



Characteristics and Source Identification of Environmental Trace Metals in Beach Sediments Along the Littoral Zone of Cameroon

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Abstract

Beach sediment samples collected along the central part of the Littoral zone of Cameroon were geochemically analyzed using ICP–MS to investigate the distribution characteristics and to identify trace metal concentrations. The textural characteristics of these sediments revealed that they are dominated by sand. Metal concentrations are distributed in the following decreasing order: Fe > Mn > Cr > V > Ni > Co > Cs. Indices of pollution, such as enrichment factor values are generally less than 1.5, except for Cr; index of geo-accumulation, where values of all metals in the sediments were < 0; contamination factor shows that in the Yoyo and Mouanko stations, values of elements, such as Co, Cs, Ni and V range between 0.1 and 0.3, while other elements have values between 0.3 and 0.6. At the Mbiako station, the values of all selected elements are between 0.1 and 0.3, except Fe and Mn, which are between 0.3 and 0.6. The degree of contamination and pollution load index shows low values in all stations, where values in all sampling sites are less than 1. The principal component analysis, cluster and correlation matrix indicate that the heavy metals maintained fair trends with both anthropogenic and natural sources. This study showed that this coastal area is not highly concentrated in heavy metals, and equally revealed that the central part of the Cameroon coastline is slightly polluted by trace metals. The results can be used for future investigations focusing on evaluation of heavy metals and their pollution sources especially in coastal regions.

Keywords Beach sediments · Trace metals · Contamination · Pollution sources · Littoral Cameroon

1 Introduction

Costal zones are particularly important, because they constitute a small portion of physical space where all four spheres interact, namely, the lithosphere, hydrosphere, atmosphere and biosphere. Hundreds of tons of pollutants are dumped into the atmosphere every day. Among these pollutants, heavy metals are considered the most serious, especially in aquatic environments because of they tend to bioaccumulate inside aquatic organisms (Sundararajan et al. 2017; Noa Tang et al. 2021; Chougong et al. 2021).

Heavy metals in living environments most often originate from natural processes (e.g., volcanic eruptions, rock weathering, erosion and deposition of dust) and anthropogenic activities (e.g. urban development, industry, agriculture and change in rivers and lacustrine environments) (Jha et al. 2019; Ayala-Pérez et al. 2021). Compared to other contaminants, heavy metals are widespread persistent contaminants, which are potentially toxic, non-biodegradable,

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and accumulate in living organisms through the food chain (Fan et al. 2002; Buccolieri et al. 2006; Mapel-Hernández et al. 2021). In most cases, these heavy metals cause toxic effects in many organisms (Bryan and Langston 1992) after reaching certain concentrations. They can thus cause a serious threat to ecological safety and human health. Some heavy metals such as Zn, Cu, Mn and Fe are essential for the growth and well-being of living organisms, including humans. Other elements, such as Pb, Hg, and Cd, are not required for metabolic functions and have hazardous effects (Biney et al. 1994). Sediments are one of the principal storages of heavy metals, as they are used as an efficient mean to appraise the level of contamination of marine environments (Ke et al. 2017; Mandeng et al. 2019).

Several factors must be taken into consideration when identifying the source of heavy metals in terrestrial and coastal environments, including grain size, mineral composition and sedimentary environment. On the other hand, metals that have reached sediments from anthropogenic sources are more often found in relatively more bioavailable forms (Gleyzes et al. 2002; Ekoa Bessa et al. 2018a, b; Tehna et al. 2019; Noa Tang et al. 2021). They are deposited within beach sediments by adsorption, hydrolysis and coprecipitation, whereas a smaller portion of free metal ions remains in the water column (Bartoli et al. 2012).

The pollution of aquatic and coastal environments by organic and inorganic micropollutants, such as persistent organic pollutants, pharmaceutical drugs and agricultural uses, is of concern (Thevenon et al. 2011; Mubedi et al. 2013). With such a broad coastal environment, very few works based on environmental studies have been done in Cameroon. Whereby too many pollutants are found along the coasts. The aim of this work is to (i) investigate the distribution of heavy metal contents along the central part of the littoral zone of Cameroon, (ii) evaluate the level of contamination based on indices of contamination, and (iii) identify the possible source of pollutants.

2 Materials and Methods

2.1 Study Area

The study area is located in the central part of the littoral zone of Cameroon, more precisely, the outlet of the Sanaga River found on the coast of the Atlantic Ocean, ranging from 3°37' to 3°41' N and 9°37' to 9°40' E, in the south west (SW) of Cameroon (Fig. 1). The dry season occurs between December and February, whereas the rainy season occurs between March and November, with a peak in August. The main activities carried out in this sector are artisanal fishing and agriculture. Geologically, the central part of the coast is dominated by sedimentary formations linked mainly to the

Douala Basin. These formations were put in place by marine transgressions from the Upper Cretaceous to the Tertiary (Ngueutchoua et al. 2019; Mbesse et al. 2020).

The Cameroonian coastline lies unconformably on the Precambrian basement and begins with a marine series made up of marls and fossiliferous limestones of inferior Turoonian–Campanian age and continues with a continental series of superior Campanian–Paleocene age to present (Ntamak-Nida et al. 2010). Also called the Dizangué series, it is made up of small conglomerate at the base, and fine and coarse sandstone at the top. It also presents intercalations of clay, kaolinite and ferruginous sandstone with intersecting stratification (Ngueutchoua et al. 2019; Ekoa Bessa et al. 2021).

Another continental sedimentary series of the middle Cretaceous is observed in the upstream basin of the Sanaga, made up of a succession of fine sandstones, black and beige, and arkosic conglomerate sandstone (Ekoa Bessa et al. 2021). The study area includes activities, such as fishing, leisure and popular touristic areas. This part of the coastline is also affected by activities, such as agriculture and industries. Studies of the pollution of sediments by heavy metals along the littoral of Cameroonian coast are still not well known (Ekoa Bessa et al. 2020).

2.2 Sampling and Analysis

Sediment samples have been collected from three different stations, making a total of 24 sampling points, chosen based on environment, sea level, slope, water-sampling and lithological nature along the central part of littoral. The three stations include the Yoyo, Mouanko and Mbiako beaches (Table 1). The samples were collected in December 2019, from the designated sites using a trowel. A trowel is used to remove the top (5–10 cm) layer of the sediments to avoid contamination. Polythene bags were used to package and transport the samples to the laboratory, approximately 2 kg of each sample was collected. The samples were dried in the open air, crushed and then sieved. 0.2 g of sample powder was dissolved with 1.5 g of LiBO₂. The intensity of metal concentration of Fe, Mn, Cr, Ni, Co, Cs and V was resolved into air/acetylene fire using the Inductively Coupled Plasma Mass Spectrometry (ICP–MS) pulp at ALS (Australian Laboratory Services), Vancouver (Canada). Analytical precision varies from 0.1 to 0.5% for trace metals. The detection limits range from 0.05 × 10^{−6} to 4.0 × 10^{−6} mg/g depending on the element. Total organic carbon (TOC) was determined using a Primacs SLC analyzer in the laboratories of the International Institute for Tropical Agriculture (IITA; Yaoundé, Cameroon). Total Carbon (TC) was first determined by combustion at 105 °C, then the inorganic carbon (IC) at 105 °C. Prior to the analysis, the sample is put in a test tube in which oxygen is purged to remove CO₂. To decompose the inorganic bounded carbon to gaseous carbon dioxide,

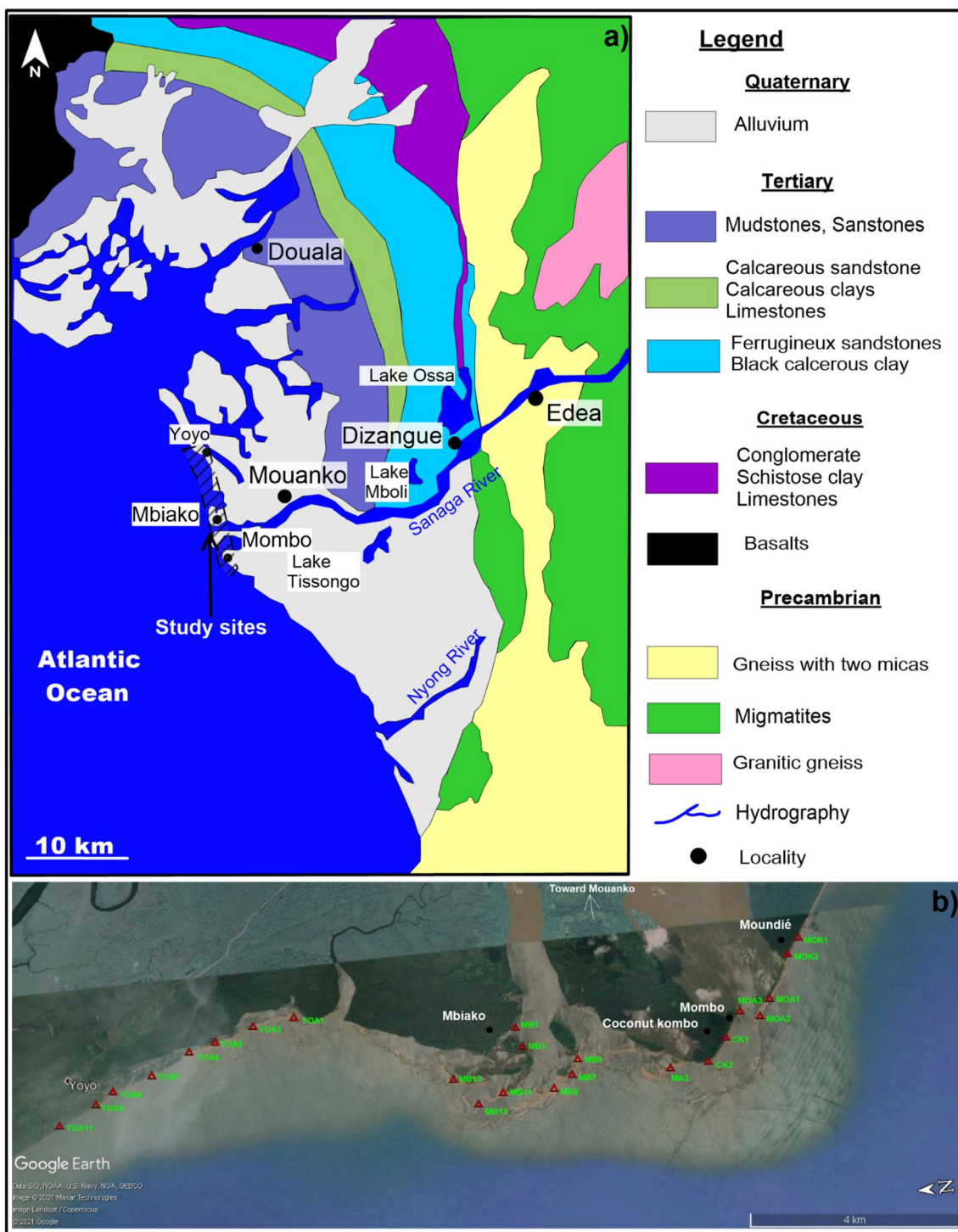


Fig. 1 Investigated area and sampling location: **a)** location of the study area in Cameroon; **b)** Location of sampling area and station along the Central part of the Littoral of Cameroon

orthophosphoric acid is added to the sample. The flow oxygen purges the carbon dioxide from the liquid into the IR detector to be measured again. The concentration of TOC is determined using the formula: $TOC = TC - IC$. The amount of organic matter (OM) was obtained by the calculation of

Walkley and Black (1934) formula where $OM (\%) = TOC (\%)$.

Descriptive statistics of heavy metals, TOC and OM were calculated using PAST program (multivariate statistical package, version 1.72). The box and whisker plots of soil

Table 1 Latitude and longitude of sampling tested sites along the Central part of the Littoral of Cameroon

No	Code	Site Name	Latitude (N)	Longitude (E)	Different activities nearby sampling locations
1	YO1	Yoyo	3°37'55"	9°39'07"	Fishing, tourism and agriculture
2	YO3	Yoyo	3°38'11"	9°39'05"	Fishing, tourism and agriculture
3	YO5	Yoyo	3°38'30"	9°38'36"	Fishing, market and agriculture
4	YO6	Yoyo	3°38'50"	9°38'30"	Fishing, habitations, market and agriculture
5	YO7	Yoyo	3°39'01"	9°38'12"	Fishing, habitations, market and agriculture
6	YO8	Yoyo	3°39'10"	9°38'05"	Fishing, tourism and agriculture
7	YO9	Yoyo	3°40'36"	9°38'00"	Fishing, tourism and agriculture
8	YO11	Yoyo	3°41'12"	9°37'40"	Fishing, tourism and agriculture
9	MA3	Mouanko	3°34'41"	9°38'20"	Fishing, market, habitation and agriculture
10	CK1	Coconut Kombo	3°34'31"	9°38'23"	Fishing
11	CK2	Coconut Kombo	3°35'12"	9°38'26"	Fishing
12	MOA1	Mombo	3°33'52"	9°38'24"	Fishing, habitations and agriculture
13	MOA2	Mombo	3°33'46"	9°38'41"	Fishing, habitations and agriculture
14	MOA3	Mombo	3°33'12"	9°38'51"	Fishing and agriculture
15	MOK1	Moundié	3°32'48"	9°38'36"	Fishing and agriculture
16	MOK3	Moundié	3°32'35"	9°38'38"	Fishing and agriculture
17	MB1	Mbiako	3°25'19"	9°38'58"	Fishing, garage, habitations, market and agriculture
18	MB3	Mbiako	3°35'24"	9°38'44"	Fishing garage, habitations, market and agriculture
19	MB6	Mbiako	3°35'39"	9°38'01"	Fishing garage, habitations, market and agriculture
20	MB7	Mbiako	3°36'09"	9°38'14"	Fishing, habitations and agriculture
21	MB8	Mbiako	3°36'35"	9°38'30"	Fishing and agriculture
22	MB11	Mbiako	3°37'00"	9°38'09"	Fishing and agriculture
23	MB13	Mbiako	3°37'15"	9°38'09"	Fishing
24	MB15	Mbiako	3°37'29"	9°39'01"	Fishing

quantification (soil indices) have also been drawn for the three stations to show the variations of studied HMs (Heavy metals) value using the PAST program. In addition, the HMs data of the three stations was subjected to an agglomerative hierarchical cluster (AHC) and principal component analysis (PCA) to construct a matrix of correlation, and to identify whether a significant difference exists between different treatments. PCA was performed using XLSTAT statistical computer software package, version 14.

2.3 Data Processing

2.3.1 Enrichment Factor (EF)

The enrichment factor (EF) is a tool generally used to distinguish between natural and anthropogenic sources of heavy metals in sediments (Salati and Moore 2010):

$$EF = \frac{[M]_{\text{Sample}}/[Fe]_{\text{sample}}}{[M]_{\text{Background}}/[Fe]_{\text{background}}}, \quad (1)$$

where $[M]_{\text{Sample}}/[Fe]_{\text{sample}}$ is the sample concentration of metals in the analyzed sediment samples and $[M]_{\text{Background}}/[Fe]_{\text{background}}$ refers to the background value of the metal. Iron (Fe) is the normalizing metal for the

following reasons: Fe is associated with fine to medium solid elements; its geochemistry is comparable to that of many heavy metals; and its natural concentration in the study area tends to be uniform (Bhuiyan et al. 2010). Enrichment factor (EF) values have been defined in conjunction with Acevedo-Figueroa et al. (2006), $EF < 1$ denotes no enrichment; 1–3 denotes minor; 3–5 denotes moderate; 5–10 denotes fairly bad; 10–25 denotes bad; 25–50 denotes quite severe; and > 50 denotes extremely serious enrichment.

2.3.2 Geo-accumulation Index (Igeo)

The geoaccumulation index (*I*-geo) is a quantitative measurement of the level of metal pollution in aquatic sediments. Muller's geoaccumulation index was originally described as

$$I - \text{geo} = \text{Log}_2 \left[\frac{C_n \text{ Sample}}{(1.5 \times C_n \text{ Background})} \right], \quad (2)$$

where C_n sample is the obtained concentration of metal n , and C_n background is the standard value for the metal n . Factor 1.5 has been used in the environment due to potential fluctuations in background values for a given metal, as well as very slight anthropogenic impacts. While *I*-geo was designed to work with worldwide standard shale values as

background metals rates, Rubio et al. (2000) found that regional background values yielded more acceptable results.

2.3.3 Contamination Factor (CF), Degree of Contamination (DC) and Pollution Load Index (PLI)

The contamination factor (CF) is the ratio calculated from the equation of Tomlinson et al. (1980a, b)

$$CF = (C_{\text{metal}}/C_{\text{background}}), \tag{3}$$

where C_{metal} represents the pollutant concentration in the sediments and $C_{\text{background}}$ refers to metal background values. According to Hakanson (1980), contamination factor is classified into four classes. When CF values are ≤ 0.1 this indicates low contamination; $0.1 \leq CF < 0.3$ indicates moderate contamination; $0.3 \leq CF < 0.6$ shows considerable contamination and $CF \geq 0.6$ indicates very high contamination.

The degree of contamination (DC) is the sum of all contamination factors for a given site (Hakanson 1980). The DC can be calculated by the following equation:

$$DC = \sum_{i=1}^n CF_i, \tag{4}$$

where CF is the single contamination factor and n is the amount of the element present. $DC < n$, would indicate low degree of contamination; $n \leq DC < 2n$, moderate degree of contamination; $2n \leq DC < 4n$, considerable degree of contamination and $DC > 4n$, very high degree of contamination. For this study, the number of elements selected is 7 ($n=7$).

The pollution load index (PLI) is derived as factors of concentration (CF). The PLI commonly was defined by Tomlinson et al. (1980a, b), as follows:

$$PLI = \sqrt[n]{CF_1 \times CF_2 \times CF_3 \times \dots \times CF_n}, \tag{5}$$

where CF is the contamination factor and n is the number of metals. The pollution load index (PLI) value > 1 is polluted, while < 1 indicates no contamination (Harikumar et al. 2009). amination and when $CF \geq 0.6$ indicate very high contamination by the different metals.

3 Results

3.1 Sediment Characteristics

The beach sediments were predominantly sandy in nature. The mean grain size distribution (Φ) ranges from 1 to 1.75 Φ , classified as medium-grained sand. However, in most of the observations, the sand was found to be medium to fine-grained in size. This can be attributed to a dynamic deposition linked to an agitated environment

or to the higher wave energy regime, resulting from the local topography which would prevent the sedimentation of fine-grained particles. The TOC and organic matter (OM) contents vary from 0.42 to 5.80% and 0.72 to 9.98%, respectively (Table 2; Fig. 2), with the highest OM values observed at Yoyo beach. Spatial distribution of heavy metals observed in the beach sediments along the Central part of the Littoral Cameroon reveals that mean concentrations (mg/kg) were found in the following decreasing order: Fe (13,638.30–24,339.12) $>$ Mn (38.73–387.25) $>$ Cr (20.53–54.74) $>$ V (16.00–40.00) $>$ Ni (10.00–35.00) $>$ Co (3.40–5.60) $>$ Cs (0.50–0.80) (Table 2; Fig. 2).

3.2 Enrichment Factor and Geo-accumulation Index

The level of metal enrichment is evaluated based on the obtained results, listed in Supplementary Appendix 1 (Fig. 3). The results obtained are presented according to each site and in the order of abundance of each metal. The decreasing order of the EF metals of Yoyo beach is $Cr > Ni > Mn > Fe > V > Co > Cs$; the decreasing order of the EF metals of Mouanko is $Cr > Mn > Fe > Ni > V > Co > Cs$ and the decreasing order of the EF metals of Mbiako is $Mn > Cr > Fe > Co > Ni > V > Cs$. The order of average metal EF of the three sites is $Cr > Mn > Ni > Fe > V > Co > Cs$. The Yoyo beach presents more enrichment in Fe, Mn, Cr and Ni compared to Mouanko and Mbiako beaches (Fig. 4).

The I-geo values of all metals in the sediments of the study area are < 0 , unpolluted at all sites.

3.3 Contamination Factor, Degree of Contamination and Pollution Load Index

In this study, contamination factor is classified into two classes (Fig. 5; Supplementary Appendix 2). In the Yoyo and Mouanko beaches CF values for Co, Cs, Ni and V range from 0.1 to 0.3, suggesting that the sediments are moderately contaminated; Fe, Mn, Cr and Ni ranged from 0.3 to 0.6 which show that the sediments are considerably contaminated. On the other hand, in Mbiako beach, values for Mn, Cr, Ni, Co, Cs and V ranged from 0.1 to 0.3, showing that the sediments are moderately contaminated, while Fe and Mn ranged from 0.3 to 0.6, showing the considerable contamination of the sediments. The DC values range between 1.29 and 2.36. DC values belongs to a low degree of contamination. The results for each site are presented in Fig. 6.

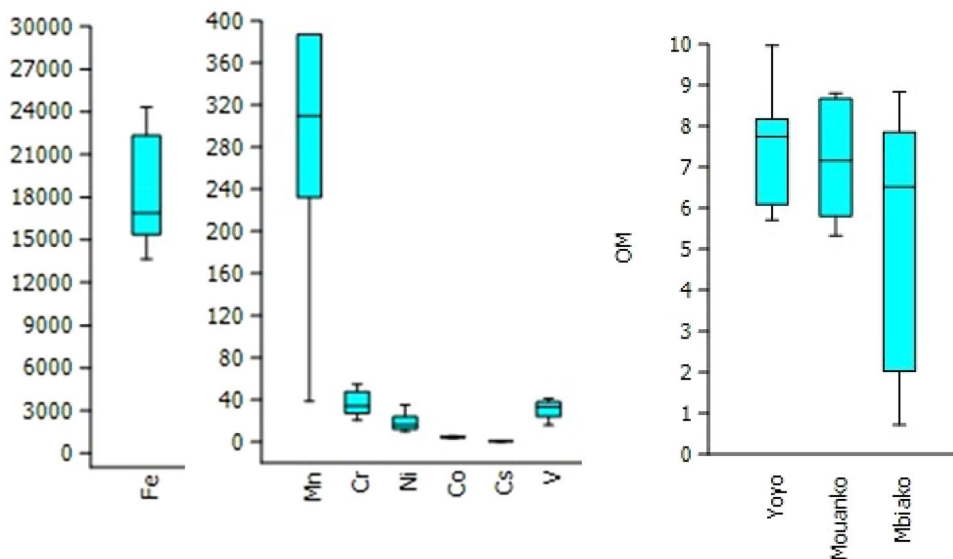
However, the values of PLI recorded for all the stations ranged from 0.11 to 0.22 (Supplementary Appendix 3). The PLI values in all sampling sites are less than 1 (Fig. 7), which suggests no contamination.

Table 2 Descriptive statistical of metals concentration (mg/kg), TOC (%) and OM (%) of surface sediment samples along the Central part of the Littoral of Cameroon

Stations	Statistic	Heavy metals (mg/kg)							TOC (%)	OM (%)
		Fe	Mn	Cr	Ni	Co	Cs	V		
Yoyo (<i>n</i> =8)	Min	16,016.26	309.80	34.21	12.00	4.30	0.60	31.00	3.32	5.71
	Max	18,673.98	387.25	47.89	35.00	4.80	0.80	38.00	5.80	9.98
	Mean	17,170.27	348.53	37.63	24.25	4.44	0.64	34.00	4.36	7.49
	±SD	1070.53	41.40	5.17	7.42	0.17	0.07	3.02	0.81	1.39
	Median	16,645.72	348.53	34.21	24.00	4.40	0.60	33.50	4.50	7.74
	Skewness	0.58	0.00	1.32	-0.14	1.60	1.95	0.37	0.40	0.40
	Kurtosis	-1.76	-2.80	0.88	-0.29	2.91	3.20	-1.73	0.24	0.24
	%CV	6.23	11.88	13.74	30.60	3.80	11.67	8.89	18.53	18.53
Mouanko (<i>n</i> =8)	Min	19,653.14	38.73	41.05	11.00	4.70	0.60	36.00	3.10	5.33
	Max	24,339.12	387.25	54.74	27.00	5.60	0.80	41.00	5.12	8.81
	Mean	22,957.80	304.96	49.60	17.63	5.30	0.68	38.75	4.20	7.22
	±SD	1849.21	114.20	6.06	6.05	0.33	0.09	1.67	0.79	1.36
	Median	23,849.54	309.80	51.32	18.00	5.35	0.65	39.00	4.17	7.16
	Skewness	-1.28	-2.20	-0.62	0.29	-0.77	0.62	-0.46	-0.21	-0.21
	Kurtosis	0.00	5.51	-1.48	-1.24	-0.28	-1.48	-0.60	-1.34	-1.34
	%CV	8.05	37.45	12.23	34.30	6.22	13.13	4.31	18.81	18.81
Mbiako (<i>n</i> =8)	Min	13,638.30	154.90	20.53	10.00	3.40	0.50	16.00	0.42	0.72
	Max	17,065.36	309.80	27.37	16.00	5.20	0.80	26.00	5.14	8.84
	Mean	15,010.87	203.31	24.80	14.00	4.29	0.68	21.25	3.23	5.55
	±SD	1103.28	57.62	3.54	2.14	0.57	0.10	3.88	1.81	3.12
	Median	15,107.04	193.63	27.37	14.00	4.20	0.70	21.00	3.79	6.52
	Skewness	0.65	0.82	-0.64	-0.94	0.11	-0.39	0.00	-0.96	-0.96
	Kurtosis	0.58	-0.15	-2.24	0.35	-0.17	-0.45	-1.59	-0.59	-0.59
	%CV	7.35	28.34	14.28	15.27	13.28	15.33	18.27	56.22	56.22
Background value	47,200	850	90	68	19	5	130			
Toxic response factor	-	1	2	5	5	-	2			

CV Coefficient of variation, SD Standard deviation

Fig. 2 Distribution patterns of total metal concentration (mg/kg) and OM (%) in the beach sediments



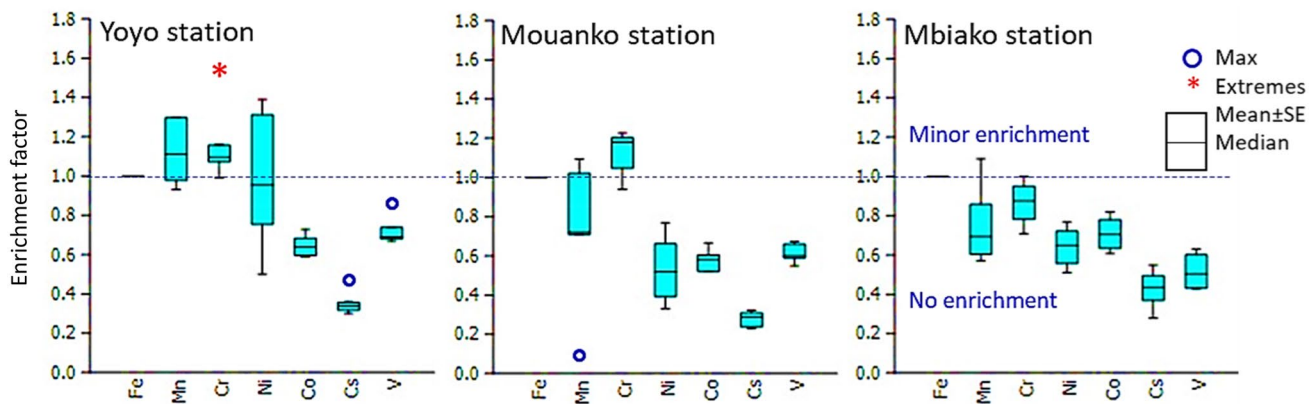


Fig. 3 Variations of enrichment factor (EF) of different metals in the Yoyo, Mouanko and Mbiako beach sediments

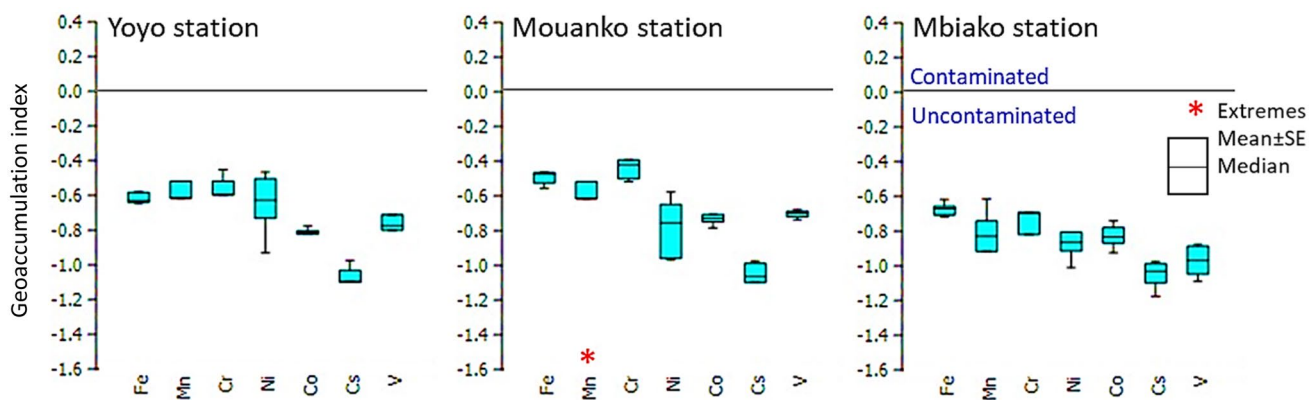


Fig. 4 Calculation of geoaccumulation indices of metal concentrations in sediments of the Central part of the Littoral of Cameroon

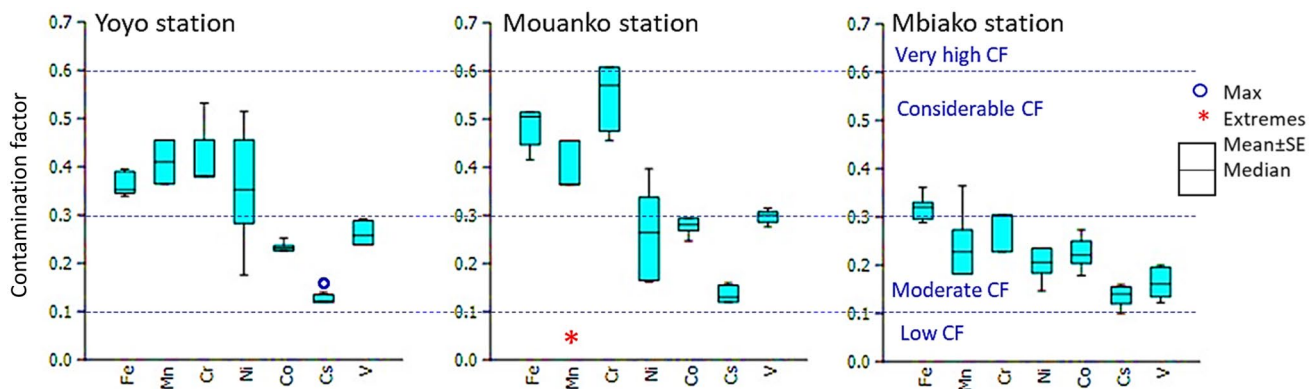


Fig. 5 Contamination factors of different metals in the sediment of Central part of Littoral of Cameroon

3.4 Statistical Analysis

A multivariate statistical analysis (Pearson correlation cluster and PCA) was used to identify links among variables. The multivariate analysis was conducted using estimated

metal concentrations, derived indexes, and surface sediment properties (Figs. 8 and 9).

A correlation matrix analysis was realized using COS-TAT 6.3 software. The correlation coefficient values are listed in Table 3. Correlation matrix indicates that the Fe

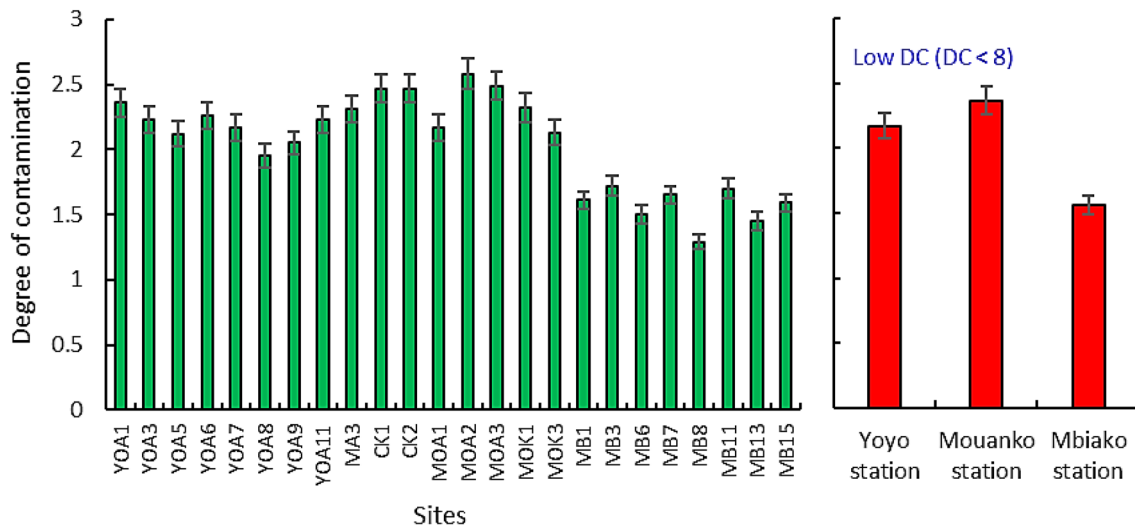


Fig. 6 Degree of contamination for trace metals in the sediments

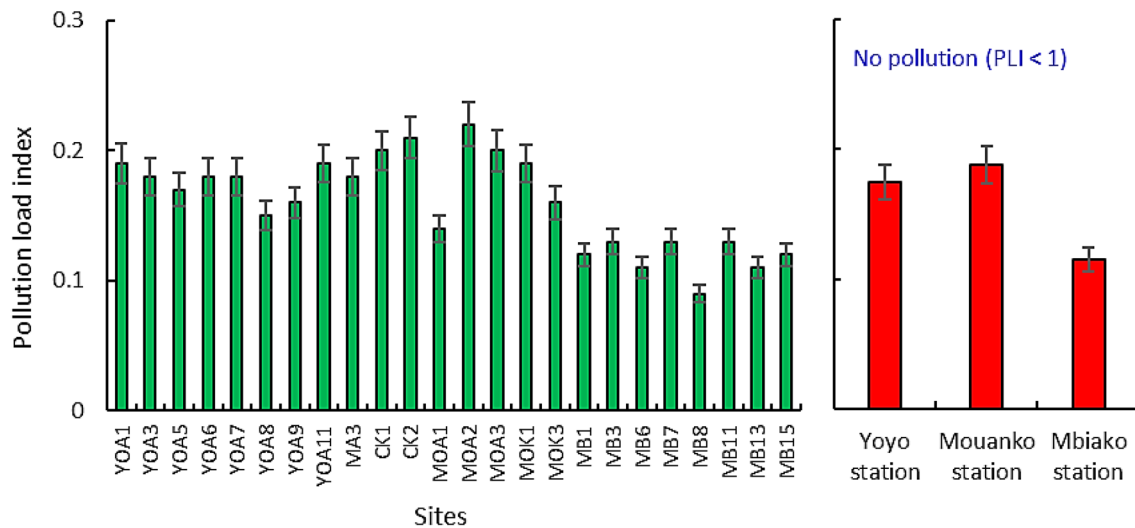


Fig. 7 Pollution load index (PLI) of trace metals for different locations in the Central part of the Littoral zone of Cameroon

concentration was significantly positive ($P < 0.01$) with Cr (0.89), V (0.81) and Co (0.72). However, several elements such as V and Co had significant positive correlations ($P < 0.01$) with Cr (0.87), Mn (0.52) and Cr (0.72), V (0.62), respectively. The elements such as Ni vs TOC (0.46), Ni vs OM (0.46), TOC vs V (0.45), OM vs V (0.45) and Ni vs V (0.41) reveal a significant positive correlation ($P < 0.05$).

Principal component analysis (PCA) was conducted on the sediment properties and heavy metals to better understand the relationship between these variables and identify their origin. As shown in Supplementary Appendix 4 and Fig. 9, the first two principal components with eigenvalues greater than 1 are accounted for 67.6% of the

total variance. Therefore, these two components play an important role in explaining contamination with heavy metals and their source in the studied area. The results demonstrated that the first principal components (PC1) accounted for 51.9% of total variance, with high loadings of Cr, V, Fe and Co, these results could indicate that these elements have a natural origin by the presence of Fe in the same component. The second PC (PC2) accounted for 15.67% of the total variance with load of Cs, which could indicate that these elements have an artificial origin by the presence of high value of Cs. Therefore, the high values of Fe in the component PC1 indicates that its presence in the sediments will be mainly from natural sources, unlike PC2

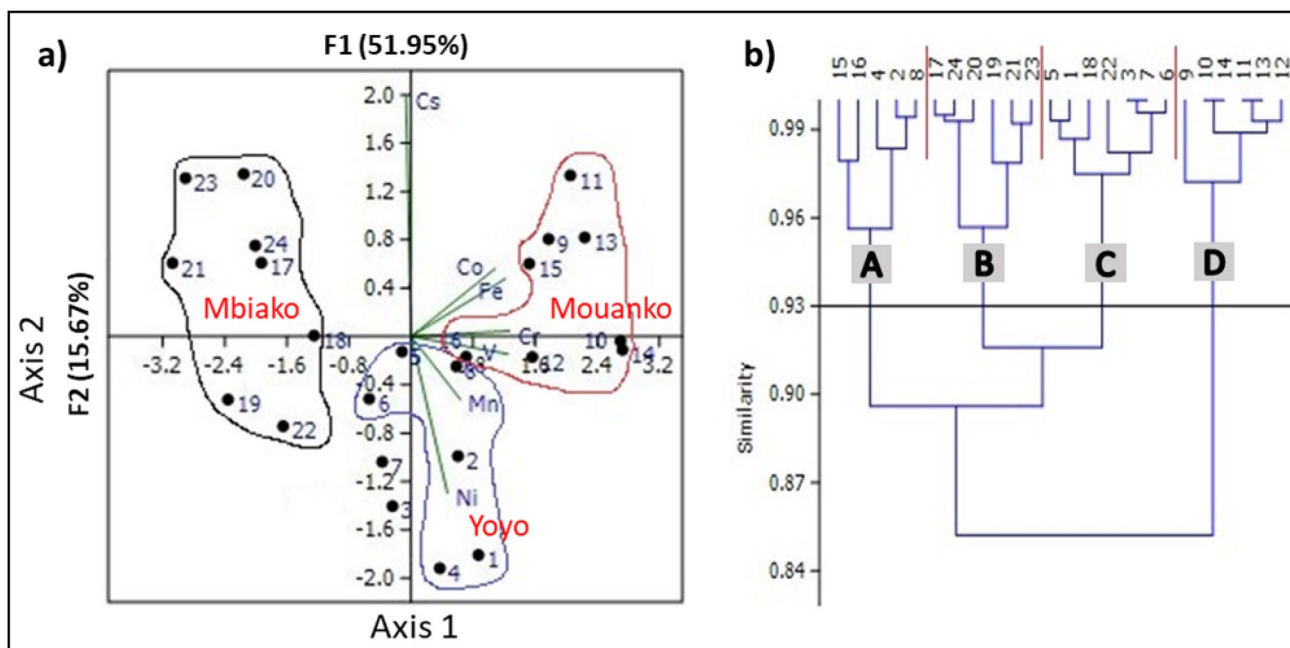
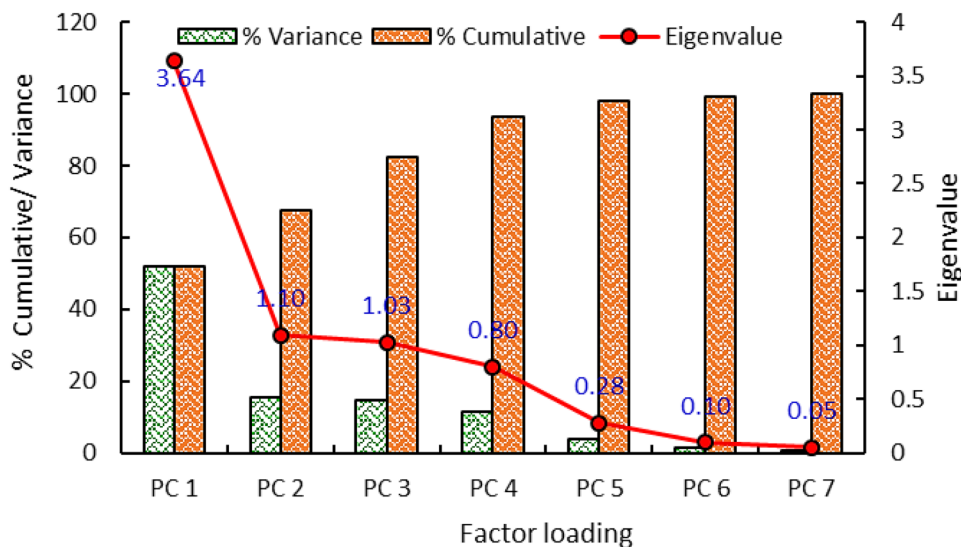


Fig. 8 Statistical analysis of sampling sites according to trace metals in sediment samples along the beaches **a)** Principal component analysis (PCA) **b)** Similarity dendrogram

Fig. 9 Scree plot, eigenvalue and variance of principal components



which will have an artificial origin due to the chemicals released by the industries. Figure 8a shows that the sediment samples from the Yoyo station are clustered in the negative side of PC1, and mainly consist of the variables Ni and Mn, which show the maximum concentrations in these sediment samples. However, sediment samples from the Mouanko beach grouped in the positive side of PC2, and mainly consist of the most variable (Co, Fe, Cr and V) which show the maximum concentrations in these samples. Sediment samples from the Mbiako station grouped in the negative side of PC2 (Fig. 8a).

Cluster analysis (CA) was further used to assess the relationships among sediments. The aim of the hierarchical agglomerative grouping is to measure the greatest similarity between each of the variables, then to group the sites close to each other (Šulc and Řezanková 2019). In the present study, the cluster analysis by metals of the sediment sites maintained quite similar trends, presenting four distinct clusters (A–D) (Fig. 8b), each composed of similar studied sites distributed among these three beach stations. The cluster model indicates that the similarity index of cluster sampling sites is as follows: A to D. Group A simultaneously represents

Table 3 Pearson correlation matrix for selected parameters analyzed in the sediment samples

	Fe	Mn	Cr	Ni	Co	Cs	V	TOC	OM
Fe	1								
Mn	0.217	1							
Cr	0.888**	0.364	1						
Ni	0.17	-0.009	0.35	1					
Co	0.787**	0.275	0.715**	0.065	1				
Cs	0.008	-0.132	-0.026	-0.103	-0.019	1			
V	0.814**	0.524**	0.873**	0.410*	0.622**	0.006	1		
TOC	0.265	0.027	0.28	0.463*	0.055	0.037	0.451*	1	
OM	0.266	0.027	0.28	0.463*	0.056	0.037	0.451*	1.000**	1

** Correlation is significant at the 0.01 level (2-tailed)

* Correlation is significant at the 0.05 level (2-tailed)

the Mouanko and Yoyo stations, while group B is mainly made up of Mbiako station. Group C is made up of Yoyo and Mbiako stations, but mostly those of Yoyo. Group D represents most of the Mouanko station. A similarity index is observed among all the sites and stations following the same trend. In all groups, all sites have 99% similarities.

4 Discussion

The most important factors controlling the spatial variations of metals in the littoral regions include grain size, organic matter, sediment sources, and anthropogenic pollution (Lin et al. 2002). The sediment samples of the littoral Cameroon are classified as medium to fine-grained. This characteristic of beach sediments can be attributed to the higher wave energy regime due to the topography, which would present the sedimentation of fine-grained particles, where metal traces are accumulated preferentially (Ellis and Revitt 1982; Lin et al. 2002; Armstrong-Altrin et al. 2019, 2021).

The OM in these sediments is of great importance, because it allows metals to be concentrated either by ion exchange and/or complexation (Leenheer et al. 1982). Relatively high OM can be due to influx of organic waste through surface runoff as well as delocalization of solid waste dumped into the riverbed from the continent and the waves from Mediterranean Sea (El-Said and Youssef 2013; Armstrong-Altrin 2020). The sediments from the studied sites can be moderately polluted by organic matter (OM) due to their high content in the selected samples.

The enriched levels of Fe may mostly be attributed to natural processes such as leaching of source rocks, transported from the continent and directly from the Ocean by watercourses and wave movements (Ekoa Bessa et al. 2020). Some researchers have reported that Mn is a naturally occurring trace element found in crude oils, used to enhance fuel oil combustion (Long et al. 1998); according to Srichandan et al. (2016), Mn is also an essential transition metal at low

concentration but becomes lethal for human at very high concentrations ($> 5 \text{ mg/m}^3$). In this study, the average concentrations obtained would be due to the degree of natural erosion (Szefer et al. 1995) and the presence of mangrove vegetation (Kasilingam et al. 2016). The sources of Cr are river drainage, dredging sludge and household waste (Noa Tang et al. 2021). The presence of Cr would be due to the incineration of plastic waste, anthropogenic waste dumping and dredging sludge through tourism and agriculture. The considerable values of V would be caused by the combustion of fossil substances, and more by natural weathering of rocks (Ramos-Vázquez and Armstrong-Altrin 2021) and certain anthropogenic sources, such as garages and markets (Li et al. 2015). Nickel is a very important metal that helps in algal growth (Price and Morel 1991). The moderate concentration of Ni could be attributed to fishing, touristic activities and leaching of rocks. Cesium and Co enrichments are not significant in this study.

The EF values of selected metals ranged between 1 and 3, reflecting minor enrichment; this value shows that a significant portion of metals, different from crustal materials or natural weathering processes may contaminate the sediments. In the present study, EF values are > 1 for all the metals, except Co, Cs and V, which showed no enrichment. These low levels of enrichment factors have been largely attributed to both natural mechanisms, such as mineral spoilage and anthropogenic activities according to Abraham and Parker (2008). In addition, these low values suggest a primary natural source. This result is the same as that made by Li et al. (2013) in the Shandong Peninsula and in the northern part of the Cameroonian coast (Ekoa Bessa et al. 2020). The geo-accumulation indices (I-geo) values of all metals of the study area, characterize the sediments as unpolluted, this should be explained by the fact that none of the anthropogenic activities in the area contribute to sediment contamination. In the same order of ideas, the values obtained for I-geo in this study indicate that there is no metal pollution in the whole studied area, although a certain difference is observed depending on each metal and the location of

sampling points. This result correlates with those obtained on coastal sediments in the Shandong Peninsula (Li et al. 2013), but different from those obtained in the northern part of the same littoral, where oil extraction and many other human activities are present (Ekoa Bessa et al. 2020). In the Yoyo and Mouanko stations, we observe considerable contamination for selected metals, such as: Fe, Ni, Mn and Cr. In addition, the Mbiako station is moderately contaminated with all metals. In the same way, this observation is also made with the Yoyo and Mouanko stations, but only V, Co, Cs and some samples for Ni. In general, in this study, the sediments have moderate and considerable contamination for these metals due to the influence of main natural sources, such as leaching of nearby rocks and alteration of sand grains. It can also be the result of agricultural runoff and other anthropogenic activities, such as dumping of household waste, tourism and fishing activities. This result is slightly similar to that obtained by Ekoa Bessa et al. (2021) in the sediments of Limbé coastal areas in the northern part of the littoral.

The results obtained on the CF lead to the conclusion that the sediments of all beach stations have low DC; this could be due to natural sources (weathering and alteration of sands) and little anthropogenic inputs. The values of PLI in this study are very low and the sediments are classified as unpolluted. The PLI in the present study are very low compared to other coastal environments reported by Sankarapan et al. (2021), Ekoa Bessa et al. (2021) and Wang et al. (2020).

Statistical analyses were applied to confirm the similarity between metals and the influence of natural sources on the sediment's quality. Therefore, these metals were probably not influenced by anthropogenic factors, but rather by natural sources, such as weathering and erosion of nearby rocks. In addition, the results showed that the three metals (Mn, Ni and V) were mainly distributed in sediments by nearby urbanized areas and urban constructions. It is likely considered that urban pollution contributed to the accumulation of Mn and V in the beach sediments (Saiful Islam et al. 2015). The results of the statistical analysis indicated that the concentrations were grouped into stations with a probability level of 0.05 for all selected stations grouped by hierarchical cluster analysis. Contaminants from point sources could be responsible for the highly polluted stations, whereas those from non-point sources could be responsible for the less polluted stations.

5 Conclusions

Sediment samples along the central part of the littoral of Cameroon have been investigated to infer the distribution and source of metal contamination in sediments. Results of the present study revealed that most of the beach sediment

grain size was medium to fine. This study showed that the coastal zone is weakly concentrated in heavy metals, except Fe and Mn, which showed higher contents exceeding the average values. The I-geo values of all metals of the study area, characterize the sediments as unpolluted, and this would be attributed to the non-use of fertilizers in agricultural activities. In the same order of ideas, the values obtained for I-geo in this study indicate that there is no pollution of the studied metals in the whole studied area, although a certain difference is observed depending on each metal and the location of sampling points. The results of pollution indices (EF, I-geo, CF, DC and PLI) revealed that all the sites in the central part of the coast were not polluted by the studied metals. Statistical analyses were applied to confirm the similarity between metals and the influence of anthropogenic activities. This low level of pollution by various metals in this study implies low anthropogenic activities near the beaches of the central coast but show diagenetic processes with high leaching and erosion which contributes to the contaminated level of pollution in these beaches. In general, this study can be considered as a baseline study presenting the current contamination risk and will serve as a reference for future environmental studies.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

- Abraham GM, Parker RJ (2008) Assessment of heavy metal enrichment factors and the degree of contamination in marine sediments from Tamaki Estuary, Auckland, New Zealand. *Environm Monitor Assess* 136(1):227–238
- Acevedo-Figueroa D, Jiménez BD, Rodríguez-Sierra CJ (2006) Trace metals in sediments of two estuarine lagoons from Puerto Rico. *Environ Pollut* 141(2):336–342
- Armstrong-Altrin JS (2020) Detrital zircon U-Pb geochronology and geochemistry of the Riachuelos and Palma Sola beach sediments, Veracruz State, Gulf of Mexico: A new insight on palaeoenvironment. *J Palaeogeogr* 9(1):1–27
- Armstrong-Altrin JS, Botello AV, Villanueva SF, Soto LA (2019) Geochemistry of surface sediments from the northwestern Gulf of Mexico: implications for provenance and heavy metal contamination. *Geolog Quarterly* 63(3):522–538
- Armstrong-Altrin JS, Madhavaraju J, Vega-Bautista F, Ramos-Vázquez MA, Pérez-Alvarado BY, Kasper-Zubillaga JJ, EkoaBessa AZ (2021) Mineralogy and geochemistry of Tecolutla

- and Coatzacoalcos beach sediments, SW Gulf of Mexico. *Appl Geochem* 134:105103
- Ayala-Pérez MP, Armstrong-Altrin JS, Machain-Castillo ML (2021) Heavy metal contamination and provenance of sediments recovered at the Grijalva River delta, southern Gulf of Mexico. *J Earth Syst Sci* 130:88
- Bartoli G, Papa S, Sagnella E, Fioretto A (2012) Heavy metal content in sediments along the Calore river: relationships with physical-chemical characteristics. *J Environ Manage* 95:S9-14
- Bhuiyan MAH, Parvez L, Islam MA, Dampare SB, Suzuki S (2010) Heavy metal pollution of coal mine-affected agricultural soils in the northern part of Bangladesh. *J Hazard Mater* 173:384-392
- Biney CA, Amuzu AT, Calamari D, Kaba N, Mbome IL, Naeve H, Ochumba PB, Osibanjo O, Radegonde V, Saad MA (1994) Review of heavy metals in the African aquatic environment. *Ecotoxicol Environ Saf* 28(2):134-159
- Bryan GW, Langston WJ (1992) Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environ Pollut* 76(2):89-131
- Buccolieri A, Buccolieri G, Cardellicchio N, Dell'Atti A, Di Leo A, Maci A (2006) Heavy metals in marine sediments of Taranto Gulf (Ionian Sea, southern Italy). *Mar Chem* 99(1-4):227-235
- Chougong DT, Nguetchoa G, Dicka EH, EkoaBessa AZ, Ghepdeu GFY, Bilounga UJF, Yongue RF, Ntyam SC, Armstrong-Altrin JS (2021) Distributions of trace metals and radionuclides contamination in alluvial sediments from the Lobé River in Cameroon. *Earth Syst Environ*. <https://doi.org/10.1007/s41748-021-00251-4>
- EkoaBessa AZ, El-Amier YA, Doumo EPE, Nguetchoa G (2018a) Assessment of sediments pollution by trace metals in the moloundou swamp, southeast Cameroon. *Annu Res Revue Biol* 30:1-13
- EkoaBessa AZ, Nguetchoa G, Ndjigui PD (2018b) Mineralogy and geochemistry of sediments from Simbock Lake, Yaoundé area (southern Cameroon): provenance and environmental implications. *Arab J Geosci* 11(22):1-8
- EkoaBessa AZ, Nguetchoa G, Janpou AK, El-Amier YA, Nguetnga OA, Kayou UR, Bisse SB, Mapuna EC, Armstrong-Altrin JS (2020) Heavy metal contamination and its ecological risks in the beach sediments along the Atlantic Ocean (Limbe coastal fringes, Cameroon). *Earth Syst Environ*. <https://doi.org/10.1007/s41748-020-00167-5>
- EkoaBessa AZ, Ndjigui PD, Fuh GC, Armstrong-Altrin JS, Betsi TB (2021) Mineralogy and geochemistry of the Ossa Lake Complex sediments, Southern Cameroon: implications for paleoweathering and provenance. *Arab J Geosci* 14(4):1-7
- Ellis JB, Revitt DM (1982) Incidence of heavy metals in street surface sediments: solubility and grain size studies. *Water Air Soil Pollut* 17(1):87-100
- El-Said GF, Youssef DH (2013) Ecotoxicological impact assessment of some heavy metals and their distribution in some fractions of mangrove sediments from Red Sea, Egypt. *Environm Monitor Assessm* 185(1):393-404
- Fan W, Wang W, Chen J, Li X, Yen YF (2002) Cu, Ni, and Pb speciation in surface sediments from a contaminated bay of northern China. *Mar Pollut Bull* 44(8):820-826
- Gleyzes C, Tellier S, Astruc M (2002) Fractionation studies of trace elements in contaminated soils and sediments: a review of sequential extraction procedures. *TrAC Trends Anal Chem* 21(6-7):451-467
- Håkanson L (1980) An ecological risk index for aquatic pollution control. *Sedimentol Approach Water Res* 14:975-1001
- Harikumar PS, Nasir UP, Rahman MM (2009) Distribution of heavy metals in the core sediments of a tropical wetland system. *Int J Environ Sci Technol* 6(2):225-232
- Islam S, Ahmed K, Masunaga S (2015) Potential ecological risk of hazardous elements in different land-use urban soils of Bangladesh. *Sci Total Environ* 512:94-102
- Jha DK, Ratnam K, Rajaguru S, Dharani G, Devi MP, Kirubakaran R (2019) Evaluation of trace metals in seawater, sediments, and bivalves of Nellore, southeast coast of India, by using multivariate and ecological tool. *Mar Pollut Bull* 146:1-10
- Kasilingam K, Gandhi MS, Krishnakumar S, Magesh NS (2016) Trace element concentration in surface sediments of Palk Strait, southeast coast of Tamil Nadu, India. *Marine Pollut Bull* 111(1-2):500-508
- Ke X, Gui SF, Huang H, Zhang HJ, Wang CY, Guo W (2017) Ecological risk assessment and source identification for heavy metals in surface sediment from the Liaohe River protected area, China. *Chemosphere* 175:473-481
- Leenheer JA, Noyes TI, Stuber HA (1982) Determination of polar organic solutes in oil-shale retort water. *Environ Sci Technol* 16(10):714-723
- Li F, Huang J, Zeng G, Yuan X, Li X, Liang J, Wang X, Tang X, Bai B (2013) Spatial risk assessment and sources identification of heavy metals in surface sediments from the Dongting Lake, Middle China. *J Geochem Explor* 132:75-83
- Li C, Chengwen S, Yanyan Y, Menghan S, Ping T, Mihua S (2015) Spatial distribution and risk assessment of heavy metals in sediments of Shuangtaizi estuary, China. *Marine Pollut Bull* 98:358-364
- Lin S, Hsieh JJ, Huang KM, Wang CH (2002) Influence of the Yangtze River and grain size on the spatial variations of heavy metals and organic carbon in the East China Sea continental shelf sediments. *Chem Geol* 182(2-4):377-394
- Long ER, Field LJ, Macdonald DD (1998) Predicting toxicity in marine sediments with numerical sediment quality guidelines. *Environ Toxicol Chem* 17:714-727
- Mandeng EPB, Bidjeck LMB, Bessa AZE, Ntomb YD, Wadjou JW, Doumo EPE, Dieudonné LB (2019) Contamination and risk assessment of heavy metals, and uranium of sediments in two watersheds in Abiete-Toko gold district, Southern Cameroon. *Heliyon* 5(10):e02591
- Mapel-Hernández MD, Armstrong-Altrin JS, Botello AV, Lango-Reynoso F (2021) Bioavailability of Cd and Pb in sediments of the National Park Veracruz Reef System, Gulf of Mexico. *Appl Geochem* 133:105085
- Mbesse CO, Bessong M, Ntamak-Nida MJ, Gerrienne P, Owono FM, Bessa AZE, Helenes J (2020) Palynology and palynofacies analyses in the Douala sub-basin: Implications on palaeoenvironment evolution of the Souellaba Formation/west Cameroon. *J African Earth Sci* 172:104004
- Mubedi JJ, Devarajan N, Le Faucheur S, Mputu JK, Atibu EK, Sivalingam P, Prabakar K, Mpiana PT, Wildi W, Poté J (2013) Effects of untreated hospital effluents on the accumulation of toxic metals in sediments of receiving system under tropical conditions: case of South India and Democratic Republic of Congo. *Chemosphere* 93(6):1070-1076
- Nguetchoa G, Bessa AZ, Eyong JT, Zandjio DD, Djaoro HB, Nfada LT (2019) Geochemistry of cretaceous fine-grained siliciclastic rocks from Upper Mundeck and Logbadjeck Formations, Douala sub-basin, SW Cameroon: Implications for weathering intensity, provenance, paleoclimate, redox condition, and tectonic setting. *J Afr Earth Sc* 152:215-236
- Noa Tang D, EkoaBessa AZ, Brice TK, Ange WK, Jacques E, Paul B (2021) Heavy Metal Contamination and Ecological Risk Assessment of Overlying Water and Sediments of Nkozoa Lake (Southern Cameroon). *Ann Res Rev Biol*. <https://doi.org/10.9734/arrb/2021/v36i430366>
- Ntamak-Nida MJ, Bourquin S, Makong JC, Baudin F, Mpesse JE, Ngouem CI, Komguem PB, Abolo GM (2010) Sedimentology and sequence stratigraphy from outcrops of the Kribi-Campo sub-basin: Lower Mundeck Formation (Lower Cretaceous, southern Cameroon). *J Afr Earth Sc* 58(1):1-8

- Price NM, Morel FM (1991) Colimitation of phytoplankton growth by nickel and nitrogen. *Limnol Oceanogr* 36(6):1071–1077
- Ramos-Vázquez MA, Armstrong-Altrin JS (2021) Provenance of sediments from Barra del Tordo and Tesoro beaches, Tamaulipas State, northwestern Gulf of Mexico. *J Palaeogeogr* 10(20):1–17
- Rubio B, Nombela MA, Vilas F (2000) Geochemistry of major and trace elements in sediments of the Ria de Vigo (NW Spain): an assessment of metal pollution. *Mar Pollut Bull* 40(11):968–980
- Salati S, Moore F (2010) Assessment of heavy metal concentration in the Khoshk River water and sediment, Shiraz, Southwest Iran. *Environm Monitor Assessm* 164(1):677–689
- Sankarappan R, Gopalakrishnan G, Shanmugam R, Magalingam R, Chockalingam K, Ayyamperumal R (2021) Diffusion, textural characteristics, and source identification of the heavy metals in the Karankadu mangrove sediments, South India. *Arabian J Geosci* 14(4):1–1
- Srichandan S, Panigrahy RC, Baliarsingh SK, Pati P, Sahu BK, Sahu KC (2016) Distribution of trace metals in surface seawater and zooplankton of the Bay of Bengal, off Rushikulya estuary, East Coast of India. *Mar Pollut Bull* 111(1–2):468–475
- Šulc Z, Řezanková H (2019) Comparison of similarity measures for categorical data in hierarchical clustering. *J Classif* 36(1):58–72
- Sundararajan S, Khadanga MK, Kumar JP, Raghuraman S, Vijaya R, Jena BK (2017) Ecological risk assessment of trace metal accumulation in sediments of Veraval Harbor, Gujarat, Arabian Sea. *Marine Pollut Bull* 114(1):592–601
- Szefer P, Glasby GP, Pempkowiak J, Kaliszczak R (1995) Extraction studies of heavy-metal pollutants in surficial sediments from the southern Baltic Sea off Poland. *Chem Geol* 120(1–2):111–126
- Tehna N, Sababa E, EkoaBessa AZ, Etame J (2019) Mine waste and heavy metal pollution in Betare-Oya Mining Area (Eastern Cameroon). *Environm Earth Sci Res J* 6(4):167–176
- Thevenon F, Graham ND, Chiaradia M, Arpagaus P, Wildi W, Poté J (2011) Local to regional scale industrial heavy metal pollution recorded in sediments of large freshwater lakes in central Europe (lakes Geneva and Lucerne) over the last centuries. *Sci Total Environ* 412:239–247
- Tomlinson D, Wilson J, Harris C, Jeffrey D (1980a) Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen* 33:566–575
- Tomlinson DL, Wilson JG, Harris CR, Jeffrey DW (1980b) Problems in the assessment of heavy-metal levels in estuaries and the formation of a pollution index. *Helgoländer Meeresuntersuchungen* 33(1–4):566–575
- Walkley A, Black IA (1934) An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci* 37(1):29–38
- Wang J, Jiang Y, Sun J, She J, Yin M, Fang F, Xiao T, Song G, Liu J (2020) Geochemical transfer of cadmium in river sediments near a lead-zinc smelter. *Ecotoxicol Environ Saf* 196:110529