area is located in the Congo Craton (Toteu et al., 1994; Vicat et al., 1996). This is known as the Ntem Group (Tchameni et al., 2001). It consists of the Nyong complex and the Ntem complex (Shang et al., 2004; Owona et al., 2012). The Ntem Complex, in which the study area is located, is formed by a plutonic complex composed of granitoids of the TTG (tonalites, trondjenite, and granodiorite) suite and potassic granitoids (Nsifa et al., 2001; Tchameni et al., 2001, 2004).

2.2. Sample collection

Twenty-one surface sediment samples were collected at three sites, including ten stations in the EML (La1, La2, La3, La4, La5, La6, La7, La8, La9, and La10), seven in the Mfoumou stream (NF1, NF2, NF3, NF4, NF5, NF6), and four in the Bengo'o stream (Be1, Be2, Be3 and Be4) (Figure 1), using an Eckman grab sample. This allowed the collection of the first few centimeters of the active sediment layer. In situ, the hydrogen potential (pH) and the redox potential (Eh) were measured on all the samples using a HANNA H192982/20 multi-parameter device (accuracy of 0.01 for pH and 1mV for Eh). For this purpose, the appropriate electrodes for every parameter were dropped into the wet sediment.

2.3. Analytical methods

In the laboratory, the samples were air-dried, powdered with mortar and pestle, stored in clean polyethylene bags, and sent to the laboratory (Australian Laboratory Services (ALS) geochemistry in Johannesburg, South Africa). A total of eight metals (Cr, Co, Mo, Cu, Cd, Pb, Ni, and Al) were analyzed by inductively coupled plasma-mass spectrometry (ICP-MS). Their digestion was carried out using two diacid mixtures (HCl + HClO₄) at 120 °C and (HNO₄+ HCl). The reliability of the analyses was

verified by the blank's method using three certified reference materials (INTL 15-23810, DUP-17-41709, and BLANK-17-28360). The accuracy of this method is 5%. The particle size analysis was carried out at the University of Yaoundé's Surficial Geology Laboratory. The Robinson Khlon pipette method, as described by Ndjigui et al. (2014), was implemented to determine the different particle size fractions of clays, fine silts, coarse silts, fine sands, and coarse sand fractions. Based on these fractions, cumulative curves were drawn, showing on the x-axis the grain size fractions (d) in φ units (φ = -Log2d) and on the y-axis the cumulative percentage. The values of the mean grain (Mz) were calculated using the cumulative values corresponding to 16, 50, and 84 fractions. According to the formula:

$$Mz = \frac{16 + 50 + 84}{3}$$

The International Institute for Tropical Agriculture (Yaoundé, Cameroon) did the TOC analysis. The organic matter rate was calculated using the following formulae (%) = C (%) × 12 (Walkley and Black, 1934).

2.4. Assessment of pollution

Natural background values are crucial for the interpretation of geochemical data (Varol, 2011). The Upper Continental Crust (UCC) values served as the study's geochemical foundation. This was done in order to get around limitations brought on by differences in the average grain size of the sediments, which frequently make it challenging to select a local geochemical background, and the lack of precise information on the petrographic type that feeds the catchment, on the other hand. The degree of pollution of the sediments can be determined using the Enrichment Factor (EF), Contamination Factor (CF), Geoaccumulation index (Igeo), and Pollution Load Index (PLI). The reference metal for the geochemical normalizations was alumina (Al). Being a common mineral in the Earth's crust, being insensitive to anthropogenic influences, and having the ability to build intricate structures with numerous trace metal elements (Varol et al., 2020).

2.4.1. Contamination factor (CF) and Pollution Load Index (PLI)

According to Hakanson (1980), the CF is a comparison between the element concentration at the sampling site and the background value or reference value. From Eq. (1) the CF was calculated.

$$CF = C_i/C_{bg} \quad (1)$$

Where; C_i is the metal concentration at sampling site, C_{bg} is the background (UCC values) of the metal at the site. The results were interpreted in table 1.

PLI displays the site's overall toxicity for the elements being studied (Tomlilinson et al., 1980).

$$PLI = (CF_1 \times CF_2 \times CF_2 \dots \times CF_n)^{1/n} \quad (2)$$

Where; n is the number of heavy metal parameters analyzed. The interpretation of this parameter is also seen in table 1.

2.4.2. Enrichment factor (EF)

The metal enrichment factor is typically used to evaluate the impact of human and geological activity on sediment quality. This is how the EF is expressed (Sinex and Wright, 1988).

$$EF = (C_i/CAI)_{\text{sample}} / (C_i/CAI)_{\text{background}} \quad (3)$$

Where; C_i represents the concentrations of metals in the sample, Al is concentration of background (UCC values). The interpretation of EF is given in Table 1.

2.4.3. Geo-accumulation index (Igeo)

The geo-accumulation index (Igeo) was frequently utilized, particularly in investigations of metal pollution. This index, is frequently used to

Table 1. Pollution and ecological risk indices and their classifications.

Indices	
CF	CF < 1 (low CF)
	1 ≤ CF < 3 (moderate CF)
	3 ≤ CF < 6 (considerable CF)
	CF ≥ 6
PLI	PLI = 0 (perfection)
	PLI = 1 (baseline levels of pollutants present)
	PLI > 1 (progressive deterioration of site)
EF	EF: 2–5 (Moderate enrichment)
	EF: 5–20 (significant enrichment)
	EF: 20–40 (very high enrichment)
	EF > 40 (extremely high enrichment)
Igeo	Igeo < 0 class 0 (Uncontaminated)
	0 < Igeo < 1 class 1 (uncontaminated to moderately contaminated)
	1 < Igeo < 2 class 2 (moderately contaminated)
	2 < Igeo < 3 class 3 (moderately to heavily contaminated)
	3 < Igeo < 4 class 4 (heavily contaminated)
	4 < Igeo < 5 class 5 (heavily to extremely contaminated)
RI	PERI < 110 (low risk)
	PERI: 110–220 (moderate risk)
	PERI: 220–440 (high risk)
	PERI > 440 (significantly high risk)
	E _r ⁱ < 30 (low risk)
	E _r ⁱ : 30–60 (moderate risk)
	E _r ⁱ : 60–120 (considerable risk)
	E _r ⁱ : 120–240 (high risk)
E _r ⁱ > 240 (significantly high risk)	

CF = Contamination Factor; PLI = Pollution Load Index; EF = Enrichment Factor; Igeo = Geo-Accumulation Index; PERI = Potential Ecological Risk Index; Co = Observed Element Concentration; Cb = Background Concentration of the Element; M = Element; R = Reference Element; Bn = Background Concentration; i Er = Monomial Ecological Risk Index; r Ti = Toxic Response Factor.

evaluate metal pollution in various aquatic habitats. By calculating the difference between the current and reference concentrations. The Igeo was calculated from Eq. (4).

$$Igeo = \log_2(Ci/1.5 \times Bn) \tag{4}$$

Where; Ci is the concentration of metal n in the sediment and Bn is the background value (UCC) of element in the sample. The factor 1.5 is to cater for variations in the background values (Müller, 1981). The interpretation of Igeo is given in Table 1.

2.5. Environmental risk assessment

The potential ecological risk factor (Er), the potential ecological risk index (RI), and comparison with the sediment quality requirements were used to evaluate ecological risk (SQGs). The Probable Effect Level (PEL) and the Threshold Effect Level (TEL) were utilized in this investigation because there are no rules governing sediment quality in the study area. TEL is the concentration at which an element's effects are not discernible, whereas PEL is the concentration above which the element's unfavorable effects are apparent (Manoj and Krumar, 2014; Varol et al., 2020).

2.5.1. Potential ecological risk factor (Er)

Potential ecological risk factor is used to assess the potential ecological risk of a single element in sediments (Hakanson, 1980), which is expressed as follows:

$$Er = Tr \times CF \tag{5}$$

Where Tr is the toxic-response factor of metal, they are 40 for Hg, 30 for Cd, 2 for Cr, 5 for Cu, Ni and Pb, and 1 for Zn (Hakanson, 1980). Cf is the contamination factor of metal. The Er classes are presented in Table 1.

2.5.2. Potential ecological risk index (RI)

RI is used to assess the ecological risk of multi element in soils. It is defined as the sum of the ecological risk factors (Hakanson, 1980).

$$RI = \sum Er \tag{6}$$

Where Er is the potential ecological risk factor of metal and n is the number of metals (it is 6 in this study). In Table 1, the RI classes are given.

2.6. Statistical analyses

An independent sample test was done to evaluate whether there were any significant TME differences across sampling sites. TME and physical variables were correlated using the Pearson correlation test (p < 0.05). The researchers Principal Component Analysis (PCA)/FA analysis to identify potential sources of TME in sediments. Hierarchical Cluster Analysis (HCA) was used to group TME. Prior to PCA/FA and HCA, z-scale transformation was used to normalize all data. With the aid of the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests, the data's appropriateness for PCA/FA was determined.

3. Results and discussion

3.1. Physical parameters

The results of the physical analyses of the sediments are presented in Table 2. These results show that the EML sediments are dominated by the fine fraction (Mz < 4φ). This fraction occupies more than 52% of the space. It is observed in the central, western, southwestern, and northeastern parts of the lake. This preponderance of the fine fraction is linked to the fact that the lakes are calm environments, which favor the deposition of this type of element (Vinha et al., 2016). The

Table 2. Distribution of physical parameters of sediments.

Ech	pH	Eh (mV)	Mz (φ)	TOC
La01	5,57	-18	1,58	9,25
La02	6,74	-35	1,66	8,32
La03	5,77	-30	1,46	10,46
La04	6,86	-29	5,05	12,65
La05	6,88	-43	4,81	11,04
La06	6,95	-48	4,04	8,35
La07	6,95	-42	4,39	8,1
La08	6,89	-39	4,53	10,8
La09	5,14	-10	-0,4	2,63
La10	5,9	-5	-0,67	2,08
Mean	6,37	-29,90	2,65	8,37
NF1	7,5	-25,53	1,56	8,18
NF2	5,43	94,23	0,99	8,98
NF3	6,98	3,6	-0,87	5,69
NF4	5,44	93,43	-0,96	7,06
NF5	6,83	13,33	1,2	4,31
NF6	6,2	49,77	-0,5	3,68
NF7	5,35	98,63	4,31	10,42
Mean	6,25	46,78	0,82	6,90
Be1	5,67	86,27	-0,54	8,21
Be2	7,22	7,1	-0,89	8,21
Be3	5,77	74,6	-0,79	7,07
Be4	7,74	-39,66	-0,97	7,9
Mean	6,60	32,08	-0,80	7,85

Mfoumou and Bengo'o rivers are dominated by the coarse fraction. This is linked to the fact that rivers are environments with high hydrodynamics, which keeps the fine elements in suspension and the coarse elements deposited. The fine particles observed at station NF7 can be explained by the fact that this station is an extension of the lake due to the activities carried out there. TOC contents vary between 2.08 and 11.65%. This abundance of TOC would be associated in the Bengo'o stream with the presence of forested vegetation, whose leaves and debris flow into the stream bed and whose decomposition gives a black color to the water, as highlighted in the work of [Braun et al. \(2005\)](#) in the South Cameroon Forest zone. On the other hand, the high TOC content in the Mfoumou stream and EML is linked to the household waste from domestic and market activities observed in the surrounding area. The low values observed towards the lake outlet (La09 and La10) would be linked to hydrodynamic conditions which are not favourable to the deposition of the lower density particles

(Vinha et al., 2016). These high TOC values may play a significant role in the variation of TME concentrations in sediments. Indeed, Kumar et al. (2009) have shown that organic matter plays a role in metal absorption through organometallic complex formation. The pH of the sediments is acidic on average at all three sites (Tab 2). These values are 6.37, 6.25, and 6.60 for the EML, Mfoumou, and Bengo'o, respectively. These values are associated with the acidic nature of the basement, which is made up of granitoids and gneisses. Indeed, the work of Haddad et al. (2014) showed the pH values of the water and sediments are related to the nature of the geological formations crossed. These acidic values may promote the release of TME from the sediment ([Serpaud et al., 1994](#)). Eh values are below 0 in the EML, reflecting a reducing environment. In the Mfoumou and Bengo'o rivers, on the other hand, it is higher than 0, illustrating oxidizing environments. These characteristics show that the lakes are stagnant environments, whereas the rivers are flowing environments.

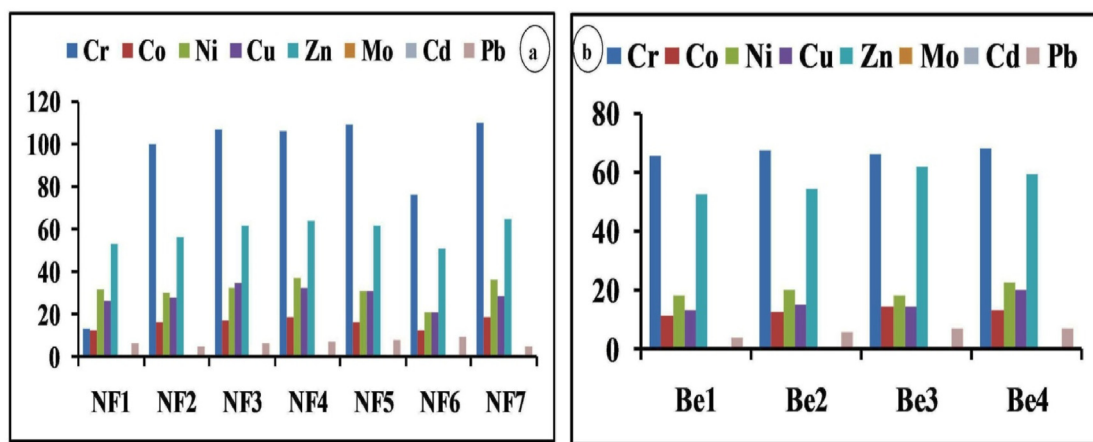


Figure 2. Distribution of trace metal elements in the sediments of the rivers: (a) Mfoumou; (b) Bengo'o.

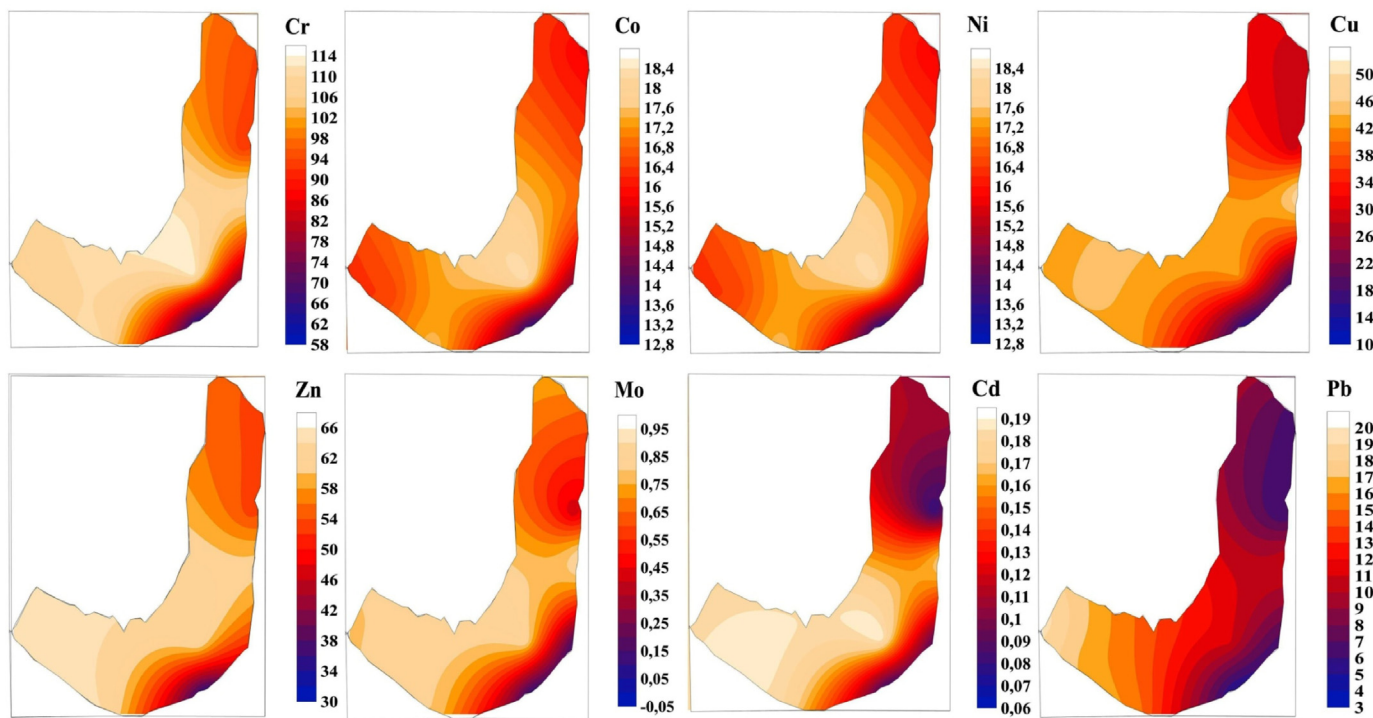


Figure 3. Distribution of trace metal elements in the EML sediments.

3.2. Trace element distribution

3.2.1. Trace metal distribution in the study area

In the Mfoumou stream, the decreasing classification of the average concentrations of TME is as follows: Cr > Zn > Cu > Ni > Co > Pb > Mo > Cd (Tab 3). This site has higher mean Cr (88.83 mg/kg), Ni (31.25 mg/kg), Co (15.86 mg/kg), Cd (0.15 mg/kg), and Cu (28.71 mg/kg) contents than the UCC (Tab 3). There is no gradual variation in concentrations from upstream to downstream (Figure 2a). This illustrates that TME has a proximal source. Thus, the high concentrations observed in sites NF2, NF4, NF5 and NF7 would be linked to the fact that they receive effluents from the anthropic activities observed there, notably agricultural activities, commercial activities, and household waste, in addition to direct discharges of metallic objects into the riverbed. The low values at NF6 (Figure 3a) can be explained by the presence of coarse particles, which according to Lario et al. (2016) do not favour the retention of TME. The low values observed at NF3 could be explained by the presence of one of the sources (soil water gushing) of the Mfoumou stream.

The TME concentrations in the Bengo'o stream are the lowest of the three sites. Only Cr (66.78 mg/kg) and Co (12.82 mg/kg) are higher than

in the UCC (Table 3). These low concentrations would be related to the fact that the Bengo'o River flows mainly through uninhabited areas and therefore is subject to negligible anthropogenic influence. The presence of the highest concentrations in the sites located in urban areas (Be3 and Be4) seems to corroborate this hypothesis (Figure 2b). A coarse fraction of sediments due to high hydrodynamism would also explain these low concentrations.

The spatial distribution of TME in the EML is presented in Table 3. The decreasing classification of the average is the same as on all other sites. However, compared to the UCC values (Turekian and Wedepohl 1961), the contents of Cr, Ni, Co, Cd, and Cu appear to be high (Tab 3). These values are, respectively, 96.46, 30.77, 16.14, 0.14, and 34.04 mg/kg. These high values would be related to the fact that the EML is under the most significant anthropogenic pressure (Nadem et al., 2015). Indeed, besides the waste transported by its two tributaries, it receives waste from the activities of the market which runs alongside it. Added to this is the waste from the tourist activities that take place there, and the domestic waste drained by the pipes that flow into it. Also, on this site, the values of these elements show a large spatial variation. Indeed, the highest values are observed in the central, western, and southwestern

Table 3. Distribution of trace metals.

Samples	Al	Cr	Co	Ni	Cu	Zn	Mo	Cd	Pb
La01	122700	96.16	16.2	29.87	31.11	53.42	0.74	0.1	9
La02	122400	94.27	15.75	30.21	28.35	53.24	0.65	0.11	6.75
La03	121100	92.59	16.51	30.28	28.98	53.27	0.41	0.08	6
La04	142300	109.67	16.76	35.25	51.22	60.92	0.94	0.18	11.25
La05	181700	113.43	18.44	36.24	42.24	63.18	0.85	0.19	11.25
La06	164300	110.5	17.6	35.21	42.36	63.91	0.79	0.18	15.75
La07	158400	108.17	16.42	34.25	44.25	64.68	0.83	0.19	16.5
La08	159100	107.43	16.31	36.24	43.21	63.95	0.78	0.18	19.5
La09	92100	73.69	14.43	21.02	15.25	51.19	0.06	0.08	5.9
La10	65500	58.69	12.98	19.08	13.12	31.67	0.05	0.07	3.92
Mean	133000	96.46	16.14	30.77	34.01	55.94	0.61	0.14	10.58
NF1	101100	12.92	12.19	31.25	26.22	53.44	0.18	0.14	6.53
NF2	97800	100.16	16.5	30.21	27.94	56.52	0.18	0.11	4.88
NF3	92100	106.91	17.26	32.24	34.25	61.92	0.11	0.16	5.85
NF4	88300	106.51	18.21	36.54	32.21	63.84	0.65	0.11	6.75
NF5	90600	108.91	15.98	31.02	31.02	61.66	0.72	0.16	7.5
NF6	75100	76.52	12.16	21.05	21.05	51.05	0.41	0.17	9
NF7	115800	109.93	18.74	36.47	28.25	64.58	0.74	0.23	4.65
Mean	95300	88.83	15.86	31.25	28.71	59	0.43	0.15	6.45
Be1	101600	65.55	11.44	18.24	13.24	52.69	0.09	0.06	4.05
Be2	106800	67.28	12.59	19.72	15.24	54.44	0.16	0.08	5.85
Be3	100000	66.27	14.18	17.89	14.45	61.76	0.18	0.07	6.68
Be4	108500	68.02	13.08	22.23	19.87	59.46	0.2	0.06	6.75
Mean	104200	66.78	12.82	19.52	15.7	57.09	0.16	0.07	5.83
UCC	154000	35	10	20	25	71	1.5	0.098	20
TEL		37.3	nd	18	37.7	123	nd	0.596	35
PEL		90	nd	36	197	315	nd	3.53	91.3

Table 4. Comparison of trace metal concentrations (mg/kg) in EML sediments with other lakes and reservoirs.

Site	Location	Cr	Co	Ni	Cu	Zn	Mo	Cd	Pb	Reference
EML	Cameroun	96.46	16.14	30.77	34.01	55.94	0.61	0.14	10.58	This study
Simbock lake	Cameroun	150.5	25	35	39	83	1.7	0.13	17	Ekoua et al. (2018)
Hazar lake	Turkey	174.2	30.8	126.7	55.2	87.8		0.24	18.1	Varol et al. (2020)
Poyonglake	Chine	141.6			62	108.9		0.5	44.4	Dai et al. (2018)
Malter Reservoir	Allemagne	210			196	1362		37.5	465	Müller et al. (2000)
Lagoon of Khnifiss	Morocco	26.6	3.57	16.5	6.60	51.70		0.16	1.21	Tnoumi et al. (2021)
Dares Salaam coast	Tanzania	4.28	0.37	1.12	0.83	5.75		0.217	1.21	Rumisha et al. (2012)

Table 5. Distribution of pollution indices.

Samples	CF							FE							Igeo							PLI			
	Cr	Co	Ni	Zn	Cu	Mo	Cd	Pb	Cr	Co	Ni	Cu	Zn	Mo	Cd	Pb	Cr	Co	Ni	Cu	Zn		Mo	Cd	Pb
La01	2.75	1.62	1.49	0.75	1.24	0.49	1.02	0.45	4.07	2.40	2.21	1.84	1.11	0.73	1.51	0.67	0.13	0.27	0.16	0.13	0.05	-0.19	-22.60	0.11	0.26
La02	2.69	1.58	1.51	0.75	1.13	0.43	1.12	0.34	4.09	2.39	2.29	1.72	1.14	0.66	1.70	0.51	0.12	0.27	0.16	0.13	0.05	-0.28	-21.66	0.09	0.26
La03	2.65	1.65	1.51	0.75	1.16	0.27	0.82	0.30	3.72	2.32	2.13	1.63	1.06	0.38	1.15	0.42	0.12	0.27	0.16	0.13	0.05	-0.57	-24.79	0.09	0.29
La04	3.13	1.68	1.76	0.86	2.05	0.63	1.84	0.56	4.24	2.27	2.38	2.77	1.16	0.85	2.48	0.76	0.13	0.27	0.17	0.15	0.06	-0.04	-16.83	0.12	0.21
La05	3.24	1.84	1.81	0.89	1.69	0.57	1.94	0.56	2.69	1.53	1.51	1.40	0.74	0.47	1.61	0.47	0.13	0.28	0.17	0.14	0.06	-0.10	-16.30	0.12	0.24
La06	3.16	1.76	1.76	0.90	1.69	0.53	1.84	0.79	3.63	2.02	2.02	1.95	1.03	0.61	2.11	0.90	0.13	0.28	0.17	0.14	0.06	-0.15	-16.83	0.13	0.25
La07	3.09	1.64	1.71	0.91	1.77	0.55	1.94	0.83	4.21	2.24	2.34	2.41	1.24	0.75	2.64	1.12	0.13	0.27	0.17	0.15	0.06	-0.12	-16.30	0.13	0.24
La08	3.07	1.63	1.81	0.90	1.73	0.52	1.84	0.98	4.04	2.15	2.39	2.28	1.19	0.68	2.42	1.28	0.13	0.27	0.17	0.14	0.06	-0.16	-16.83	0.14	0.26
La09	2.11	1.44	1.05	0.72	0.61	0.04	0.82	0.30	3.47	2.38	1.73	1.01	1.19	0.07	1.35	0.49	0.12	0.26	0.15	0.10	0.05	-1.80	-24.79	0.09	0.31
La10	1.68	1.30	0.95	0.45	0.52	0.03	0.71	0.20	3.92	3.03	2.23	1.23	1.04	0.08	1.67	0.46	0.11	0.25	0.14	0.10	0.05	-1.92	-26.10	0.07	0.30
Mean	2.76	1.61	1.54	0.79	1.36	0.41	1.43	0.53	3.73	2.19	2.08	1.84	1.07	0.55	1.93	0.72	0.13	0.27	0.16	0.14	0.05	-0.32	-19.30	0.11	0.27
NF1	0.37	1.22	1.56	0.75	1.05	0.12	1.43	0.33	0.48	1.59	2.04	1.37	0.98	0.16	1.87	0.43	0.07	0.24	0.17	0.13	0.05	-1.10	-19.30	0.09	0.28
NF2	2.86	1.65	1.51	0.80	1.12	0.12	1.12	0.24	4.44	2.56	2.35	1.74	1.24	0.19	1.74	0.38	0.13	0.27	0.16	0.13	0.05	-1.10	-21.66	0.08	0.30
NF3	3.05	1.73	1.61	0.87	1.37	0.07	1.63	0.29	5.27	2.98	2.78	2.36	1.50	0.13	2.81	0.50	0.13	0.27	0.17	0.14	0.06	-1.42	-17.99	0.08	0.31
NF4	3.04	1.82	1.83	0.90	1.29	0.43	1.12	0.34	4.79	2.87	2.88	2.03	1.42	0.68	1.77	0.53	0.13	0.28	0.17	0.13	0.06	-0.28	-21.66	0.09	0.27
NF5	3.11	1.60	1.55	0.87	1.24	0.48	1.63	0.38	5.48	2.81	2.73	2.18	1.53	0.84	2.87	0.66	0.13	0.27	0.17	0.13	0.06	-0.21	-17.99	0.10	0.25
NF6	2.19	1.22	1.05	0.72	0.84	0.27	1.73	0.45	3.45	1.92	1.66	1.33	1.14	0.43	2.74	0.71	0.12	0.24	0.15	0.12	0.05	-0.57	-17.39	0.11	0.27
NF7	3.14	1.87	1.82	0.91	1.13	0.49	2.35	0.23	4.12	2.46	2.39	1.48	1.19	0.65	3.08	0.30	0.13	0.28	0.17	0.13	0.06	-0.19	-14.42	0.07	0.24
Mean	2.54	1.59	1.56	0.83	1.15	0.29	1.53	0.32	3.87	2.42	2.38	1.75	1.27	0.44	2.34	0.49	0.12	0.27	0.17	0.13	0.06	-0.54	-18.62	0.09	0.28
Be1	1.87	1.14	0.91	0.74	0.53	0.06	0.61	0.20	2.27	1.39	1.11	0.64	0.90	0.07	0.74	0.25	0.11	0.23	0.14	0.10	0.05	-1.54	-27.61	0.07	0.30
Be2	1.92	1.26	0.99	0.77	0.61	0.11	0.82	0.29	2.46	1.61	1.26	0.78	0.98	0.14	1.04	0.37	0.12	0.24	0.14	0.10	0.05	-1.18	-24.79	0.08	0.29
Be3	1.89	1.42	0.89	0.87	0.58	0.12	0.71	0.33	2.59	1.94	1.23	0.79	1.19	0.16	0.98	0.46	0.12	0.26	0.14	0.10	0.06	-1.10	-26.10	0.09	0.30
Be4	1.94	1.31	1.11	0.84	0.79	0.13	0.61	0.34	2.99	2.01	1.71	1.22	1.29	0.21	0.94	0.52	0.12	0.25	0.15	0.12	0.06	-1.03	-27.61	0.09	0.30
Mean	1.91	1.28	0.98	0.80	0.63	0.29	0.71	0.11	2.56	1.72	1.31	0.84	1.08	0.14	0.96	0.39	0.12	0.25	0.14	0.11	0.05	-1.18	-26.10	0.08	0.30

Table 6. Distribution of ecological risk indices.

Samples	Er						RI
	Cr	Ni	Cu	Zn	Cd	Pb	
La01	5.49	7.47	6.22	0.75	30.61	2.25	52.80
La02	5.39	7.55	5.67	0.75	33.67	1.69	54.72
La03	5.29	7.57	5.80	0.75	24.49	1.50	45.40
La04	6.27	8.81	10.24	0.86	55.10	2.81	84.10
La05	6.48	9.06	8.45	0.89	58.16	2.81	85.86
La06	6.31	8.80	8.47	0.90	55.10	3.94	83.53
La07	6.18	8.56	8.85	0.91	58.16	4.13	86.79
La08	6.14	9.06	8.64	0.90	55.10	4.88	84.72
La09	4.21	5.26	3.05	0.72	24.49	1.48	39.20
La10	3.35	4.77	2.62	0.45	21.43	0.98	33.60
Mean	5.51	7.69	6.80	0.79	42.86	2.65	66.30
NF1	0.74	7.81	5.24	0.75	42.86	1.63	59.04
NF2	5.72	7.55	5.59	0.80	33.67	1.22	54.55
NF3	6.11	8.06	6.85	0.87	48.98	1.46	72.33
NF4	6.09	9.14	6.44	0.90	33.67	1.69	57.92
NF5	6.22	7.76	6.20	0.87	48.98	1.88	71.91
NF6	4.37	5.26	4.21	0.72	52.04	2.25	68.85
NF7	6.28	9.12	5.65	0.91	70.41	1.16	93.53
Mean	5.08	7.81	5.74	0.83	45.92	1.61	66.99
Be1	3.75	4.56	2.65	0.74	18.37	1.01	31.08
Be2	3.84	4.93	3.05	0.77	24.49	1.46	38.54
Be3	3.79	4.47	2.89	0.87	21.43	1.67	35.12
Be4	3.89	5.56	3.97	0.84	18.37	1.69	34.31
Mean	3.82	4.88	3.14	0.80	21.43	1.46	35.53

parts of this lake. The lowest values are obtained in the southern part (Figure 3). The high values observed in the central and western parts would be linked to the inputs associated with the Mfoumou watercourses and the outlets of the drains, as well as the market activities. Indeed, it is this part of the lake that is the most exposed to these activities. This hypothesis is supported by the low concentrations in the eastern part, which seems to be exposed only to the inflow of the Bengo'o stream and to tourism activities. The southern part constitutes the outlet of the lake, a part characterized by high hydrodynamics. According to Vinha et al. (2016), these conditions do not favour the deposition of particles, especially TMEs, which are, according to several authors, associated with fine particles.

3.2.2. Comparison of the EML with other urban lakes

The average TME concentrations were compared with the sediments of other lakes and lagoons around the world (Table 4). These results showed that the levels found in this study are much lower than those of lakes in major Asian and European cities. These low concentrations

Table 7. Pearson correlation matrix showing the relationships between the different trace metals at $p < 0.05$

	Al	Cr	Ni	Co	Zn	Pb	Cd	Mo	Cu
Al	1.00								
Cr	0.50	1.00							
Ni	0.61	0.65	1.00						
Co	0.52	0.85	0.84	1.00					
Zn	0.57	0.58	0.63	0.61	1.00				
Pb	0.77	0.44	0.52	0.34	0.49	1.00			
Cd	0.51	0.55	0.75	0.59	0.56	0.57	1.00		
Mo	0.71	0.71	0.78	0.69	0.57	0.68	0.71	1.00	
Cu	0.75	0.69	0.89	0.73	0.62	0.74	0.74	0.83	1.00

Bold: significant values ($p < 0.05$)

Table 8. Factor loading for some physical and TME parameters.

	F1	F2
pH	0,14	0,67
Eh (mV)	0,28	0,54
Mz (φ)	0,84	0,02
TOC	0,78	0,07
Al	0,94	0,00
Cr	0,87	0,03
Co	0,94	0,02
Ni	0,96	0,00
Cu	0,96	0,00
Zn	0,93	0,00
Mo	0,90	0,01
Cd	0,87	0,01
Pb	0,81	0,02

Bold: significant values ($p < 0.05$)

obtained in the framework of the present study would be linked to the absence of mining activities and large-scale industrial activities. They would also be associated with a smaller population than that observed in the major metropolitan areas. They are nevertheless close to those of the large Cameroonian cities. The Cd levels (0.14) are higher than those of Lake Simbock (0.13) and much higher than those of the Knifiss lagoons in Morocco and the Dares Salaam coast in Tanzania. The higher values compared to the lagoons would illustrate a minor contamination of this environment.

3.3. Evaluation of environmental risks

3.3.1. Contamination factor (CF)

The contamination factor is a tool for assessing the degree of contamination of sediments by evaluating the degree of pollution of a single element in a given station (Hakanson, 1980). The values of the concentration factor are summarized in Table 5. These results show that the values of this parameter are a function of the concentrations of the TME concerned. The sediments of the EML show considerable Cr contamination in 50% of the stations ($3 < FC < 6$), and moderate ($1 < FC < 3$) in the remaining 50% of the stations. In the Mfoumou stream, it is considerable in 57% of the stations, moderate in 27%, and low ($FC < 1$) in the remaining stations. Cr contamination is moderate in all stations in Bengo'o. Co is moderately contaminated at all stations in all three sites. Ni contamination is moderate in all EML and Mfoumou river sites. It is low in all the stations along the Bengo'o watercourse, except at the Be4 station. Cd contamination is moderate in 70% of the EML sites, 100% of the Mfoumou stations, and low contamination in 30% of the EML stations and 100% of the Bengo'o stations. Cu contamination is moderate in 80%

of the EML stations and 86% of the Mfoumou stations, and low contamination in all Bengo'o stations and the remaining EML and Mfoumou stations. Zn, Pb, and Mo concentrations are low in all three sites. The contamination of the sediments of the EML and the Mfoumou stream with Cr, Co, Cd, and Cu is linked to their exposure to domestic activities. In accordance with the use of agricultural inputs in the cultivation of tomatoes observed near the NF2 site, the discharge of contaminated water from household activities that reach the lake via the drains. In addition, there is the discharge of solid waste and waste from market activities. This enrichment of sediments in these elements had already been observed by Ekoa et al. (2018) in the sediments of Lake Simbock. For these authors, it would be associated with the agricultural practices implemented in this locality.

3.3.2. Enrichment factor (EF)

EF is commonly used to identify and quantify anthropogenic traces of metallic elements. The values of this parameter are summarized in Table 5. These results of the sediments show moderate ($2 < EF < 5$) to low ($EF < 2$) enrichment for all elements studied. Cr is moderately enriched at all three sites (except NF1). Ni is moderately enriched at 80% of the EML stations, 6 of the 7 stations in the Mfoumou stream, and there is no enrichment at the other stations. Co has moderate enrichment in the EML and Mfoumou, and no enrichment in Bengo'o. Mean Cd values show moderate enrichment at the Mfoumou site and no enrichment at the other sites. All of the sites investigated have average values of Zn, Pb, Mo, and Cu, indicating a lack of enrichment for all of the sites investigated. According to Zhang and Liu

(2002), metals from natural processes and the earth's crust have EF values of between 0.5 and 1.5. Thus, Cr, Ni, Co, and Cd whose average contents are higher than these values would have an anthropogenic source. These include agricultural inputs for tomato and vegetable production, and the discharge of contaminated water from household activities into the lake via drains. In addition, there is the discharge of solid waste and waste from market activities. This enrichment of sediments in these elements had already been observed by Ekoa et al. (2018) in the sediments of Lake Simbock. For these authors, it would be associated with the agricultural practices implemented in this locality.

3.3.3. Geo-accumulation index (igeo)

Like the contamination factor, the Geoaccumulation Index allows the level of contamination of sediment in a single element to be assessed. The Igeo values are summarized in Table 5. These results show that the sediments at the three sites are uncontaminated to moderately contaminated with Cr, Ni, Co, Zn, Pb, and Cu ($0 < Igeo < 1$: class 1). The sediments are not contaminated with Cd and Mo ($Igeo < 0$) for all sites. These values, illustrating a quasi-absence of contamination, do not reflect reality. According to Sahi et al. (2014), the coefficient of 1.5, which a priori takes into account the heterogeneity of the sediment, does not always represent reality. Indeed, for these authors, TMEs are mainly associated with fine particles and organic matter.

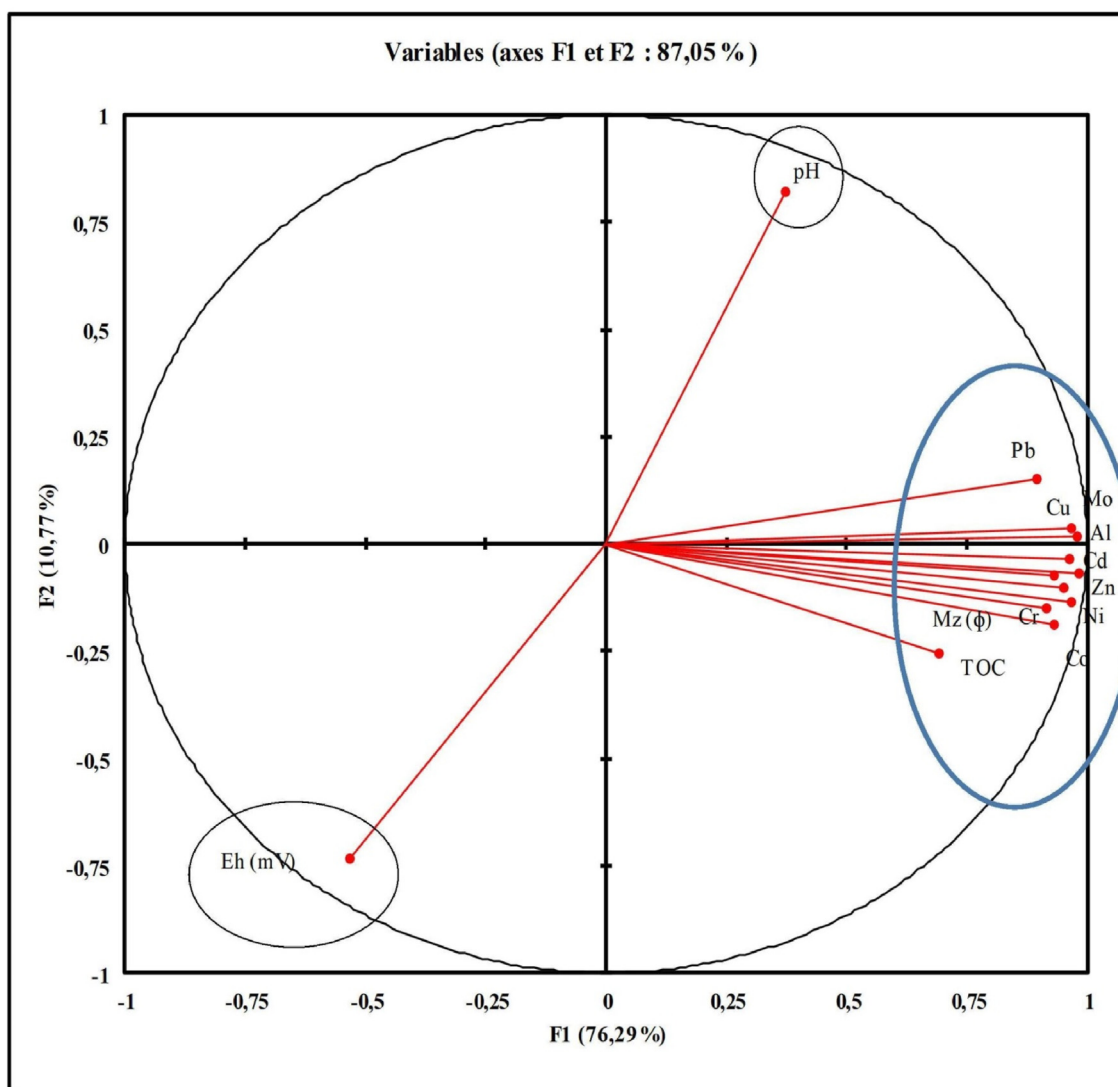


Figure 4. Principal component analysis classifying trace elements into two groups.

3.3.4. Pollution Load Index

PLI allows assessing the pollution of all the elements of a site (Manoj and Krumar, 2014). Its values are presented in Table 5. In all sites, the PLI values are below 1, illustrating the absence of anthropogenic pollution. These results illustrate that the activities carried out do not have a great influence on the watercourses. However, the studies carried out by Madjiki et al. (2013) showed that the EML, the main collector of the catchment area, is undergoing accelerated eutrophication. For these authors, this state of affairs is linked to the anthropogenic activities taking place in the catchment. Thus, the low values indicated by PLI would be linked to the absorption of TMEs by organic matter in suspension, as highlighted by the work of Madjiki et al. (2013). Indeed, several authors (Choi et al., 2015; Ali et al., 2016; Bing et al., 201) have stated that organic matter has a very large specific surface area, which allows it to form organometallic complexes.

3.4. Ecological risk assessment

According to Rath et al. (2000) and Chakravarty et al. (2005), the ecological risk of an element represents the toxicity associated with it in an environment. In the EML, Cr has concentrations above the TEL and PEL at La01 to La08. These values are below the PEL at La09 and La10. The Ni values are above the TEL but still below the PEL. The other elements have concentrations below these standards. In the Mfoumou stream, sites NF2, NF3, NF4, NF5 and NF7 have Cr concentrations above the TEL and the PEL, while sites NF1 and NF6 have values below the PEL. The Ni concentrations are above the TEL but below the PEL. As in the EML, the other elements are below the SQGs. The concentrations of Co, Zn, Cd, Cu, Mo, and Pb in the sediments of the Bengo'o stream are similar to those of the other two environments with respect to the TEL and PEL. They also show higher concentrations of Cr than the TEL and PEL, and higher than the TEL and lower than the PEL for Ni (Tab 3). Thus, only the damaging effects of chromium could be felt by aquatic fauna and the population in contact with these waters. However, these effects are only associated with trivalent chromium. This risk is modest because the chromium in the sediments is mostly in metallic form (Ali et al., 2016).

Some traces metallic elements are considered essential for the proper functioning of organisms and plant growth. Others, however, have adverse effects at varying concentrations. The ecological risk factor is

used to assess the unpleasant effects of an element on the environment. The Er values are summarized in Table 6. These results illustrate that the sediments from the three sites present a low ecological risk ($Er < 30$) in Cr, Ni, Cu, Zn, and Pb; a moderate ecological risk ($30 < Er < 60$) in Cd in 70% of the stations of the EML; and all the stations of the Mfoumou stream. Nevertheless, the values observed in the EML (mean: 42.86) are lower than those in the Mfoumou stream (45.92). According to Ahmad et al. (2020), the ecological risk factor values of Cd are associated with its high toxic response factor (Tr) (30). The ecological risk classification based on Er values across sites is as follows: $Cd > Ni > Cu > Cr > Pb > Zn$. The potential ecological risk (RI) values are reported in Table 6. These results show that the sediments at the three sites represent a low ecological risk ($RI < 110$). Thus, the classification of the sites according to their ecological risk is as follows: $Mfoumou > EML > Bengo'o$.

3.5. Multivariate statistical methods

The Pearson correlation matrix shows significant correlations ($p < 0.05$) between Al and all other elements (Table 7). These values are: 0.50, 0.61, 0.62, 0.77, 0.51, 0.71, and 0.75 for Cr, Ni, Co, Zn, Pb, Cd, Mo, and Cu, respectively. These good correlations illustrate that at least part of the concentrations recorded by the sediments would have a lithogenic origin. Indeed, the studies carried out by Alloway (2013) have shown that TME are the minor constituents of rocks. They occupy the interstices between the major elements. The release of major elements during the chemical weathering process would also lead to their release and concentration in the sediments (Nriagu, 1996). Thus, the intense chemical weathering noted in the area by the work of Akono et al. (2022), and their low mobility during this process, would play an important role in the concentration of these elements. Pb does not show significant correlations with the other elements, but significantly correlates with Al (0.51), suggesting that Pb would have derived only from lithogenic sources. The significant correlations between TME and Cr, which is the element with abnormally high concentrations, illustrate that part of these concentrations would have an anthropogenic origin. These correlations are: 0.84, 0.63, 0.58, 0.75, 0.71, and 0.69, respectively for Ni, Co, Zn, Cd, Mo, and Cu. Chromium comes mainly from mining and industrial activities, but also from mineral fertilizers, especially phosphate fertilizers, where they are present as impurities, and from animal waste, metal waste, batteries, hydrocarbons, and insecticides (Savary, 2003; Ikenaka et al., 2010; Hanif et al., 2016). In the

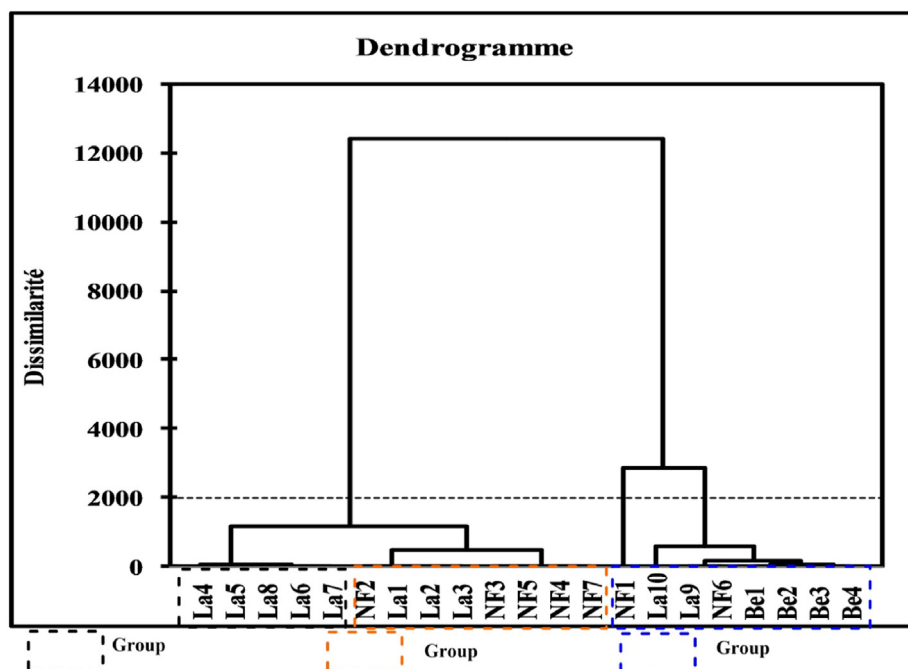


Figure 5. Dendrogram of the hierarchical ascending cluster.

absence of large-scale industrial and mining activities, Cr would be derived from phosphate fertilizers used in the catchment for vegetable cultivation and also from animal manure related to livestock farming observed in the catchment. These high concentrations could also be explained by direct discharges of metal objects, oil spills from cars, and household waste. Significant correlations between Cr and the other elements would demonstrate their relationships in various sources.

PCA was performed using the normalized values (Figure 4). The normalized values were obtained using the formula $(C_i \times Al_i)/Al_{UCC}$ where C_i : Concentration of the element in the sample, Al_i : Concentration of Al in the sample; Al_{UCC} : Concentration of Al in UCC. The main component analysis consists of three main eigenvectors PC1 (Cr, Ni, Co, Zn, Cu, Pb, Mo, TOC and Mz) PC2 (pH) and PC3 (Eh) (Table 8). No correlation between pH, Eh and TME suggests these parameters do not influence the distribution of these elements. However, the good correlation between Mz, TOC and TME suggests an important role for these parameters in their distributions. These results are in agreement with those of Krishna et al. (2013) and Lario et al. (2016), who showed that particle size controls coprecipitation and surface adsorption. For these authors, the adsorption power of particles depends on the size of their specific surface area. Fine particles (63 μm) have a high degree of cohesion. Therefore, they have very large specific surfaces. It is these characteristics that allow them to adsorb to the surface of clay particles and form complexes of several elements (Burton, 1992; Bonnet, 2000). These good correlations between TME and TOC also agree with the work of Kumar et al. (2009) who showed that TOC plays an important factor in TME absorption processes through the formation of organometallic complexes.

HCA between the different sites groups them into two clusters (Figure 5). The first one includes two sub-clusters: sub-clusters 1 and 2. Sub-cluster 1 includes: La4, La5, La6, La7, and La8. Sub-cluster 2 includes: La1, La2, La3, La4, La5, La6, La7, and La8; La1, La2, La3, NF2, NF3, NF5, and NF7. The second cluster is composed of a single subgroup that includes NF1, La9, La10, NF6, Be1, Be2, Be3 and Be4. The classification of the sub-clusters according to the TME concentrations and pollution index values is as follows: cluster 1 > cluster 2 > cluster 3. This result confirms that the contamination of the sediments of the EML and the Mfoumou River have the same origin.

4. Conclusion

This study has enabled us to assess the spatial distribution, degree of pollution, ecological risk, and source of TMEs (Cr, Ni, Cu, Cd, Mo, Co, and Pb) in the EML and its tributaries in order to ensure the preservation of the Ebolowa municipal lake, which is a source of water that can be easily mobilized aside from being a recreation area. The spatial distribution of TMEs seems to be influenced by autochthonous inputs of domestic effluents and parameters such as particle size and organic matter content. The pollution index values illustrate low to moderate contamination and pollution of Cr, Ni, Co, Cd, and Cu. The Er values indicate a moderate ecological risk for Cd. The RI values indicate a low ecological risk for all sites. Poor home waste management, non-compliant automobile buildings, and agricultural operations are all contributing to the high levels.

This work is the first of its kind in the area. It has provided information on both the quantification of pollutants and their sources. However, this study still has grey areas that should be clarified for better conservation of these types of environments. Indeed, it was based on superficial sediments, which cover a very short period of time. Also, the toxicity of an element depends on the state in which it is found in the environment. Thus, sediment core studies and speciation studies should be carried out.

Declarations

Author contribution statement

Daniel Florent Akono & Emile Ekomane: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Philippe Samba Assomo, Jacqueline Ntsama Atangana, Ashukem Ethel Nkongho & Cédric Belinga: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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