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Assessment of trace metal pollution in sediments and intertidal fauna at the coast of Cameroon

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Abstract Coastal systems act as a boundary between land and sea. Therefore, assessing pollutant concentrations at the coast will provide information on the impact that land-based anthropogenic activities have on marine ecosystems. Sediment and fauna samples from 13 stations along the whole coast of Cameroon were analyzed to assess the level of trace metal pollution in sediments and intertidal fauna. Sediments showed enrichment of As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn. However, pollution of greater concern was observed for Cd, Cr, Cu, Ni, and Zn at the northern stations. Some sites recorded trace metal levels higher than recommended in sediment quality guidelines. Species diversity was low, and high bioaccumulation of trace metals was observed in biological samples. Some edible gastropod species accumulated trace metals above the safety limits of the World Health Organization, European Medicine Agency, and the US Environment Protection Agency. Although industrial pollution is significant along Cameroon's coast, natural pollution from the volcano Mount Cameroon is also of concern.

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Introduction

The increasing global population is reducing the earth's carrying capacity (Asangwe 2006). This is the result of the need for more land-based activities, and the consequence of this is unavoidable land degradation. Coastal ecosystems are one of these environmental compartments that are degrading at an alarming rate. In the Agenda 21 of the UN, it was agreed upon that all countries with a coast "commit themselves to integrated management and sustainable development of coastal areas and marine environments under their national jurisdiction" (UNCED 1992). This approach of a call for a collective but individual action is difficult to implement in African developing countries, like Cameroon, plagued with poverty, limited expertise and equipment, limited research, poor enforcement of laws and inter-institutional conflicts amongst other issues (Odada 2010; Alemagi et al. 2006).

Trace metal concentrations in sediment samples have been studied in many areas of the world (Bai et al. 2014, 2015; Xiao et al. 2013, 2015; Wang et al. 2015), indicating that they are a good marker for environmental monitoring. Sediment samples have been preferred for analysis, because they are known to act as sinks of trace metals and can give more accurate measurements of the pollution levels than water samples (Du Laing et al. 2009; Alyazichi et al. 2015). In addition, assessing the amount of trace metals in biological samples reveals the potential of their transfer from sediments to food webs. Sources of pollutants originating from human activities can vary from household waste to industrial by-products (Alyazichi et al. 2015). Fresh water input is an important transport vector of trace metals, contaminating estuarine sediments (Bai et al. 2015). The polluting impact of anthropogenic activities is well documented (Govers et al. 2014), and pollution in urban rivers was shown to be higher than in rural areas in the Pearl River delta in southern China (Xiao et al. 2013). Pollution of natural origin is also of great relevance (Lv et al. 2015). Trace metals can occur in bioavailable forms and as complexes of oxides of iron or manganese (Xiao et al. 2015). Several processes have been shown to influence trace metal levels and remobilisation, such as changes in the physicochemical parameters of sediments (Du Laing et al. 2009; Charriau et al. 2011) and also forest fires (Odigie and Flegal 2014). Trace metal concentrations have also been shown to vary with seasons, especially in areas with high hydrological fluctuations (Bai et al. 2014).

The 400-km coastline of Cameroon is intertwined with many rivers and influenced by anthropogenic and natural pressures (Alemagi et al. 2006; Folack and Gabche 2007), such as the volcanic eruption of Mount Cameroon. Poor waste management coupled with industrialization and urbanization is causing the up surge of pollutants in coastal environments, especially in developing countries (Rumisha et al. 2012). The relevance of trace metals as marker for the monitoring of coastal ecosystem health makes studies like this of great significance. However, very few studies conducted in Cameroon on the effect of trace metals on these marine systems had focused on the Cameroon estuary in the Douala metropolitan area. For instance, the fish *Arius heudelotii* was identified as bioindicator of trace metal pollution in Douala and the concentration of trace metals in fish and water samples were noted to be higher than safety limits of the World Health Organization (Fonge et al. 2011). Also, subsurface soils in the Bassa industrial zone Douala showed enrichments of trace metals (Asaah et al. 2006). Therefore, this study has the objectives of (1) assessing the levels of trace metals in sediment samples and biota, (2) linking observed pollution levels to potential sources, and (3) comparing pollution levels in industrialized and non-industrialized areas. Therefore, this study is fundamental to close knowledge gaps on the overall health status of the coast of Cameroon. It is hypothesized that Cameroon's Atlantic coast is (1) heavily polluted with trace metals, (2) that there is a gradient of pollution, highest in the central portion of the coastline around the Douala metropolitan area, and (3) that trace metal pollution has adverse effects on the intertidal fauna.

Materials and methods

The study area and sampling

The coast of Cameroon stretches 400 km in the tropical Eastern Atlantic from Nigeria in the North to Equatorial Guinea in the South (Fig. 1). The northern part of the coast around Idenau (1), Debundscha (2), Batoke (3), Bota (4), and Down Beach (5), is characterized by a small population size and very few industries. However, volcanic eruptions of Mount Cameroon impact this part of the coastal area. The central part of the coast (Douala) has an estuarine system of the Wouri River and the most anthropogenically disturbed coastal zone of Cameroon. It has the largest coastal population size and about 60 % of the country's industries (Alemagi et al. 2006). The southern parts of the coast (Kribi) has the smallest coastal population size and also very few industries. The 13 sites sampled for this study, arranged from North to South, were Idenau (1), Debundscha (2), Batoke (3), Bota (4), Down Beach (5), Douala A (6), Douala B (7), Douala C (8), Douala D (9), Douala E (10), Kribi A (11), Kribi B (12), and Kribi C (13) (Fig. 1).

Sediment and intertidal fauna were sampled at thirteen stations along the coast of Cameroon. At each station, three sediment samples were collected from an area of about 30×30 cm and from these samples; subsamples of the sediment for granolumetry and trace metal analysis were obtained and kept in plastic bottles. The rest of the sample was sieved via a 5-mm mesh size to obtain fauna. In areas were no fauna was obtained after sieving, gastropod samples were obtained from boulders along the coast. Sediment samples were refrigerated, while biological samples were preserved in 75 % ethanol.

Identification of fauna

Identification was successfully accomplished to species level of each specimen using Bandel and Kowalke

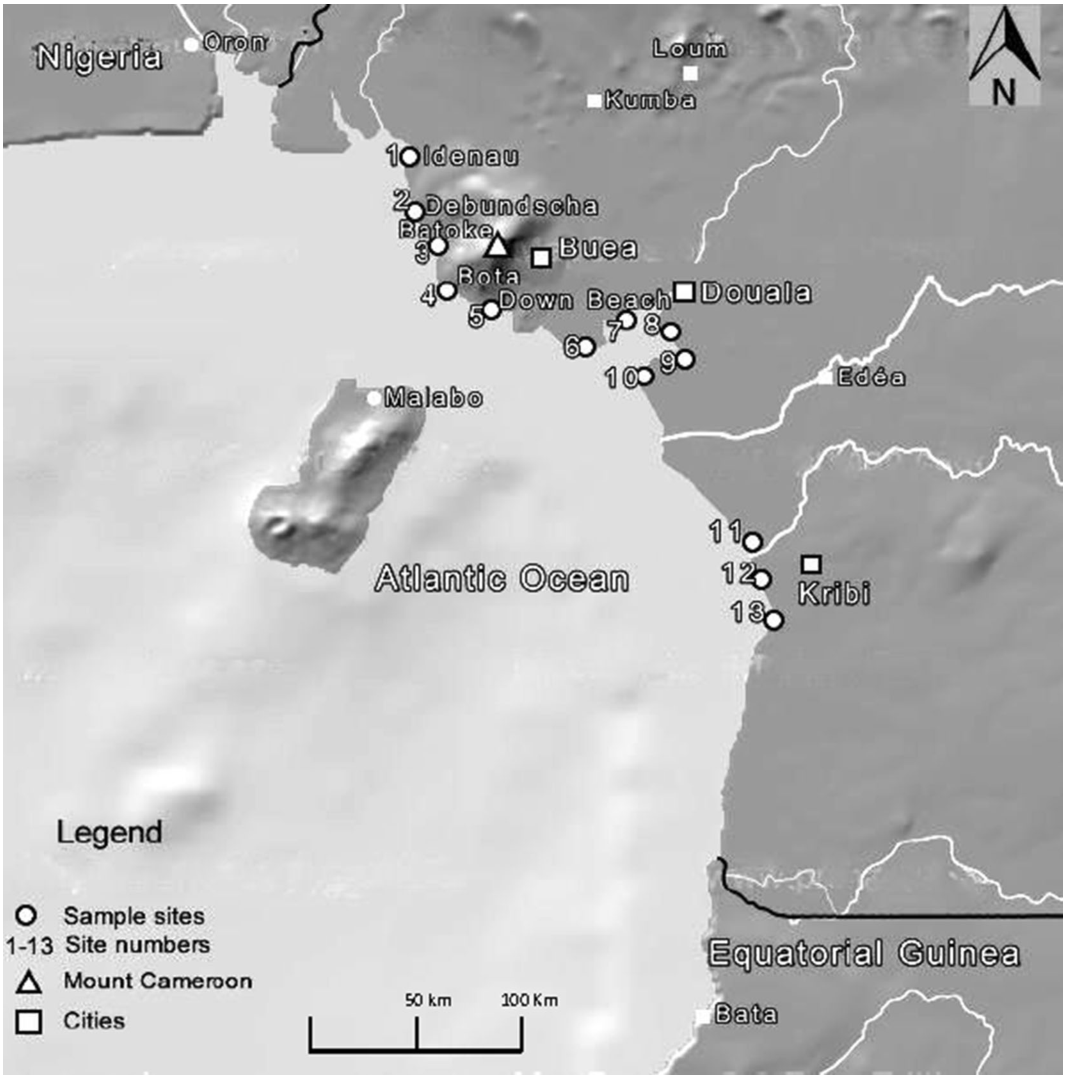


Fig. 1 The coast of Cameroon showing coastal cities (*squares*), sampling sites (*circles*), and volcanic mount Cameroon (*triangle*)

(1999), Oliver (2004), and Harasewych and Moretzsohn (2010), as well as Internet resources, such aswww.conchology.be, www.marinespecies.org, and www.gastropods.com. Sixteen species were identified in total, 15 gastropods and one maxillopod.

Table 1 Enrichment factors for contamination categories

Enrichment factor (EF)	Contamination category
<2	Deficiency to minimal contamination
2–5	Moderate enrichment
5–20	Significant enrichment
20–40	Very high enrichment
>40	Extremely high enrichment

Source: Yongming et al. (2006)

Table 2 Geoaccumulation index (I_{geo}) and pollution grades

I_{geo} class	I_{geo} value	Sediment quality
0	$Igeo \leq 1$	Unpolluted
1	$0<Igeo \leq 1$	Unpolluted to moderately polluted
2	$1<Igeo \leq 2$	Moderately polluted
3	$2<Igeo \leq 3$	Moderately to strongly polluted
4	$3<Igeo \leq 4$	Strongly polluted
5	$4<Igeo \leq 5$	From strongly to extremely polluted
6	$Igeo \geq 5$	Extremely polluted

Source: Muller (1979)

Table 3 Average trace metal concentrations in sediment samples (µg/g dry weight) from the coast of Cameroon

Stations	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Idenau (1)	63,240	2.2	0.17	43.3	113.1	64	87,039	1325	83	4.79	277	141
Debundscha (2)	37,952	1.6	0.1	77.1	100.1	46	75,425	1128	457	3.01	139	96
Batoke (3)	11,519	0.7	0.14	61.1	139	11	86,941	1326	255	1.14	305	117
Bota (4)	29,475	8.8	0.21	54.5	213	27	84,693	1108	277	13.6	219	101
Down Beach (5)	67,102	18	0.19	80.4	328	31	136,762	1800	138	15.4	305	212
Douala A (6)	13,605	1.9	0.13	6.16	25.16	12	16,459	254	10.5	21	31.9	74
Douala B (7)	5922	1	0.05	3.16	11	3.5	7199.7	114	4.31	6.2	14.1	24
Douala C (8)	4431	1.5	0.04	2.74	32.86	5.4	16,022	159	6.11	10.3	39.2	19
Douala D (9)	3365	0.6	0.04	1.28	6.765	6.6	3861.2	61	2.45	3.75	9.02	14
Douala E (10)	2980	1.3	0.23	2.74	14.53	17	12,215	139	7.71	13.2	13.4	79
Kribi A (11)	2248	7.1	0.01	1.33	5.13	0.6	5616.2	79.1	2.43	2.05	8.39	11
Kribi B (12)	2034	3.8	0.01	0.89	4.355	0.7	3473.9	45.8	1.59	5.49	5.88	7.9
Kribi C (13)	4304	8.5	0.01	1.75	7.19	1	6622.5	104	3	3.05	10.7	14

Stations are arranged from north to south

Sample pre-treatment

Sediment samples were lyophilized, and about 70 mg of sediment from each sample was grounded and then digested in a *CEM MARS 5* oven (CEM Corporation, Matthews, NC). Sediment digestion was done with *aqua regia* (6 ml of HCl and 2 ml of HNO_3). Soft tissue of fauna samples was removed and dried in an air hood for 28–48 h depending on the species. The dried tissues were digested in a *CEM MARS 5* oven with 1 ml H_2O_2 and 5 ml HNO_3.

Sediment grain size determination

Grain size of lyophilized sediment samples was determined by sieve analysis. Sediments were graded as

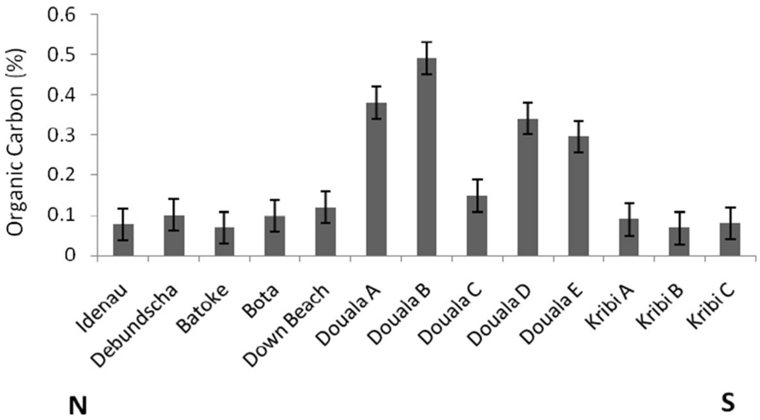
Table 4 Correlation between trace metals, organic carbon, and sediment grain size in sediments from the coast of Cameroon

	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn	OrgC	Sgran
Al	1													
As	0.48*	1												
Cd	0.47*	0.17	1											
Co	0.79*	0.38*	0.48*	1										
Cr	0.79*	0.65*	0.55*	0.86*	1									
Cu	0.86*	0.09	0.55*	0.69*	0.54*	1								
Fe	0.88*	0.49*	0.55*	0.95*	0.94*	0.71*	1							
Mn	0.87*	0.43*	0.54*	0.96*	0.91*	0.73*	0.99*	1						
Ni	0.48*	0.07	0.33*	0.86*	0.56*	0.57*	0.68*	0.7*	1					
Pb	0.19	0.23	0.52*	0.04	0.26	0.12	0.14	0.09	−0.08	1				
V	0.79*	0.35*	0.52*	0.88*	0.87*	0.67*	0.96*	0.97*	0.6*	0.05	1			
Zn	0.86*	0.45*	0.71*	0.83*	0.86*	0.73*	0.92*	0.91*	0.51*	0.39*	0.87*	1		
OrgC	−0.3*	−0.4*	−0.1	−0.4*	−0.4*	−0.3*	−0.4*	−0.4*	−0.4*	0.2	−0.5*	−0.28	1	
Sgran	−0.3*	0.1	−0.2	−0.4*	−0.3*	−0.3*	−0.3*	−0.4*	−0.27	−0.1	−0.4*	−0.4*	0.12	1

OrgC organic carbon, *Sgran* sediment grain size

*$p<0.05$

Fig. 2 Percentage organic carbon in sediment from the coast of Cameroon. Stations are arranged from north to south



gravel (≥2 mm), very coarse sand (<2 to 1 mm), coarse sand (<1 to 0.5 mm), medium sand (<0.5 to 0.25 mm), fine sand (<0.25 to 0.125 mm), very fine sand (<0.125 to 0.063 mm), and mud (silt and clay) (<0.063 mm). From the sediments retained by each sieve, the median grain size (D_{50}) was determined.

Trace metal analysis

All digested sediment and fauna samples were analyzed for trace metals using a high-resolution inductively coupled plasma mass spectrometer (HR-ICP-MS) Thermo Element II (Thermo Scientific). As quality control, certified reference material was digested: river clay sediment (LGC 6139) for sediments and lobster hepatopancreas (TORT-3) for biological samples. Twelve trace metals (Al, As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn) were measured in all samples.

Organic carbon analysis

Twenty milligrams of dried sediment was weighed from each sample in silver cups. This was then treated to remove all forms of inorganic carbon by adding 5 % HCl. The samples were dried in an oven at 60 °C for 4 h. Afterward, 5 % HCl was added into each sample to ensure that all inorganic carbon has been removed and samples were dried at 60 °C. Particulate organic carbon (POC) was measured using a CN Elemental Analyser Flash EA 1112 coupled to a Delta Plus XL IRMS with a Conflo III interface (Thermo Finnigan).

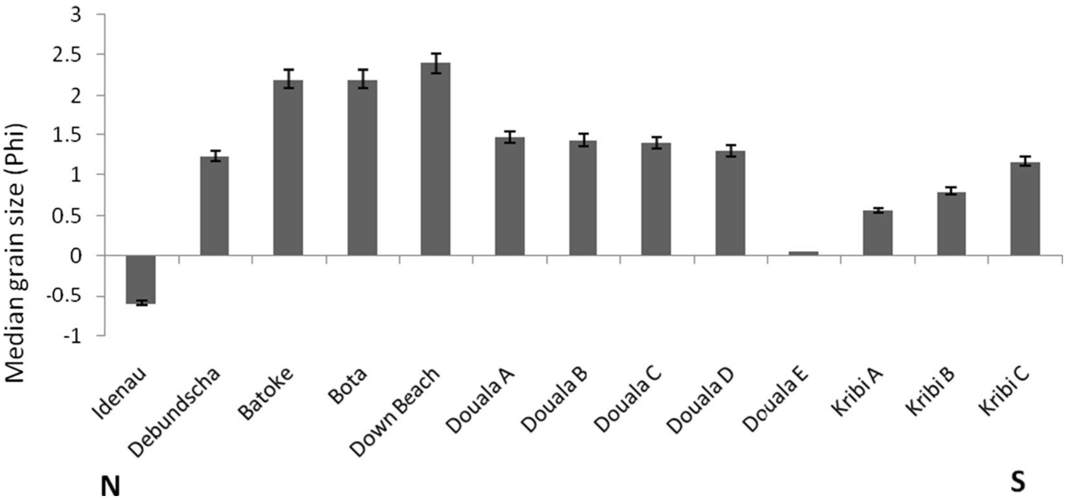


Fig. 3 Median grain size of sediments from the coast of Cameroon. Stations are arranged from north to south

Table 5 Sediment enrichment factor for metals normalised with Al in sediments from the coast of Cameroon

Stations	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
Idenau (1)	1.1[a]	5[a]	6.1[a]	3	5.5[a]	4.2	3.2	4.3	0.7	7[a]	5.1[a]
Debundscha (2)	1.34[a]	5[a]	18[a]	4.4	6.6[a]	6.1[a]	4.6	39.4[b]	0.7	5.8[a]	5.8[a]
Batoke (3)	1.92[a]	21.4[b]	47[c]	20.2[a]	5.5[a]	23[b]	17.7[a]	72.5[c]	0.9	42[c]	23[b]
Bota (4)	9.62[a]	12.2[a]	16[a]	12.1[a]	5	8.8[a]	5.8[a]	30.8[b]	4.2	12[a]	7.9[a]
Down Beach (5)	8.6[a]	5[a]	11[a]	8.2[a]	2.5	6.2[a]	4.1	6.73[a]	2.08	7.2[a]	7.3[a]
Douala A (6)	4.57	16.8[a]	4	1320[c]	5	3.7	2.9	2.52	14[a]	3.7	13[a]
Douala B (7)	5.52[a]	15[a]	4.7	3.1	3.3	3.7	2.9	2.39	9.5[a]	3.8	9.2[a]
Douala C (8)	10.7[a]	16.8[a]	5.5[a]	12.4[a]	6.7[a]	11	5.5[a]	4.52	21.1[b]	14[a]	9.7[a]
Douala D (9)	5.26[a]	21[b]	3.4	3.4	11[a]	3.5	2.8	2.38	10.1[a]	4.3	9.6[a]
Douala E (10)	13.8[a]	130[c]	8.2[a]	8.2[a]	31[b]	13[a]	7.2[a]	8.48[a]	40[b]	7.1[a]	61[c]
Kribi A (11)	101[c]	8[a]	5.3	3.8	1.5	7.6[a]	5.4[a]	3.54	8.2[a]	5.9[a]	11[a]
Kribi B (12)	60.7[c]	11.8[a]	3.9	3.6	1.9	5.2[a]	3.47	2.56	24.5[b]	4.6	8.9[a]
Kribi C (13)	63.5[c]	3.5	3.6	2.8	1.3	4.7	3.7	2.28	6.42[a]	3.9	7.6[a]

Stations are arranged from north to south

[a] Significant enrichment

[b] Very high enrichment

[c] Extremely high enrichment

Table 6 Sediment geoaccumulation index for sediments from the coast of Cameroon

Stations	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	V	Zn
Idenau (1)	−1.9	−1.7	0.3[a]	0.7[a]	−0.3	0.6[a]	0.2[a]	−0.2	0.2[a]	0.9[a]	0.5[a]
Debundscha (2)	−2.6	−2.2	−0.4	1.6[b]	−0.5	0.1[a]	−0.003	−0.4	2.7[c]	−0.1	−0.1
Batoke (3)	−4.3	−3.4	0.1[a]	1.2[b]	0.01[a]	−1.9	0.2[a]	−0.2	1.9[b]	1.1[b]	0.2[a]
Bota (4)	−3.0	0.3[a]	0.6[a]	1.1[b]	0.6[a]	−0.6	0.2[a]	−0.4	2.0[c]	0.6[a]	0.01[a]
Down Beach (5)	−1.8	1.3[b]	0.5[a]	1.6[b]	1.2[b]	−0.4	0.9[a]	0.3[a]	1.0[a]	1.1[b]	1.1[b]
Douala A (6)	−4.1	−1.9	0.0	−2.1	−2.5	−1.8	−2.2	−2.6	−2.8	−2.2	−0.4
Douala B (7)	−5.3	−2.8	−1.4	−3.0	−3.6	−3.6	−3.4	−3.7	−4.0	−3.4	−2.1
Douala C (8)	−5.7	−2.3	−1.6	−3.2	−2.1	−3.0	−2.2	−3.2	−3.5	−1.9	−2.4
Douala D (9)	−6.1	−3.7	−1.7	−4.3	−4.4	−2.7	−4.3	−4.6	−4.8	−4.0	−2.8
Douala E (10)	−6.3	−2.5	0.7[a]	−3.2	−3.2	−1.3	−2.6	−3.4	−3.2	−3.4	−0.4
Kribi A (11)	−6.7	0.0	−3.7	−4.3	−5.0	−6.1	−3.8	−4.2	−4.9	−4.1	−3.2
Kribi B (12)	−6.8	−0.9	−3.3	−4.9	−5.0	−5.9	−4.4	−5.0	−5.5	−4.6	−3.7
Kribi C (13)	−5.7	0.2[a]	−3.9	−3.9	−4.3	−5.4	−3.5	−3.9	−4.6	−3.8	−2.8

Stations are arranged from North to South

[a] Unpolluted to moderately polluted

[b] Moderately polluted

[c] Moderately to strongly polluted

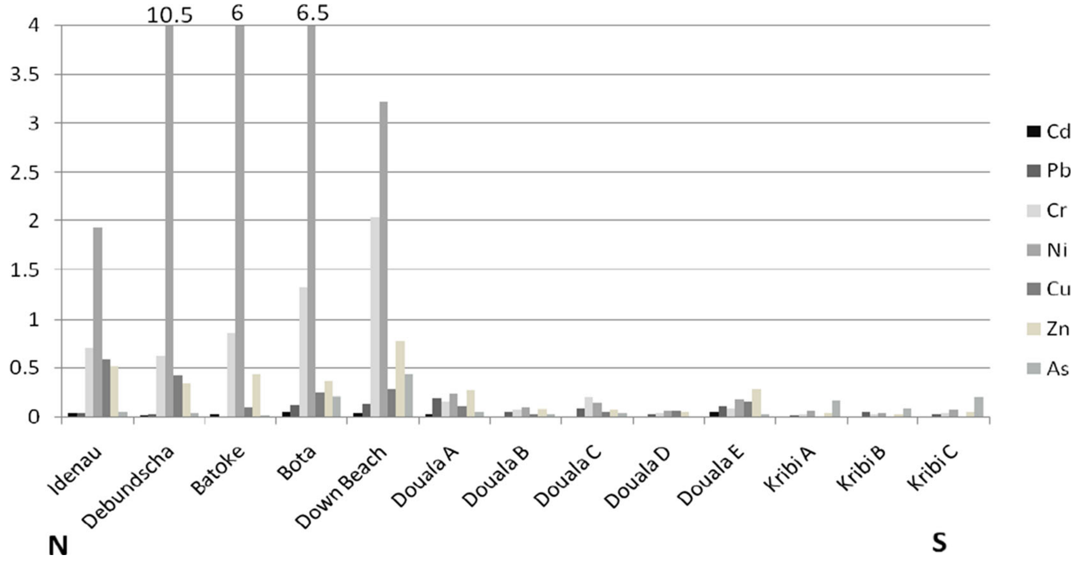


Fig. 4 Toxic units of trace metals in sediments from the coast of Cameroon. Stations are arranged from north to south

Data analysis

Univariate statistics

One-way ANOVA was carried out to assess the significance of variation among sites for the environmental variables measured (trace metals, organic carbon, and sediment grain size). Where the assumptions of ANOVA were not fulfilled, a nonparametric Kruskal-Wallis ANOVA by ranks was performed. These significance tests were done using the software STATISTICA 7.0 (Statsoft).

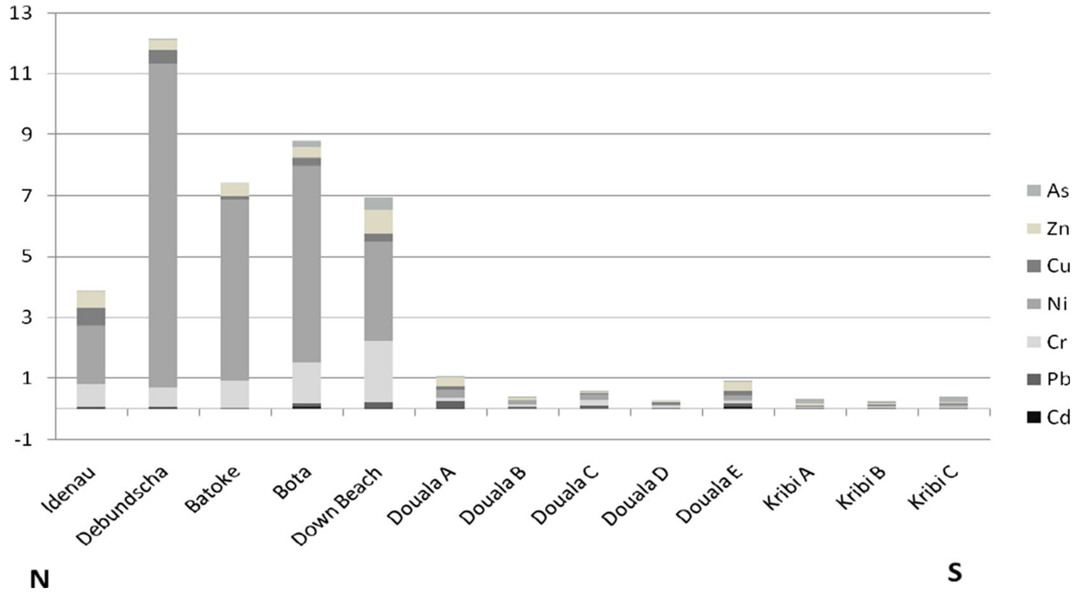


Fig. 5 Potential acute toxicity of contaminants in sediments from the coast of Cameroon. Stations are arranged from north to south

Table 7 Bioaccumulation factors for boulder-attached gastropods from the coast of Cameroon

Station^{species}	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
(1) Debundscha$^{Nes)}$	0.68	29.7[a]	17.28[a]	0.41	0.2	4.02[a]	0.51	0.69	0.27	1.8[a]	0.83	4.27[a]
(1) Debundscha^{Thc}	0	8.5[a]	28.42[a]	0	0	0.3	0	0.01	0	0	0.01	2.82[a]
(4) Bota^{Nes}	0.33	1.67[a]	9.952[a]	0.24	0.1	7.48[a]	0.13	0.36	0.27	0.5	0.3	5.05[a]
(4) Bota^{Thc}	0.01	0.2	12.44[a]	0.01	0	9.61[a]	0.01	0.02	0.01	0	0.01	4.21[a]
(8) Douala_C^{Thc}	0.63	0.49	9.437[a]	0.67	0.1	13.6[a]	0.16	2.27[a]	0.34	0.5	0.12	41.3[a]
(11) KribiA^{Nes}	0.41	2.79[a]	97.13[a]	1.4[a]	0.7	162[a]	0.4	1.71[a]	4.42[a]	1.3[a]	1.43[a]	39.6[a]
(11) KribiA^{Tes}	0.21	0.72	71.61[a]	0.48	0.3	66.2[a]	0.15	0.52	1.5[a]	1	0.31	8.84[a]
(12) Kribi_B^{Nes}	0.77	5.58[a]	84.56[a]	2.46[a]	1.2[a]	98.7[a]	1.31[a]	4.55[a]	5.25[a]	0.3	2.69[a]	46[a]
(13) Kribi_C^{Nes}	0.1	0.44	57.3[a]	0.35	0.2	34.7[a]	0.11	0.52	1.7[a]	0.7	0.33	12[a]
(13) Kribi_C^{Tes}	0.08	0.08	33.74[a]	0.14	0.1	6.67[a]	0.04	0.24	0.6	0.3	0.06	2.6[a]
(13) Kribi_C^{Thc}	0.03	0.29	564[a]	0.26	0.1	69.5[a]	0.06	0.1	0.31	0.2	0.06	39.9[a]

Stations are arranged from north to south

^{Nes} *Nerita senegalensis*, ^{Thc} *Thaisella coronate*, ^{Tes} *Tectarius striatus*

[a] Bioacculumation occurring

Index analysis of sediment pollution

Geoaccumulation index (I_{geo}) and enrichment factor (EF) was used to assess the amount of metals in sediments that were from allochthonous origin. For the enrichment factor, trace metals were normalized to aluminum both in the background and in the sediments. The background concentrations were those of the upper continental crust (Rudnick and Gao 2003). I_{geo} and EF were calculated using the $EF=(X_s / Al_s) / (X_b / Al_b)$ and $I_{geo}=\log2\ (C_n/1.5B_n)$. X_s is the concentration of the element in sample, and Al_s is the concentration of aluminum in the sample. X_b and Al_b are the respective background concentrations. C_n and B_n are concentration of the element in sediment and background, respectively. Enrichment and pollution levels of the sediments were interpreted with reference to Tables 1 and 2.

Table 8 Bioaccumulation factors for soft substrate gastropods and pelagic barnacle from the coast of Cameroon

Station^{species}	Al	As	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
(3) Batke^{Lan}	1.3[a]	74[a]	386[a]	0.6	0.26	14.6[a]	0.42	1.34[a]	0.43	3.13[a]	0.23	15[a]
(4) Bota^{Lan}	0.06	0.21	34.5[a]	0.04	0.01	1.33[a]	0.03	0.16	0.01	0.04	0.02	1.55[a]
(5) Down Beach^{Lan}	1.68[a]	2.14[a]	372[a]	1.89[a]	0.91	4.97[a]	1.5[a]	1.88[a]	2.02[a]	2.45[a]	1.29[a]	8.87[a]
(6) Douala_A^{tyf}	3.06[a]	7.48[a]	18.5[a]	5.61[a]	2.48[a]	110[a]	0.35	34.8[a]	4.82[a]	1.48[a]	2.3[a]	14.4[a]
(7) Douala_B^{Pac}	0.3	1.24[a]	11.9[a]	1.03[a]	0.28	72.4[a]	0.29	3.02[a]	0.88	0.31	0.26	10.9[a]
(8) Douala_B^{Tyf}	2.82[a]	8.26[a]	28.7[a]	7.71[a]	2.23[a]	224[a]	2.59[a]	29[a]	5.14[a]	3.01	2.21[a]	33.9[a]
(9) Douala_C^{Pac}	0.08	0.07	1.88[a]	0.1	0.01	2.44[a]	0.02	0.49	0.06	0.06	0.02	11.4[a]
(9) Douala_C^{tyf}	0.25	0.18	1.13[a]	0.18	0.06	3.22[a]	0.08	0.61	0.16	0.41	0.06	8.31[a]
(10) Douala_D^{Pac}	1.64[a]	13.3[a]	35.5[a]	8.11[a]	1.41[a]	83[a]	1.82[a]	21.1[a]	5.31[a]	1.59[a]	1.28[a]	72.1[a]
(10) Douala_D^{Tyf}	0.62	5.63[a]	15.5[a]	3.99[a]	0.57	33.8[a]	0.64	4.81[a]	2.59[a]	0.63	0.44	33.5[a]
(10) Douala_E^{Pac}	1.98[a]	6.09[a]	6.74[a]	4.05[a]	0.7	35.4[a]	0.61	9.89[a]	1.8[a]	0.48	0.92	13.8[a]

Stations are arranged from north to south

^{Lan} *Lapas anatifera*, ^{Tyf} *Tympanotonos fuscatus*, ^{Tyfra} *Tympanotonos fuscatus* var. *radula*, ^{Pac} *Pachymelania aurita*

[a] Bioacculumation occurring

Sediment toxicity was calculated by dividing the concentration of each metal in samples by the probable effect level (PEL) of the metal, while the potential acute toxicity is the sum of all toxic units (TU) in that site (Zheng et al. 2008). When the TU of any metal is greater than 1, then it is assumed that metal has adverse effects.

Biological samples and physicochemical variables

Bioaccumulation of each metal was calculated using the following formula:

$$\mathrm{BAF} = X_b / X_s$$

where BAF is the bioaccumulation factor, X_b and X_s are the concentrations of a given metal in a given species and in the sediment, respectively. When the BAF is higher than 1, it indicates bioaccumulation.

Results

Physicochemical variables in sediments

The northern stations (Down Beach, Bota, Batoke, Debundscha, and Idenau) are generally more polluted than all others (Table 3). There is a trend of decreasing trace metals concentrations from north to south. The highest concentration of Al, As, Co, Cr, Fe, Mn, and Zn were recorded from Down Beach. Cd was highest in Bota, vanadium in Bota and Down Beach, and Ni in Debundscha. Douala D and Kribi C had the lowest concentration of most trace metals. Significant positive correlation was detected between Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, V, and Zn (Table 4). Significantly positive correlation are also observed between Al, As, Co, Cr, Fe, Mn, V, and Zn. Pb was positively correlated with Zn and Cd. Organic carbon and sediment grain size showed negative correlations with some trace metals (Al, Cr, Co, Cu, Fe, Mn, and V). The percentage of organic carbon content in sediments was low (<1 %) at all sites (Fig. 2), with the highest values observed around the central estuarine area of Douala. Sediment grain size varied among sites. Sediment from Idenau was very coarse sand while Douala E, Kribi A, and Kribi B were classified as coarse sand. Debundscha, Douala A, Douala B, Douala C, and Douala D were graded as medium sand, while Batoke, Bota, and Down Beach were classified as fine sand (Fig. 3).

Table 9 Comparison of trace metal concentration in sediments from the coast of Cameroon with other regions

Metals/area	Cameroon coast	Soil of Bassa Industrial zone, Cameroon	Mokwé Lagoon, Ghana	Roro Bay Lagos Nigeria	Dar es Salaam coast, Tanzania	Galacia, NW Iberian Pennisular	Tuscan and E. Corsican Coast, Italy
Al	2034–67102	–	–	–	461–5128	–	3235–17400
As	0.6–18	0–63.7	–	–	0.2–1.3	13.1–88.8	–
Cd	0.009–0.2	0–7.3	0.2–1.09	0.9–3.4	0.01–0.04	–	0.02–0.39
Co	0.9–80.4	0–30.6	–	–	0.2–2.6	0.62–32.9	–
Cr	4.4–328	27.8–422.7	1.0–1681	14.0–65.8	1.0–9.6	38.1–365.8	11.1–510.2
Cu	0.6–46	12.1–909		8–29.5	0.3–2.1	16.4–2097	1.1–9.0
Fe	3474–136762	1.5–47.3	–	–	461–5352	–	3163–23328
Mn	45.8–1801	55.4–3282	–	–	17.0–219	182–580.5	138.1–1648
Ni	1.6–457	9–283.7	1.0–504	–	0.3–2.9	14.5–60.1	–
Pb	1.14–21	0–3320	0.5–29.3	8.8–37	0.8–2.2	42.4–1108	3.37–12.30
V	5.9–305	26.1–110.3	–	–	1.1–13.7	–	–
Zn	7.9–212.4	24–3782	1.5–77.5	187.1–1532	2.6–9.3	97.3–5589	18.3–58.5
Source	This study	Asaah et al. (2006)	Addo et al. (2012)	Majolagbe et al. (2012)	Rumisha et al. (2012)	Beiras et al. (2003)	Ungherese et al. (2010)

Sediment pollution

Douala A showed high enrichment for all trace metals while Kribi A, Kribi B, and Kribi C were enriched in As and Pb (Table 5). The northerly stations (Idenau, Debundscha, Batoke, Bota, and Down Beach) were also enriched in As, Cd, Co, and Zn. Cd enrichment was observed at all stations except Kribi A. Following I_{geo} Kibi A and Douala A are classified as unpolluted to moderately polluted for As and Cd, respectively (Table 6). The northern stations Idenau, Batoke, Bota, and Down Beach were those with indications of higher metal pollution according to I_{geo}, and they were ranked as either unpolluted to moderately polluted or moderately to strongly polluted for different metals. However, Debundscha had indication of pollution only in terms of Co, Ni, and Cu.

The toxic units of metals were generally less than 1 at most sites (Fig. 4), and the potential acute toxicity of all contaminants was greater than 3 at all the northern stations from Idenau to Down Beach (Fig. 5). In these stations, Cr and Ni had very high toxic units. The highest value for Ni was observed at Debundscha with values of about 11, while the highest value for Cr was recorded at Down Beach with a value of about 2. Generally, the toxic units in sediments follow this trend: Ni>Cr>Zn>Cu>As>Pb>Cd.

Accumulation of trace metals in tissue samples

A total of 677 individuals from 15 species were obtained during sampling. Five out of the 15 species were boulder-attached gastropods, and 10 were obtained from sieving the sediment. The average concentrations of trace metals in tissue samples were generally higher than average values in sediment samples (data not shown).

Boulder-attached gastropods showed bioaccumulation of Cd, Cu, and Zn in most species (Table 7). *Nerita senegalensis* accumulates more trace metals in comparison to other boulder-attached gastropods. The site with the highest bioaccumulation is Kribi A, where *Nerita senegalensis* accumulates all trace metals, except Al, Cr, and Fe.

Soft bottom gastropods from all sites showed bioaccumulation of Cd, Cu, and Zn (Table 8). *Tympanotonos fuscatus* at Douala A, Douala B, and Douala D showed bioaccumulation of all trace metals. *Lapas anatifera* from Down Beach also showed bioaccumulation of all trace metals except Cr. Bioaccumulation of As was observed in all species from Douala A, Douala B, Douala D, Douala E, and Down Beach.

Discussion

Despite the high industrialization and population of the central Littoral Region (Douala), average concentrations of trace metals in sediments were higher in the northern stations Idenau (1), Debundscha (2), Batoke (3), Bota (4), and Down Beach (5). This suggests that the input of trace metals at these stations could be from a natural source. The anthropogenic contribution to these observed levels would be very low because of the lower anthropogenic pressure (less industries and population) at the northern coastal area of Cameroon. However, southward flowing ocean currents could transport some pollutants to the northern stations from the coast of Nigeria, an area of higher anthropogenic pressure than Cameroon (UNEP 2006). Compared to some other areas

Table 10 Comparison of trace metal levels in sediments from the coast of Cameroon with SQGs (μg/g dry weight)

Trace metal	TEL	PEL	ERL	ERM	Cameroon coast
As	7.24	41.6	8.2	70	0.55–18
Cd	0.68	4.21	1.2	9.6	0.01–0.23
Cr	52.3	160	81	370	4.36–213
Cu	18.7	108	34	270	0.6–64
Ni	15.9	42.8	20.9	51.6	1.5–457
Pb	30.2	112	46.7	218	1.15–21
Zn	124	271	150	410	7.9–212
Source	Macdonald et al. (1996)	Macdonald et al. (1996)	Long et al. (1995)	Long et al. (1995)	This study

SQGs sediment quality guidelines, *TEL* threshold effect level, *PEL* probable effect level, *ERL* effect range low, *ERM* effect range medium of Africa and Europe, the coast of Cameroon has higher levels of Al and Fe (Table 9). Concentrations of As, Ni, Pb, V, and Zn were about ten times higher at the coast of Cameroon (West Africa) in comparison with the coast at Dar es Salaam in Tanzania (East Africa). However, in comparison with other countries along the West African coast, such as Ghana and Nigeria, Cameroon showed lower levels of Cd and Pb. Concentrations of Cr are lower than in Ghana, but higher than in Nigeria. Concentrations of Cu are lower than in Nigeria, while the concentration of Zn in the coast of Cameroon was intermediate between Ghana's Mokwé Lagoon in Accra (Addo et al. 2012) and Nigeria's Roro Bay in Lagos (Majolagbe et al. 2012). Compared to observations in subsurface soils of the Bassa industrial zone in Douala, trace metals in samples were lower except for Co, Fe, and Ni at some sites.

This variation observed at the coasts of other West African countries suggests that there are different anthropogenic pressures on the coastal systems of these countries. These anthropogenic pressures largely contribute to the observed trace metal concentrations rather than the mineralogical composition of the crust along the East Atlantic coast. However, the higher trace metal levels observed in samples from Cameroon compared to those of Dar es Salaam (Rumisha et al. 2012) could be due to differences in the geologic composition of both margins of the African continent (Schlüter 2008; UNEP 2001), differences in the kind and magnitude of anthropogenic pressures on the coasts studied, and differences in industrial and household waste management of the two countries. However, the last two factors are likely to be the most significant cause to the observed differences. When compared with results from other developing nations, the concentrations measured in this study are much lower than those of both rural and urban rivers of the Pearl River delta in China (Xiao et al. 2013). However, the two to seven times higher concentration of Ni at some of the northern stations (Table 9) in our study is most likely due to volcanic activity.

Significant positive correlation existed between Al, Cd, Co, Cr, Cu, Fe, Mn, Ni, and Zn. This indicates that they all could have the same origin, while As and Pb could have another. Significant positive correlation between all metals, except Pb with Fe and Mn, suggests that they are transported as complexes of Mn and Fe oxides (Du Laing et al. 2009; Charriau et al. 2011).

The lower organic carbon content (<0.6 %) at all sites could be due to a lower retention of organic matter by

Table 11 Comparison of trace metal concentrations in periwinkles from the coast of Cameroon and safety limits

Species	Cr	Cu	Fe	Mn	Ni	Pb	V	Zn
P. aurita (μg/g)	0.49–10.2	13.1–586.5	364.7–7484.6	78.8–13723	0.39–13.9	0.62–6.35	0.67–12.3	211.7–1084.2
T. fuscatus (μg/g)	0.28–24.5	34.2–792.8	537–18659.3	89.14–3296.3	1.4–22.2	0.77–18.7	0.27–31	349.2–801.7
T. fuscatus var. radula (μg/g)	1.02–62.5	17.3–1366.3	1153.7–5760.4	97.9–8844.04	0.98–50.4	0.76–31.2	1.68–73.4	47.8–1071.7
WHO (μg/g)	1.3	10	0.3	–	0.012	0.2	–	5
EMA ^{PDE} (μg/day)	300	2500	–	2500	300	–	300	13000
US (EPA and FDA)^{ADI} (μg/day)	120		–	–		–	6.2–18	

ADI allowable daily intake, *PDE* permitted daily exposure, *WHO* World Health Organization (tolerable levels of metals in drinking water), *EMA* European Medicine Agency, *US* (*EPA and FDA*) United States Environment Protection Agency and Food and Drug Administration the coarse sediment types at the sample sites, especially at the more exposed coastline at the southern and northern stations. The higher levels in the estuarine system of Douala could be due to higher input of sewage from the metropolitan area of Douala, mangroves in the proximity of sampling sites, and higher retention due to finer sediments in this wave-protected estuarine system.

Sediments along the coast of Cameroon were enriched with most metals, indicating allochthonous input of trace metals. It could be due to industrial and domestic waste in the central and southern areas. At the northern stations, volcanic ash, especially from the last Mount Cameroon eruption of 1999, is rather a source of trace metals. The northern stations showed enrichment of most trace metals (Fe, Co, Cr, Zn, Ni), which could be a case of natural pollution from the volcano Mount Cameroon. Concentrations of Pb were higher in the central part of the coast, which could be attributed to higher domestic and industrial pollution. At some stations, As, Cr, Cu, Ni, and Zn were above the threshold effect level (Macdonald et al. 1996) and the effect range low (Long et al. 1995) (Table 10). This indicates high pollution of some sites at the coast of Cameroon, especially Debundscha, the closest station to the last Mount Cameroon lava flow. This is also supported by the high sediment toxic units (TU) and potential acute toxicity of sediments of the northern stations, with high Ni and Cr concentrations (TU >1).

The low species diversity observed at sample sites could be due to several interacting factors. Although bottom dwellers generally prefer medium grain sized sediments (Jayaraj et al. 2008), the low organic content in these sediments implies less food for deposit and suspension feeders. Additionally, sediment pollution by trace metals could also account for this low diversity (Rumisha et al. 2012; Dauvin 2008). This is supported by the fact that the most abundant species assemblages in this study were boulder-attached gastropods, which are not in direct contact with the highly polluted sediments. Some of the periwinkles species sampled are eaten in Nigeria. The levels of trace metals in these were above the threshold intake levels set by the World Health Organisation, the European Medicine Agency, and the US Environment Protection Agency (Table 11). This indicates human health risk and risk for other top predators. Bioaccumulation of trace metals in fauna was also detected in boulder-attached gastropods, indicating high levels of trace metals not only in sediments but also in coastal waters. The average concentrations of trace metals in biological samples were higher than those in sediment samples of the same site. Also, the biota bioaccumulation factor showed a much clearer signal of pollution than sediments, supporting the idea that the assessment of a coastal ecosystem state is best done on biological samples since many factors influence the amount of trace metals in sediments. Additionally, sediments are not always available, like at rocky shores (Guerra-García et al. 2009; Joksimovic et al. 2011).

Conclusion

This study shows that the coast of Cameroon is highly polluted with trace metals and that there is a decreasing trend of trace metals from north to south, with the northern stations (Idenau, Debundscha, Batoke, Bota, and Down Beach) being highly polluted. The pollution of the northern stations is most likely natural pollution from volcanic eruptions of mount Cameroon. This study also reveals bioaccumulation of trace metals, with levels above safety limits.

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