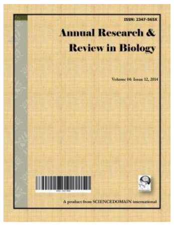

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Assessment of Sediments Pollution by Trace Metals in the Moloundou Swamp, Southeast Cameroon

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Authors' contributions

This work was carried out in collaboration between all authors. Author AZEB designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors YAEA and EPED managed the analyses of the study. Author GN managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present study aimed to assess the selected trace metal pollutants in the sediments of the Moloundou swamp. Sediments from typical swamp around Moloundou area, southeast Cameroon were collected from various depths of sediment profile (from surface to 120 cm depth). Five sites were chosen for this study, Fe, Co, Ni, Cr, Zn, Cu, and Pb were measured in the sediment. Different trace metals indices (enrichment factor, contamination factor, degree of contamination, ecological risk assessment and geo-accumulation index) were calculated. The results showed that all the swamp is slightly polluted and core 3 is the most polluted. Heavy metal indices give some indication for the pollution of sediments of all cores with Cu. The enrichment factor showed that the source of those metals in Moloundou swamp was from natural (Fe, Ni, Zn and Pb) and anthropogenic sources (Cu, Cr and Co). The degree of contamination and contamination factor showed low values along the cores, like the ecological assessment and

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pollution load index. The geo-accumulation index showed that sediments are more polluted with Cu, Cr and Co. It is urgent to control anthropogenic waste in order to avoid probable pollution in this zone.

Keywords: Heavy metals indices; Moloundou swamp; sediments; pollution.

1. INTRODUCTION

Swamps are considered to play a significant role in catchment hydrodynamics by capturing and storing rainwater and then releasing that water slowly as base flow in dry periods [1]. The magnitude of the 'sponge' phenomenon of upland swamps is dependent on the volume of water in the sediment profile, which is influenced by the antecedent groundwater level, the magnitude and duration of rainfall, and the presence of any springs or seeps discharging from regional aquifers [2, 3]. This means that the ability of swamps to act as water storage reservoirs and flood attenuators will change under different hydrological conditions. Numerous pollutants adsorb to sediments that accumulate at the bottom of reservoirs. These sediments accumulate over the time and can be considered as new pollutant sources to the overlying water [4,5]. The forms and types of pollutants usually vary from sediments to others because bonding forces vary with respect to grain size [6,7] which results in different release times and release potentials. Trace metal contamination is a serious threat in aquatic systems due to their toxicity, abundance, persistence in the environment and subsequent accumulation in water habitats [8-10]. It has been recently reported that contamination of water sources from trace metals includes geological weathering and erosion [5,11], atmospheric deposition [12], disposal of treated and untreated liquid effluents [13], trace metals containing fertilizers and pesticides [14,15] and chemicals originating from various urban, industrial and agricultural activities [16-18]. Moreover, few studies have suggested that sediment quality could serve as an indicator for the pollution levels and sediments could act as a screening tool to fingerprint the historical as well as the recent contamination in the surrounding environment [19-21]. In this context, the main aims of the present study were to determine the levels of trace metals in the sediments from the sediments of Moloundou swamp in order to identify their naturally enriched or anthropogenic sources using heavy metals indices, as well as to assess the environmental risk of heavy metal in the investigated area by comparing the acquired metal values with Sediment Quality Guidelines (SQGs). This spatial survey is also useful to assess pollution in the Moloundou swamp and to provide basic information for the judgment of environmental health risks and management of urgent environmental pollution issues in the sediments.

2. EXPERIMENTAL METHODS

2.1 Study Area

Moloundou Swamp (01°58'N-02°02'N, 15°25'E-15°29' E), is located at about 28 km Northeast of the Moloundou district, in the East region of Cameroon (Fig. 1). The study area is made up swampy hydromorphic soils. The vegetation cover corresponds to a dense forest. It is composedof Cryogenian tillite and schisto-limestone [22,23]. Input of materials in this swamp is considered to have been derived from the surrounding areas and transported by surface runoff and rivers which was controlled primarily by precipitation, and established favorable conditions for the development of lacustrine sediments.

2.2 Sampling and Analysis of Sediments

A total of 48 sediment samples were collected from all the selected sites using standard protocol [5]. The sediment samples were taken at five different sites (1; 2; 3; 4 and 5) inside the swamp using a core sampler (raft of wood placed in the middle of the sampling location with PVC pipe), and at each site, composite sediment samples were prepared. In the laboratory, samples were air-dried to reduce the water content. Dried samples were analyzed in 48 representative samples (at 10 cm intervals) for trace metals by inductively coupled plasma–atomic emission (ICP–AES), using the pulp at ALS Global Group (Vancouver, Canada). The samples were pulverized to obtain a homogeneous sample out of which 50–60 g was obtained for the analyses. 0.2 g of rock powder was fused with 1.5 g $LiBO_2$ and then dissolved in 100 ml 5% HNO_3. Analytical uncertainties vary from 0.01% to 6%.

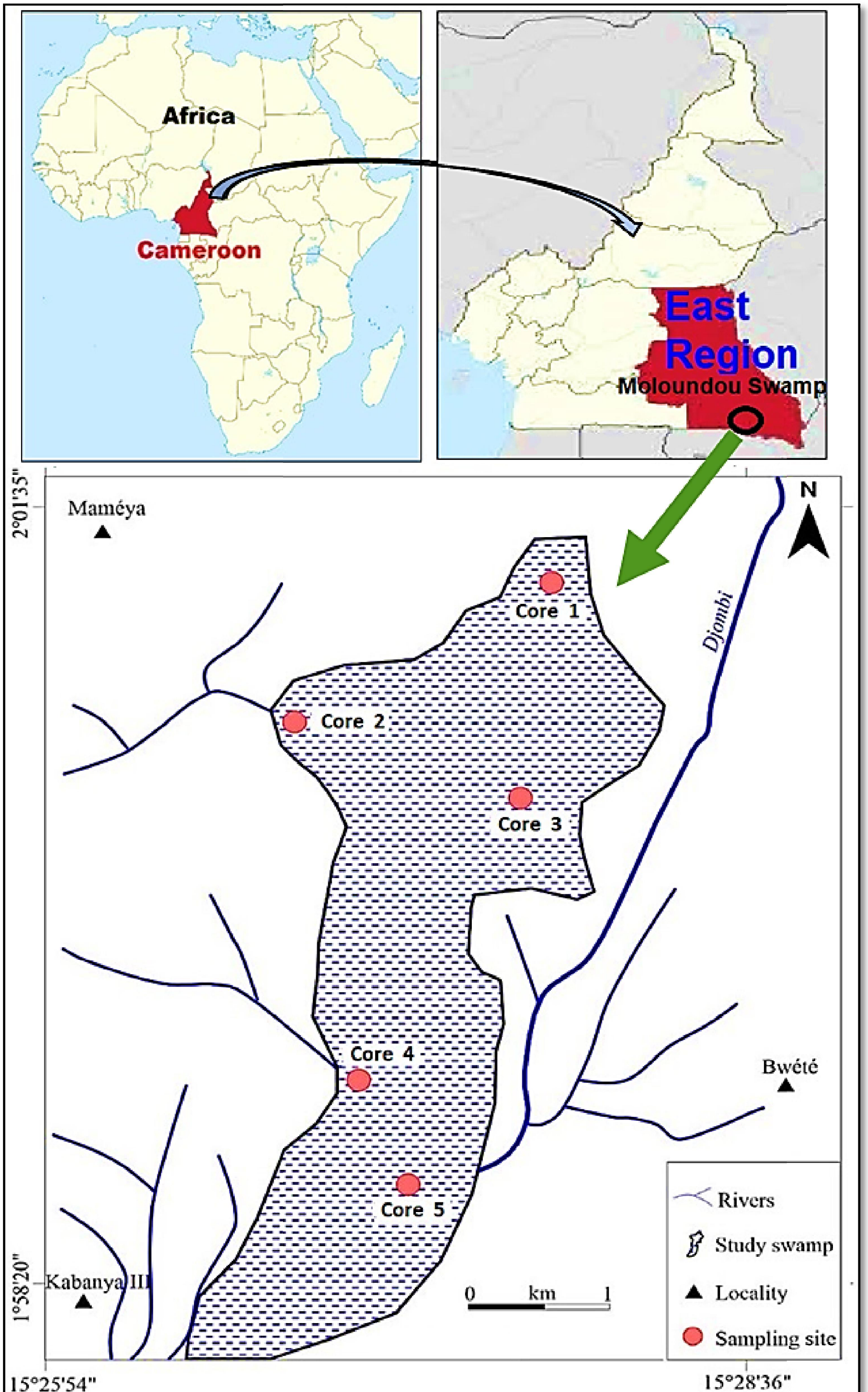

Fig. 1. Investigated area and sampling sites inside the sediments of Moloundou swamp

2.3 Heavy Metals Indices

2.3.1 Enrichment Factor (EF)

Iron (Fe) was chosen as a stationary reference element to perform this calculation [24]. The EF values < 2 indicate that the metal is entirely from crustal materials or natural processes; whereas EF values > 2 reveal that the sources are more likely to be anthropogenic [25].

$$EF = \frac{[M]Sample/[Fe]sample}{[M]Background/[Fe]background}$$

where, M is the metal concentration. The background value is that of average shale [26]. About six categories are recognized for FE: ≤ 1 background concentration, 1-2 depletion to minimal enrichment, 2-5 moderate enrichment, 5-20 significant enrichment, 20-40 very high enrichment and > 40 extremely high enrichment [27].

2.3.2 Contamination Factor (CF)

The CF is the ratio calculated by dividing the concentration of each metal in the sediment by the baseline or background value [28]. Contamination Factor (CF) = C_{metal} / $C_{background}$, the following expressions are used to describe the contamination factor: CF < 1 (low contamination factor); 1 ≤ CF < 3 (moderate contamination factors); 3 ≤ CF < 6 (considerable contamination factors) and CF ≥ 6 (very high contamination factor).

2.3.3 Degree of Contamination (DC)

The Degree of Contamination (DC) is the sum of all contamination factors for a given site [29]:

$$DC = \sum_{i=1}^{n} CFi$$

where CF is the single contamination factor and n is the amount of the elements present. DC < n, would indicate low degree of contamination; n ≤ DC < 2n, moderate degree of contamination; 2n ≤ Dc < 4n, considerable degree of contamination; and Dc > 4n, very high degree of contamination. For the studied heavy metals, n=7.

2.3.4 Ecological risk assessment

The ecological risk assessment was carried out potential ecological risk index (RI) for this study. The potential ecological risk index (RI) of the heavy metals is known as the sum of the risk factors and developed for six toxic metals using equations of Hakanson [29] and Zhu et al. [30].

$$RI = \sum_{1}^{n} Er \quad \text{and} \quad Er = Tr \times CF$$

where Er is the single index of ecological risk factor, and n is the amount of the heavy metal class, Tr = toxic response factor suggested by Hakanson [29] for six metals Cr (5), Co (5), Cu (5), Pb (5), Ni (5), Zn (1). Er and RI express the potential ecological risk factor of individual and multiple metals, respectively. The following expressions was used for the potential ecological risk factor: Er < 40, low potential ecological risk; 40 ≤ Er < 80, moderate potential ecological risk; 80 ≤ Er < 160, significant potential ecological risk; 160 ≤ Er < 320, high potential ecological risk; and Er ≥320, very high ecological risk. Furthermore, the potential ecological risk index: RI < 150, low ecological risk; 150 ≤ RI < 300, moderate ecological risk; 300 ≤ RI < 600, significant ecological risk; and RI > 600, very high ecological risk [29].

The pollution load index (PLI) of a single site is the root of number (n) of multiplied together contamination factor (CF) values.

$$PLI = \sqrt[n]{(CF1 \times CF2 \times CF3 \times \ldots \ldots \times CFn}$$

where, n is the number of metals and CF is the contamination factor. A PLI = 0, indicates perfection; a value < 1 indicates no pollution, and values > 1 is polluted area [31].

2.3.5 Geo-Accumulation Index (I*geo*)

The index of geo-accumulation (I*geo*) was firstly defined by Muller [32] to determine and define the metal contamination in sediments by comparing current concentrations with preindustrial levels [33].

$$Igeo = Log2\ (Cn/1.5Bn)$$

where, Cn is the concentration of metals (mg/kg) in sediments, Bn is the geochemical background value (mg/kg) in average shale of element n and 1.5 is the background matrix correction due to anthropogenic influences. The geo-accumulation index (I*geo*) was distinguished into seven classes by Buccolieri et al., [34]: I*geo* ≤ 0, class 0 (unpolluted); 0 < I*geo* ≤ 1, class 1 (unpolluted to moderately polluted); 1 < I*geo* ≤ 2, class 2 (moderately polluted); 2 < I*geo* ≤ 3, class 3 (moderately to strongly polluted); 3 < I*geo* ≤ 4, class 4 (strongly polluted); 4 < I*geo* ≤ 5, class 5 (strongly to extremely polluted); and I*geo* > 5, class 6 (extremely polluted).

3. RESULTS AND DISCUSSION

3.1 Heavy Metal Pollution

The basic descriptive statistical values and spatial distributional patterns of the studied trace metals are presented in Table 1 and Fig. 2. On the average basis, the metals follow a decreasing concentration order Fe > Cu > Cr > Zn > Ni > Co > Pb. Comparison of the average concentrations of heavy metals in the different samples shows that the average Fe concentration is higher (5788 mg/kg) than that of other metals. This average of Fe concentration in Moloundou sediments is less than the Average Shale (46700 mg/kg) [26] and UCC [35] reference values. On the other hand, the average concentrations of the other metals in this study are higher than the reference values of Average Shale [26] and UCC [35], These abnormal values can be attributed to the pollutant load provided by the various discharges from agricultural and artisanal mining activities. The maximum concentrations of the different elements analysed are recorded in the cores 3 and 5 samples, in particular for Fe (7133 mg/kg), Cu (206.67 mg/kg), Pb (23.33 mg/kg), Ni (76.33), Cr (191.33 mg/kg) and Zn (134.67 mg/kg). The high levels of these metals could be attributed to human activities such as ores extraction and agricultural activities inside and around the Moloundou swamp.

3.1.1 Copper (Cu)

Copper is an essential micronutrient for aquatic life in freshwaters and sediments but it becomes toxic at higher level. It is released to the environment from natural sources such as volcanic eruptions, decaying vegetation, forest fires, and sea spray up to 50 mg/kg [36, 37] and anthropogenic activities, including municipal and industrial wastewater [36, 38]. After a series of natural processes such as weathering and leaching, the water-borne Cu finally accumulates in the sediment and the quantity of Cu contained in the sediment reflects the degree of pollution of the water body. The average concentration values were ranging from 192.67 to 206.67 mg/kg with a mean of 200.22 mg/kg (Table 1; Fig.2), relatively lower than those found in previous studies in the paddy fields sediments from mangrove swamp in Pearl River Estuary, China [15], but higher than those measured in the sediments from Turfy Swamps, Northeastern China [18] and sediments from Simbock Lake in Yaounde, Cameroon [5]. However, possible sources of Cu toxicity in the sediments of the Moloundou swamp might include agriculture and artisanal gold exploitation around the study area.

3.1.2 Chromium (Cr)

The toxicity of chromium depends on its degree of oxidation. Hexavalent chromium salts are very toxic [39]. Chromium is more toxic in fresh water than in hard water and also more toxic to invertebrates than to fish [40]. The Cr content in Moloundou swamp is about 180 to 191.33 mg/kg, with an average of 183.77 mg/kg (Table 1; Fig.2), which exceeds the French sediment quality standards set by the ATSDR [36] for Cr (100mg/kg). Compared with previously published results, Chromium values of this study are closed to Simbock Lake sediment in Yaounde, Cameroon [5] and higher than those from mangrove swamp in Pearl River Estuary, China [9] and the coastal sediments of the South Sea of Korea [41]. This high content would be justified by the deposition of atmospheric particles and the leaching of chromium-containing in source rock.

3.1.3 Zinc (Zn)

Natural background levels of zinc are usually found up to 100 mg/kg in sediments [42]. The concentrations of Zn in the present study ranged from 113 to 134.67 mg/kg with an average of 126 mg/kg (Table 1; Fig.2), which are lower than those reported for the in sediments from mangrove swamp in Pearl River Estuary, China [9], but higher than sediment of Turfy Swamps, Northeastern China [18] and Simbock Lake sediments in Yaounde, Cameroon [5]. However, these Zn levels were similar to those previously found in the coastal sediments of the South Sea of Korea [41]. This high concentration is of anthropogenic origin, which is the mining practiced in this locality.

3.1.4 Nickel (Ni)

Nickel can enter the environment as a result of the natural weathering and leaching of rocks [43]. The average concentrations of Nickel (Ni) present in the earth's crust are about 17 to 20 mg/kg [26, 35]. The average concentration values (mg/kg) were ranging from 66.66 to 76.33 with a mean of 70.22 (Table 1; Fig.2), relatively lower than those found in previous studies in the paddy fields sediments from mangrove swamp in Pearl River Estuary, China [9] but higher than those measured in the sediments from Turfy Swamps, Northeastern China [18] and sediments from Simbock Lake in Yaounde, Cameroon [5]. This concentration could be explained by the pollutant load provided by the various residues from mining operations, this is agreed with Biney [44] who found same impacts.

3.1.5 Cobalt (Co)

The average concentrations of cobalt present in the earth's crust are about 20-25 mg/kg [36]. The concentrations of Co (mg/kg) found in the sediments Moloundou sediments ranged from 31.66 to 39.66 with average of 32.88 (Table 1; Fig.2). Compared with previously published results, Co levels were lower than those reported for Tigris river, Turkey [45] and higher than sediment of Turfy Swamps, Northeastern China [18]; Simbock Lake in Yaounde, Cameroon [5] and from mangrove swamp in Pearl River Estuary, China [9]. This high concentration could be linked to the presence of iron and manganese oxyhydroxides in Moloundou sediments because in sediments Co is considered to be a low-mobility element and has a high affinity with iron and manganese oxyhydroxide.

3.1.6 Lead (Pb)

Lead is a non-essential and toxic element released from natural and anthropogenic activities. Major sources include vehicular emissions, volcanoes, airborne soil particles, forest fires, waste incineration, effluents from leather industry, lead containing paints and pesticides [38, 46, 47]. Natural concentration of Pb in the earth's crust varied from 15 to 20 mg/kg [46]. The current study reported that Pb concentrations (mg/kg) in the sediments ranged from 6.43 to 23.33 with an average of 15.43

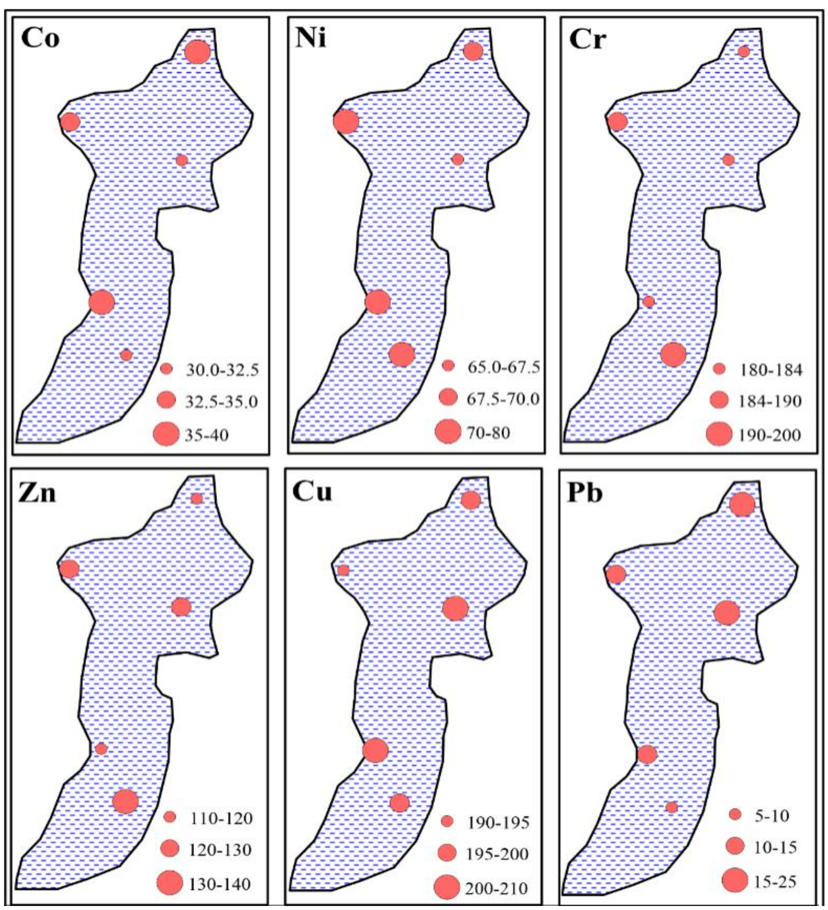

Fig. 2. Distribution maps of the concentration of selected heavy metals (mg/kg) in sediments of Moloundou swamp

(Table 1; Fig.2). The comparison between Pb concentrations in the sediments of the Moloundou swamp and other areas showed that Pb levels in these sediments had higher levels than those measured in the sediments of Indus and Pakistan [48] rivers and Turfy Swamps, Northeastern China [18] but lower concentrations than those measured in the sediments from the Nile river, Egypt [49, 50]; soils from El Mahalla El-Kobra area, Gharbia governorate, Egypt [51] and Simbock Lake in Yaounde, Cameroon [5]. Most likely, the concentration of Pb reported in this study originated from both natural and anthropogenic sources which drain out their waste from mining [52, 53]. Moreover, use of fertilizers and pesticides is also a common practice in the catchment areas of which could contribute significantly to the presence of Pb in the swamp.

3.2 Heavy Metals Indices

3.2.1 Enrichment Factor (EF)

The enrichment factors of heavy metals in Moloundou swamp were as shown in Fig. 3 and Table 2. The sequence of EF in the sediments was Cu > Cr > Co > Zn > Ni > Pb. The enrichment factor of heavy metals in all core sediments is between 5-20 range, indicated significant enrichment and that the source of those metals was from anthropogenic activities. Except Cu enrichment factor values are between very high enrichment (for cores 2, 3 and 5) and extremely enrichment (for cores 1 and 4) (Fig. 3 and Table 2). It is obvious that Cu is most abundant in all core sediment; this could be attributed to agricultural wastes and artisanal gold exploitation.

3.2.2 Contamination Factor (CF) and Degree of Contamination (DC)

The contamination factor (CF) used to determine the contamination status of the sediment in the present study. According to Hakanson classification [29], CF of all metals in the sediments of Moloundou showed moderate contamination factor except for Pb which showed low and Cu which is considerable (Table 3). The degree of contamination (DC) show moderate degree of contamination ($7 \leq DC < 14$) in all cores of the sediments in Moloundou swamp (Table 3 and Fig. 4). The sediments were moderately and considerably contaminated by theses metals due to the influence of external discrete sources like industrial activities, agricultural runoff, and other anthropogenic inputs.

3.2.3 Ecological risk assessment

3.2.3.1 Ecological Risk Factor (Er) and Ecological Risk Index (RI)

The Er and RI of the heavy metals in the investigated cores is given in Table 4 and Fig. 5. All analysed metals showed low potential ecological risk, it varied from 1.19 to 22.96 (Er < 40). The RI of the studied trace metals in sediments of Moloundou swamp ranged from 43.24 to 47.36 It is clear that all the cores showed low ecological risk index, this indicates low polluted according to Hakanson [29].

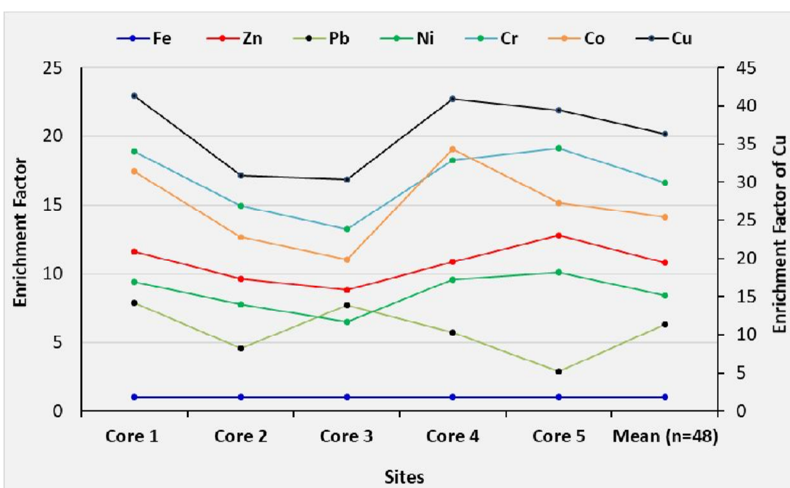

Fig. 3. The enrichment factor of heavy metals in the sediments of Moloundou swamp

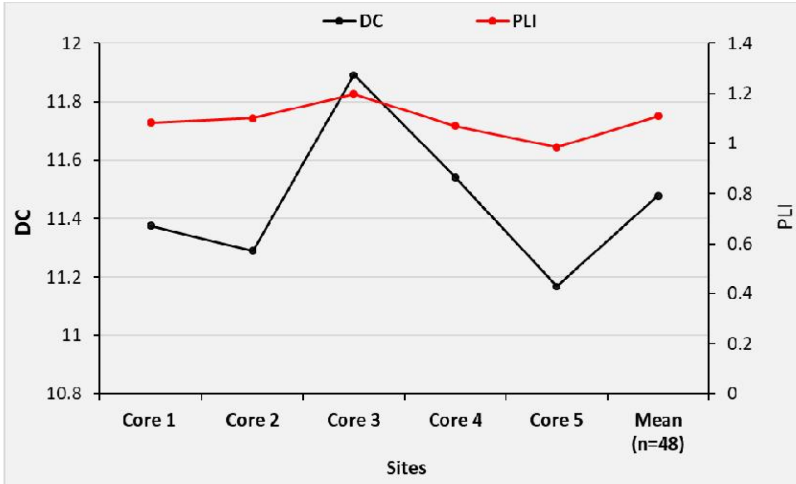

Fig. 4. The degree of contamination (DC) and pollution load index (PLI) of heavy metals in the sediments of Moloundou swamp

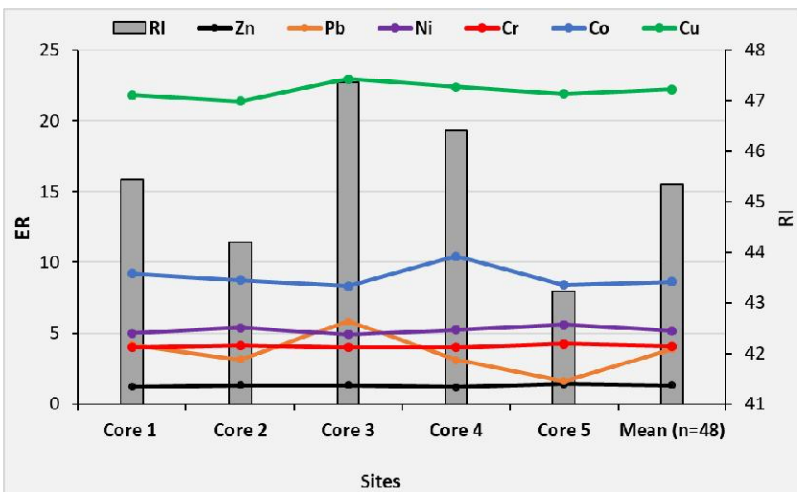

Fig. 5. The ecological risk factor (Er) and the ecological risk index (RI) of heavy metals in the sediments of Moloundou swamp

3.2.3.2 Pollution Load Index (PLI)

Pollution severity and its variation along the rivers was determined with the use of pollution load index. This index is a quick tool in order to compare the pollution status of different places [54]. The values of Pollution Load Index indicated that core 5 <1 therefor considered unpolluted, while as cores 1, 2, 3 and 4 considered polluted because of the value of PLI >1 (Table 3 and Fig. 4). These results attributed principally to anthropogenic sources, such as agriculture and ores extraction.

3.2.4 Geo-Accumulation Index (Igeo)

The geo-accumulation index is a quantitative measure of the degree of pollution in sediments [55]. Table 5 presents the geo-accumulation index for the quantification of heavy metal accumulation in the Moloundou swamp. The I*geo* grades for the study area sediments varies from metal to other and between cores (Table 5 and Fig. 6). Iron, Zinc, Lead and Nickel, and remain in grade 0 (unpolluted) at all core which suggesting that the study area sediments are in background value with respect to this metal. The I*geo* for cobalt, chromium and copper while

Table 1. Heavy metal concentrations (Mean ± SD) in the sediment samples of Moloundou swamp (mg/kg)

Sites	Fe	Co	Ni	Cr	Zn	Cu	Pb
1 (n = 8)	4993 ± 907	35 ± 4.36	67.66 ± 6.81	180 ± 45.83	116.66 ± 20.82	196.66 ± 81.45	16.7 ± 5.94
2 (n = 10)	6546 ± 1176	33.33 ± 7.23	73.33 ± 5.86	186.66 ± 25.17	126.66 ± 11.55	192.66 ± 57.46	12.6 ± 6.83
3 (n = 12)	7133 ± 830	31.66 ± 3.6	66.66 ± 6.43	180 ± 22.72	126.66 ± 11.02	206.66 ± 47.43	23.33 ± 3.76
4 (n = 8)	5163 ± 1056	39.66 ± 2.08	71.33 ± 5.13	180 ± 40	113 ± 6.08	201.66 ± 74.89	12.5 ± 2.26
5 (n = 10)	5240 ± 392	32 ± 2.89	76.33 ± 5.77	191.33 ± 30	134.66 ± 20.82	197.33 ± 80.83	6.43 ± 4.72
Mean (n = 48)	5788 ± 872	32.88 ± 4.03	70.22 ± 6	183.77 ± 32.74	126 ± 14.06	200.22 ± 68.41	15.48 ± 4.70
UCC values	46700	11	19	35	52	14	17

Table 2. The Enrichment Factor (EF) of heavy metals in the sediment samples of Moloundou swamp

Sites	Enrichment Factor (EF)						
	Fe	Zn	Pb	Ni	Cr	Co	Cu
Core 1	1	11.61	7.89	9.41	18.91	17.41	41.31
Core 2	1	9.61	4.54	7.78	14.96	12.65	30.87
Core 3	1	8.82	7.72	6.49	13.23	11.03	30.39
Core 4	1	10.87	5.71	9.59	18.28	19.09	40.97
Core 5	1	12.77	2.90	10.11	19.15	15.17	39.50
Mean (n=48)	1	10.82	6.32	8.42	16.65	14.12	36.28

Table 3. The contamination factor (CF), Pollution Load Index (PLI) and degree of Contamination (DC) of Moloundou swamp

Sites	Contamination Factor (CF)							DC	PLI
	Fe	Zn	Pb	Ni	Cr	Co	Cu		
Core 1	0.11	1.23	0.84	1.00	2.00	1.84	4.37	11.38	1.08
Core 2	0.14	1.33	0.63	1.08	2.07	1.75	4.28	11.29	1.10
Core 3	0.15	1.33	1.17	0.98	2.00	1.67	4.59	11.89	1.20
Core 4	0.11	1.19	0.63	1.05	2.00	2.09	4.48	11.54	1.07
Core 5	0.11	1.42	0.32	1.12	2.13	1.68	4.39	11.17	0.98
Mean (n=48)	0.12	1.33	0.77	1.03	2.04	1.73	4.45	11.48	1.11

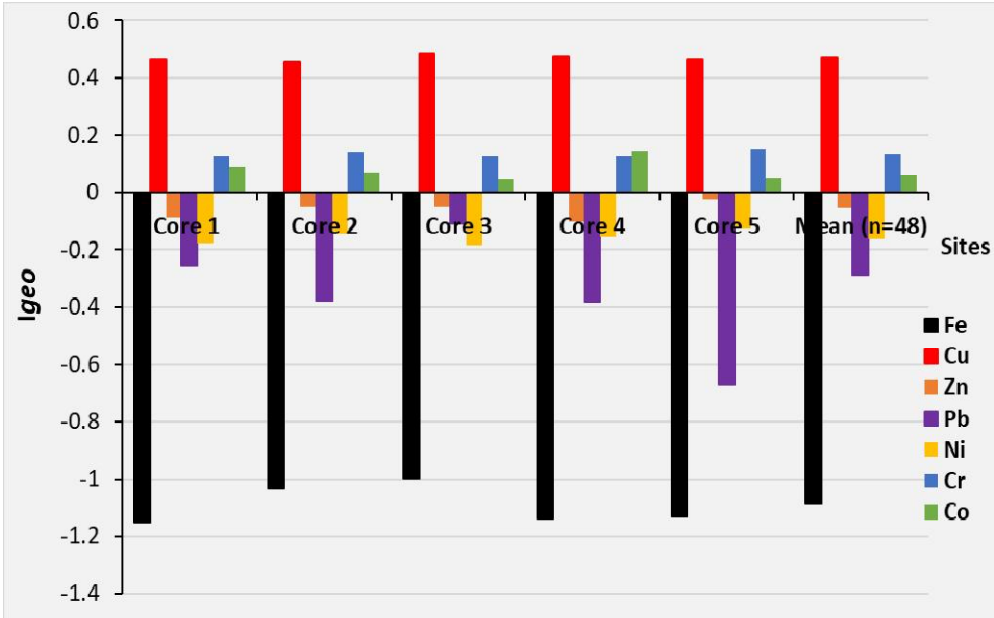

Fig. 6. The geo-accumulation index (Igeo) of heavy metals in the sediments of Moloundou swamp

Table 4. Pollution indices (Er and RI) in the sediment of Moloundou swamp

Sites	Ecological Risk (Er)						RI
	Zn	Pb	Ni	Cr	Co	Cu	
Core 1	1.23	4.18	4.98	4.00	9.21	21.85	45.44
Core 2	1.33	3.15	5.39	4.15	8.77	21.41	44.20
Core 3	1.33	5.83	4.90	4.00	8.33	22.96	47.36
Core 4	1.19	3.13	5.25	4.00	10.44	22.41	46.41
Core 5	1.42	1.61	5.61	4.25	8.42	21.93	43.24
Mean (n=48)	1.33	3.87	5.16	4.08	8.65	22.25	45.35

Table 5. The geo-accumulation index (I*geo)* of heavy metals in the sediments of Moloundou swamp

Sites	Geo-accumulation Index (I*geo*)						
	Fe	Zn	Pb	Ni	Cr	Co	Cu
Core 1	-1.15	-0.09	-0.25	-0.18	0.12	0.09	0.46
Core 2	-1.03	-0.05	-0.38	-0.14	0.14	0.07	0.46
Core 3	-1.00	-0.05	-0.11	-0.18	0.12	0.05	0.49
Core 4	-1.14	-0.10	-0.38	-0.16	0.12	0.14	0.48
Core 5	-1.13	-0.02	-0.67	-0.13	0.15	0.05	0.47
Mean (n=48)	-1.09	-0.05	-0.29	-0.16	0.13	0.06	0.47

reach grade 1 at all cores (from unpolluted to moderately polluted). This may be due to the agriculture and mining exploitation.

4. CONCLUSION

The aims of the present study were to assess the heavy metals levels and indices in the sediments of Moloundou swamp (Southeast-Cameroon). The distribution of these metals in the sediments is almost uniform over the whole swamp and the change in concentration was due to the release of these metals from different anthropogenic and natural sources.

In the present investigation, concentrations of Cu were higher than the safe recommended values, which suggested sediments of Moloundou swamp are polluted by Cu and might create an adverse effect on the swamp ecosystem.

Evaluation of metal toxicity based on heavy metals indices revealed that the sediments are seriously contaminated with Cu preferentially. The others metals (Fe, Co, Ni, Cr, Zn and Pb) are not negligible, but not more than the threshold toxicity values. Heavy metal levels and distribution was found higher at that cores sediments which were in vicinity of artisanal ores extraction and agricultural areas. Government authorities must ensure strict enforcement of industrial and artisanal effluents to save the swamp from further degradation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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