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Trace Metals Behaviors in the Superficial Sediments from a Tropical Lagoon

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Abstract

The aim of this study is to assessment the effects of the seasonal water inputs on the seasonal dynamic of trace metals in the superficial sediments from the lagoon area II of Ébrié system. This study was implemented during one year (from June 2020 to May 2021) and all the physical and chemical parameters of these sediments, used in this study, were all obtained according to AFNOR standards. In hot season, the trace metal contents of these sediments, dominated by coarse sands in all seasons, were on the whole favored by the marine inputs; which would induce their very slightly basicity and reduce characters, low salinity and conductivity. However, the majority of their trace metals content decreases in rainy season with the meteorite inputs; would induce their slightly acidic and oxidizing characters and, the increase in their salinity and conductivity. These were again for the slightly basic and reduce characters of the open waters at the interface water-sediment, as their relative important salinity, conductivity and organic matter content in this season. The same effects were observed in flood season but a less marked by the important presence of Comoé river in this ecosystem.

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Keywords and phrases: metal pollution; lagoon; Ébrié system; Atlantic Ocean; meteorites inputs.

1. Introduction

Trace metals are among the most investigated chemical pollutants in aquatic ecosystems. This fact results from their harmful effects on the health of aquatic biota, with repercussions on the entire trophic chain, especially on Human. All trace metals become toxic to living organisms at some so-called lethal contents. Some trace metals, such as Fe, Cu, Se and, Zn, are important for the physiology of living organisms; but become toxic at very high contents. For other trace metals, such as As, Cd, Cr, Hg and, Pb, they are very toxic to these organics at very low contents [1].

In aquatic ecosystems, sediments are the most used for the assessment of their metal pollution. These substrates are considered memory indicators for this kind of pollution. This fact is illustrated by numerous recent scientific works, such as those by Kalkan [2], Shetaia et al. [3] and Chen et al. [4]. One of the most explored axes in this kind of study is the approach to knowledge of the trace metals behaviors in them, particularly their seasonal dynamics [5-8]. The seasonal dynamics of trace metals in sediments is governed by the hydrosystem and the hydroclimate; both of which condition a plethora of physical and biogeochemical factors involved in this process. Those commonly used in this context are pH, redox potential, salinity, conductivity, organic matter content, moisture content and, particle size of sediments [5,9]. This is also the case of the physical and chemical characteristics of the open waters at the water-sediment interface (pH, redox potential, salinity, conductivity, organic matter and oxygen contents, etc.), through interstitial waters [10,11].

One of transitional waters with a relatively high state of pollution in Côte d'Ivoire is the area II of Ébrié system. This fact has been highlighted by the recent works of Mahi et al. [12-14]. These studies showed that the open waters of this lagoon area present a relatively significant state of degradation with likely high ecological risks. Recent studies of metal pollution of the superficial sediments from this lagoon area are those of Keumean et al. [15], showing low metal pollution of these substrates. Which contrasts with the studies of Mahi et al. [12,13]. So, given the important socio-economic, eco-tourism roles and the great biodiversity of this lagoon area, it is important to carry out investigations in this direction for a better estimate of its metal pollution for possible actions for its protection and for its sustainable development. It is in this context this study was carried out. Its main aim is the seasonal monitoring of the dynamics of the total forms of As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn in its superficial sediments. The secondary aims are the assessment of the simultaneous influences on this process of the particle size, pH, redox potential, conductivity, salinity, moisture content and, organic matter content of these sediments. It is the same for the temperature, pH, conductivity, salinity and, dissolved oxygen and TOC contents of the open waters at the water-sediment interface, on the other. This constitutes the originality of this study.

2. Material and methods

2.1. Characterization of the study area

Located at the extreme East of Ébrié system, the lagoon area II is one of the six areas of this system, established by Durand and Guiral [16] taking into account its hydrology. It is located precisely within latitudes 5°200000-5°21176471 N and longitude 3°400000-3°500000 W. Its length is estimated to 17,143 km and, that its width is 5,714 m. Its water surface is around to 87 km^2 [17]. Taking into account its mean depth of 2,785 m according to Mahi et al. [12], its mean water volume is therefore 242,295 m^3. It represents the greatest estuary of this system [18] (Figure 1).

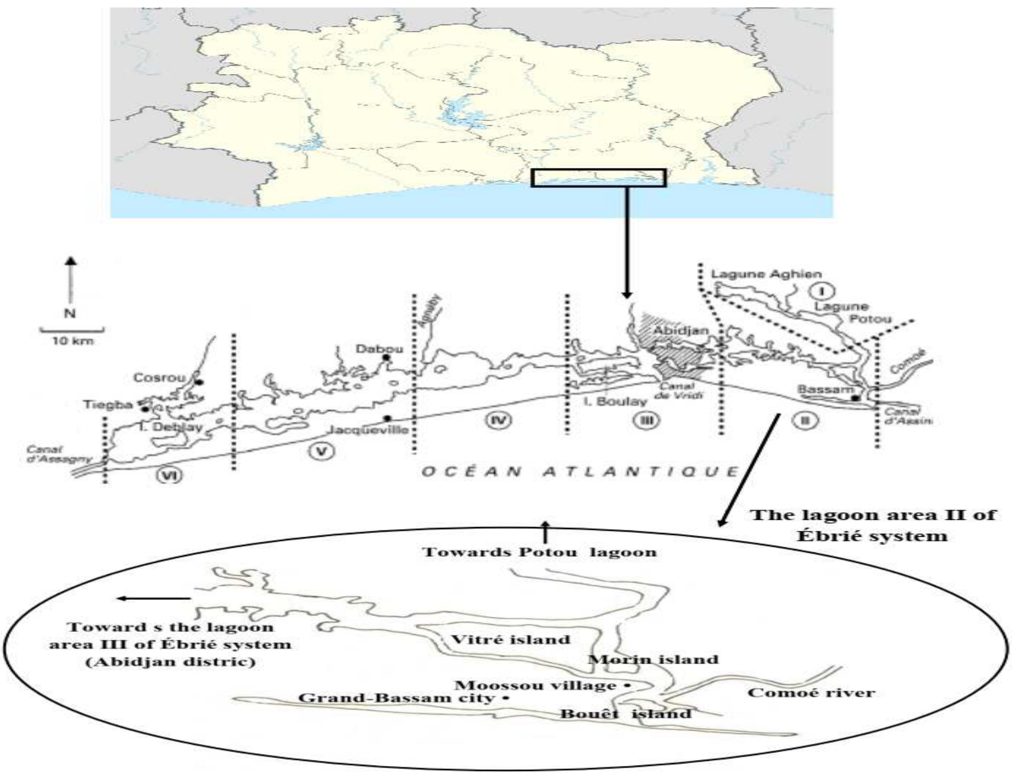

Figure 1. Localization of the lagoon area II of Ébrié system [12,14].

This aquatic ecosystem is dominated by depths below -3 m [18;19]. Its basin is relatively low slopes that vary between 0.4 to 2.6%. Adopo et al. [20] mentioned that this estuary is generally subject to a phenomenon of deposition whose mean thickness is about 10 cm per year in the period from 2005 to 2007. As a result, the depths of this estuary decreased by 1.3 m over the study period compared to the period from 2005 to 2007.

Its hydrology is dominated the marine inputs from Atlantic Ocean on the one hand and, those of Mé river and Comoé river, on the other. The water seasons of Mé river depend on the rainfall on the Ivorian coastline and, those of Comoé river are consecutive to the rainfall on the whole of this country. Thus, Mahi et al. [12], taking into account the water seasons of these rivers, deduced the water seasons of this ecosystem as:

- Hot Season (HS), where the influence of the marine waters from Atlantic Ocean is relatively maximum due to low meteorite inputs. During this season, these marine waters inputs carry into this estuary the inputs from lagoon area III;
- Rainy Season (RS), where meteorite inputs are significant and reduce the effects of the marine inputs from Atlantic Ocean on this estuary. These meteorite inputs are dominated by those of meteorite runoff waters by leaching from the banks of this ecosystem and, Mé river draining those of Potou lagoon and Aghien lagoon which it crosses to flow into this lagoon site. The same is true for those Comoé river from its watershed located in Southern Côte d'Ivoire;
- Flood Season (FS), characterized by the high presence of Comoé river in this lagoon area. Nevertheless, this aquatic ecosystem also receives the inputs of runoff meteorite waters and those of Mé river, Adjn lagoon and, Potou lagoon in favor of the short rainy season on the coastline of this country. These meteorite inputs in this season are less important than those brought in RS.

The marine waters inputs from Atlantic Ocean in the front of Abidjan district are more polluted by trace metals [21]. It is the same for the inputs from the lagoon area III of Ébrié system [22-24], carried in the lagoon area by these marine waters. That is also the case of Comoé river [26], Mé river, Adjin lagoon and, Potou lagoon [27,28].

This aquatic ecosystem is subject to strong anthropogenic pressures. This fact results in strong urbanization and the intensive practice of agriculture, especially agro-industry in its watershed [12]. Added to this are mining activities, particularly clandestine gold panning [29], on the one hand, and industrial activities, the majority of which are located in Abidjan district, near this lagoon site (Mahi et al., 2022a) [12].

2.2. Experimental techniques

2.2.1. Samples collection

This study was conducted in the same time as those Mahi et al. [12-14]. So, the samples of the superficial sediments from this aquatic ecosystem were monthly collected in the five sampling sites (Figure 2), that the characteristics were given by Mahi et al. [12]. These samples were collected using a Van Veen grab at 5 cm below of the surface of its sediments. Immediately collected, they were stored in polyethylene bottles as recommended NF EN ISO 5667-15 [31].

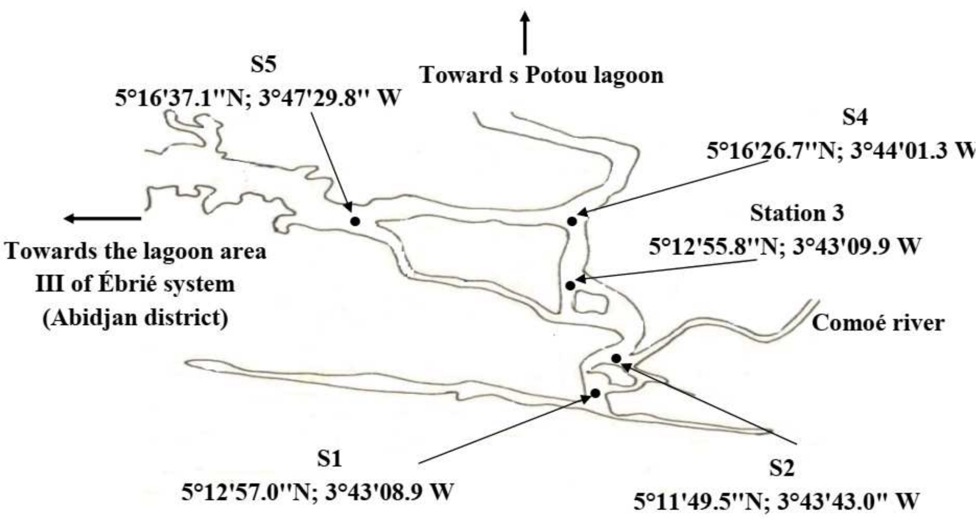

Figure 2. The five sampling sites used in this study [12-14].

2.2.2. Analysis performed to lab

2.2.2.1. Samples preparation

To lab, the samples of the superficial sediments from this lagoon area were divided in two part: the first (the less important) was used for the moisture determination, and the second (the most important) was used the determination of the other physical and chemical parameters. This second part was been before freeze dried according to NF EN 16179 standard [31] before its use.

2.2.2.2 Determination of pH, redox potential, salinity, conductivity, particle size distribution and, organic matter content and, moisture content

The pH and redox potential of these sediment samples were determined by using NF

EN ISO 10390 standard [32] and NF ISO 11271 standard [33] respectively. Their salinity and conductivity were obtained according NF ISO 11265 [34]. Their particle distribution was determined by sieving and sedimentation methods as recommended to ISO 11277 standard [35]. As concerned to their moisture content, it was determined by the gravimetric method as described by NF ISO 11465 standard [36]. Finally, their organic matter content was obtained by the method of determination of organic carbon content by sulfochromic oxidation according to NF ISO 14235 [37].

2.2.2.3. Determination of the contents of the trace metals studied

Ten trace metals contents were determined in these sediments samples: As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Hg, Pb and, Zn.

The determination of their trace metals contents, excepted those of Hg, was done according NF X31-147 standard [38]. An Agilent tandem mass spectrometer coupled to an argon plasma emission source model 7890B was used in this case. For their Hg contents, they were obtained by direct measurement using automatic mercury analyzer solid-liquid Milestone DMA 80.

2.2.3. Source of the data used in this study and Statistical processing of results:

The seasonal pH, redox potential, salinity, conductivity, particle size distribution, as well organic matter, dissolved oxygen and moisture contents of the open water at the water-sediment interface used in this study were obtained by Mahi et al. [14] in this lagoon area in same the study period. The mean (m), standard deviation (s), Variation Coefficient (VC (%)), Minimum and Maximum values (Min-Max) of the different results obtained were implemented using Statistica software version 13.2

3. Results and discussion

3.1. Results

3.1.1. Seasonal particle size distribution

The superficial sediments of this lagoon area presented a coarse sand texture over the study period. The annual mean value of their very coarse sands content was very slightly higher than that of their coarse and medium sands content. The seasonal mean values of their very coarse sands contents and those of their coarse and medium sands contents were the most important of these four mineralogical fractions. On the other hand, the seasonal mean values of their silt and clay contents were the lowest overall this period. These sediments were dominated by very coarse sands in HS and RS, while they were predominantly coarse and medium sands in RS. The mean values of their fines sands contents was relatively high in HS and FS, but low in RS. As for those of their silt and clay contents, they were relatively high in RS and FS, but relatively low in HS. The seasonal variations of their contents in these mineralogical fractions were relatively high in all seasons. It was the opposite with their annual variations, all relatively low in this period (Table 1).

Table 1. Seasonal particle size distribution of the superficial sediment from the lagoon area II of Ébrié system from June 2020 to May 2021.

Sand fractions			Very coarse sand (Ø ≤ 2 mm)	Coarse and medium sands (0.2 ≤Ø< 2 mm)	fine sand (0.63 ≤Ø< 0.2 mm)	Slit and clay (Ø < 0.063 mm)
Seasons	HS	m±s	48.22±39.41	46.84±37.64	4.60±4.30	0.34±0,19
		VC	(81.73%)	(80.36%)	(89.71%)	(56.42%)
		min-max	7.50-98.19	1.61-81.29	0.20-10.75	0,00-0.45
	RS	m±s	53.29±41.09	43.05±39.27	3.28±2.97	0.37±0,21
		VC	(77.10%)	(91.22%)	(86.47%)	(57.14%)
		min-max	5.65-99.14	0.86-90.95	0.00-8.17	0.00-0.42
	FS	m±s	46.55±42.58	48.72±42.82	4.26±2.48	0.47±0.26
		VC	(91.48%)	(87.90%)	(55.31%)	(55.84%)
		min-max	2.42-94.77	3.48-93.48	1.68-7.80	0.00-0.66
	Mean annual value	m±s	49.36±1,59	46.20±2.65	4.05±0.94	0.39±0.04
		VC	(3.21%)	(5.74%)	(22.22%)	(9.69%)
		min-max	2.42-99.14	0.86-93.48	0.00-10.75	0.00-0.42

HS: Hot Season, RS: Rainy Season; FS: Flood Season; m: mean value; s: standard deviation; VC: Variation Coefficient; min: minimal value; max: maximum value.

3.1.2. pH, redox potential, salinity, conductivity, moisture content and, organic matter content

The superficial sediments of this lagoon area were very slightly acidic and oxidizing characteristics, with the relatively low organic matter content, salinity and, conductivity. Its moisture content was medium during all this period. The annual variations in their pH, organic matter content and, moisture content were very low; unlike those of salinity, redox potential and, conductivity, which were important. The highest seasonal mean value of their pH and organic matter content were obtained in HS and, the lowest in RS. As for the highest seasonal value of their salinity, redox potential and, moisture content, they were all determined in RS. The lowest seasonal mean value of their salinity and conductivity were determined in RS. Those of their redox potential and moisture content were obtained in FS. The seasonal variations of their pH and moisture content were low; the opposite of those of their redox potential, salinity and, conductivity, which were all significant in all seasons. The seasonal variations of their organic matter content were low in HS and FS, but significant in RS.

Table 2. Seasonal and annual mean values (m±s) of pH, salinity, potential redox, conductivity, moisture content and, organic matter content of the superficial sediment from the lagoon area II of Ébrié system from June 2020 to May 2021.

Physical and chemical parameters			pH	Salinity (mg/l)	Potential redox (mV)	Conductivity (mS/cm)	Moisture content (%)	Organic matter content (%)
Seasons	HS	m±s	7.10±0.26	1.11±0.55	-8.13±14.19	0.57±0.29	27.93±2.75	4.85±1.37
		VC	(3.66%)	(49.51%)	(-174.65%)	(50.04%)	(9.84%)	(28.20%)
		min-max	5.47-7.90	0.10-3.80	-48.40 - 80.10	0.05-1.95	10.21-42.66	0.55-15.21
	RS	m±s	6.28±0.44	1.91±1.32	35.17±24.16	0.98±0.68	31.23±2.42	4.71±2.96
		VC	(7.07%)	(68.83%)	(68.70%)	(69.34%)	(7.75%)	(62.82%)
		min-max	3.86-7.71	0.10-7.60	-41.90 - 164.90	0.04-3.91	7.00-60.00	0.25-15.08
	FS	m±s	6.91±0.19	0.82±0.81	0.89±9.28	0.42±0.40	30.52±0.84	4.89±1.83
		VC	(2.69%)	(99.52%)	(1048.67%)	(95.44%)	(2.76%)	(37.44%)
		min-max	6.40-7.80	0.00-4.60	-44.80 - 27.60	0.01-2.26	18.00-57.57	0.42-11.19
Annual		m±s	6.78±0.21	1.23±0.76	8.47±11.45	0.63±0.39	29.64±1.18	4.82±1.32
		VC	(3.03%)	(61.69%)	(135.33%)	(61.50%)	(3.98%)	(27.30%)
		min-max	3.86-7.90	0.00-7.60	-48.40 - 164.90	0.01-3.91	11.74-51.27	0.25-15.21

HS: Hot Season, RS: Rainy Season; FS: Flood Season; m: mean value; s: standard deviation; VC: Variation Coefficient; min: minimal value; max: maximum value.

3.1.3. Trace metals

The table 3 presents the results of the seasonal and annual mean values of the trace metals contents of these superficial sediments in this period. The seasonal and annual mean values of their Fe contents were very important. Those of their As, Cr and, Pb contents were relatively considerable; unlike to those of their Cu, Mn, Hg and, Zn, all relatively low. The seasonal mean values of their Mn and Ni contents increased from HS to FS. It was be the opposite for the seasonal mean values of their As contents, which decreased from HS to FS. The highest seasonal values of their Cd, Cu, Hg and, Pb contents were determined in HS and, the lowest were in RS. As for their seasonal values Fe and Zn contents, their highest value was determined in FS and, the lowest in RS. The highest seasonal value of their Cr content was obtained in SP and, the lowest in FS. All the seasonal variations of their trace metals contents were relatively low. The same was true for the annual variations of their trace metals contents in this period.

The increasing orders of the seasonal and annual of their trace metals contents are as follows:

HS	Hg < Cu < Cd < Mn < Zn < Pb < As < Cr < Ni < Fe
RS	Hg < Cd < Cu < Mn < Zn < Pb < As < Cr < Ni < Fe
FS	Hg < Cd < Cu < Mn < Zn < Pb < As < Cr < Ni < Fe
Annual	Hg < Cd < Cu < Mn < Zn < Pb < As < Cr < Ni < Fe

Fe, followed respectively by Ni, Cr and As were the most important, while Cd followed by Cu and Hg were the least important of these trace metals in these sediments in all seasons during this period.

The pollution of the superficial sediments of this lagoon area by Cr, Mn, Pb and, Zn would have experienced an important decrease, unlike their pollution by Cu which would have been very important and that by Ni which would have been constant on this decade, by comparing these results obtained to those determined by Keumean et al. [15]. These superficial sediments were presented a very high Fe content compared to those of Abouabou lagoon Bay (lagoon area III of Ébrié system), while being less polluted by Cd, Mn and, Zn, and more polluted by Cu and Hg relative to them [23]. Their Cu, Cr, Fe, Mn, Ni, Pb and, Zn contents obtained in this period were all higher than those of the superficial sediments of Biétri and Koumassi bays from lagoon area III of Ébrié system [24]. With the exception of As, these superficial sediments showed lower Cd, Cr, Pb and, Zn contents than those on average of all the superficial sediments of Abidjan district lagoon bays [22]. This is also the case for their Cu, Pb and, Zn contents, which were lower than those on average of the superficial sediments of all of the lagoon areas II and III of Ébrié system, except for those of Cd and Ni [25] (Table 4).

Table 3. Seasonal and annual mean values (m±s) the trace metals contents of the superficial sediment from the lagoon area II of Ébrié system from June 2020 to May 2021.

Trace metals			As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
Seasons	HS	m±s	40.85±6.40	1.05±0.19	46.77±1.92	0.99±0.07	1619.07±6.55	0.79±0.07	3.44±0.27	58.31±1.78	13.41±0.24	5.82±0.34
		CV	(15.67%)	(17.67%)	(4.11%)	(6.98%)	(106.01%)	(9.10%)	(7.93%)	(3.06%)	(1.75%)	(5.90%)
		min-max	27.15-56.19	0.72-1.49	40.39-63.55	0.81-1.35	1055.67-2048.00	0.47-1.37	2.42-4.22	37.43-77.19	10.52-15.23	4.20-7.23
	RS	m±s	41.11±0.01	0.82±0.08	47.81±1.14	0.84±0.03	1549.50±105.08	0.73±0.04	3.37±0.19	57.58±0.39	11.44±0.17	5.66±0.08
		CV	(0.03%)	(9.29%)	(2.38%)	(4.05%)	(6.78%)	(6.06%)	(5.59%)	(0.67%)	(1.45%)	(1.42%)
		min-max	26.56-57.42-	0.52-1.12	39.28-59.03	0.61-1.17	1016.50-1932.50	0.40-1,09	2.42-4.38	35.45-76,49	7.66-14.42	3.96-6.85
	FS	m±s	41.39±1.18	0.85±0.11	46.20±3.64	0.90±0,10	1632.05±121.86	0.73±0.05	3.31±0.10	57.41±1.14	12.42±0.79	6.08±0.76
		CV	(2.86%)	(13.51%)	(7.89%)	(11.18%)	(7.47%)	(6.38%)	(3.01%)	(1.98%)	(6.35%)	(12.50%)
		min-max	26.53-58.86	0.48-1.14	39.55-52.40	0.61-1.31	1119.75-2068.75	0.38-1.32	2.68-4.00	35.94-77.20	9.35-14.59	4.27-7.70
Annual		m±s	41.15±3.29	0.91±0.16	46.75±2.55	0.92±0.10	1609.38±104.63	0.75±0.06	3.37±0.18	57.75±1.22	12.53±0.92	5.90±0.53
		CV	8.00%	17.59%	5.45%	10.29%	6.50%	7.56%	5.17%	2.11%	7.33%	8.96%
		min-max	26.53-58.86	0.48-1.49	39.28-63.55	0.61-1.35	1016.50-2068.75	0.38-1.37	2.42-4.38	35.45-77.20	7.66-15.23	4.27-7.70

HS: Hot Season, RS: Rainy Season; FS: Flood Season; m: mean value; s: standard deviation; VC: Variation Coefficient; min: minimal value; max: maximum value.

Table 4. Comparison of the mean annual values of the trace metals contents of these superficial sediments obtained in this study to those recently obtained in some lagoon areas II and III of Ébrié system by various authors.

Trace metals	Trace metals in mg/g dry weight						
	Mean annual value obtained in this study	Lagoon area II of Ébrié System [15]	Abou Abou lagoon bay (Lagoon area III of Ébrié System) [23]	Koumassi lagoon bay (Lagoon area III of Ébrié System) [24]	Biétri lagoon bay (Lagoon area III of Ébrié System) [24]	All the lagoon bays of Abidjan district (Lagoon area I of Ébrié System) [22]	Lagoon areas II and III of Ébrié System) [25]
As	41.15					19.25	
Cd	0.91		5.57			7.85	0.75
Cu	46.75	14.77	25.13	< 0.005	< 0.005		54.02
Cr	0.92	65.43		< 0.090	< 0.040	138.34	
Fe	1609.38		34.50	8.065	8.860		
Hg	0.75		0.50				
Mn	3.37	131.95	391.87	< 0.050	< 0.050		
Ni	57.75	56.70		< 0.050	< 0.050		13.42
Pb	12.53	54.85		< 0.010	< 0.010	59.33	118.88
Zn	5.90	46.68	60.32	4.455	0.605	245.73	132.33

3.2. Discussion

The particle size distribution of these superficial sediments from this lagoon area would be essentially due to its hydromorphology. Indeed, its bathymetry, dominated by depths less than -3 m, would favor mostly the retention of the coarse sands [18-19]. So, its siltation would be disadvantaged, unlike to Abouabou bay lagoon located in the lagoon area III of Ébrié system [19,39] and Adjin lagoon [40,41], both having depths of between -6 and -14 m. According to Akobe et al. [42], these sands, of continental origin, come from fluvio-lagoon transport short-term and reworking of the sands in their catchment areas. In the case of this lagoon area, its sedimentary inputs are coming from Comoé river [18-20], Mé river, Adjin lgoon and, Potou lagoon [40-41;43]. Added to this are the sedimentary inputs from the reworking of the sands on the banks of this lagoon estuary by meteorite runoff waters. According to Irié et al. [19], the coarse fraction of these substrates is dominated by quartz at 83%. Its fine fraction is by non-clay minerals, essentially composed by quartz at 46.22%, and kaolinite at 53.78%. This could essentially explain the low organic content of these superficial sediments during all this period. Biogeochemical processes and the reducer character of its open waters, particularly that of its open water at the water-sediment interface [12-14], contribute to the reduction of organic into these substrates. The dominance of these superficial sediments by coarse sand would lead to the obtaining of their medium moisture content.

The dynamics of the particle size distribution of the superficial sediments of this lagoon estuary and that of their physical and chemical characteristics are dependent on seasonal exogenous inputs, just as in the case of the open waters of this aquatic ecosystem, particularly the open waters at the interface water-sediment [12,14].

In HS, the relative important marine influence from Atlantic Ocean on this lagoon area would lead to a coarse texture of these substrates very slightly dominated by very coarse sands and an relatively important presence of fine sands. This would be explained by the physical and biogeochemical phenomena induced by these marine inputs on the sands brought mainly during FS by Comoé river. In this season, the relatively important presence of these marine waters, of slightly basic and reducing characters, with relatively high salinity, conductivity and organic matter content, would have contributed significantly to the modification of the physical and chemical characteristics of these superficial sediments. This would have been the case with the inputs from the lagoon area III that these marine waters bring to this estuary in this season [12]. So, it would be explain the very slightly basic and reducing characters and, the relatively important salinity, conductivity and organic matter content of these superficial sediments in this season. The low presence of slit and clay in these superficial sediments contribute to the obtaining of their low moisture content.

In RS, the water inputs are dominated by those of meteorite runoff waters, Mé river, Adjin lagoon, Potou lagoon and, Comoé river, inhibiting partially the influence of Atlantic Ocean on this lagoon area [12,14]. The same would apply to sedimentary inputs. The reworking of the banks of this lagoon ecosystem by meteorite runoff waters and the sedimentary inputs of Mé river, Adjin lagoon, Potou lagoon and, Comoé river would supply this lagoon area with more very coarse sands, as well as silt and clays. So, this would lead to the obtaining of the highest value of their very coarse sands content in this period. These meteorite sedimentary inputs would induce the increase in their silts and clays content in one hand, and the very slight decrease in their medium and coarse sand content, as well as that of their fine sands content, related to previous season, on other. These meteorite waters inputs are slightly acidic and oxidizing, but also desalinated and weakly mineralized. This is especially the case for Mé river, Adjin lagoon, Potou lagoon [45,46] and, Comoé river [26]. This same would be true for their sedimentary inputs. This would justify the very slight acidic and oxidizing characters of these superficial sediments, as well as the decrease in their organic matter content in this season compared to the previous season. Their relative high salinity and conductivity in this season contrast with the desalinated and weakly mineralized characters of these meteorite waters inputs in this season. This would probably be explained by the spread in most of this lagoon estuary of waters and/or sediments with relative high salinity and conductivity trapped in its pits from -6 to 14 m [20] under the effect of these meteorite inputs. The increase in their slit and clay content would contribute to the obtaining of the highest value of their moisture content.

In FS, the same phenomena observed in RS would occur, but with a less marked amplitude. This would be explained by the dominance of the meteorite inputs by those of Comoé river. The dominance of the sediments of this river by coarse and medium sands [18-20] would result in a relatively high presence of these minerals in these superficial sediments compared to that of very coarse sands. This situation would be accompanied by the slightly increase in their clay and silt content and by the slightly decrease in their fine sand content in this season compared to the previous season. The corollaries of the inputs from this river are also the slightly increase in their acidity, unlike the slightly decreases in their oxidizing character, salinity and, conductivity, due to the weakly acidic and oxidizing, desalinated and weakly mineralized characters of the waters of this river

[26], as well as their sedimentary inputs. The high presence of aquatic plants, drain by this river into this lagoon area [12-14], contributed to the slightly increase in their organic matter content of these substrates in this season compared to the previous season, the most important obtaining in this period [12,14]. these sedimentary inputs would contribute to the slightly decrease in their moisture content.

The very important seasonal and annual Fe contents of these superficial sediments simultaneously with those of their coarse sandy fractions throughout this period could be explained by the high dominance of these sandy fractions by quartz [19]. Indeed, this mineral, belonging to the group of silicates, has a strong affinity with Fe due to its structure [47,48]. The very slightly acidic to neutral and oxidizing characters of these substrates, as well as their high Fe content over most of this period, would have been conducive to the adsorption and/or precipitation of other trace metals on and/or with Fe and its (oxy)hydroxides, especially As, Cd, Ni and, Zn [50,51]. The pH of these substrates in this period would be favorable in the presence of Cr into them, because this trace metal is stable under CrO_4^{2-} form at pH above 6.5 [51]. So, this would have explained their relatively high Cr content in this period. The relatively low Mn contents of these substrates throughout this period contrast with their relatively high Fe contents in this period, because these two trace metals are highly present in the Ivorian geological and sedimentary basement according to Kokoa et al. [52] and Wrohou et al. [53]. Their relatively low Mn contents could be explained by their low slits and clay contents, given the strong affinity of this trace metal with this sedimentary fraction [50]. Also, the very slightly acidic and oxidizing characteristics of these substrates over the most of this period would contribute to the solubilization of Mn within them, which under these conditions is 6 to 7 times greater than that of Fe [54]. This would have been unfavorable to a significant formation of the precipitates and/or the insoluble complexes of these trace metals, especially As, Cd, Cr, Ni and Zn, with Mn and its (oxy)hydroxides of Mn [50,51]. The Acidic to neutral and slightly oxidizing characters are unfavorable to the stability of carbonates [55]. This would have contributed to their relatively low Pb, Cd and, Zn contents in this period, given the high affinity of these trace metals with carbonates [51], especially in slits and clay [15,50]. Their relatively high Ni contents in this period could also be explained again by the instability of the carbonates in this pH, since the solubility of Ni would be due to the carbonates in the form of $NiCO_3$ from sediments [51]. Their relatively high As contents could be explained by the high presence of this trace metal in the form of arsenates, due to their very slight to neutral acidity and oxidizing characters over the most of this period [51,56]. Their relatively low organic matter content would have contributed weakly to the presence of these trace metals into these substrates under the form of insoluble organometallic complexes [51]. Their relatively low conductivity would favor the presence of these trace metals into them by the decrease of competition effect of the other major cations with these metal ions onto its different adsorption sites [57]. It would be the same for their relatively low salinity, also reflecting the low presence of halogens in them, which would favor the decrease in solubility of the trace metals in these substrates. This would be the case of Cd and Hg, by their low solubility in the form of halides of Cd and Hg, in particular in the form of $CdCl_2$ and $HgCl_2$ [51]. However, the relatively important organic matter content in the open waters of this lagoon estuary, especially those of the open waters at the interface water-sediment [12,14], would have partially favored the solubilization of these trace metals from these sediments under the form of soluble organometallic complexes. This would be especially so for Cu, which has a complexing affinity with the soluble forms of fulvic and humic acids by the contact of these open waters with these sediments [51]; thus leading to their low Cu content in this period. Also, the relative important Fe and Mn contents of the waters at the interface water-sediment [12,14], would also have contributed to the partial decrease in their trace metals contents [49,50]. It would also the case for relative important sulphide content [58,59], reducing character [50,51] and, conductivity [57] of these open waters. The same would be true for the relatively important salinity of these open waters, which partially contribute to the decrease of the trace metal contents of these superficial sediments, especially those Cd and Hg by their partial solubility in the form of $CdCl_2$ and $HgCl_2$ [51]. For the particular case of Hg, the salinity of these open waters would favor their solubilization from the hydrolyzed species of the mercuric ion [60]. This would have contributed more to obtaining their low Cd and Hg contents in this period. The relatively medium moistures of these sediments and those of temperatures of this lagoon area [12,14] would play important roles in all these processes mentioned above during all this period [50,51].

In HS, the marine inputs, rich in these trace metals [21], would contribute to the metallic enrichment of these superficial sediments, as well as those of the lagoon area III also rich in these trace metals [22-23; 25]. The very slightly basic and reducing characters of these superficial sediments would favor their relatively important Fe content and; that of their Mn content in these substrates, which was the highest obtained in this season over this period [54]. This process would contribute to the presence of the other trace metals studied in these superficial sediments in the form of precipitates and/or insoluble complexes with Mn and Fe, but also with their (oxy)hydroxides [50,51]. This would be especially so for As, Cd, Cr, Ni and, Zn. Also, these very slightly basic and reducing characters would be very conducive to the formation of insoluble complexes and/or precipitates of metal sulphides [58-59], given the eutrophic nature of this lagoon estuary [17]. This would be again for carbonates, stable in these condition [55], particularly by the formation of insoluble carbonate complexes with Pb, Cd, Cr and, Zn in these substrates. The relatively low content of organic matter of these substrates would weakly contribute to this presence of these trace metals by the formation insoluble organometallic complexes. These different processes would have contributed to the obtaining of relatively important values of their trace metals contents, especially those Cd, Cu, Hg, Mn and, Pb which were the highest obtained in this season during this study period. However, the reducing nature of these substrates would have partially inhibited the contents of these trace metals by reduction of the organic matter [51]. This would also have been the case for the relative high dissolved organic matter, conductivity and salinity of the open waters at the water-sediment interface [14], which through contact with these superficial sediments would further affect their trace metals contents by their solubization [51,57], particularly their Cu, Hg and Cd contents [51]. Also, the probable significant carbonates and sulphides dissolved in these open waters, due to their very slight basicity [14], would have contributed to this process, particularly to the solubilization of Pb, Cd and, Zn from these superficial sediments [51]. In the particular case of As, the very slight basicity, probable reducing character and the relatively important organic matter content of these open waters in this season [14] would have partially favored its volatilization from these superficial sediments through the formation of arsines (AsH_3) and arsenate methylation [51,56]. This would be again the case of the slightly basicity and reducing character of these sediments, but very weakly due to their relatively low organic matter content. These reactions would contribute with those mentioned above to the obtaining of their lowest As content in this season during this period.

In RS, the very slight acidity and oxidizing character of these superficial sediments, due to the continental inputs, would have resulted in a relatively high solubility of Mn from them. This would have been especially so for Fe [54], given their lower Fe content obtained in this season over the study period. These processes would therefore lead to a decrease in the formation of precipitates and/or insoluble complexes of other trace metals with Fe and Mn, as well as with their oxides in these substrates [50,51]. Also, the decrease in the carbonates content of these superficial sediments, due to their pH, would also have contributed to this process, particularly in the decrease in their Pb, Cd and, Zn contents related to those determined the previous season [51]. Their oxidizing character in this season will also be favorable for the solubilization of these trace metals from these superficial sediments following the oxidation of sulphides into sulphates [58,59]. This would also be the increase in their salinity and conductivity, which would particularly affect their Hg and Cd contents [51,57] on the one hand, and the decrease in their organic matter content [51] in this season, on the other hand. This would also have been the case for very slight basicity [51], the increases in conductivity [57] and organic matter content of the open water at the water-sediment interface [14]. These processes would have more affected their Cd, Cu, Hg, Ni, Pb and, Zn contents, which were the lowest obtaining in this season over this period. However, the slightly acidic of these sediments would have mainly contributed to the increase in their Cr content in this season related to that determined in HS, due to the stability of this metal in the trivalent chromium form at pH values below 6.5 [51]. Their pH and slightly oxidizing character would also explain the increase in their As compared to the previous season, as they would favor the reduction of As volatilization [51,56]. The decrease in the salinity of these open waters would also have contributed to the reduction in the solubilization of these trace metals in these substrates [51].

In FS, the very slight acidity and oxidizing character of these superficial sediments, less important than those obtained in RS, would have led to an increase in their Fe content and a decrease in that of Mn compared to RS [54]. This would have been favorable to the presence of these trace metals in these substrates by the formation of insoluble complexes and/or precipitates of these trace metals with Fe and its oxides, but less with Mn and its oxides [50,51]. Also, the decreases in their salinity and conductivity would have contributed to this process [51,57]. The very slight oxidizing character, the decreases in salinity and conductivity of the open waters at the water-sediment interface relative to those obtained the previous season [14] would have favored the presence of these trace metals in these substrates. This could explain the increase in their Cd, Cu, Pb and, Zn contents in this season in comparison to those determined in RS. This would be especially for their As content, which was the highest obtained in this season during this period, less volatile from these substrates in these physical and chemical conditions [51,56]. These facts would have been partially inhibited by the partial solubilization of these trace metals from these superficial sediments, following the reduction of sulphides into sulphates [58,59], the instability of carbonates at this pH [55]. Their low organic matter would contribute to this. Cr, Ni and, Hg would seem to be more affected by these reactions in these substrates this season in view of the decrease in their Cr and Ni contents and, the non variation of their Hg content compared to those obtained in RS.

The low mean annual of the Cr, Mn, Pb and, Zn of these superficial sediments in this period with regard to those obtained by Keumean et al. [15] could be explained by the phenomenon of self-purification. Indeed, this lagoon estuary is one of the hypereutrophic area of Ébrié system [17]. So, the high presence of aquatic plants, increasing over the years and due to its poor renewal [12], would lead to an intensive manifestation of this phenomenon. This would hide by their relative important Cu and Ni contents. This would also be the case of its high pollution due to meteorite inputs, especially those of Comoé river which is responsible for 2/3 of the metal pollution of Ébrié system [61]. The high renewal of Koumassi and Biétri lagoon bays by the marine inputs from Atlantic Ocean, located near to Vridi channel (single entrance pass of the marine inputs into Ébrié system during this period [12,14]) would explain their low metal contamination [24] relative to this lagoon estuary, very far from this channel. However, the strong anthropogenic pressures on Abidjan district lagoon bays, receiving all kind discharges in their majority, would cause their relatively important metal pollution [22] in addition to that linked to Comoé river in SCr. All these metal inputs in zones II and III of this system would result in their relatively high metal pollution [25].

3. Conclusion

This study were highlighted the very important effects of the water inputs in the dynamic of trace metals in the superficial sediments from surface waters. In the particular case of the superficial sediments from the lagoon area II of Ébrié system, the marine inputs would favor their trace metals contents; unlike the meteorites inputs on the whole. For the real assessment of the metal pollution status of this lagoon area, this study should be continuous by the assessment of the ecological and health risks due to the pollution metal of its superficial sediments. It is the same for the distribution and mobility of trace metals in these substrates in one hand and, the assessment of flux exchange of trace metals at the interface water-sediment from this aquatic ecosystem, on other.

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