



Baseline Information on the Metallic Pollution of Sediments of the Lakes of the Ossa Complex, Dizangue, Cameroon

Nziéleu Tchapgnoou Joseph Guy^{1,2*}, Zébazé Togouet Serge Hubert²,
Foto Menbohan Samuel², Njiné Thomas² and Bernadette Pinel-Alloul³

¹Department of Hydraulics and Water Management, University of Maroua, Higher Institute of the Sahel, P.O.Box 46 Maroua, Cameroon.

²Laboratory of General Biology, University of Yaounde I, P.O.Box 812 Yaounde, Cameroun.

³Department of Biological Science, GRIL (Groupe de Recherche Interuniversitaire en Limnologie), University of Montreal, C.P. 6128, Succ., Centre-ville, Montreal, QC H3C 3J7, Canada.

Authors' contributions

This work was carried out in collaboration between all authors. Author NTJG designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors ZTSH and FMS managed the analyses of the study and then, authors NT and BPA supervised the research. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/24001

Editor(s):

(1) Verlicchi Paola, Department of Engineering, University of Ferrara, Via Saragat 1, Ferrara, Italy.

Reviewers:

(1) Peiyue Li, Chang'an University, China.

(2) Shruti Murthy, Bangalore University, India.

(3) Yovana Todorova, Sofia University "St. Kliment Ohridski", Sofia, Bulgaria.

Complete Peer review History: <http://sciencedomain.org/review-history/13565>

Original Research Article

Received 31st December 2015

Accepted 10th February 2016

Published 5th March 2016

ABSTRACT

The aim of this study was to evaluate the state of metallic pollution of the sediments of the three main Lakes (Mevia, Ossa and Mwembe) of the Ossa lake complex by the analysis of some heavy metals from May to July 2011. Copper, Nickel, Lead, Zinc, Cadmium and Iron were measured using atomic absorption spectrophotometry method. According to the standard values of GESAMP (group of Experts on the Scientific Aspects of Marine Pollution), lead concentrations were low in Lake Mwembe ($4.985 \pm 0.060 \text{ mg.kg}^{-1}$, dry weight), closer to standard values in Lake Mevia ($12.935 \pm 0.815 \text{ mg.kg}^{-1}$, dry weight) and very high in Lake Ossa ($39.935 \pm 2.480 \text{ mg.kg}^{-1}$, dry weight).

*Corresponding author: E-mail: jgtnzieleu@yahoo.fr;

As for Zinc and Cadmium, the contents were superior to standard values in the three lakes. The level of sediment contamination was evaluated using the Pollution Index (PI) and Enrichment Factor (EF). Only cadmium had a PI value greater than 3 and the highest EF (491.456 in Lake Mevia, 480.310 in Lake Ossa and 1761.099 in Lake Mwembe). All heavy metals presented EF values superior to 50 exception being observed for lead in Lake Mwembe (EF value less than 30). Generally, gross values of the different heavy metals measured, associated with EF values, indicated an anthropogenic pollution of these waters. This pollution could be linked to the use of chemical fertilizers and biocides around the neighborhood of Ossa lake complex by the African Forestry and Agriculture Company of Cameroon (SAFACam).

Keywords: Ossa lake complex; heavy metals; sediments; Dizangué; Cameroon.

1. INTRODUCTION

For the preservation of environmental equilibrium and its biodiversity, man has raised across the world so-called protected areas. The Ossa lake complex is one of such protected wildlife reserves in Cameroon and is classified as a "World Heritage site" by UNESCO. Like all wetlands, this complex is part of the most productive areas of the world, which serves as a source of goods, varied and multiple services and the cradle of biodiversity [1]. The classification of the Ossa lake complex as a protected zone takes its international significance in terms of ecology, botany, zoology, limnology and hydrology [1]. The vegetation surrounding these lakes is a young coastal forest of anthropogenic origin [2], which is made up of Pandanus, Myrtagyne, Raphia, Uapaca, and also industrial palm oil crops and rubber plantation [3,4]. This forest unquestionably contributes to the development of the Cameroon economy, but it could equally constitute, nowadays, a factor of aquatic ecosystem disturbance in the Ossa lake complex. Agricultural activities (establishment of nurseries, use of fertilizers and biocides, production of palm oil, resin processing etc.) contribute to the discharge of large quantities of pollutants into the environment. The development of intensive agriculture, with intensive use of synthetic pesticides and fertilizers to fight against weeds and pests, contributes to soil pollution. These products contain non-degradable elements that can remain in the soil or be driven by the runoff into groundwater, surface water and even be transferred to plants, animals and humans. Agriculture is thus an important factor of chemical pollution in the environment [5]. Among the chemical pollutants found in the environment are heavy metals. Their sources are multiple and sometimes unexpected.

Industrial wastewater, sewage wastewater, fossil fuel combustion and atmospheric deposits

related to industrial activities are important pathways of aquatic pollution by heavy metals deposition [6-11]. Rapid economic development, urbanization and industrialization together with agriculture, have added huge loads of metal contaminants into rivers [12,13]. Heavy metals are indeed contained in pesticides (fungicides, molluscicides, herbicides, insecticides and others) and fertilizers.

Heavy metals which constitute some elements of the food chain can be essential as trace in living organisms (copper, cobalt, iron, manganese, nickel) while others (such as cadmium, mercury and lead) can be harmful to the development of species in hydrosystems and even to humans [14,15]. Due to their toxicity, durability in soils, groundwater, lakes or streambed sediments [16-19], their non-degradability by biological and chemical processes and their bioaccumulation in the food chain [20,21], it is crucial to control the concentrations of heavy metals (density > 5 g.cm⁻³) in hydrosystems [22]. The main metals considered in hydrosystem studies are copper, nickel, chromium, lead, zinc, cadmium and arsenic [23,24]. Their presence determines the type of pollution. In addition, if the trace metals are transported in liquid form by suspended solids, or are present in the form of colloidal particles [25], heavy metals meanwhile settle more easily and are concentrated in sediments. Sediments are the main repository and source of heavy metals in aquatic systems and can play an important role in the transport and storage of potentially hazardous metals [26]. The bioavailability and environmental behavior of metals are related to their total concentrations and their chemical speciation [27]. According to [28] and [29], heavy metals concentrations in sediment can be used to reveal the history of the type and quantity, and the intensity of local and regional pollution. Its study has become one of the most important areas of environmental research [30]. Measuring the amount of heavy metals in sediments of a hydrosystem proves to

be an important tool for assessment, continuous monitoring and control of pollution in aquatic environments [31]. It gives a clearer indication of the contributions and accumulation of heavy metals in aquatic environments [25-32]. The toxicological quality of sediments reflects indeed the level of pollution of anthropogenic activities [33,34].

Heavy metals in soils and sediments have a direct impact on aquatic systems, water quality and bioassimilation and bioaccumulation of metals in aquatic organisms. Indeed, elevated concentrations of heavy metals, exceeding certain thresholds, are known to endanger ecosystems and introduce a potential risk to living organisms [35-38,12,39], since these are biomagnified in the food chain [40,41]. Under certain conditions such as dredging, chemical elements accumulated in the bottom sediments of water bodies can migrate back into the water [42,43]. Re-suspension may mean that all of the animals in the water, and not just the bottom dwelling organisms, will be directly exposed to toxic contaminants [44].

Despite the importance of the Ossa lake complex and its vulnerability to pollution, very few studies have been conducted on its waters to determine its trophic status, its evolution in time and the structure of living communities, as well as to understand its operation. The works so far known are those of [45,46]. Likewise, there is a paucity of information on pollution by heavy metals of lentic ecosystems in Cameroon. However, one can cite the works of [47,48] who evaluated the concentrations of heavy metals in the marine habitat in Cameroon, those of [49,50] on heavy metals in water and sediments of Yaounde Municipal Lake and its main tributary Mingoa and that of [51] on the level of pollution by heavy metals of two lakes in Adamaoua region. The results of these studies cannot be generalized to the whole country, given that ecosystems are different and pollution sources are varied, as well as the amounts of pollutants. It is in aim of enriching the documentation of pollution of Hydrosystems in Cameroon that this study was carried out to evaluate the concentration of heavy metals (copper, nickel, lead, zinc, cadmium and iron) in the sediments of lakes Mevia, Ossa and Mwembe. Results obtain could be vital to undertake measures for the protection of these habitats and their biodiversity.

2. MATERIALS AND METHODS

2.1 Study Area

The basin of Lake Ossa (245 km²) is located about 40 km East from the Atlantic coast of the Gulf of Guinea. It lies between latitude 3°45'42" and 3°53' North and between longitude 9°9' and 10°4'12" East [52]. The relief is dominated by flat tops of 80 meters altitude, but the slopes and lake depressions are quite strong [4].

The Ossa lake complex (Fig. 1) submerges the bottom of an ancient deep valley that was blocked by the alluvia of the Sanaga River, probably at the end of the last ice age. It is located at an altitude of 8 m above sea level and is part of a North-South rectangular orientation of about 12 km by 10 km [4]. The maximum water depth is 10 meters for an average of 3 meters [53]. The lakes are fed by rainfall (\approx 2.9 m/year - data of the SAFACam station and those of the city of Dizangue for the period of 1930-1990) and draining of two watersheds that extend respectively over 55 km² and 110 km².

The waters from the largest watershed transit Lake Mevia. Losses are carried out by evaporation (678 mm/year on average over a period of 14 years - [4]) and an outlet towards the Sanaga River. The water surface area of Ossa complex is estimated at 3779 hectares, for a total area of 4507 ha, including the islands. The complex is formed from two basins; the Ossa basin (3103 ha) and the Mevia basin (676 ha) communicating with a water arm [4]. A third arm of the complex Ossa, Lake Mwembe, which is less important, is not far from the agglomeration of Dizangue.

The Ossa lake complex harbours the West African manatee (*Trichechus senegalensis*), the dwarf crocodile (*Osteolaemus monticola*), pythons, soft-shelled turtles, fishes, rodents such as the brush-tailed porcupine (*Atherurus africana*), the aulacode (*Trynomys swinderianus*) and the Gambian rat (*Cricetomys gambianus*). It also includes about 30 species of aquatic and mangrove birds [4-54]. The vegetation around the complex is a swampy forest on the Southeast border [3]. The western border is occupied all along the riparian zone by industrial palm oil crops and rubber plantation of the (SAFACam) [4]. The forest which is made up of planted palm trees and rubber exist since 1897 and covered 95 hectares in 1914 [4], which extended to 6800 hectares in 1967, with only 3850 hectares being exploited as of the 1st of January 1989 [55-4].

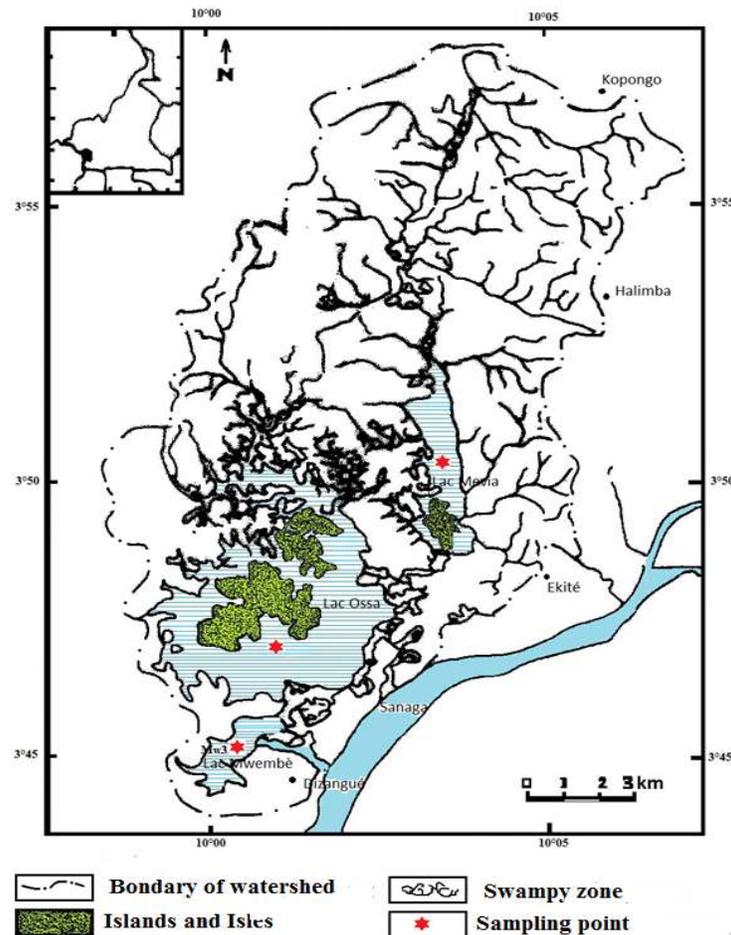


Fig. 1. Geographical location of the Ossa lake complex with the various sampling stations (National Institute of Cartography, modified by Nziéleu Tchagnouo)

2.2 Sampling

Samples for physicochemical analysis and heavy metal analysis were collected thrice during the months of May, June and July 2011, at the same station in lakes Mevia, Ossa and Mwembé. The choice of the sampling period of sediments (mud) of the lakes was justified as a result of earlier studies carried out by [46] who showed during that particular period, a decrease in dissolved oxygen (O_2) thus favoring the release of heavy metals into the aqueous phase and therefore, its reduction in the sediment. The sediments were collected using an Eckmann tipper. 2 mL of 65% nitric acid (a conservative substance) was added to the samples and then stored in polyethylene bottles of 250 cc and placed in a dark chamber maintained at 4°C for the analysis of the following heavy metals: lead, cadmium, iron, nickel, copper and zinc [56]. Samples were

analysed at "OCEAC" (Coordinating Organization for the Fight against Endemic Diseases in Central Africa) laboratory in Yaounde.

2.2.1 Sediments analysis for heavy metals

Heavy metals in sediments were determined by the atomic absorption spectrophotometric method using the technique of [57]. The degree of pollution of hydrosystems by heavy metals [58] and their origin in sediments [59,60] were determined using the calculation of the PI and the EF. These two expressions take into account the reference values of the levels in the earth's crust. Comparison of the mean concentration of heavy metals in the sediments and sediment quality guidelines of Environment Agency [61] were done to identify the contaminants of the different component in the ecosystem.

2.2.2 Physicochemical analysis of water samples

Temperature, pH and dissolved O₂ content of waters were measured in situ between the surface and a 50 cm depth, respectively using a graduated (1/100th of a degree) column mercury thermometer, a pH meter (SCHOTT, CG818) and an oxymeter (52YSI). These parameters were chosen because of their impact on the form, and toxicity of heavy metals.

2.2.3 Pollution Index (PI)

A solution in determining the degree of pollution by heavy metals in bottom sediments of water systems is the calculation of the PI [58].

$$PI = \frac{[M]_s}{[M]_{RM}}$$

Where:

- [M]_s = Concentration of metal M in the sample;
- [M]_{RM} = Concentration of metal M in the reference material.
- If PI < 3, the origin of metal is terrestrial, lithogenic or natural
- 3 < PI < 9, the origin is suspicious
- If PI > 9, the pollution is certain, the zone is risky.

2.2.4 Enrichment Factor (EF)

In such studies, it is recommended to calculate the EF, which provides the number of times an element is enriched compared to its abundance in the reference material [62-51], and its determine whether an element has a natural or anthropogenic origin [59,60].

$$EF = \frac{[M]_s / [Fe]_s}{[M]_{RM} / [Fe]_{RM}}$$

The metal of reference used worldwide is iron, which is known as a concentration reference in non-polluted zones [62-64].

Where:

- [M]_s = Concentration of metal M in the sample;
- [M]_{RM} = Concentration of metal M in the reference material;
- [Fe]_s = Iron concentration in the sample;
- [Fe]_{RM} = Iron concentration in the reference material.

EF values can be interpreted in terms of the level of contamination [65] or the origin of the pollutants [66]:

- EF < 1: no enrichment;
- 1 < EF < 3: Low enrichment;
- 3 < EF < 5: moderate enrichment;
- 5 < EF < 10: moderately to high enrichment;
- 10 < EF < 25: high enrichment;
- 25 < EF < 50: Very high enrichment;
- FE > 50: extremely high enrichment.
- Or EF < 2: lithogenic origin (natural); FE > 2: anthropogenic origin

2.2.5 Sediment Quality Guidelines (SQGs)

The works of [67-69] estimate that sediment quality guidelines (SQGs) are important for the protection of benthic organisms in aquatic ecosystems and can be used to identify contaminants of concern in these ecosystems and to rank areas of concern on a regional or national basis. For this study, the set of sediment for freshwater sediment were used. The threshold effect level (TEL) and the probable effects level (PEL) values were considered (Table 1) and compared to the metal concentrations from lakes. The two assessment levels were used to define three ranges of concentrations: rarely (below the TEL), occasionally (above the TEL) and frequently (equal to and above the PEL) associated with adverse biological effects as clearly proposed by [70].

Table 1. Proposed sediment quality guidelines (SQGs): TEL (threshold effect level); PEL (probable effects level)

Metal	TEL	PEL
Cu	35.7	197
Ni	18.0	35.9
Pb	35.0	91.3
Zn	123	315
Cd	0.6	3.53

3. RESULTS AND DISCUSSION

3.1 Physicochemical Quality of Water

Values of temperature, pH and O₂ of the three lakes are presented (Table 2).

The temperature of the water varied between 28.90°C and 29.30°C in Lake Mevia, between 29.30°C and 30.20°C in Lake Ossa and between 29.90°C and 30.20°C in Lake Mwembe. As in most tropical lakes, water temperature was

relatively stable. The small amplitude in variation is a characteristic of most tropical lakes [71]. In general, water temperature fell between May and July, the months corresponding to the rainy season. The cooling of water during this period was definitely related to the flood season as described by [72,73].

Mean pH values in the three lakes were respectively 6.55; 6.48 and 6.56 for Mevia, Ossa and Mwembe. Overall, the values of this parameter increased in the waters but these waters remained slightly acidic. This slight acidity of water could be attributed to the total hydrolysis of primary minerals resulting from sedimentary ferrallitic yellow rocks found in Lake Ossa. It could equally result from the elimination of the major part of the exchangeable bases, especially calcium and magnesium [74,75]. Water acidification can be accelerated by the contributions of mineral salts in some fertilizers [76]. [77] had already identified a pH of 7.00 in Lake Ossa, which shows that the waters became more acidic since 1987, and that agricultural activity around the complex contributes to water acidification. When pH is low, heavy metals dissolve easily and are found in the aqueous phase of the hydrosystem while neutral or basic pH lead to their precipitation and concentration in the sediments [78]. The pH values of the waters of the three lakes therefore portend a reduction in the content of heavy metals in the sediment.

The O₂ saturation values varied between 59.92% and 75.48% in Lake Mevia, between 57.32% and 72.16% in Lake Ossa and between 51.23% and 72.43% in Lake Mwembe. The average of this parameter in the three media was respectively 69.19%, 62.60% and 60.86%. Except for Lake Mevia where an increase in O₂ content was observed, the quantity of this gas decreased in lakes Ossa and Mwembe. Generally, oxygen solubility decreased with increase temperature although in the last two lakes the rate of oxygen in water decreased with temperature. This could

be attributed to the greater concentration of fermentable organic matter during the rainy season due to the mixing of the Sanaga River water with runoffs of the watershed, concentration which causes rapid consumption of O₂ by bacteria, consequently leading to its decrease.

3.2 Heavy Metal Contents in Sediments of Lakes Mevia, Ossa and Mwembe

The concentrations of heavy metals in sediments are reported (Table 3).

In Lake Mevia, the mean concentrations (mg.kg⁻¹, dry weight) of various heavy metals were 14.250±1.230 for Cu, 42.570±4.450 for Ni, 12.935±0.815 for Pb, 1.450 to ±100.807 for Zn, 0.320±0.002 for Cd and 201.133±9,190 for Fe.

In Lake Ossa, these values (mg.kg⁻¹, dry weight) were 18.250±0.950 for Cu, 50.680±0.920 for Ni, 39.935±2.480 for Pb, 121.908±6.230 for Zn, 0.420±0.005 for Cd and 270.113±2.150 for Fe.

The mean concentration of heavy metals (mg.kg⁻¹, dry weight) in Lake Mwembe were 16,750±1,040 for Cu, 51.740±0.230 for Ni, 4.985±0.060 for Pb, 149.414±0.620 for Zn, 1.824±0.350 for Cd and 319.933±4.350 for Fe.

Iron is by far the metal whose concentration was highest in the sediments. Yet, it is the only metal whose values are much lower than in non-polluted sediments (41000 mg.kg⁻¹, dry weight) and the continental crust (30890 mg.kg⁻¹, dry weight). Copper concentrations in the sediments were inferior to standard concentrations in non-polluted sediments (33 mg.kg⁻¹, dry weight), but all higher than the rates in the continental crust (14 mg.kg⁻¹, dry weight). Generally, the mean concentrations of Cu and Pb were higher in the Lake Ossa while those of Ni, Zn, Cd and Fe were higher in Lake Mwembe.

Table 2. Values of physicochemical parameters taken from lake water samples

Lake	Parameters	May-11	June-11	July-11	Mean
Mevia	Temperature	29.30	29.00	28.90	29.07
	pH	6.12	6.82	6.71	6.55
	Dissolve oxygen	59.92	72.16	75.48	69.19
Ossa	Temperature	30.20	29.50	29.30	29.67
	pH	6.23	6.67	6.53	6.48
	Dissolve oxygen	72.16	58.31	57.32	62.60
Mwembe	Temperature	30.20	29.90	29.90	30.00
	pH	6.20	6.72	6.75	6.56
	Dissolve oxygen	72.43	58.93	51.23	60.86

Cadmium concentrations in the three lakes are both higher than the standard (0.11 mg.kg^{-1} , dry weight) of [79] and that of the continental crust (0.1 mg.kg^{-1} , dry weight). The harmful properties of this metal are among others its high bioaccumulation in food chains and its high toxicity to living organisms [80,81]. Its impact on human health has not yet been established [82]. It is therefore considered a toxic trace element [81]. Its presence in large quantities in lake sediments could reflect risks to human health because of its potential accumulation in the tissues of fishes and other organisms [83-85].

With regards to zinc, it is a soluble contaminant in water [86,87]; the rainy season and low pH values could have favoured the release of a certain amount of this metal in the aqueous phase. Zinc concentrations however, remained very high in the sediments and exceeded the threshold values in the continental crust (79 mg.kg^{-1} , dry weight). This suggests that it was highly concentrated in these waters. The values of zinc in the Ossa complex were compared to those obtained in some lakes in Cameroon. They remained below the values recorded in the Yaounde Municipal Lake [51], but very high compared to those of lakes Bini and Dang [51].

Lead presented higher mean values with respect to the reference values in Lake Ossa while in lakes Mevia and Mwembe, the values were lower than those of the continental crust (17 mg.kg^{-1} , dry weight). In Lake Ossa, its value was twice the concentration in the continental crust, and even

in sediments considered unpolluted (19 mg.kg^{-1} , dry weight). The values recorded for this pollutant whose accumulation in sediments was relatively high due to its low solubility in water [88] testify their high concentrations in this environment. The low concentration of lead in Lake Mwembe and its high concentrations in lakes Mevia and Ossa could be justified by the fact that the most important part of the rubber and palm oil plantation is found on the largest watershed which harbours lakes Mevia and Ossa, thus, by leaching, water passing through Lake Mevia to reach Lake Ossa bring more lead contained in fertilizers. This water input could be accompanied by particles, including organic material to which heavy metals bind [89,90]. The water which enters Lake Mevia, then Lake Ossa could bring and maintain in these hydrosystems enough lead clogged to particles. When the rain stops and at the beginning of the dry season, suspended particles might be deposited, causing sedimentation of the metal. Compared to other lakes in the country, lead concentrations in the Ossa lake complex were lower than those in lakes Bini and Dang of the Adamaoua region, two lakes polluted by heavy metals (especially cadmium and lead) [51], and in the Yaounde Municipal Lake in the Centre region, a eutrophic to hypertrophic lake [91].

Taking into account Cu, Pb, Zn, Cd and Fe, the PI and the EF were calculated. The results are shown (Table 4). The comparison of the results was made with respect to the concentrations of these metals in the earth's crust, with reference to iron.

Table 3. Mean values (standard error) of heavy metals concentrations in lake sediments samples

	Heavy metal (mg.kg^{-1} , dry weight)					
	Copper (Cu)	Nickel (Ni)	Lead (Pb)	Zinc (Zn)	Cadmium (Cd)	Iron (Fe)
Mevia	14.250±1.230	42.570±4.450	12.935±0.815	100.807±1.450	0.320±0.002	201.133±9.190
Ossa	18.250±0.950	50.680±0.920	39.935±2.480	121.908±6.230	0.420±0.005	270.113±2.150
Mwembe	16.750±1.040	51.740±0.230	4.985±0.060	149.414±0.620	1.824±0.350	319.933±4.350

Table 4. Values of PI and EF of different heavy metals

Lakes		Cu	Pb	Zn	Cd	Fe
Mevia	Pollution index	1.017	0.760	1.276	3.200	0.006
	Enrichment factor	156.322	116.856	195.974	491.456	/
Ossa	Pollution index	1.303	2.349	1.543	4.200	0.008
	Enrichment factor	149.076	268.644	176.473	480.310	/
Mwembe	Pollution index	1.196	0.293	1.890	18.240	0.010
	Enrichment factor	115.517	28.312	182.609	1761.099	/

The PI varied between 0.006 (Fe) and 3.200 (Cd) in Lake Mevia. The index ranged from 0.008 (Fe) and 4.200 (Cd) in Lake Ossa and from 0.010 (Fe) and 18.240 (Cd) in Lake Mwembe. With the exception of Cd whose values were higher than 3, all the other metals had PI values lower than 3.

For the EF, values fluctuated between 116.856 (Pb) and 491.456 (Cd) in Lake Mevia, between 149.076 (Cu) and 480.310 (Cd) in the Lake Ossa and between 28.312 (Pb) and 1761.099 (Cd) in Lake Mwembe. Cd also presented highest values. Apart from Pb whose EF value in Lake Mwembe was less than 30, all the other heavy metals had values superior to 50.

The gross values of various heavy metals measured showed an anthropogenic pollution of water. This pollution could be linked to the intense agricultural activity around the Ossa lake complex and the use of chemical fertilizers and fungicides by SAFACam, with consequent of leaching these phytosanitary products to the hydrosystems [92,93]. It can also be due to the presence of poorly managed solid waste that generate many uncontrolled landfills [93].

The results of PI did not seem to confirm this anthropogenic pollution of the waters of the Ossa complex by heavy metals. Only Cadmium had a PI higher than 3. A PI value ranging between 3 and 9 indicate a suspicious situation of pollution [58]: Cd could be the only metal whose enrichment in the lakes could be of exogenous origin. Nevertheless, [62,59,60] recommend the calculation of the EF to complete the PI and determine whether an item is of natural or anthropogenic origin. From this point of view, the EF values were greater than 50. According to [66], an EF value superior to 50 expresses an extreme enrichment of the environment by heavy metals. Considering these values and taking into account that gross values of Cu, Zn, Cd and Pb were higher than the concentrations in the earth's crust, one is able to say that the waters of these lakes were enriched with heavy metals. Indeed, biocides (pesticides, herbicides, preservatives) contain As, Hg, Pb, Cu, Sn, Zn, Mn and fertilisers contain Cd, Hg, Pb, Al, As, Cr, Cu, Mn, Ni and Zn [94]. These various products are used in intensive farming.

Moreover, in this study, Cd had the highest and Pb had the lowest EF and PI values in lakes Mevia and Mwembe while in Lake Ossa, the lowest EF or PI value is that of Cu. For [95],

generally, refining, manufacture and application of phosphate fertilizers are the main anthropogenic sources of Cd in the environment. [96] and then [97] showed that the distribution of Cd is closely related to the intensive use of phosphate fertilizers, as the later contain significant amount of metals, particularly Cd, as impurities. This has been found by [98] in a water reservoir between Iran and Afghanistan. The high enrichment of Cd in lakes can then be explained by the agricultural activity of SAFACam. According to these results, Lake Mevia has the highest values of EF for Cd, Zn and Cu compared to the two other lakes, meaning that it is the most enriched lake especially due to Cd, Zn and Cu while Lake Mwembe is the less enriched.

Comparison of the mean concentration of heavy metals in the sediments and sediment quality guidelines indicate that all sites studied were below the PEL guideline for Pb, Cd, Cu and Zn, exception being for Ni whose value were greater than 35.9 (Table 5). This shows that Ni could frequently have adverse biological effects on benthic organisms. The higher value of Ni has already been seen in China [69]. The results also show that for Pb (in Lake Ossa), Cd, Zn (in Lake Mwembe) and Ni (in the three lakes), the concentrations are above the TEL guideline but below the PEL guideline. This suggests that those metals in indicated lakes can be occasionally responsible for adverse effects on organisms. For metals with values below the TEL guideline, they rarely constitute a risk for living organisms.

Table 5. Classification of sediment samples based on the proposed sediment quality guidelines (SQGs)

Metal	Percentage of samples exceeding SQGs (%)		
	< TEL	TEL-PEL	> PEL
Cu	100	0.00	0.00
Ni	0.00	0.00	100
Pb	66.66	33.33	0.00
Zn	66.66	33.33	0.00
Cd	66.66	33.33	0.00

4. CONCLUSION

Water temperature values between May and July remained within the range of characteristic values of tropical lakes. The pH was slightly acidic, favouring the release of heavy metals in the water column. As for dissolved oxygen, its

variation in time justifies a high concentration of fermentable organic matter in water: waters of the Ossa lake complex could be undergoing a process of eutrophication. Analysis of heavy metals in the sediments revealed that mean concentrations of Cu and Pb were higher in Lake Ossa while those of Ni, Zn, Cd and Fe were higher in Lake Mwembe. Moreover, with respect to the standards of [79], Pb, Zn and Cd in Lake Ossa presented high values. If the PI presents Cd as the single metal whose enrichment in lakes have an exogenous origin, the EF reveals an extreme enrichment of the environment by heavy metals. The waters of the Ossa lake complex, given the results of this research, are enriched with heavy metals. The main cause of this pollution could be the practice of intensive agriculture around the lakes by SAFACam which uses pesticides whose composition is generally rich in heavy metals. The high values of heavy metals measured in lake sediments portend a risk of bioaccumulation in lake complex fish products, which should be studied.

ACKNOWLEDGEMENTS

We are grateful to Nina Sulem and Lucia Nkengazong, for their contribution in the translation of the original text into English.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. UICN/PAPACO. Evaluation de l'efficacité de gestion d'un échantillon de sites RAMSAR en Afrique de l'Ouest; 2009. French.
2. Letouzey R. Etude phytogéographique du Cameroun. Lechevalier: Encyclopédie Biologique, Paris; 1968. French.
3. Cénadefor. Cartes Forestières NA-32-XXII (Mouanko) et NA-32-XXIII (Edéa) au 1/200 000, Cameroun; 1987. French.
4. Wirrmann D. Le lac Ossa: une monographie préliminaire. Revue de Géographie du Cameroun. 1992;11(1):26-38. French.
5. Godin PM, Feinberg MH, Ducauze CJ. Modeling of soil contamination by airborne lead and cadmium around several emission sources. Environ Pollut. 1985;10: 97-114.
6. Linnik PM, Zubenko IB. Role of bottom sediments in the secondary pollution of aquatic environments by heavy metal compounds, lakes and reservoirs. Res Manage. 2000;5(1):11-21.
7. Campbell LM. Mercury in Lake Victoria (East Africa): Another emerging issue for a Beleaguered Lake? Ph.D. dissertation, Waterloo, Ontario, Canada; 2001.
8. Lwanga MS, Kansiime F, Denny P, Scullion J. Heavy metals in Lake George, Uganda with relation to metal concentrations in tissues of common fish specie. Hydrobiologia. 2003;499(1-3):83-93.
9. Schulin R, Curchod F, Mondeshka M, Daskalova A, Keller A. Heavy metal contamination along a soil transect in the vicinity of the iron smelter of Kremikovtzi (Bulgaria). Geoderma. 2007;140:52-61.
10. El Diwani G, El Rafie SH. Modification of thermal and oxidative properties of biodiesel produced from vegetable oils. Int J Environ Sci Tech. 2008;5(3):391-400.
11. Idrees FA. Assessment of trace metal distribution and contamination in surface soils of Amman. Jordan J Chem. 2009; 4(1):77-87.
12. Gao X, Chen CTA. Heavy metal pollution status in surface sediments of the coastal Bohai Bay. Water Resources. 2012;46: 1901-1911.
13. Li J, Li FD, Liu Q, Zhang Y. Trace metal in surface water and groundwater and its transfer in a yellow river alluvial fan: Evidence from isotopes and hydrochemistry. Sci Total Environ. 2014;472: 979-988.
14. Biney C, Amuzu AT, Calamari D, Kaba N, Mbome LI, Naeve H, Ochumba O, Osibanjo O, Radegonde V et Saad MAH. Etude des métaux lourds. Revue de la pollution dans l'environnement aquatique africain, FAO. 1994;25:37-67. French.
15. Wang QR, Cui YS, Liu XM, Dong YT, Christie P. Soil contamination and plant uptake of heavy metals at polluted sites in China. J Environ Sci Health Part A Toxic/Hazard Subst Environ Eng. 2003;38:823-838.
16. Kabata-Pendias A, Pendias H. Trace elements in soils and plants. CRC Press. Boca Raton; 2001.
17. Bruyère S, Dassargues A, Hallet V. Migration of contaminants through the unsaturated zone overlying the Hesbaye

- chalky aquifer in Belgium: A field investigation. *J Contam Hydrol.* 2004;72: 135-164.
18. Maldonado VM, Rubio Aria HO, Quintana R, Saucedo RA, Gutierrez M, Ortega JA, Nevarez GV. Heavy metal content in soils under different wastewater irrigation patterns in Chihuahua, Mexico. *Int J Environ Res Public Health.* 2008;5:441-449.
 19. Klimek B. Effect of long-term zinc pollution on soil microbial community resistance to repeated contamination. *Bull Environ Contam Toxicol.* 2012;88:617–622.
 20. Harte J, Holdren C, Schneider R, Shirley C. A guide to commonly encountered toxics. In: Harte J, Holdren C, Schneider R, Shirley C, editors. *Toxics A to Z - A guide to everyday pollution hazards.* Berkeley. University of California Press; 1991.
 21. Jorgensen SE. Ecotoxicological research-historical development and perspectives. In: Schuurmann G, Markert B, editors. *Ecotoxicology-Ecological Fundamentals, Chemical Exposure, and Biological Effects.* Wiley-Spectrum. New York, Heidelberg; 1998.
 22. Huynh TMD. Impacts des métaux lourds sur l'interaction plante/ ver de Terre/microflore tellurique. Thèse de Doctorat, Université Paris Est, France; 2009. French.
 23. Babut M, Bedell JP, Bray M, Clement B, Devaux A, Delolme C, Durrieu C, Garric J, Montuelle B, Perrodin Y, et Vولات B. Évaluation écotoxicologique de sédiments contaminés ou de matériaux de dragage. Synthèse de rapport d'étude. CETMEF, VNF; 2001. French.
 24. Boulkrah H. Etude comparative de l'adsorption des ions plomb sur différents adsorbants. Mémoire de Magister, Université du 20 août 1955 Skikda, Algérie; 2008. French.
 25. OMS. Les micropolluants dans les sédiments fluviaux. Rapport et études EURO 61, Bureau régional de l'Europe, Copenhague; 1980. French.
 26. Yu RL. Ecological risk of heavy metals in intertidal sediments of Quanzhou Bay, China. *Environ Monit Hu GR, Wang LJ. Speciation Assess.* 2010;163:241–252.
 27. Yang SL, Zhou DQ, Yu HY, Wei R, Pan B. Distribution and speciation of metals (Cu, Zn, Cd, and Pb) in agricultural and non-agricultural soils near a stream upriver from the Pearl River, China. *Environ Pollut.* 2013;177:64–70.
 28. Nyangababo JT, Henry E, Omutange E. Lead, cadmium, copper, manganese and zinc in wetland waters of Victoria Lake Basin, East Africa. *Bull Environ Contam Toxicol.* 2005;74(5):1003-1010.
 29. De villiers J, Squilbin M et Yourassowsky C. Qualité physicochimique et chimique des eaux de surface : Cadre général. Institut Bruxelloise pour la gestion de l'environnement/Observatoire des données de l'environnement, Bruxelles; 2005. French.
 30. Chakraborty P, Babu PVR, Sarma VV. A study of lead and cadmium speciation in some estuarine and coastal sediments. *Chem Geol.* 2012;294:217–225.
 31. Bendada K, Boulahradèche MW. Optimisation des conditions de dosage par spectroscopie d'absorption atomique (SAAF et SAAET): Application à la détermination de la pollution et de la bioaccumulation des métaux lourds. Mémoire de Master, Université des Sciences et de la Technologie Houari Boumediene, Algérie; 2011. French.
 32. Al-Shukry R. Détermination de la pollution des sédiments d'un cours d'eau par des métaux lourds (Cu, Zn, Cd, Pb, Ni). Etude de leur accumulation et de leur relargage: rôle du pH, de la température et de la composition du sédiment. Thèse de Doctorat, Université de Limoges, France; 1993. French.
 33. Mah S. Influence of pollution on Lake Mariout, Egypt III. Heavy metals. *Rapp. P-V. Reun. CIESM.* 1985;29(4):145-147.
 34. Gnandi K, Tométy-Mensah F, Amey Apoh Y, Etorh P. Distribution, biodisponibilité et bioaccumulation des métaux lourds dans le système lagunaire de Lomé. *J Rech Sci Univ, Lomé (Togo), Série A.* 2007;9(1):67-81. French.
 35. Kumar A, Dey PK, Singla PN, Ambasht RS, Upadhyay SK. Blood lead levels in children with neurological disorders. *J Tropic Pediatr.* 1998;44:320-322.
 36. Gasana J, Hlaing WM, Siegel KA, Chamorro A, Niyonsenga T. Blood lead levels in children and environmental lead contamination in Miami Inner City, Florida. *Int J Environ Res Public Health.* 2006;3:228-234.

37. Ip CCM, Li XD, Zhang G, Wai OWH, Li YS. Trace metal distribution in sediments of the Pearl River estuary and the surrounding coastal area, South China. *Environ Pollut.* 2007;147:311–323.
38. Ferreira AP. Distribution and contamination of metals in the soil of Guandu Watershed. *Rev Ambient Água.* 2015;10(4):758-769.
39. Li P, Qian H, Howard KWF. Heavy metal contamination of yellow river alluvial sediments, northwest China. *Environ Earth Sci.* 2015;73:3403-3415.
40. Ferreira AP, Horta MAP. Trace element residues in water, sediments, and organs of Savacu (*Nycticorax nycticorax*) from Sepetiba Bay, Rio de Janeiro, Brazil. *Revista Ambiente & Água.* 2010;5(1):17-28.
41. Miranda Filho A, Da Mota A, Cruz C, Matias C, Ferreira AP. Cromo hexavalente em peixes oriundos da Baía de Sepetiba no Rio de Janeiro, Brasil: uma avaliação de risco à saúde humana. *Revista Ambiente & Água.* 2011;6(3):200-209. Espanol.
42. Frignani M, Bellucci LG. Heavy metals in marine coastal sediments: Assessing sources, fluxes, history and trends. *Annali di Chimica.* 2004;94:1-8.
43. Li J, Li F, Liu Q, Zhang Y. Trace metal in surface water and groundwater and its transfer in a Yellow River alluvial fan: Evidence from isotopes and hydrochemistry. *Science of the Total Environment.* 2013;472(C):979-988.
44. Temmerman S, Meire P, Bouma TJ, Herman PM, Ysebaert T, De Vriend HJ. Ecosystem-based coastal defence in the face of global change. *Nature.* 2013; 504(7478):79-83.
45. Nguetsop VF. Évolution des environnements de l'Ouest-ameroun depuis 6 000 ans, d'après l'étude des diatomées actuelles et fossiles dans le lac Ossa. Implications paléoclimatiques. Thèse de Doctorat, MNHN, Paris, France; 1997. French.
46. Nziéleu Tchagnouo JG, Njiné T, Zébazé Togouet SH, Djutso Segnou SC, Mahamat Tahir T Safia, Tchakonté S et Pinel-Alloul B. Diversité spécifique et abondance des communautés de copépodes, cladocères et rotifères des lacs du complexe ossa (dizangué, cameroun). *Physio-Géo-Géographie Physique et Environnement.* 2012;4:71-93. French.
47. Mbome IL, Agbor ET, Martin GE, Njock C, Ikome F, Mbi C. Preliminary survey on mercury and cadmium levels in some marine fishery products. Cameroon: Institut de recherches médicales et d'études des plantes médicinales, Yaoundé, Station de recherches halieutiques de Limbé. IOC Workshop Report; 1985.
48. Mbome IL. Heavy metals in marine organisms from Limbé and Douala. Report presented to Second Workshop of participants in the Joint FAO/IOC/WHO/IAEA/UNEP Project on pollution in the marine environment of the west and central African region (WACAF/2-First Phase), Accra, Ghana, 13–17 June 1988. Paris, IOC of Unesco, Mesres/Orstom; 1988.
49. Demanou J, Brummett RE. Heavy metal and faecal bacterial contamination of urban lakes in Yaoundé, Cameroon. *African Journal of Aquatic Science.* 2003;28(1):49-56.
50. Ekengele NL, Jung MC, Ombolo A, Ngatcha N, Ekodeck G, Mbome L. Metals pollution in freshly deposited sediments from river Mingoa, main tributary to the municipal lake of Yaounde, Cameroon. *Geosciences Journal.* 2008;12(4):337-347.
51. Oumar B, Ekengele Nga L et Balla Ondo AD. Evaluation du niveau de pollution par les métaux lourds des lacs Bini et Dang, Région de l'Adamaoua, Cameroun. *Afrique Science.* 2014;10(2):184-198. French.
52. Wirrmann D, Elouga M. Discovery of an iron age site in Lake Ossa, Cameroonian littoral Province. *Comptes rendus de l'Académie des sciences, serie 2a: Sciences de la terre et des planètes.* 1998;326(5):383-389.
53. Pourchet M, Pinglot JF, Giresse P, Ngos S, Maley J, Naah E et Pugno JC. Programme sur les lacs à risqué d'éruption gazeuse au Cameroun et en France. Évolution des risques et des tentatives de prévision des éruptions gazeuses (résultats scientifiques). Rapport d'activité du Ministère de l'Environnement, France; 1991. French.
54. MINFOF. Stratégie 2020 du sous-secteur forêts et faune, Ministère des Forêts et de la Faune, Yaoundé; 2012. French.
55. Anonymous. Note de présentation de la SAFA-Cameroun, Rapport multigraphié, Dizangué, Cameroun; 1990. French.

56. ISO. Qualité de l'eau: échantillonnage. Partie 3: l'analyse de l'eau. 9ème édition. Dunod. Paris. 2003;1526. ISBN: 978-2-10-054179-9. French.
57. Devez A. Caractérisation des risques induits par les activités agricoles sur les écosystèmes aquatiques. Thèse de Doctorat, Montpellier, ENGREF, France; 2004. French.
58. Bendjama A. Niveaux de contamination par les Métaux lourds du complexe lacustre "Tonga, Obéira, El-Mellah" du Parc National d'El-Kala. Mémoire de Magister en Sciences de la Mer, Université d'Annaba, Algérie; 2007. French.
59. Soubrand-Colin N. Localisation, distribution et mobilité des ETM dans des sols développés sur roches basaltiques en climat tempéré. Thèse de Doctorat, université de Limoges, France; 2004. French.
60. Boussem S. Evolution de haldes plombo-zincifères dans le nord de la Tunisie: l'exemple d'un context carbonate. Thèse de Doctorat, Universités de Tunis El Manar/Limoges, Tunisie/France; 2010. French.
61. Hudson-Edwards KA, Macklin MG, Brewer PA and Dennis IA. Assessment of metal mining-contaminated river sediments in England and Wales. Science Report: SC030136/SR4. Environment Agency; 2008.
62. Turekian KK, Wedepohl KH. Distribution of the elements in some major units of the earth's crust. American Geological Society Bulletin. 1961;72:175-182.
63. Liu W, Zhao J, Ouyang Z, Soderlund L, Liu G. Impacts of sewage irrigation on heavy metal distribution and contamination in Beijing, China. Environment International. 2005;31:805-812.
64. Fang TH, Hwang JS, Hsiao SH, Chen HY. Trace metals in seawater and copepods in the ocean outfall area off the northern Taiwan coast. Marine Environment Resources. 2006;61:224-243.
65. Acevedo-Figueroa D, Jiménez BD, Rodríguez-Sierra CJ. Trace metals in sediments of two estuarine lagoons from Puerto Rico. Environ Poll. 2006;141: 336-342.
66. Hernandez L, Probst A, Probst JL, Ulrich E. Heavy metal distribution in some French forest soils: Evidence for atmospheric contamination. The Science of the Total Environment. 2003;312:195-219.
67. Cevik F, Goksu MZL, Derici OB, Findik O. An assessment of metal pollution in surface sediments of seyhan dam by using enrichment factor, geoaccumulation index and statistical analyses. Environ Monit Assess. 2009;152:309-317.
68. Xu L, Wang TY, Ni K, Liu SJ, Wang P, Xie SW, Meng J, Zheng XQ, Lu YL. Ecological risk assessment of arsenic and metals in surface sediments from estuarine and coastal areas of the southern Bohai Sea, China. Hum Ecol Risk Assess. 2014;20: 388-401.
69. Li Xu, Jing Li. Speciation and degrees of contamination of metals in sediments from upstream and downstream reaches along the catchment of the Southern Bohai Sea, China. Int J Environ Res Public Health. 2015;12:7959-7973.
70. Smith SL, MacDonald DD, Keenleyside KA, Ingersoll CG, Jay FL. A preliminary evaluation of sediment quality assessment values for freshwater ecosystems. J Great Lakes Res. 1996;22:624-638.
71. Lewis WJ. Tropical limnology. Ann Rev Ecol Syst. 1987;18:159-184.
72. Suchel B. La répartition des pluies et des régions pluviométriques au Cameroun. Travaux et documents de géographie tropicale. C-E-G-CNRS. 1987;5:1-288. French.
73. Suchel B. Les climats du Cameroun. Thèse de Doctorat d'État, Université de Bourgogne, France; 1988. French.
74. Vallerie M. Carte pédologique du Cameroun Occidental au 1/1 000 000. Notice explicative No 45:ORSTOM, Yaoundé; 1968. French.
75. Segalen P. Les sols et la géomorphologie au Cameroun. Cahiers ORSTOM sér Pédologie. 1967;2:137-188.
76. Brunet F, Potot C, Probst A, Probst JL. Stable carbon isotope evidence for nitrogenous fertilizer impact on carbonate weathering in a small agricultural watershed. Rapid Communications in Mass Spectrometry. 2011;25(19):2682-2690.
77. Kling GW. Comparative limnology of lakes in Cameroun, West Africa Ph.D thesis, Duke University, England; 1987.
78. Anonymous. Qualité physicochimique et chimique des eaux de surface: cadre

- général. Données de IBGE/ODE, Bruxelles, Belgique; 2005. French.
79. GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint group of Experts on the Scientific Aspects of Marine Pollution). Review of the health of the oceans. GESAMP Reports and Studies No 15; 1982.
 80. Picot A. Le trio: Mercure, plomb, cadmium. Les métaux lourds: de grands toxiques. Biocontact. 2002;120:61-71. French.
 81. Kayalto B, Mbofung CMF, Tchatchueng JB et Ahmed A. Contribution à l'évaluation de la contamination par les métaux lourds de trois espèces de poissons, des sédiments et des eaux du Lac Tchad. Int J Biol Chem Sci. 2014;8(2):468-480. French.
 82. Altindag A and Sibel Y. Assessment of heavy metal concentrations in the food web of lake Beysehir, Turkey. Elsevier Chemosphere. 2005;60:552-556.
 83. Clarkson TW, Magos L. The toxicology of mercury and its chemical compounds. Crit Rev Toxicol. 2006;36:609-662.
 84. Islam E, Yang XE, He ZL, Mahmood Q. Assessing potential dietary toxicity of heavy metals in selected vegetables and food crops. J Zhejiang Univ Sci B. 2007;8:1-13.
 85. Mergler D, Anderson HA, Chan LH, Mahaffey KR, Murray M, Sakamoto M and Stem AH. Methylmercury exposure and health effects in humans: A worldwide concern. Ambio. 2007;36(1):3-11.
 86. Camobreco VJ, Richards BK, Steenhuis TS, Pererty JH, Mc Bride MB. Movement of heavy metals through undisturbed and homogenized soil columns. Soil Science. 1996;161:740-750.
 87. Adam S, Etorh PA, Totin H, Koumolou L, Amoussou E, Aklikokou K et Boko M. Pesticides et métaux lourds dans l'eau de boisson, les sols et les sédiments de la ceinture cotonnière de Gogounou, Kandi et Banikoara (Bénin). Int J Biol Chem Sci. 2010;4(4):1170-1179. French.
 88. Ablain F. Rôle des activités lombriciennes sur la redistribution des éléments traces métalliques issus de boue de station d'épuration dans un sol agricole. Thèse de Doctorat, Université de Rennes 1 UMR ECOBIO, Paris, France; 2002. French.
 89. Lions J. Etude hydrogéochimique de la mobilité de polluants inorganiques dans des sédiments de curage mis en dépôt. Expérimentations, étude in situ et modélisations. Thèse de Doctorat, Ecole Nationale Supérieure des Mines de Paris, France; 2004. French.
 90. Deschamps T, Bansaazoua M, Bussière B, Belem T et Mbonimpa M. Mécanismes de rétention des métaux lourds en phase solide: Cas de la stabilisation des sols contaminés et des déchets industriels. VertigO-La revue électronique en sciences de l'environnement. 2006;7(2):18. French.
 91. Zébazé Togouet SH. Eutrophisation et dynamique de l'abondance de la composition spécifique et de la structure de la communauté zooplanctonique d'un petit lac peu profond situé en zone tropicale urbanisée, le Lac Municipal de Yaoundé (Afrique Centrale). Thèse de Doctorat Ph.D, Université de Yaoundé I, Cameroun; 2008. French.
 92. Dufour P, Lemoalle J, Albaret JJ. Le système Ebrié dans les typologies lagunaires. In: Durand J-R, Dufour P, Guiral D & Zabi S, editors. Environnement et ressources aquatiques de Côte-d'Ivoire. Tome II-Les milieux lagunaires. ORSTOM; 1994. French.
 93. Traoré A, Soro G, Ahoussi KE, Bamba BS, Soro N et Biemi J. Niveau de contamination en métaux lourds des sédiments d'une lagune tropicale: la lagune Aghien (Sud-Est de la Côte d'Ivoire). Afrique Science. 2014;10(3):73-88. French.
 94. Calamari D, Naeve H. Revue de la pollution dans l'environnement aquatique africain. Document technique du CPCA, N°25, Rome, FAO; 1994. French.
 95. Sayadi MH, Rezaei MR, Rezaei A. Fraction distribution and bioavailability of sediment heavy metals in the environmental surrounding MSW landfill: case study. Environmental Monitoring and Assessment. 2015;187(1):4110. French.
 96. Zhang H, Shan BQ. Historical records of heavy metal accumulation in sediments and the relationship with agricultural intensification in the Yangtze- Huaihe region, China. Science of the Total Environment. 2008;399:113-120.
 97. Xia P, Meng XW, Yin P, Cao ZM, Wang XQ. Eighty-year sedimentary record of heavy metal inputs in the intertidal sediments from the Nanliu River

- estuary, Beibu Gulf of South China Sea. Environmental Pollution. 2011;159: 92-99.
98. Rashki Ghaleno O, Sayadi MH, Rezaei MR. Potential ecological risk assessment of heavy metals in sediments of water reservoir case study: Chah Nimeh of Sistan. Proceedings of the International Academy of Ecology and Environmental Sciences. 2015;5(4):89-96.

© 2016 Guy et al.; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
<http://sciencedomain.org/review-history/13565>