ISSN 1996-3416

International Journal of Chemical Technology

http://knowledgiascientific.com

Knowledgia SCIENTIFIC
A Place to Publish Outstanding Research

International Journal of Chemical Technology 5 (1): 10-21, 2013
ISSN 1996-3416 / DOI: 10.3923/ijct.2013.10.21

Contamination of Surface Sediments by Heavy Metals in Ebrié Lagoon (Abidjan, Ivory Coast)

[1,2]Adama Diarrassouba Tuo, [3]Kandana Marthe Yeo, [1]Métongo Bernard Soro, [2]Albert Trokourey and [2]Yobou Bokra

[1]Centre de Recherches Océanologiques (Cro), 29 Rue des Pêcheurs, Treichville-Bp V18 Abidjan, Côte D'ivoire
[2]UFR SSMT, Laboratoire de Chimie Physique, Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire
[3]UFR SGE, Laboratoire Géosciences et Environnement, Université Nangui Abrogoua, 02 BP 801 Abidjan 02, Côte d'Ivoire

Corresponding Author: Adama Diarrassouba Tuo, Centre de Recherches Océanologiques (CRO), 29 Rue des pêcheurs, Treichville-BP V18 Abidjan, Côte d'Ivoire

ABSTRACT

Abidjan city, the economical capital is located in the estuarine part of the Ebrié lagoon. This part of the Ebrié lagoon as become the main receptacle of several discharges from industrial, agricultural, port and urban sewage. Surface sediments were collected from eighteen stations around Abidjan city in order to assess the catchment activities on organic matter and heavy metals inputs into the lagoon. Some important physicochemical parameters (pH, temperature, salinity and conductivity) were also measured. Samples were analyzed using titration method and with an Atomic Absorption Spectrophotometer (AAS) for organic matter and heavy metals, respectively. Levels of physicochemical parameters were found save for aquatic life according to WHO guidelines. Levels of organic matter were ranged within 8.05±7.32 and 67.74±14.07% with highest contents observed in samples collected in the urban area close to Abidjan city. The analysis of sediment samples showed Pb, Cd, Ni, Mn and Zn levels of mean values 404.75±142.08, 2.85±1.97, 45.63±2.73, 107.46±6.51 and 208.77±81.34 mg kg^{-1} (dry weight), respectively. Apart from Mn and for samples collected in the rural zone close to Bingerville, sediments were found polluted by Pb, Cd, Ni and Zn with concentrations higher then effects ranged severe levels. Except for Mn ($p>0.05$), spatial and seasonal variations were significant ($p<0.0001$) for Pb, Cd, Ni and Zn. Therefore, it is urgent to promote treatment of discharges from industries, urban sewage, port, agricultural, etc., before their input in the Ebrié lagoon as its sediments contamination by heavy metals remains a public health problem.

Key words: Heavy metals, organic matter, surface sediments, anthropogenic inputs, toxicity, Ebrié lagoon

INTRODUCTION

Several human activities (agriculture, industry, transport, fishing, port, etc.) are developed around water points because water still the most important natural resource (Tuo *et al*., 2012). Thus, estuarine and coastal areas exhibit a wide array of anthropogenic inputs that might compromise their ecological integrity, with their rapid population growth and uncontrolled development in many coastal regions worldwide. Waters of estuarine environment are in continuous interactions with marine waters. These interactions influence the heavy metal speciation into water, sediments, plants and aquatic organism (Ip *et al*., 2007). Metals are neither created nor destroyed by human, they are just transformed for several needs. Except for contamination, metals also occur in low concentrations in aquatic system (Adefemi *et al*., 2007; Ndimele *et al*., 2011). Different pollutants such as heavy metals, from domestic, industrial, port activities can be easily stabilized and mobilized in the sediments (Siddique and Aktar, 2012). These heavy loads of pollutants are responsible for the availability of heavy metals in coastal areas. In Ivory Coast, more than 80% of the industries and factories are located on the bank of the bays or very close to the Ebrié lagoon system and most of them don't have any waste treatment facilities. Consequently, they discharge the untreated wastes into the nearest water bodies which finally reach into the Ebrié lagoon through different canal system. Thus, the urban area of this important lagoon is increasingly contaminated with toxic substances, threatening all forms of life (Al-Hashem and Brain, 2009; Sarma, 2011; Orlu and Gabriel, 2011; Tuo *et al*., 2012). Heavy metals are known to be accumulated by marine organisms through a variety of pathways that include respiration, adsorption and ingestion (Zhou *et al*., 2001). Heavy metals can be accumulated in waters, sediment, plants and aquatic organisms in estuarine ecosystems. Thus, due to their toxicity, contamination of these ecosystems by heavy metals is of major concern for all forms of life. Pollution by heavy metals is a threat to human life and the total environment (Igwe and Abia, 2006). Heavy metals are an important class of pollutants in the aquatic environment. Monitoring the heavy metals concentrations in sediments is important for toxicological studies in aquatic environments. Due to their long residence time, heavy metals concentrations in sediments remain a vital source of information regarding their sources, speciation and degree of contamination or pollution (Adefemi *et al*., 2007; Madkour *et al*., 2012). This is for the fact that sedimentation has been regarded as one of the most important fluxes in aquatic systems (Asaolu *et al*., 1997). In natural waters, metals distribution processes are controlled by a dynamic set of physical-chemical interactions and equilibria and their solubilities are controlled by pH, concentration, type of metal species, organic ligands, the oxidation state of mineral components and the redox environment of the aquatic system (Huang and Lin, 2003; Jeon *et al*., 2003; Millward and Liu, 2003; Warren *et al*., 2005; Grosbois *et al*., 2006).

Some heavy metals such as Pb, Cu, Zn, etc., have been shown in some previous investigations to occur at a significant level in the waters, sediments and aquatic organisms (Metongo and Gbocho, 2007; Kone *et al*., 2008; Marcellin *et al*., 2009; Yao *et al*., 2009; Tuo *et al*., 2012). However, there are no reports available regarding large scale assessment of organic matter and heavy metals contents in sediments of the estuarine area of the Ebrié lagoon.

This study represents baseline information regarding anthropogenic impacts on the Ebrié lagoon by the assessment of organic matter levels and concentrations of some heavy metals (Pb, Cd, Ni, Mn and Zn) in the estuarine part of the Ebrié lagoon. The degree of heavy metals contamination of the area was evaluated by calculating the Contamination Index (CI) and the Mean Contamination Index (MCI) for the different locations. Hence, it will be useful for the management and sustainable development of this socio-economical area.

MATERIALS AND METHODS

Study area: The Ebrié lagoon has an area of 566 km^2 and stretches on 125 km along the coast of Ivory Coast, between 3°40' and 4°50' West, at latitude 5°50' North (Table 1). Its volume is estimated at 2.5×0^9 m^3, with an average depth of 4.8 m and a few pits near Abidjan

Table 1: Names and No. and GPS coordinate of the sampling stations in the Ebrié lagoon

Bay	Station	No.	Latitude	Longitude	Bay	Station	No.	Latitude	Longitude
Banco	Carena	1	5°20.031'	4°01.946'	Biétri	SIR	11	5°16.149	3°59.358'
	Sebroko	2	5°20.358'	4°02.183'		Bidet	10	5°15.598'	3°58.511'
	Bolibana	3	5°21.750'	4°02.548'		Abattoir	11	5°15.890'	3°58.333'
Cocody	Hôtel-Ivoire	4	5°19.396'	4°00.565'		Unilever	12	5°16.970'	4°00.203'
	Bnetd	5	5°19.598'	4°00.898'		SIVOA	13	5°17.284'	3°59.540'
	Stade FHB	6	5°19.774'	4°01.025'		Marina	14	5°17.119'	4°00.071'
Milliardaires	S1	15	5°15.989'	4°04.638'	Marcory	Grand Caniveau	7	5°18.666'	4°00.101'
	S2	16	5°15.998'	4°04.744'		Biafra	8	5°18.898'	4°00.383'
	S3	17	5°16.989'	4°04.896'	Bingerville	R	18	5°19.500'	3°53.590'

(Bay Abou-Abou) that exceed 20 m (Dufour, 1982). This lagoon communicates with the Atlantic Ocean by the Vridi channel, drilled in 1951, for the building of Abidjan port, the most important in West Africa.

Collection of sediment samples: For this study, 144 surface sediment (approximately 0-2 cm layer) samples have been collected in Ebrié Lagoon from February 2008 to December 2009, using a stainless steel Van Been grab, at a mean distance of 25-50 m from domestic and/or industrial inputs. The exact position of each sampling site was recorded using Global Positioning System (GPS). The sampling sites were selected on the accessibility and the inputs nature. Samples were collected from eighteen stations located in five urban bays (Banco, Cocody, Biétri, Marcory and Milliardaires) and in a rural one (Bingerville chosen as the reference), close to Bingerville city and far from urban inputs (Table 1). Lagoon surface sediments were chosen for this study as this layer controls the exchange of metals between sediments and water (El Nemr *et al*., 2006; Praveena *et al*., 2008). All sampling equipment and laboratory apparatus were acid washed and rinsed thoroughly first with tapwater and then with distilled water to ensure any traces of cleaning reagent were removed before the sampling and/or analysis. Finally, they were dried at room temperature (25°C) and store in a clean place. The sediments were kept cool in an icebox during transportation to the laboratory.

Physicochemical characterization: The physicochemical parameters such as pH, salinity, conductivity and temperature were measured *in situ* with a multi-parameter (type WTW pH/340i).

Analysis of sediment samples: Organic matter and heavy metals were carried out in duplicates and the average data were considered. Each sediment sample was mixed well and then 30 g was taken into a glass dish and dried at 105°C in a Gallen Kamp oven for 24 h. Samples were then homogenize using pestle and Mortar, passed through a 2 mm and <63 μm mesh screens, respectively and stored in polyethylene bags. The Walkley and Black (1934) method was used to determine the organic carbon content. In this procedure, organic carbon was determined using sulphuric acid and aqueous potassium dichromate ($K_2Cr_2O_7$) mixture. After complete oxidation from the heat of solution and external heating, the unused or residual $K_2Cr_2O_7$ (in oxidation) was titrated against ferrous ammonium sulphate. The used $K_2Cr_2O_7$ (the difference between added and residual $K_2Cr_2O_7$), gave a measure of organic carbon content of the sediment. For heavy metals, about 0.3 g of the prepared sediment sample was weighed accurately to 0.01 g accuracy and completely digested in a Teflon bomb by using 1 mL of acid mixture (HNO_3: HCl; 1/3, v/v) and 4 mL of fluorhydric acid, respectively. Acid were slowly added to the dried sample and left overnight before heating. Samples were heated for 2 h 30 min on hot plate at temperature of approximately 120°C. After cooling, the digested samples were filtered and kept in plastic bottles and the solution was justified to volume 25 mL with distilled water. The concentrations of the elements were determined by Atomic Absorption Spectrophotometer (AAS) (Perkin-Elmer, 3030 Model) with air/acetylene flame, at specific wavelengths and after preparation of calibration standards.

The degree of metal pollution was assessed using the Contamination Index (CI) and the Mean Contamination Index (MCI). In the absence of "background levels" (natural content) without anthropogenic inputs, several authors have proposed the calculation of the index of contamination to establish the degree of contamination of a site compared to overall pollution in the whole region (Chafika *et al.*, 2001; Kaimoussi *et al.*, 2002), according to the equation:

$$CI_x \text{ (Metaly)} = \frac{M_x}{M}$$

where, Mx = metal mean value at station x (in mg kg^{-1}); M = y mean level for all stations (in mg kg^{-1}). Mean Contamination Index (MCI) was determined using the following equation in order to classify the stations:

$$MCI = \frac{\sum_{i=1}^{n} CIi}{n}$$

where, n is the total number of metals analyzed (for the present study, n= 5).

Statistical analysis: All statistical analyzes (Mean, standard deviation, Two-way ANOVA, etc.) were performed with STATISTICA software (2005, 7.1 Version), a complete integrated statistical data analysis. Factorial analysis was necessary to capture the main effects and possible interactions between locations and seasons. Correlation circle and matrix were performed with ADE-4 to capture the main differences between locations. Significant treatment means were compared using least significant difference at 5% probability level.

RESULTS AND DISCUSSION

Physicochemical parameters: The estuarine area of the Ebrié lagoon is the main receptacle of domestic, industrial and port effluents, torrents of tropical rainfall from Abidjan city. Almost all of these effluents are untreated, leading to the pollution of this ecosystem by several hazardous pollutants such as heavy metals. Some immediately measurable physicochemical parameters were assessed and their mean values and standards deviations were presented in Table 2.

The highest mean value for temperature was recorded at S1 (26.25±5.44°C) while the least (21.70±5.72°C) was recorded in sediments collected at BNETD. Significant differences ($p<0.05$) were observed between sites. For temperature, significant differences ($p<0.05$) were observed between seasons.

The highest mean value for pH was recorded at Sebroko (7.90±0.23) while the least (7.04±0.04) was recorded at S3. Sites were significantly different ($p<0.01$) for pH due to their individual characteristics (depth, renewal rate, hydrodynamism, chemical characteristics of domestic and/or industrial inputs, etc.) (Arfi and Guiral, 1994). For the present study, pH levels were appropriate for the support of aquatic life (4.50-10.00) (Yao *et al.*, 2009).

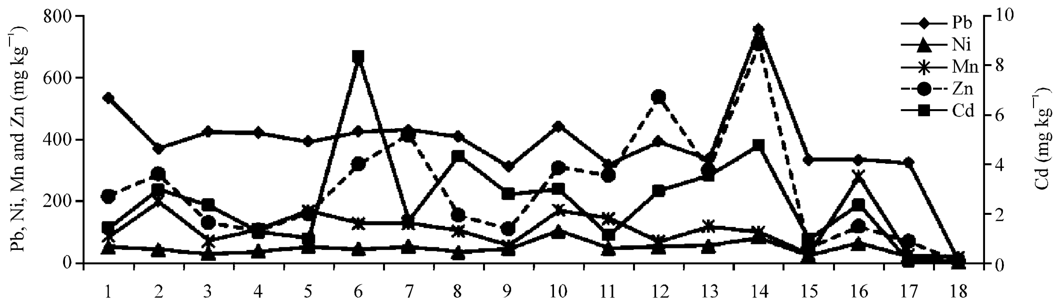

Fig. 1: Variations of heavy metal concentrations in Ebrié Lagoon sediments

Table 2: Analysis of some limnological parameters in the Ebrié Lagoon sediments

Station	Temperature (°C)	Salinity (%)	pH	Conductivity (mS cm^{-1})	Organic matter (%)
CARENA	24.15±3.46	1.12±0.01	7.68±0.12	18.72±1.120	30.89±23.03
Sebroko	24.10±2.54	2.11±0.43	7.90±0.23	30.90±11.59	15.64±9.080
Bolibana	24.55±3.60	1.92±0.02	7.38±0.37	30.70±1.83	29.20±17.83
Hôtel-Ivoire	23.23±1.64	1.12±0.59	7.46±0.09	17.05±9.71	20.67±17.18
BNETD	21.70±5.72	1.32±0.50	7.65±0.21	24.90±4.24	36.65±26.53
Stade FHB	24.50±2.96	0.75±0.58	7.39±0.41	12.49±8.63	28.13±30.14
Grand Caniveau	22.30±4.45	1.09±0.24	7.88±0.33	20.50±1.44	28.80±10.69
Biafra	21.75±5.16	0.66±0.15	7.60±0.19	08.24±0.31	22.14±11.77
SIR	22.40±1.08	0.74±0.19	7.49±0.21	12.56±2.10	43.45±30.14
Bidet	24.60±3.73	1.28±0.54	7.27±0.14	27.56±6.37	49.17±26.68
Abattoir	24.36±3.91	1.15±0.36	7.22±0.13	22.6±1.010	48.66±3.350
SIVOA	24.53±3.78	0.90±0.15	7.08±0.48	17.87±1.41	67.37±14.07
Marina	24.70±2.96	1.01±0.42	7.15±0.01	23.75±0.77	64.74±27.82
Unilever	24.36±4.20	1.08±0.32	7.56±0.33	22.1±0.810	52.83±21.57
S1	26.25±5.44	0.97±0.38	7.13±0.16	12.71±7.26	32.00±22.46
S2	24.90±4.41	0.79±0.49	7.17±0.18	10.14±5.65	21.33±12.36
S3	24.66±4.18	0.73±0.44	7.04±0.04	10.63±6.40	08.88±5.960
R	24.38±3.14	0.35±0.48	7.23±0.47	08.62±5.21	08.05±7.320

Values are Mean±SD

The highest mean values for salinity and conductivity were recorded at Sebroko (2.11±0.43%, 30.90±11.59 mS cm^{-1}) while the least (0.35±0.48%, 8.62±5.21 mS cm^{-1}) were recorded at R, farther from Vridi channel (Fig. 1). For salinity and conductivity, sites were not significantly different ($p>0.05$). At the opposite, values of salinity and conductivity have significantly varied with seasons ($p<0.01$). Indeed, the highest levels of salinity were observed on dry seasons, when marine waters dilute the lagoon waters. In contrast, on rainy seasons, fresh waters predominate which leads to the decrease of salinity and conductivity.

The highest mean value of organic matter was observed at SIVOA (67.37±14.07%) while the least was observed at R (8.05±7.32%). During the whole period of the study, highest levels of organic matter have been observed at Biétri bay (Fig. 1). Organic matter accumulation observed in sediments collected at urban bays were the result of organic inputs through untreated domestic, industrial, etc., effluents that often contain highest loads of organic components. No significant difference was observed between locations and seasons for organic matter during the present study, due to continuous inputs of organic loads in each site whatever their location and the seasons.

Heavy metals

Spatial variations: Sediments represent a potential source of contaminants to the overlying water and hence can influence water quality. The natural release of sediment contaminants is controlled by their dissolution into the sediment pore waters. Diffusion of these contaminants to the water column will occur if the pore water concentration exceeds that of the overlying water. Indeed, due to interactions between surface sediments and water at water-sediment interface, knowledge about heavy metals in sediments is a necessity in toxicological studies. Spatial variations of heavy metals are presented in Fig. 1.

Highest value of Pb (536.09±217.70 mg kg^{-1}) was recorded at CARENA and the least (1.45±5.45 mg kg^{-1}) at R. For Cd, highest value (8.36±12.92 mg kg^{-1}) was recorded at Stade FHB while the least (0.05 mg kg^{-1}) was observed at S3 and R. Highest value of Ni (103.25±164.68 mg kg^{-1}) was observed at Bidet and the least (0.54±2.36 mg kg^{-1}) at R. The maximum value for Mn (281.0±405.0 mg kg^{-1}) was observed at S2 and the minimum value (18.28±5.23 mg kg^{-1}) at R while the highest value for Zn (710.12±36.30 mg kg^{-1}) was recorded at Unilever and the lowest value (4.68±6.13 mg kg^{-1}) at R.

In general, levels of all heavy metals observed were lower and found save for aquatic life in sediments collected at R, close to Bingerville city. The lowest levels of heavy metals observed at R were due to its location, farther from Abidjan. Also, highest values of heavy metals often observed in sediments at Bay Milliardaires may be due to several construction jobs made in recent years, without any sanitation system. At Bay Marcory, highest levels for Pb, Zn, Ni and Cd were recorded at Biafra. Highest levels of Pb and Zn were observed at S2 and at Biafra, respectively. These highest values observed at Biafra for these metals might be the result of several activities (car repair shops, car wash, domestic and industrial activities, etc.) conducted without control over the station's watershed. Highest levels of zinc observed could affect reproductive capacity of some organisms such as fishes, oysters and larval growth (Osman *et al.*, 2009). Except for manganese levels observed by Ochieng *et al.* (2007) in Lakes of Kenya, levels observed for the present study were higher than those observed elsewhere (Table 5) (Ochieng *et al.*, 2007; Issola *et al.*, 2009; Marcellin *et al.*, 2009; Ndimele *et al.*, 2011; Madkour *et al.*, 2012). Pb and Zn concentrations observed by Marcellin *et al.* (2009) were lower than those observed during the present study, leading to the fact that these elements were still introduced in the lagoon through anthropogenic inputs (Marcellin *et al.*, 2009). Except for Mn, significant differences ($p<0.0001$) were observed between sites. Spatial variations have revealed that hazardous pollutants sources in Ebrié lagoon waters depend on the location of each site (Fig. 1). Except for Mn, for which higher concentrations (90-1471 mg kg^{-1}) were observed in El-Hamrawein Harbour (Red Sea, Egypt) sediments, the concentrations of the other metals (Pb, Cd, Ni and Zn) observed in the Ebrié lagoon were higher than those observed elsewhere (Table 5). To appreciate the degree of pollution of the studied sediments, some guideline values established according to the different effects observed on living organisms following toxicology tests were considered (Table 3 and 4). Table 3 and 4 represent five increasing categories of observable effects on aquatic organisms. Levels of heavy metals observed in the Ebrié lagoon where then compared with the sediments guidelines and those observed by other authors (Table 5). The comparison of our values with guideline levels has revealed a polymetallic pollution of sediments in the Ebrié lagoon. Indeed, according to the Ontario Ministry of Environment Screening Guidelines Levels, apart from Mn, concentrations of the other metals might have adverse effects on benthic organisms (Persaud *et al.*, 1990). Effect range severe levels are 250, 10, 75, 110 and 820 mg kg^{-1} for Pb, Cd, Ni, Mn and Zn, respectively (Table 5) (Persaud *et al.*, 1990). In sediments collected in the Ebrié lagoon, mean values

Table 3: Screening quick reference table for heavy metals in marine sediment (Buchman, 1999)

Sediment Guideline	Description
Threshold effects level (TEL)	Maximum concentration at which no effects are observed
Effects range low (ERL)	10th percentile values in effects
Effects range median (ERM)	50th percentile values in effects
Probable effects level (PEL)	Lower limit of the range of concentration at which adverse effects are always observed
Effects range severe (ERS)	Concentration that could effectively eliminate most of the benthic organisms

Table 4: Sediment guidelines and definitions used in SQUIRT (mg kg^{-1} dry weight)

Heavy metals	Effects range low	Effects range median	Threshold effects level	Probable effects level
Pb	46.7	218.0	30.24	112.00
Cd	1.2	9.6	0.68	4.21
Ni	20.9	51.6	15.90	42.80
Zn	150.0	410.0	124.00	271.00

Values are in mg kg^{-1} dry weight, SQUIRT: Screening quick reference table for heavy metals in marine sediment

Table 5: Values of the concentrations of heavy metals compared with some sediments guidelines and those determined by other authors (mg kg^{-1} dry weight)

References	Pb	Cd	Ni	Mn	Zn
Ochieng *et al.* (2007)	10.92-38,98	0.05-1.18	11.69-39.72	667-3947	96.22-229.6
Issola *et al.* (2009)	2.0-8.0	nd-2.0	nc	1.0-39.0	2.0-16.0
Marcellin *et al.* (2009)	63.95-188.63	NL	NL	NL	37.35-490.53
Ndimele *et al.* (2011)	0.13-4.11	NL	NL	NL	40.84-98.67
Madkour *et al.* (2012)	28-66	1.7-3.7	25-53	90-1471	23-174
Effects range Low[a]	31	0.6	16	460	120
Effects range severe[a]	250	10	75	1110	820
Effects range Low[b]	47	-	-	-	150
Effects range severe[b]	218		-	-	410
Range of this study	1,45-989,66	nd-23,25	0,54-473,50	2,16-667,0	0,50-939,38
Mean value of this study	404.75	2.85	45.63	107.46	208.77

NL: Not in literature cited, nd: Not detected. [a]Ontario Ministry of Environment Screening Level Guidelines (Persaud *et al.*, 1990), obtain from Praveena *et al.* (2008). [b]Swedish environmental sediment quality guideline (Mil-Homers *et al.*, 2006)

for Pb, Cd, Ni, Zn and Mn were, respectively 404.75, 2.85, 45.63, 107.46 and 208.77 mg kg^{-1} (Table 5). These mean values were ERS range, ERL range, PEL range, PEL range and ERL range, respectively (Table 3-5).

However, according to our data, except for Mn, levels of heavy metals were generally Effects Severe Ranged (ESR) (Table 5) (Persaud *et al.*, 1990; Mil-Homers *et al.*, 2006). Consequently, Pb, Cd, Ni and Zn levels might have adverse effects on animals that live in sediments and waters and could effectively eliminate most of the benthic organisms, due to interactions between sediments and waters (Table 3-5). As example, in the urban area of the Ebrié lagoon, the gastropod *Tympanotonus fuscatus fuscatus* has disappeared at Bay Biétri, consequence of several hazardous pollutants including heavy metals from anthropogenic inputs (Kone *et al.*, 2008).

Seasonal variations: The seasonal variations of concentrations of heavy metals are presented in Fig. 2. No significant differences ($p>0.05$) were observed between seasons, apart from Mn. Highest levels for Cd and Ni were observed during the rainy season.

This could be explained by the fact that these elements are introduced into the lagoon through runoff. Manganese concentrations have decreased during flood and rainy seasons. This might result from the input of new sediments or by the fact that hydrodynamism would promote leaching

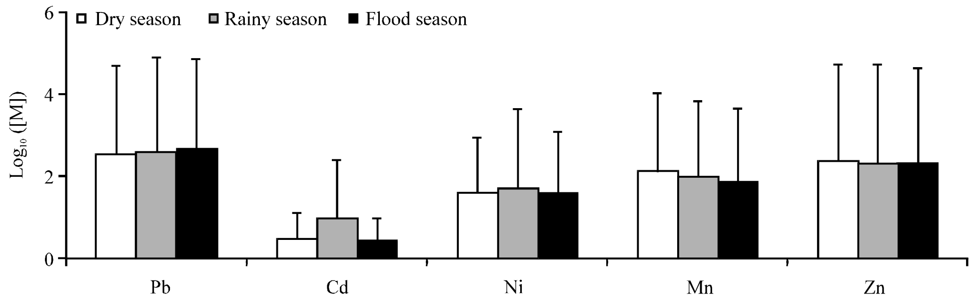

Fig. 2: Seasonal variations of heavy metals levels in the Ebrié Lagoon sediments

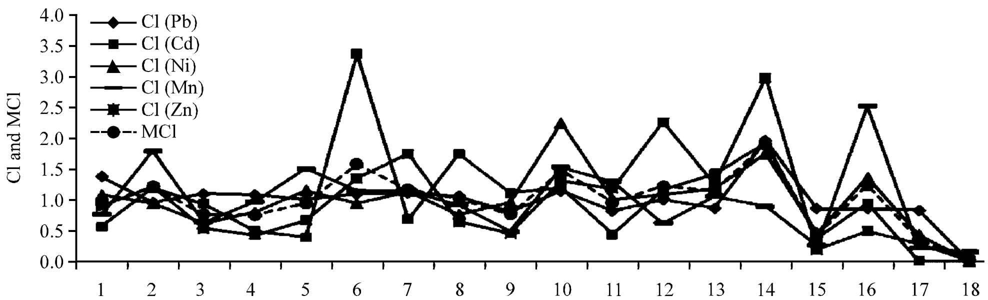

Fig. 3: Variations of Contamination Indexes (CI) and Mean Contamination Index (MCI) of heavy metals

of presents sediments. The seasonal variation of zinc concentrations remained low during the study period, suggesting that intakes of zinc might be constants, or dependant on geochemical characteristics of watersheds.

Degree of metal pollution of the different stations: The degree of metal pollution of each site was assessed by the determination of Contamination Index (CI) and the Mean Contamination Index (MCI). The results are presented in Fig. 3.

According to the data, apart from R, located at Bingerville and farther from direct inputs of wastes waters, heavy metals contamination was effective elsewhere as previously observed in waters (Tuo *et al.*, 2012). Highest contamination index for lead were recorded at Unilever, CARENA and Bidet. For cadmium, sediments were most contaminated at Stade FHB, Unilever, Biafra and Marina. Sediments were more contaminated by nickel at Bibet, Unilever and S2. Highest levels of manganese contamination indexes were recorded at S2, Sebroko, Bidet and BNETD. Highest levels of zinc contamination indexes were recorded at Unilever, SIVOA, Grand-caniveau and Stade FHB.

Mean Contamination Indexes (MCI) observed were consistent with the results of the study of spatial contamination with a gradient of pollution close to that of the mold and respecting the following descending rank: Unilever>StadeFHB>Bidet>S2>SIVOA>Sebroko>Grand-caniveau>Marina>Biafra>Abattoir>BNETD>CARENA>Bolibana # SIR>Hôtel-Ivoire>S1>S3>R. This ranking revealed that the waters were most contaminated at areas with high levels of organic matter, domestic and industrial discharges.

Correlations between the parameters were assessed by calculating the Pearson correlation coefficients. The results are presented in Table 6. For physicochemical parameters, positive correlations were observed between pH and temperature (r = 0.64), on one hand and, on the other hand, a high positive correlation between salinity and conductivity (r = 0.90). Indeed, these parameters are characteristics of waters origins in coastal waters such as lagoons. Nickel and zinc were also positively correlated with organic matter. Zinc was positively correlated to Pb, Cd and Ni, suggesting a common source of sediments contamination by these elements (Table 6). Significant positive correlation observed between Ni and Mn might be explained by a common source of inputs of these elements in the Ebrié lagoon or by the nickel adsorption on manganese oxides.

The correlation between the manganese and organic matter was low (r = 0.04), indicating diffuse sources of their inputs in the lagoon. The low affinity between manganese and the organic matter might explain the low concentrations of manganese observed. Indeed, in sediments, organic matter constitutes a trap of choice for many pollutants such as heavy metals. Sequestration of metals by organic matter is through the formation of organometallic complexes relatively stable.

Heterogeneity of studied area: Due to diffuse sources of anthropogenic inputs in the Ebrié lagoon, correlations between sites were assessed with physicochemical characteristics and heavy metals through correlation circle and factorial plan draws using ADE-4 (Fig. 4). The axis F1 (horizontal) is generally described by the conductivity, heavy metals such as Zn, Ni and Pb while

Table 6: Pearson correlation coefficients between parameters measured in sediments

Parameters	Temp. (°C)	Sal. (%)	pH	Cond. (mS/cm)	O.M. (%)	Pb	Cd	Ni	Mn	Zn
Temp. (°C)	1.00									
Sal. (%)	0.03	1.00								
pH	O.64*	0.44	1.00							
Cond. (mS cm^{-1})	0.02	0.90*	0.35	1.00						
O.M.(%)	0.10	0.06	-0.22	0.37	1.00					
Pb	-0.08	0.35	0.38	0.38	0.37	1.00				
Cd	-0.02	-0.01	0.15	0.02	0.28	0.44	1.00			
Ni	-0.05	0.25	0.16	0.45	0.58*	0.64*	0.37	1.00		
Mn	-0.11	0.35	0.26	0.32	0.04	0.20	0.24	0.60*	1.00	
Zn	0.01	0.18	0.21	0.39	0.64*	0.68*	0.50*	0.63*	0.18	1.00

Temp.: Temperature, Sal.: Salinity, Cond;: Conductivity, O.M: Organic matter, *Significant correlation at $p<0.05$

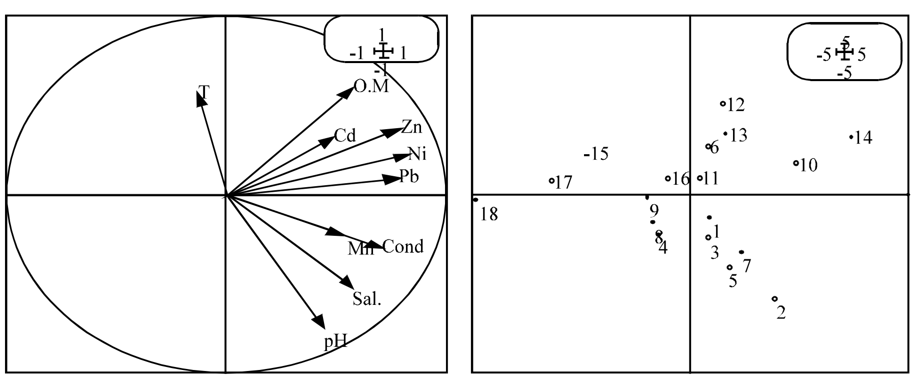

Fig. 4: Correlation circle and Correlation matrix of sediments samples collected in Ebrié Lagoon, O.M: Organic matter, T: Temperature, Sal.: Salinity, Cond.: Conductivity, numbers represent the sites (Table 1)

the axis F2 (vertical) is rather described by the temperature, pH, organic matter, salinity, etc. On axis F1, site 14 (Unilever) and 10 (Bidet) appear to be more affected by heavy metals, unlike sites 15 (S1), 17 (S3) and 18 (R). In fact, sediments at site 14 (Unilever) have recorded the highest concentration of Zn (710.12±36.30 mg kg^{-1}) while the lowest concentrations of all metals assessed were generally observed at site 18 (R), closed to Bingerville and located in a rural zone. For F2 axis, it can be observed that the maximum value of pH was recorded at site 2 (Sebroko) while the organic matter content was higher in at site 13 (SIVOA) (Table 2). In the Bay Milliardaires, site 16 (S2) was more contaminated by heavy metals compared to sites 15 (S1) and 17 (S3).

CONCLUSION

Heavy metals, Organic matter and some physicochemical parameters were assessed during this study. According to the World Health Organization (WHO, 2004) guidelines, levels of temperature, pH, salinity and conductivity were save for aquatic life. However, sediments have recorded highest levels of organic matter which mineralization might induce anoxia in the ecosystem, therefore unsuitable for all forms of life. According to sediments guidelines, except for manganese and samples collected at Bingerville, sediments collected around Abidjan city were contaminated by heavy metals, with significant differences between sites for Pb, Cd, Ni and Zn ($p<0.0001$) and seasons for Mn only. Contamination Indexes (CI) and Mean Contamination Indexes (MCI) variations, correlation circle and correlation matrix have revealed the heterogeneity of the studied area, due to the nature of diffuse sources of pollution in Ebrié lagoon. Due to numerous interactions that may exist between sediment and water layers, there is an urgent need to protect the urban area of the Ebrié lagoon. The results of this study can be use as a database for future investigations for the protection of this important ecosystem, found contaminated with heavy metals.

REFERENCES

Adefemi, O.S., O. Olaofe and S.S. Asaolu, 2007. Seasonal variation in heavy metal distribution in the sediment of major dams in ekiti-state. Pak. J. Nutr., 6: 705-707.

Al-Hashem, M. and P.F. Brain, 2009. Effects of oil pollution on body size and weight of the sand lizard *Acanthodactylus scutellatus* at the greater Al-Burgan oil field in Kuwait. Res. J. Environ. Toxicol., 3: 56-59.

Arfi, R. and D. Guiral, 1994. Un Ecosysteme Estuarien Eutrophe: La Baie de Bietri. In: Environnement et Ressources de Cote d'Ivoire. Tome II-Les Milieux Lagunaires, Durand, J.R., P. Dufour, D. Guiral and S. Zabi (Eds.). Editions de l'Orstom, Paris, ISBN: 2-7099-1134-5, pp: 60-90.

Asaolu, S.S., K.O. Ipinmoroti, C.E.C.E. Adeeyinwo and O. Olaofe, 1997. Seasonal variation in heavy metal distribution in sediment of Ondo state coastal region. Ghana J. Chem., 3: 11-14.

Buchman, M.F., 1999. Screening quick reference tables. HAZMAT Report No. 99-1. http://faculty.kfupm.edu.sa/RI/suwailem/Standards/122_squirt_cards.pdf.

Chafika, A., M. Cheggourb, D. Cossac and S.B.M. Sifeddine, 2001. Quality of morocoan atlantic coastal waters: Water monitoring and mussel watching. Aquatic Living. Resour., 14: 239-249.

Dufour, P., 1982. Influence des conditions de milieu sur la biodegradation des matieres organiques dans une lagune tropicale [Influence of environmental conditions on the biodegradation of organic sewage in a coastal tropical lagoon]. Oceanol. Acta, 5: 355-363.

El Nemr, A., A. Khaled and A. El Sikaily, 2006. Distribution and statistical analysis of leachable and total heavy metals in the sediments of the Suez Gulf. Environ. Monit. Assess., 118: 89-112.

Grosbois, C., M. Meybeck, A. Horowitz and A. Ficht, 2006. The spatial and temporal trends of Cd, Cu, Hg, Pb and Zn in Seine River floodplain deposits (1994-2000). Sci. Total Environ., 356: 22-37.

Huang, K. and S. Lin, 2003. Consequences and implication of heavy metal spatial variations in sediments of Keelung River drainage basin, Taiwan. Chemosphere, 53: 1113-1121.

Igwe, J.C. and A.A. Abia, 2006. A bioseparation process for removing heavy metals from waste water using biosorbents. Afr. J. Biotechnol., 5: 1167-1179.

Ip, C.C.M., X.D. Li, G. Zhang, O.W.H. Wai and Y.S. Li, 2007. Trace metal distribution in sediments of the Pearl River Estuary and the surrounding coastal area, South China. J. Environ. Pollut., 147: 311-323.

Issola, Y., A.M. Kouassi, B.K. Dongui, A.A. Adingra and J. Biemi, 2009. Concentration en metaux lourds des sediments d'une lagune cotiere tropicale: Lagune de Fresco (Cote d'Ivoire) [Heavy metal concentration in sediments of a tropical coastal lagoon: Lagoon of Fresco (Cote d'Ivoire)]. J. Applied Biosci., 18: 1009-1018.

Jeon, B.H., B.A. Dempsey, W.D. Burgos and R.A. Royer, 2003. Sorption kinetics of Fe(II), Zn(II), Co(II), Ni(II), Cd(II) and Fe(II)/Me(II) onto hematite. Water Res., 37: 4135-4142.

Kaimoussi, A., A. Chafik, A. Mouzdahir and S. Bakkas, 2002. Diagnosis on the state of healthiness, quality of the coast and biological resources case of the Moroccan Atlantic coast (City of El Jadida). Comptes Rendus Biologies, 325: 253-260.

Kone, M., D. Diomande, K.S. Traore, A. Dembele and P.V. Houenou, 2008. Comparison of trace element contamination levels (Cu, Zn, Fe and Pb) in the soft tissues of the gastropods *Tympanotonus fuscatus* and *Tympanotonus radula* collected in the Ebrie Lagoon (Cote d'Ivoire): Evidence of the risks linked to lead and cadmium. Afr. J. Biotechnol., 7: 811-820.

Madkour, H.A., A. El-Taher, A.N. El-Hagag Ahmed, A.W. Mohamed and T.M. El-Erian, 2012. Contamination of coastal sediments in El-Hamrawein Harbour, Red Sea, Egypt. J. Environ. Sci. Technol., 5: 210-221.

Marcellin, Y.K., S.M. Bernard, A. Trokourey and B. Yobou, 2009. Assessment of sediments contamination by heavy metals in a tropical lagoon urban area (Ebrie Lagoon, Cote d`Ivoire). Eur. J. Sci. Res., 34: 280-289.

Metongo, B.S. and G.B. Gbocho, 2007. Biological accumulation of some trace elements (Cd, Cu, Mn, Zn) in the mollusc Arca Senilis Bivalve. J. Ivoire. Oceanol. Limnol. Abidjan, 4: 11-21.

Mil-Homers, M., R.L. Stevens, F. Abrantes and I. Cato, 2006. Heavy metals assessment for surface sediment from three areas of the Portuguese continental shelf. Cont. Shelf Res., 26: 1184-1205.

Millward, G.E. and Y.P. Liu, 2003. Modeling metal desorption kinetics in estuaries. Sci. Total Environ., 314-316: 613-623.

Ndimele, P.E., C.A. Kumolu-Johnson and M.A. Anetekhai, 2011. Spatial and temporal variations of some heavy metals in water, sediment and *Chrysichthys nigrodigitatus* (Lacepede, 1803) from ologe lagoon, lagos, Nigeria. Int. J. Biol. Chem., 5: 248-257.

Ochieng, E.Z., J.O. Lalah and S.O. Wandiga, 2007. Analysis of heavy metals in water and surface sediment in five rift valley lakes in kenya for assessment of recent increase in anthropogenic activities. Bull. Environ. Toxicol., 79: 570-576.

Orlu, E.E. and U.U. Gabriel, 2011. Effect of sublethal concentrations of aqueous extract of *Lepidagathis alopecuroides* on spermatogenesis in the fresh water catfish *Clarias gariepinus*. Res. J. Environ. Toxicol., 5: 27-38.

Osman, M.M., S.A. El-Fiky, Y.M. Soheir and A.I Abeer, 2009. Impact of water pollution on histopathological and electrophoretic characters of *Oreochromis niloticus* fish. Res. J. Environ. Toxicol., 3: 9-23.

Persaud, D., R. Jaagumagi and A. Hayton, 1990. Provincial sediment quality guidelines. Water Resources Branch, Ontario Ministry of the Environment, pp: 24.

Praveena, S.M., M. Radojevic, M.H. Abdullah and A.Z. Aris, 2008. Application of sediment quality guidelines in the assessment of mangrove surface sediment in mengkabong Lagoon, Sabah, Malaysia. Iranian J. Environ. Health Sci. Eng., 5: 35-42.

Sarma, H., 2011. Metal hyperaccumulation in plants: A review focusing on phytoremediation technology. J. Environ. Sci. Technol., 4: 118-138.

Siddique, M.A.M. and M. Aktar, 2012. Heavy metal concentration in pore water of salt marsh along the Karnafully river coast, Bangladesh. J. Environ. Sci. Technol., 5: 241-248.

Tuo, A.D., M.B. Soro, A. Trokourey and Y. Bokra, 2012. Assessment of waters contamination by nutrients and heavy metals in the Ebrie Lagoon (Abidjan, Ivory Coast). Res. J. Environ. Toxicol., (In Press).

WHO, 2004. Guidelines for Drinking-Water Quality. Vol. 1, 3rd Edn., World Health Organization, Geneva, Switzerland.

Walkley, A. and I.A. Black, 1934. An examination of the degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci., 37: 29-38.

Warren, C., D. Mackay, M. Whelan and K. Fox, 2005. Mass balance modelling of contaminants in river basins: A flexible matrix approach. Chemosphere, 61: 1458-1467.

Yao, K.M., B.S. Metongo, A. Trokourey and Y. Bokra, 2009. Water pollution in the urban area of a tropical lagoon by oxidizable matter (Ebrie Lagoon, Ivory Coast). Int. J. Chem. Sci., 3: 755-770.

Zhou, J.L., S.M. Salvador, Y.P. Liu and M. Sequeria, 2001. Heavy metals in the tissues of common dolphins (*Delphinus delphis*) stranded on the Portuguese coast. Sci. Total Environ., 273: 61-76.