American Journal of Physical Chemistry
2022; 11(1): 14-24
http://www.sciencepublishinggroup.com/j/ajpc
doi: 10.11648/j.ajpc.20221101.12
ISSN: 2327-2430 (Print); ISSN: 2327-2449 (Online)

Environmental and Human Health Risk Assessment of Potential Toxic Elements in Sediments from Ebrié Lagoon, Côte d'Ivoire

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To cite this article:

Ayénan Marc-Olivier Togbé, Kakou Charles Kinimo, Adama Dit Pierre Koffi N'Goran, Ahbeauriet Ahmed Ouattara, Koffi Marcellin Yao, Kouamé Victor Kouamé, Boua Célestin Atse, Abiba Sanogo Tidou. Environmental and Human Health Risk Assessment of Potential Toxic Elements in Sediments from Ebrié Lagoon, Côte d'Ivoire. *American Journal of Physical Chemistry*. Vol. 11, No. 1, 2022, pp. 14-24. doi: 10.11648/j.ajpc.20221101.12

Received: February 21, 2022; **Accepted**: March 21, 2022; **Published**: March 29, 2022

Abstract: Ebrie lagoon is one of the largest in the West Africa lagoon system and contributes to the social and economic well-being of the habitants. Whereas, the sectors IV and V of Ebrié lagoon are increasingly threatened by potential toxic elements (PTEs) pollution due to urban growth, and industrial and agricultural activities, but few studies have focused on the contamination of sediments by PTEs and the human health risks. In the present study, surface sediments from sectors IV and V of Ebrié lagoon were sampled for the geochemical, human risk and ecological risks assessment of four potential toxic elements (PTEs) (As, Cd, Hg and Pb). Results indicate that particle of grain size of > 63 µm (sand) were the most abundant in the surface sediments with relative high TOC content. However, particle size did not affect metals distribution in sediments. PTE mean concentrations did not exceed the UCC values. The geoaccumulation index and enrichment factor values indicate that no Cd and Pb contamination has occured on the whole, but sediments have been polluted by As and Hg and suggest that Cd and Pb were influenced by from natural weathering processes, whereas As and Hg derived from anthropogenic inputs. The concentrations of Hg higher than PEC, which suggest that it may pose adverse effects to organisms. The results of this study indicated that As, Hg and Pb increase health risks via sediment ingestion for both chidren and adults. With regard to concentrations and level of risk, Hg is the most toxic metal that requires special attention including monitoring of pollution level, wastewater treatment for better environmental management in sectors IV and V of Ebrié lagoon.

Keywords: Potential Toxic Elements (PTEs), Sediments, Distribution, Health Risks, Ebrié Lagoon

1. Introduction

Sediment quality is an indicator of water pollution that manifests pollution variations. Sediment provides a biogeochemical cycling and the foundation of the food web [1]. Sediment have been used as an important tool to assess the health status of aquatic ecosystems [2], and are an integral component for functionang of ecological integrity. Sediment act as a sink of organic as well as inorganic pollutant (heavy metals) and provide a history of anthropogenic pollutant input [3] and environmental changes [4]. Potential toxic elements (PTE) enter the aquatic ecosystems through point sources such as industrial, municipal and domestic waste water effluents as well as diffuse sources which include surface runoff, erosion, and atmospheric deposition.

Sediment pollution with PTEs is a worldwide problem [5, 6] and is considered to be serious threat to the aquatic ecosystem because of their toxicity, ubiquitous and persistence nature, non-biodegradability and ability to bio-accumulate in food chain [7]. Sediments serve as the largest pool of metals in aquatic environment. More than 90% of the heavy metal load in the aquatic systems has been found to be associated with susparticulate matter and sediments [8-10]. PTEs in suspended particulates settle down and pool up in sediments [6], while the dissolved metals adsorb into fine particles which may carry them to bottom sediments [11]. Distribution of PTE sis influenced by mineralogy and chemical composition of suspended material, anthropogenic influences, deposition, sorption, enrichment in organism [12, 13], and various physico-chemical characteristic [11].

Sediments has widley been studied for anthropogenic impacts on the aquatic environment [14]. Various studies have reported sediment quality assessments, distribution and contamination of PTEs and quantification of pollution load in sediments of different lagoons such as, Fosu lagoon, Ghana [15]; Epe and Badagry lagoons, Nigeria [16]; Mingoa River, Cameroon [17], Sidi Moussa lagoon, Morocco [18]. Ebrié lagoon is one of the largest lagoon in West Africa. It drains a megacity of Côte d'Ivoire, namely Abidjan. With the economic boomin its surrounding area, numerous studies focusing on the urban part of Ebrié lagoon have indicated that increased PTEs have been observed and the aquatic ecosytem connect with has become one of the most degraded [19-22]. So data were only available for this area. The sectors IV and V located around Dabou and Jacqueville cities in rural part of the Ebrie lagoon become the canal of domestic waste water discharge, industrial cultivation which involves heavier using of chemical fertilizer and significant tourist influx. Morever, recurrent massive mortality of fish occurred in this part of the Ebrie lagoon. Whereas, informations on the transport or fate of such contaminants and their potential adverse environmantal impacts from this area was lacking, which could limit our understanding on these mortalies. In this paper, the spatial distribution of four PTEs (arsenic (As), cadmium (Cd), mercury (Hg), and lead (Pb)) in the surface sediments from sectors IV and V of Ebrié lagoon, the potential ecological and human health risks are presented.

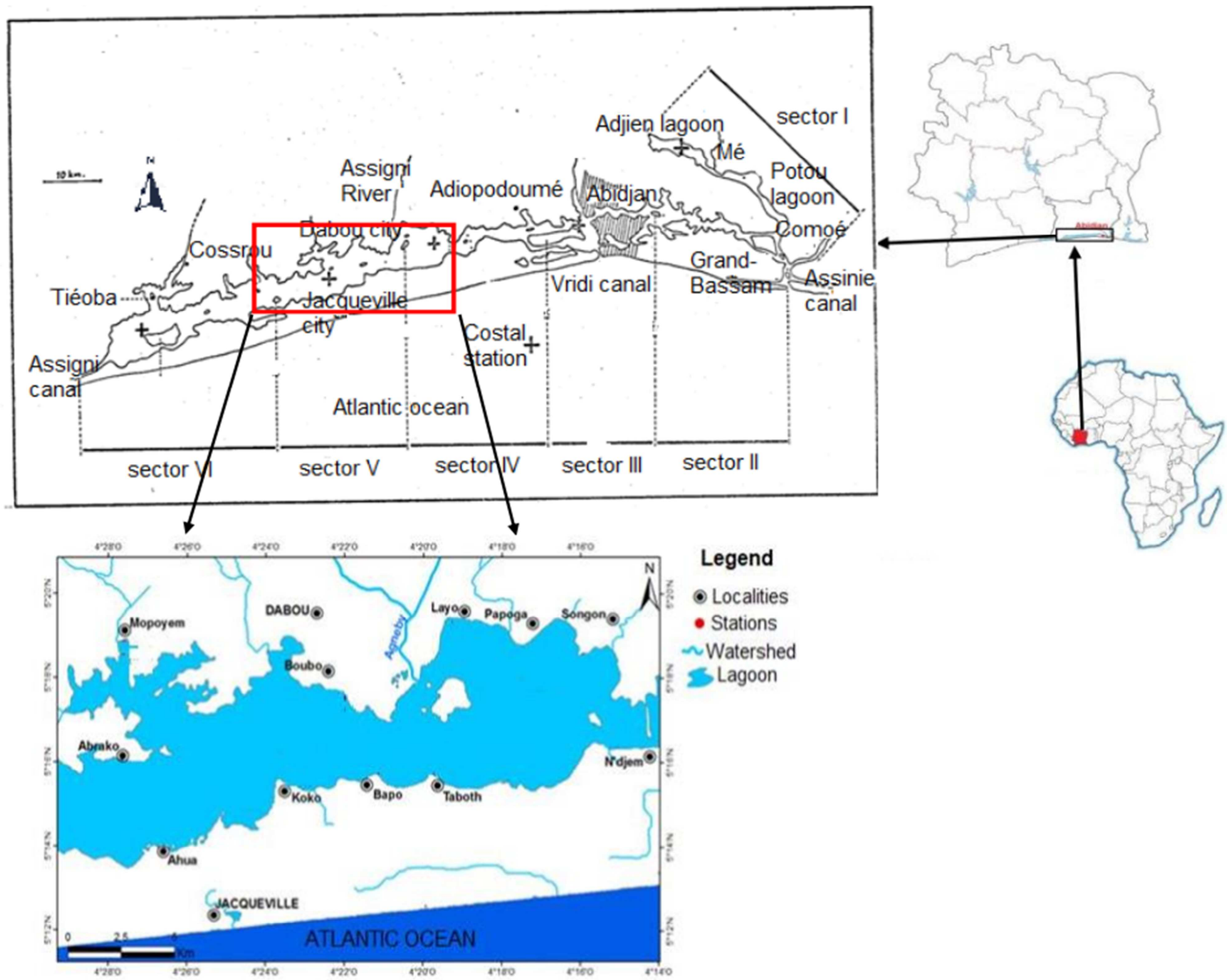

Figure 1. Study area and sampling site localisation.

2. Material and Methods

2.1. Study Area Description

The Ebrie lagoon is located in the Abidjan city, one of the most densely populated and higly deveopped areas in Côte d'Ivoire (Figure 1). Its water storage capacity is about 2.5 km^3 and mean annual outflow is 100 m^3/s [23]. The area is subequatorial humid climate with prevaling of rainy season. Its annual temperature 29°C, and the annual average precipitation varied between 1100 – 1400 mm, higly concentrated during raini season (May to june) [19]. In this region, the types of land-use mainly include arable land forest land, grass-land, residential and industrial land, and water area. The major soil type are subtropical yellow brown soil, middle subtropical red soil, strand plain salt soil, alluvial plain and paddy soil.

2.2. Sample Collection

A total of 102 sediment samples were collected from sector IV and V of Ebrie lagoon system (Figure 1). At each sitation, the samples was collected from the top (0 – 5 cm) using a stainless steel core sampler, and stored in polythene zip bag. At each sampling site, three subsamples were collected and mixed throrougly into one composite sample. Following the collection, samples were kept in a refrigerator and transported to the laboratory immedialtely.

2.3. Chemical Analysis and Quality Control

In lab, the samples were dried, passed through a 100-mesh sieve, powdered and digested, successively. Details of disgestion processes for sediments can be found in the previous study [13]. The content of potential toxic elements (PTE) were measured at the Laboratoire national d'Appui au Developpement Rural (LANADA), which certificated ISO 9001. For the 102 sediments samples six metals (As, Cd, Hg, Pb, Fe and Al) were determined using atomic absorption spectroscopy (AAS). To ensure the quality of analysis, several quality assurance and control methods were adopted including standard operating procedures, analysis of reagent blanks, recovery of spiked samples, calibration with standards and analysis of replicatess. The standard reference material was used to chek the analysis precision after every ten sample. In the study, the precision and bias of the analysis were generally below 10% and the recovery of samples spiked with standard ranged from 96% to 119%.

2.4. Physicochemical Characterization

Total organic carbon (TOC) was determined by loss on ignition of 1.0 g of dried sediment in an oven at 550°C for 4 hours [24, 25]. 5 g of the air-dried sediment were weighted and 25 ml of distilled water added and agitated for 5 min and the solution left undisturbed for 1 hour. The pH was determined using a digital pH meter (HI, 99100) by inserting the electrode in each of the sample solution after calibration of the pH meter. The granulometric composition of the sediment samples was determined by wet sieving using standards sieves, for grain sizes down to 63 µm on electronic counter (Coulter Counter, Mod. TA II, England).

2.5. Statistical Analysis

Descriptive analysis, one way analysis of variance (ANOVA) and correlation were performed. The ANOVA on ranks was performed when the equal variance test failed. The difference was considered statistically significant at $p < 0.05$. Statistical analysis were performed with Sigmaplot 12.1 software.

2.6. PTE Pollution Level Assessment Indexes and Source Apportionment

The geo-accumulation index (Igeo) and enrichment factor (EF) were used to assess the geochemical characteristic of PTE in the Ebrie lagoon sediments in the following equation

$$\mathrm{Igeo} = \log_2(\mathrm{C_i}/1.5\mathrm{B_i}) \tag{1}$$

$$\mathrm{EF} = (\mathrm{C_i}/\mathrm{C_{ref}})_{\mathrm{sample}}/(\mathrm{C_i}/\mathrm{C_{ref}})_{\mathrm{background}} \tag{2}$$

Where C_i is the concentration of the given metal (µg g^{-1}); B_i is the geochemical value of the corresponding element (µg g^{-1}); C_{ref} is the concentration of the reference element in upper continental crust (UCC) (µg g^{-1}), while 1.5 is the background matrix correction factor due to lithogenic effects. In this study, Fe was used as the reference element for geochemical normalization to calculate the EF value since it is one the largest component of earth's crust and it's positively cotrelated with studied elements. The pollution levels are given in supplemental material (Table 1).

Table 1. *Geoaccumulation index (Igeo) and enrichment factor (EF) pollution level.*

Geoaccumulation index			**Enrichment factor**		
Igeo values	**class**	**Pollution level**	**EF values**	**class**	**enrichment level**
0 >	0	Unpolluted	EF < 1	0	No contamination
0 - 1	1	Unpolluted to moderately polluted	1 < EF < 3	1	Minor contamination
1 - 2	2	Moderately polluted	3 < EF < 5	2	Moderate contamination
2 – 3	3	Moderately to heavily polluted	5 < EF < 10	3	Moderate to strongly contamination
3 - 4	4	Heavily polluted	10 < EF < 25	4	Strongly contaminated
4 - 5	5	Heavily to extremely polluted	25 < EF < 50	5	Strongly to extremly contaaminated
≥ 5	6	Extremely polluted	EF > 50	6	Extremely contaminated

For human health risk assessment, the method recommended by the US EPA was employed in the study

[26]. Here, the ingestion route exposure was considered, and the average daily intake (ADI) doses of metals was evaluated used Eqs. (3). To characterize the non-carcinogenic risk, hazard quotient (HQ) was calculated by adding the ratios that divided the ADI by the corresponding reference exposure dose (RfD, µg g^{-1} day^{-1}) (Eq. (4)), and the total hazard index (THI) posed by multiple metals was determined by summing the HQ of each pollutant (Eq. (5)). Similarly, the ADI was multiplied by corresponding slope factor (SF, per µg g^{-1} day^{-1}) to produce a carcinogenic risk (CR) (Eq. 6) and the total carcinogenic risk (TCR) was the sum of the CR of each pollutant (Eq. (7)).

$$\mathrm{ADI} = \mathrm{C} \times \frac{\mathrm{IR_{ing}} \times \mathrm{EF} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \quad (3)$$

$$\mathrm{HQ} = \frac{\mathrm{ADI_{ing}}}{\mathrm{RfD_{ing}}} \quad (4)$$

$$THI = \sum_{i=1}^{n} HQ_i \quad (5)$$

$$CR = ADI_{ing} \times SF_{ing} \quad (6)$$

$$TCR = \sum_{i=1}^{n} CR_i \quad (7)$$

Where IR_{ing} represent the ingestion rate mg day^{-1}, EF is the exposure frequency (day/year), ED is the exposure duration (year), BW is the body weight of the exposed individual (kg), AT is the time period over which the dose averaged (day) and n is the number of metals (Table 2).

Table 2. *Parameters used in health risk assessment.*

Parameters	Adults	Children	Reference
Ingestion rate (IR)	100 mg	200 mg	[27, 28]
Reference body weight	60	25	[29, 30]
Exposure duration (ED)	365 d	365 d	
Exposure frequency (EF)	56.8 a	56.8 a	[31]
Average time (AT)	20732 d	20732 d	

Note: d is the abbreviation for day, a is the abbreviation for age and 20732 d = 365 x 56.8 a.

The slope factors for carcinogenic contaminants and reference doses for non-carcinogenic PTE elements were extracted from Integrated Risk Information System [32] as given in Table 3. Whereas, due to the lack of slope factors are not available for Hg, only As, Cd and Pb carcinogen risk were estimated.

Table 3. *Potentially toxic elements reference dose and slope factor values (mg kg^{-1} day^{-1}).*

	As	Cd	Hg	Pb	Refernces
RfD	0.0003	0.001	0.0003	0.00035	[32]
SF	1.5	15	-	0.0085	[33]

3. Result and Discussion

3.1. Physochemical Characterization of the Sediments

Table 4 presents the values of pH, TOC and granulometric composition of sediments collected in sector IV and V of Ebrié Lagoon.

Table 4. *Values of pH, TOC and granulometric composition of Ebrie lagoon sediments.*

Stations	pH	TOC (%)	Granulometric composition (%)	
			Limon+clay	Sand
Abraco	7.12	0.73	7.53	81.5
Ahua	7.39	0.64	13.4	74.8
Gbougbo	7.28	1.77	8.2	84.7
Koko	7.46	0.26	28.7	51.2
Mopoyem	6.97	3.65	5.07	79.8
Bapo	7.42	17.3	4.2	78.9
Layo	6.98	10.4	5.87	84
Ndjem	7.39	0.32	3.33	83
Papoga	7.11	17.8	10.1	79
Songon	7.28	5.85	6.53	81
Taboth	7.30	27.8	8.47	73.2
Mean	7.25	7.86	9.21	77.3
Standard Deviation	0.16	8.88	6.72	8.94

The pH varied from 6.97 between 6.97 and 7.46 (Table 4) that is considered in the same order in the relation of those generally found in the sediments from lagoon in Côte d'Ivoire, which vary between 6.9 and 8.3 [34, 35]. The neutral pH or very low acidity sediment in the areas of greatest anthropic influence may be explained by the dissolution of carbonates minerals [36], which consume H^+ ions and generates aqueous carbonate species, increasing sediment pH [37].

The TOC contents varied from 0.26 to 27.8% with an average of 7.86%. In overall, the organic matter levels were medium in sediments which could be explained by the contribution of industrial and food crops cultivation and vegetation around the study area. Regardless of the sector, the sediment granulometry was classified as sandy loam (51.2-84.7%). The predominance of sandy texture could be associated to the impact of tributaries and other lateral sediment sources on Ebrie lagoon bed sediment such as Agneby. Although, positive correlation coefficients were observed between sediment sand content and PTE concentrations, correlation was not significant ($p < 0.05$) (Table 5).

3.2. PTE Contamination Level Assessment in Ebrié Lagoon Sediments

The descriptive statistic of the PTE in the sediments of the Ebrié Lagoon system are summarized in Table 5. It can be seen the maximium, minimum, mean and median values for As, Cd, Hg, Pb and Fe and their corresponding background from Upper Continental Crust (UCC).

PTE concentrations in Ebrie lagoon sediments investigated in this study are shown in Table 5. A wide range of PTE concentration (As: 1.51 – 9.79 µg.g^{-1}; Cd: 0.01 – 0.12 µg.g^{-1}; Hg: 0.86 – 1.46 µg.g^{-1}; Pb: 1.32 - 13.5 µg.g^{-1}; Fe: 21541 – 32197 µg.g^{-1}) was found in the sediment samples collected from two sectors. Compared with the PTE background concentrations in UCC [39], arsenic and Hg concentrations were 2 to 20 times higher than UCC values, while Cd, Pb and Fe concentrations were of 1-3 order lower than they corresponding values in upper continental crust. This results indicating anthropogenic impacts on As and Hg sediments from in Ebrie lagoon system.

Table 5. *Descriptive statistics of PTE concentrations in the Ebrie lagoon sediments (μg g^{-1}), the upper continental crust and the value of consensus-based sediment quality guidelines (SQGs).*

	As	Cd	Hg	Pb	Fe
Maximum	9.79	0.12	1.46	13.5	32197
Minimum	1.51	0.01	0.80	1.32	21541
Mean	5.27	0.06	1.12	5.59	25924
Median	2.83	0.03	0.18	3.60	3005
Standard deviation	4.88	0.06	1.09	4.20	24968
Coefficients of variation (CV)	53.5	56.7	15.5	64.4	11.5
Upper continental crust (UCC)	2.00	0.102	0.06	17.0	30890
TEC[a]	9.8	0.99	0.18	35.8	-
PEC[a]	33.0	5.00	1.10	125	-

[a]: Threshold effect concentration; Probable Effect Concentration [38].

When compared with the published data in other water environment in the worldwide (Table 6), the concentrations for PTE in the sediment of Ebrie lagoon system were within the middle level. Indeed, the concentrations of Cd, Hg and Pb found in this study were less than those reported in other africain country, while As concentrations were higher than the ones in other african countries. Neverthless, As, Cd and Pb concentrations were less than those reported in Berre lagoon (France) and Homa lagoon (Turkey).

Table 6. *Comparison of PTE concentrations (μg.g^{-1}) in Ebrié lagoon with other lagoons in world.*

Country	area	Potential toxic elements				Reference
		As	Cd	Hg	Pb	
Côte d'Ivoire	Ebrié lagoon	1.519.79 (5.27)	0.01 – 0.12 (0.06)	0.08 – 1.46 (1.12)	1.32-13.5 (5.59)	This study
Côte d'Ivoire	Ebrié lagoon	-	(63.9)	-	(188)	[19]
Côte d'Ivoire	Ebrié lagoon		(1.83)	-	(141)	[20]
Nigeria	Lagos lagoon	-	0.13 – 8.60	0.04 – 0.53	410 - 29570	[39]
Ghana	Fosu lagoon				1.7 – 91.7 (28.1)	[15]
Ghana	Weija reservoir	(1.43)	(0.27)	(2.17)	(1.86)	[40]
Morocco	Nador Lagoon		0.12–3.60 (1.60)	-	15.6-326 (135)	[18]
France	Berre lagoon	4 – 10 (6.41)*	0.2 – 1.6 (0.69)*	0.15-0.40 (0.32)*	18-82 (41.3)*	[41]
Turkey	Homa lagoon	-	0.06-0.19	0.22 – 0.48	2.43-17	[42]

(): represents mean concentration, ()*: Mean concentration calculated.

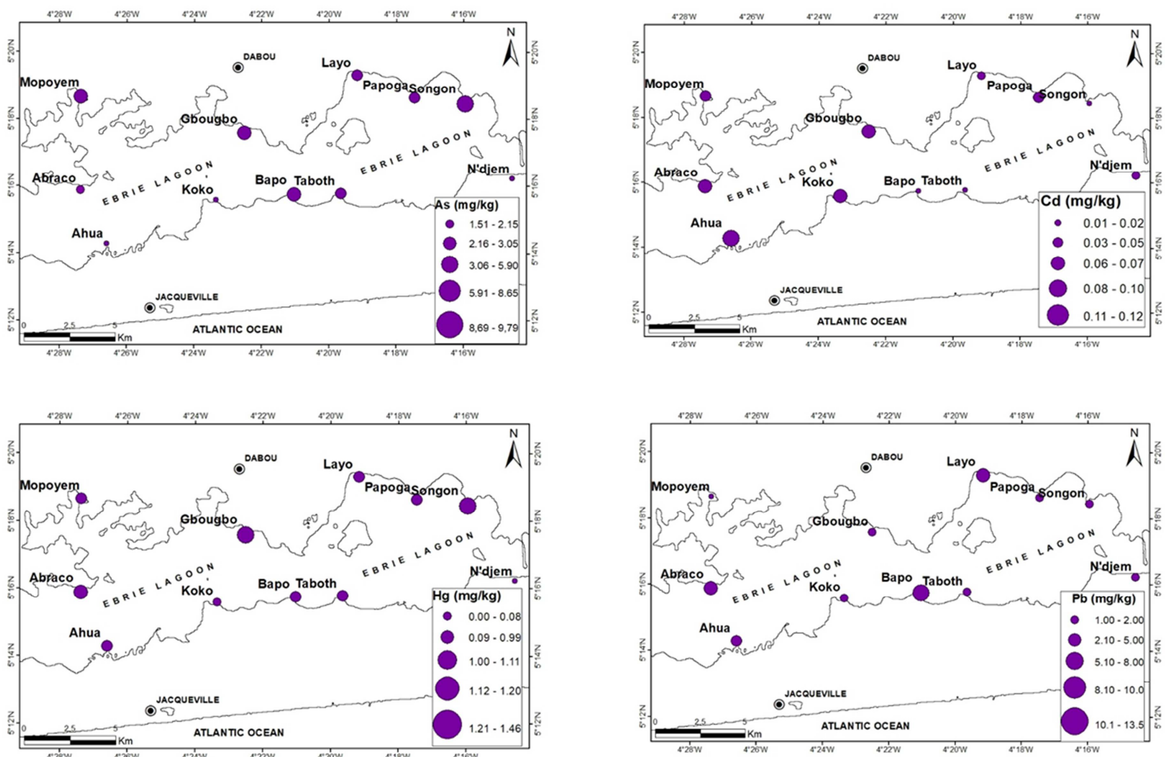

Figure 2. *Spatial distribution of As, Cd, Hg and Pb in surface sediments from the sectors IV and V of Ebrié Lagoon.*

3.3. Spatial Distribution

Spatial distribution patterns of As, Cd, Hg and Pb in surface sediments from sectors IV and V of Ebrie lagoon are showed in Figure 2. These maps illustrate the distinct zones of lower or higher concentration in surface sediments from Ebrie lagoon. Arsenic (As) is a proved human carcinogen and has potential to damage the ecological communities [43]. The patches of higher concentrations were founds at Songon, Gbougbo and Mopoyem in the northern part of the study area.

As Figure 2 shown, the distribution of Cd and Hg was similar to that of As. Whereas, inverse trend was observed for Pb, with patches of the highest concentrations appaered at Bapo, Loyo and Abraco in southern part from sectors IV and V of the Ebrie lagoon.

The similar spatial distribution patterns of As, Cd and Hg in the sediments of these sectors of Ebrie lagoon might be closed of the similar geological enrichment characteristic [44], which also showed that they might come frome the same input sources [45]. In overall, the uniform higher and lower PTE concentrations observed in northern and southern of the study area could be associated to TOC contents (0.26 – 27.8%). In fact, multiple authors repoted that organic matter could act as major sink for PTEs due to strong complexing capacity for metallic contaminants [46, 47]. The rôle of organic matter in accumulation of trace metals to the sediments was also emphasized by Wakida et al. (2008) [48]. Except for Hg, positive correlations were found between PTEs with TOC contents but those were not significant ($p < 0.05$) (Table 7).

Table 7. *Pearson correlation between heavy metals, limon+clay, and sand in surface sediments from the sectors IV and V of Ebrie lagoon.*

	As	Cd	Hg	Pb	Fe	Limon+clay	Sand
As	1						
Cd	0.919	1					
Hg	-0.045	-0.103	1				
Pb	-0.108	0.101	0.187	1			
Fe	0.625	0.611	-0.186	0.057	1		
Limon+caly	-0.450	-0.466	-0.340	-0.187	-0.260	1	
Sand	0.413	0.460	0.163	0.133	0.162	-0.943	1

In bold significant correlation at the 0.05 level (2-tailled).

3.4. PTE Contamination Level and Source Apportionment

To qualitively assess the degree of anthropogenic influence, we calculated the geo-accumulation index (Igeo) and the enrichment factor (EF) for each metal (Table 8). The EF values for As, Cd, Hg, and Pb were in the range of 0.94 – 5.29, 0.15 – 1.23, 18.4 – 37.3, and 0.07 – 0.93, respectively with medians of 3.17, 0.72, 23.9, and 0.28, respectively. PTE elements were considered as natural origin when EF value were below 1.0, whereas EF values > 1.5 indicate that the metals were orginate from anthropogenic sources [49]. Here, the median EFs of As and Hg were greater than 1.5, implying significant enrichment due to anthropogenic activities. Indeed, 100% samples for Hg and 72% for As were above strongly enrichment and moderate enrichment, respectively. This result suggested that As and Hg was significant pollutant to influence the sediment quality in the Ebrié Lagoon system, which was also confirmed by the analysis of Igeo index values for As and Hg which placing these elements into moderately contaminated to strongly contaminated.

Table 8. *Geochemical accumulation (Igeo) and enrichment factor values.*

Localities	Geoaccumulation index (Igeo)				Enrichment factor (EF)			
	As	Cd	Hg	Pb	As	Cd	Hg	Pb
Abraco	0.02	-2.02	3.69	-1.43	1.84	0.45	23.3	0.67
Ahua	-0.99	-3.61	3.71	-1.71	0.94	0.15	24.3	0.57
Gbougbo	1.43	-0.83	3.84	-3.15	5.25	1.09	27.8	0.22
Koko	-0.48	-2.89	3.66	-2.96	1.36	0.26	23.9	0.24
Mopoyem	1.53	-1.07	3.72	-4.27	4.15	0.68	18.9	0.07
Bapo	1.33	-0.77	4.07	-0.92	4.39	1.02	29.3	0.93
Layo	0.98	-0.59	3.56	-1.52	3.05	1.03	18.3	0.54
Ndjem	-0.90	-3.38	4.12	-3.22	1.15	0.21	37.3	0.23
Papoga	0.70	-1.53	3.24	-2.52	3.28	0.70	19.1	0.35
Songon	1.71	-0.40	3.66	-3.11	5.29	1.23	20.4	0.19
Taboth	0.70	-1.33	3.69	-2.60	3.02	0.74	24.0	0.31
Min	-0.99	-3.61	3.24	-4.27	0.94	0.15	18.3	0.07
Max	1.71	-0.40	4.12	-0.92	5.29	1.23	37.32	0.93
Mean	0.52	-1.73	3.72	-2.51	3.07	0.68	24.32	0.40
Median	0.70	-1.33	3.69	-2.60	3.17	0.72	23.98	0.28

The consensus-based guidelines (SQGs) are used to evaluate the adverse effects and aid in the interpretation of chemistry quality of PTE in the surface sediments of Ebrié lagoon. The SQGs include Threshold effects concentrations (TECs) and probable effects concentrations (PECs) concentrations for some substances with potential environmental risk [38]. Generally, TECs have been used to identify uncontaminated samples that pose a limited risk of toxicity; the PECs have been used to identify those sample in which chemical concentrations were sufficiently elevated to warrant further evaluation [50].

The concentrations of As, Cd and Pb in the surface sediments of Ebrié lagoon are far below or close to their corresponding TEC values. For Hg, the concentrations are between or higher than their corresponding TEC and PEC values (Table 4). Statistically, more than 80% of the sample are above the PEC values. These results suggest that the concentrations of As, Cd and Pb in all sediments could be regarded as relatively uncontaminated samples that pose a limited risk of toxicity. Whereas, Hg is the main dangerous PTE for the Ebrié lagoon sediment organisms.

3.5. Human Health Risks Assessment

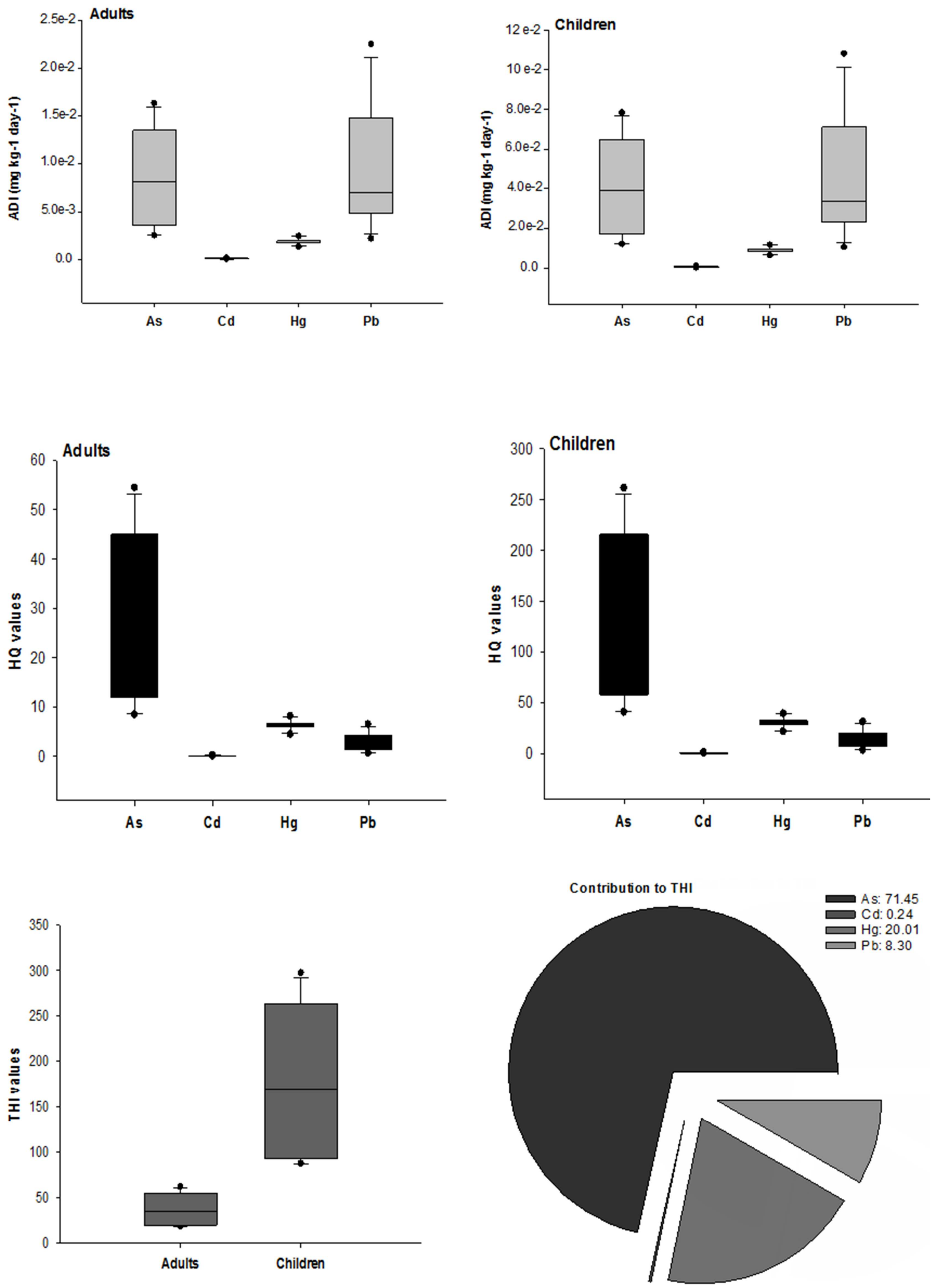

Figure 3. *Average daily intake values of PTEs via sediment ingestion and non-carcinogen risk assessment.*

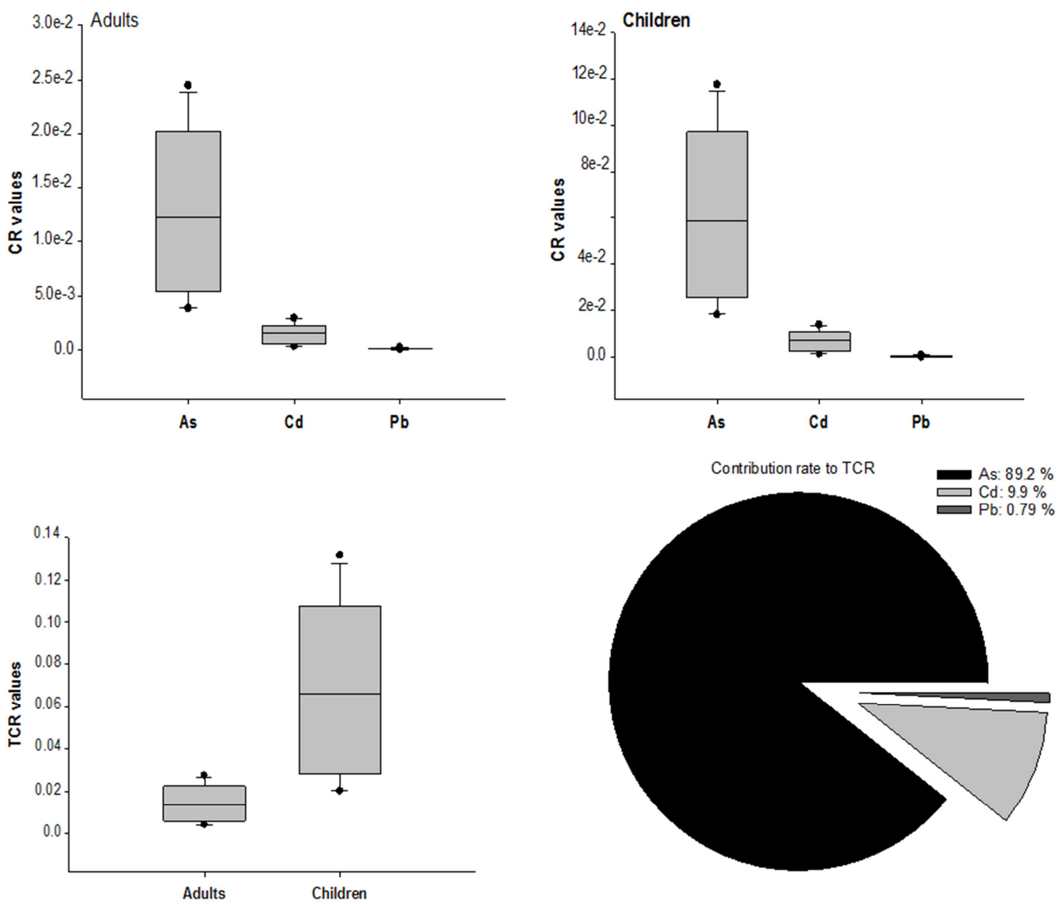

Figure 4. Carcinogen risk via sediment ingestion assessment.

3.6. Health Risk Assessment

The health risk caused by the ingestion rate of sediment to adults and children, including ADI, HQ, THI, CR and TCR, of the measured PTEs in surface sediment samples from Ebrié lagoon are shown in Figures 3 and 4, respectively.

The trends of ADIs for PTEs in sediment were in the order of Pb > As > Hg > Cd (Figure 3). The mean average daily intake values for As, Hg and Pb in sediments exceeded the US EPA (2011) [27] reference dose. The highest ADI mean values were recorded for children in the study area. Among the studies PTEs, As, Hg and Pb caused highest health risks, while Cd did not have much impact both adults and children. It can be said with certainty that As and Pb were main sources of potential non-cancer risks brought about by ingestion rate of sediment (Figure 3). Therefore, we should focus on the health risk caused by possibility of incorrectly ingesting of sediment, which could occur from foods and other way. According to Figure 3, the mean HQ values of ingestion of As, Hg and Pb are higher than 1, indicating that there are healt risk. Therefore, health risk will be conducted for sediment ingestion for both adults and children. The means values of the THI values for different population groups were 38 ± 15 and 185 ± 75 for adults and children repectively. The mean values of THI were above 1 and showed that the health risks for both groups were high.

For carcinogenic risk, the mean CR values for carcinogenic PTEs varied from $8.32 \times 10^{-5} \pm 5.10 \times 10^{-5}$ to $6.40 \times 10^{-2} \pm 3.99 \times 10^{-2}$ and were ranked a $CR_{As} > CR_{Cd} > CR_{Pb}$ both for children and adults. In addition, the CRs posed by As, Cd and Pb in sediment for children were higher than those adults. For the present results, it can indeed be concluded that the carcinogenic rsik of exposure to As, Cd and Pb is not negligible in most situations, as all calculated CRs fall out the range of internationally acceptable risk ($1.0 \times 10^{-6} - 1.0 \times 10^{-4}$). As shown in Figure 4, it very clear that the CR values for children were higher than those for adults. In other hands, As was prominent element among the three carcinogenic, as it accounted for aproximately 89.2% for the two population groups. Therefore, the carcinogenic risk associated to As exposure via ingestion pathway was highest, suggesting that the carcinogenic risk of As should receive adequate attention in pollution control by goverment for residential health concerns in the coming years. In this study, the TCRs of As, Cd and Hg is below the risk limit (1.00) (Figure 4), and the three element not posed significant carinogen risk to the population via ingestion pathway. In overall, these results could be attributed to the body weight (BW) and PTEs concentrations in sediments. In fact, previously, some authors have analyzed the sensitivity of the parameters such as PTEs concentration, IR, EF, ED aand BW on health risk indexes [51, 52]. They reported that heavy metals concentration and

BW were factors affecting children and adults health risk for 23% and 22%, respectively. On contrary to our result, Zhang et al., (2021) [53] reported that adults health risks through sediment ingestion were higher than those for children around Xinjiang coal mine in China.

4. Conclusion

The mean concentrations of As, Cd, Hg and Pb in the surface sediments of Ebrié lagoon are generally lower than upper continental crust (UCC) values of pre-industrial sediments. Combining EF, Igeo values, we suggest that the Cd and Pb in surface sediments from two sectors IV and V of Ebrié lagoon are dominantly from natural sources, the As and Hg are mainly from anthropogenic sources. The contamination levels of Cd and Pb are close to zero to minor, while to moderate to strongly contaminated for As and Hg. in overall, the concentrations for Cd, Hg and Pb wee lower than those reported in other countries, while the concentration of As were higher than the ones, except in Berre and Homa lagoons, respectively in France and Turkey. According to the consensus-based SQGs, Hg was identified as the most toxic PTE. This metal may pose high eco-risks to the sediment organism from Ebrié lagoon. Finally, we assessed ADI, HQ, THI index through oral ingestion pathway. The ADI average values for the four studied PTE exceeded the reference dose establised by US EPA for chidren and adults. Except for Cd, the HQ index for the three PTEs have significant non-carcinogenic risks for both children and adults. It should be noted that CR index for As, Cd, and Hg in two populations groups exceeded the acceptable range (10^{-6} – 10^{-4}), but the TRC index is less than 1. In view of the of this study, we recommend followings : (1) treating of effluent discharge into the sector IV and V of Ebrié lagoon, (2) implementing of monitoring system to controll the contamination level. The action plan should be competent enough to free the lagoon from the problems it is facing currently considering its great importance to the surrounding communities.

Acknowledgements

Authors are grateful for support of the Fond Interprofessionnel pour la recherché et le conseil agricole (FIRCA). We also thank all technicians for assistance in laboratory experiment. Authors would like to thank reviewers for their constructive comments.

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