Metal pollution, ecological and health risks status of the open waters from the lagoon area II of Ébrié system (Côte d'Ivoire)

.

ABSTRACT

The assessments of the seasonal metal pollution, as well as the subsequent likely ecological and health risks, of the open waters from the lagoon area II of Ébrié system were the subject of this study. For this purpose, the seasonal mean of As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn contents of these waters determined over the period from June 2020 to May 2021 were used. The water quality guidelines SEQ-Eau (version 2) and NQE DCE-UE 2018/240 were used to assess the seasonal ecological quality of these waters. As for the seasonal biota health risks, they have been assessed with the water quality guidelines of NYSDEC, US-EPA and SAVEX. Those concerning to Human health risks, they were with WQSSW of Port Gamble S'Klallam tribe. The results showed an important ecological degradation of these waters in all seasons. This has been due to As, Cd, Hg, Ni, and Pb. The likely biota health risks are also significant in all seasons, due to As, Hg, Ni, and Pb. As for the likely Human health risks, they are also important in all seasons. They are due to As, Hg, and Ni over the study period.

Keywords: Côte d'Ivoire, Ébrié system, metal pollution, open waters pollution, water quality guidelines.

1. INTRODUCTION

Because of the accessibility to their resources, surface waters have always been favorable centers for the establishment of Human and its activities. However, the implementation, modernization and development of anthropogenic activities, as well as the rapid demographic growth in their watershed, are the subject of many socio-ecological controversies, due to their pollution. This situation leads in many cases to their important ecological degradation, with the consequences of the loss and/or decline of their biodiversity and the existence of serious health risks on their biota, thus on Humans [1, 2]. Indeed, in the Sub-saharan Africa, surface waters in the whole, and coastal surface waters in particular, are the receptacle for anthropogenic discharges of all kinds without and/or partial treatment. This situation has been illustrated by many recent works, including those of [3], [4] and [5].
One of the specific forms of chemical pollution of coastal aquatic ecosystems is metal pollution. Unlike petroleum-derived hydrocarbons and macro solid wastes, the pollution of which is visible to the naked eye [6,7], that linked to trace metals is done surreptitiously [8]. Studies related to the metal pollution of sediment and the subsequent likely ecological and health risks are widely documented and updated in comparison with those of the open waters from surface waters, which are poorly documented. So, the assessments of metal pollution of these waters and its consequences always remain a major axis of scientific research. To achieve this purpose, several WQGs are commonly used, including: [9], [10], [11,12], [13-18], [19] and [20]. Sub-Saharan Africa in the whole, and Côte d'Ivoire in particular, don't have specific WQGs for the assessment of the open waters quality from surface waters. The existing ones are mainly intended for residual and/or industrial discharges. This fact is compensated by the simultaneous use of several WQGs, such as those mentioned above, for a better estimation of the metal pollution and consequences of the open waters from surface waters.

Located at the extreme East of Ébrié system, the lagoon area II is subject to strong anthropogenic pressures, highlighted by [21] with its high nutrient pollution. Few studies relating to its metal pollution have been conducted on its metal pollution. Nevertheless, those available are concern to the studies of [22], which showed very little pollution of its sediments at the beginning of the last decade. Also, the studies of [23], noticed a relatively high presence of As, Cd, Cr, Cu, Hg, Mn, Ni, Pb, and Zn in its open waters. No information relating to the status of pollution and ecological and health risks linked to the metal pollution of its open waters is available. Given the important socio-economic, ecotourism and ecological roles of this lagoon area in Côte d'Ivoire, it is necessary to unequivocally assess the status of the quality of its open waters related to metal pollution. Our main objective is to assess the metal pollution level of its open waters and its likely consequences. The secondary objective of this study concern to the assessment of the seasonal ecology quality of these open waters by using some physical and chemical other than trace metals.

2. MATERIAL AND METHODS

2.1 Characteristics of the study area

The lagoon area II of Ébrié system is located within latitudes 5°200000-5°21176471 N and longitude 3°400000-3°500000 W. It extends over 17.143 km with an average width of 5.714 km. Its water surface is around 87 km^2. It is one of the six lagoon areas of this lagoon system established by [24] taking into account its hydrology (Figure 1).

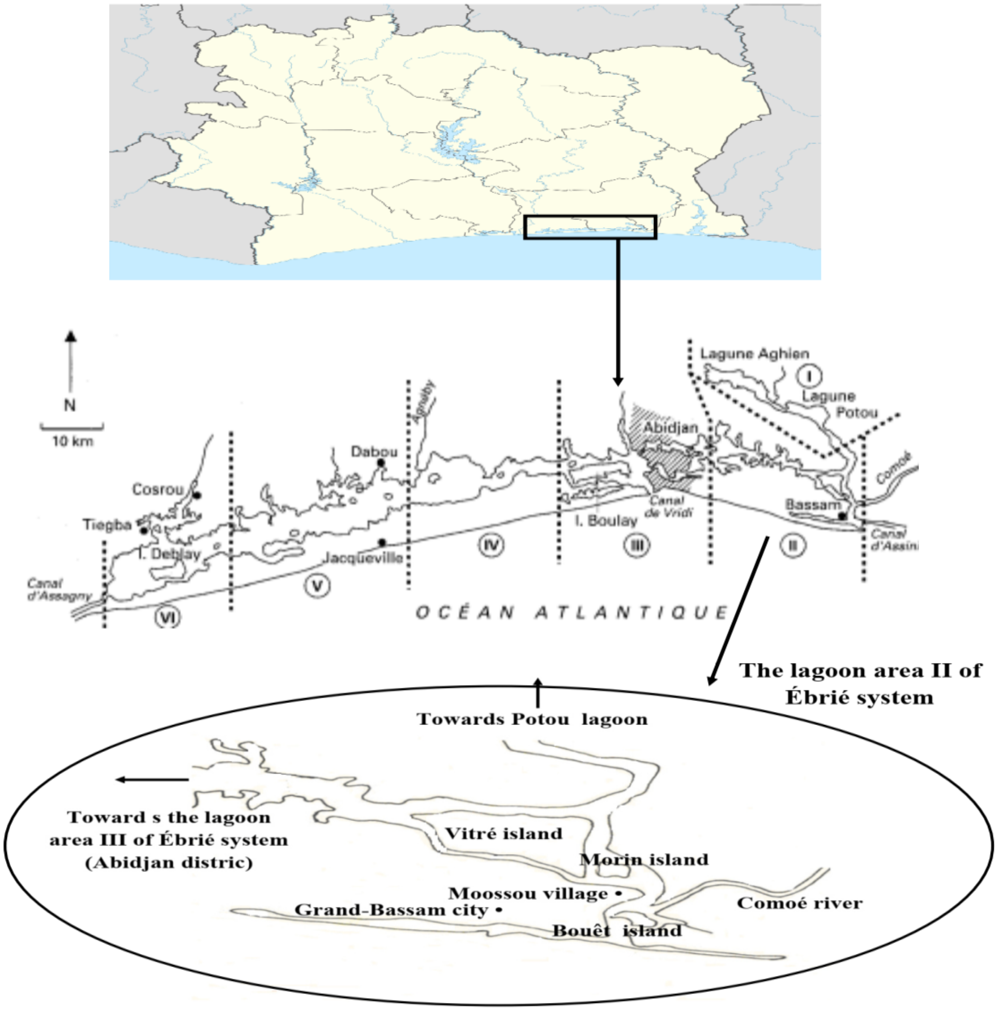

Figure 1: the study area.

As mentioned by [23], the hydrology of this lagoon area is dominated by the continental water inputs from Comoé and Mé rivers on the one hand, and the marine waters inputs from Atlantic Ocean, on the other. The water inputs from Comoé river, which is the most important river of Côte d'Ivoire, are constant throughout the year in the study area, with a maximum influence during the period from August to December when it is observed its only annual flood [25]. As for Mé river, its influence on the study area is only significant during its two annual floods: the first from June to July (the most important) and the second from October to November (coinciding with the small rainfall on land and the flooding of Comoé River) [26]. However, given the greatest watershed of Comoé river (78,000 km^2) [25] relative to that of Mé river (4,300 km^2) [26], the influence of Comoé river is very predominant in the study area compared to that of Mé river. The marine waters from Atlantic Ocean enter in this lagoon area by Vridi canal, located in the area harbor of Abidjan district. Nevertheless, they are less important than those carried out by this ocean in lagoon area II, but which remain very important to the lagoon area I and from III to IV [24]. The marine influence is important during the great terrestrial dry season (from December to April). The water seasons of this lagoon area are as follows: Hot Season (HS), from December to April; Rainy Season (RS) from May to July; and Flood Season (FS).

The vegetation on its watershed is dominated by agro-industrial plantations (oil palm, coconut, pineapple, rubber, etc.) [27]. This reflects the strong anthropogenic pressures of agricultural origin exerted on this aquatic ecosystem. This fact is accentuated by strong urbanization, punctuated by the development of human activities of all kinds. So, it is the receptacle of anthropogenic discharges of all kinds, without prior treatment due to the non-existence of a real sanitation system. It is also the receptacle for pollutants of all kinds during spring tides from Abidjan district, where the open waters from the lagoon area III and Atlantic Ocean are extremely polluted by trace metals [28-30]. Added to this is the pollutants carried by Comoé river, which according to [31] is responsible for two thirds of the metal pollution of Ébrié system. This situation is amplified by mining activities, especially by illegal gold panning [32].

2.2 Implementation of this study

2.2.1 Assessment of the seasonal ecological quality and health risks due to metal Pollution

2.2.1.1 Assessment of the seasonal ecological qualities by using some physical and chemical parameters other than trace metals

The assessment of the seasonal ecological qualities of these open waters was done taking into account the seasonal mean values of their pH, salinity, conductivity, transparency and, dissolved oxygen and TOC contents. For this purpose, these seasonal mean values were compared to those defined values for the different ecology qualities of coastal surface waters according to [9].

2.2.1.2 Assessment of metal pollution level and its likely ecological and health risks

The seasonal mean of As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn contents of these open waters were used for the assessment of the level of their seasonal metal pollution and the subsequent likely ecological and health risks. So, these seasonal mean of trace metals contents were compared to those defined values for the different qualities of coastal surface waters according to [9], [10], [11-12], [13-18], [19] and [20].

2.2.2 Source of the data used

All the seasonal and annual means values of physical and chemical parameters used in this study were obtained by [23] over the period from June 2020 to May 2021 in the open waters from the lagoon area II of Ébrié system.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Seasonal ecological qualities of these waters based on some physical and chemical parameters other than trace metals

The results (Table 1) show this lagoon area is still useful for biological activity and its uses for sports and leisure over the entire study period. This would be particularly in RS and FS, with the exception of their transparency, temperature, and dissolved oxygen content which contrast in HS, and particularly for the temperature over the study period.

Table 1. Seasonal ecological qualities of the open waters from the study area according to [9] by using some physical and chemical parameters other than trace metals

Physical and chemical Parameters	Seasons	Mean ±s [23]	Biological aptitude	Water quality by Alteration**
Temperature (°C)	HS	32.373±0.645	Very poor quality water	Very poor quality water
	RS	28.884±1.700	Medium quality water	Medium quality water
	FS	28.314±0.646	Medium quality water	Medium quality water
	Annual	29.581±1.703	Very poor quality water	Very poor quality water
*pH	HS	8.308±0.060	Good quality water	Good quality water
	RS	7.179±0.890		
	FS	6.816±0.274		
	Annual	7.457±0.812		
Transparence (m)	HS	0.705±0.288	Medium quality water	Very Poor quality water
	RS	0.477±0.336	Poor quality water (RS, FS, Annual)	
	FS	0.301±0.184		
	Annual	0.496±0.177		
Dissolved oxygen (mg/l)	HS	3.541±0.180	Poor quality water	Poor quality water
	RS	5.192±1.480	Medium quality water (RS, FS, Annual)	Medium quality water
	FS	4.509±1.062		
	Annual	4.343±10.127		
TOC (mg/l C)	HS	10.264±0.103	Medium quality water	Medium quality water
	RS	10.640±0.318		
	FS	10.499 ± 0.218		
	Annual	10.471±0.255		

* The value of pH is considered in the conditions of macrophytes proliferation.
** The assessments of the aptitude biology and use for leisure of these open waters simultaneously are carried out by crossing many physical and chemical parameters grouped in 16 indicators, called alterations.

3.1.2 Metal pollution level and likely health risks in the open waters from the study area

3.1.2.1 Contamination level of the open waters from the study area relative to those from some bays of the lagoon area III of Ébrié system

In Table 2, the open waters from of the bays of Biétri, Cocody and Koumassi have higher of these trace metals contents than those of the study area, with the exception of those in Pb and Ni. This suggests an important metal pollution, in particular in Cd, Cr, Cu, Fe, Mn, and Zn of the open waters from these lagoon bays compared to those from the study area.

Table 2. Contamination level by some trace metals of the open waters from some bays of the lagoon area III relatively to that of the open waters from the study area

Trace metals	Open waters from the study area [23] (µg/l)	Open waters from the bay of Cocody [29] (µg/l)	Open waters from the bay of Biétri [28] (µg/l)	Open waters from the bay of Koumassi [28] (µg/l)
Cd	1.2	30-47		
Cr	1.4	5-132	< 5	< 5
Cu	2.4	79-91	7.87	< 5
Fe	32	50-172	91.8	288
Mn	6.6		< 50	< 50
Ni	97		< 50	< 50
Pb	30	0-96	< 10	< 10
Zn	11.7	36-376	< 50	73.8

3.1.2.2 Seasonal ecological qualities of the open waters from the study area due to its metal pollution

The open waters from the study area present a highly degraded ecological state due to As, Cd, Hg, Ni, and Pb in all its water seasons according to [9] (Table 3) and [10] (Table 4). However, their ecological state is good and medium in all its water seasons taking their seasonal Cu and Zn contents respectively according to [10]. This is the opposite according to [9].

In the whole, these two WQGs provide the alarming ecological state of these open waters over the study period.

Table 3. Seasonal ecological qualities of the open waters from the study area related to some trace metals according to [9]

Trace metals	*Evaluation grid by alteration of water quality relating to biological suitability and uses (threshold value)					Seasonal and annual mean values of the open waters from the study area [23] (µg/l)		Ecological quality of the open waters from the study area
	Very good quality (µg/l)	Good quality (µg/l)	Medium quality (µg/l)	Poor quality (µg/l)	Very poor quality (µg/l)			
As	1	35	70	100	> 100	HS	72.2	Poor
						RS	75.2	
						FS	72.0	
						Annual	73.0	
**Cd	0.001	0.01	0.1	0.37	> 0.37	HS	2.5	Very poor
						RS	1.9	
						FS	1.5	
						Annual	1.9	
Cr	0.04	0.4	3.6	50	> 50	HS	1.8	Medium
						RS	1.2	
						FS	1.2	
						Annual	1.4	
**Cu	0.017	0.17	1.7	2.5	> 2.5	HS	3.5	Very poor
						RS	2.1	Poor
						FS	1.7	Medium
						Annual	2.4	Poor
Hg	0.007	0.07	0.7	1	> 1	HS	9.7	Very poor
						RS	7.3	
						FS	5.1	
						Annual	7.1	
**Ni	0.25	2.5	20	40	> 40	HS	106.8	Very poor
						RS	88.8	
						FS	95.8	
						Annual	97.0	
**Pb	0.21	2.1	21	50	> 50	HS	42.6	Poor
						RS	26.3	
						FS	24.3	
						Annual	30.4	
Zn	0.23	2.3	23	52	> 52	HS	15.5	Medium
						RS	10.9	
						FS	9.5	
						Annual	11.7	

*The assessments are carried out by crossing many physical and chemical parameters grouped in 16 indicators, called alterations.

** Data relating to waters having their $CaCO_3$ content ≤ 50 mg/l.

Table 4. Seasonal ecological qualities of the open waters from the study area related to some trace metals according to [10]

Trace metals	Seasonal and mean values of the open waters from the study area [23] (µg/l)		*NQE-MA (µg/l)	Ecological quality of the open waters from the study area	**NQE-MCA[2] (µg/l)	Ecological quality of the open waters from the study area
As	HS	72.2	0.83	Very poor		
	RS	75.2				
	FS	72.0				
	Annual	73.0				
Cd	HS	2.5	0.20	Very poor		
	RS	1.9				
	FS	1.5				
	Annual	1.9				
Cr	HS	1.8	3.40	Very poor		
	RS	1.2				
	FS	1.2				
	Annual	1.4				
Cu	HS	3.5	1.00	Good		
	RS	2.1				
	FS	1.7				
	Annual	2.4				
Hg	HS	9.7	0.07	Very poor	0.07	Very poor
	RS	7.3				
	FS	5.1				
	Annual	7.1				
Ni	HS	106.8	8.60	Very poor	34.00	Very poor
	RS	88.8				
	FS	95.8				
	Annual	97.0				
Pb	HS	42.6	1.30	Very poor	14.00	Very poor
	RS	26.3				
	FS	24.3				
	Annual	30.4				
Zn	HS	15.5	7.80	Poor		
	RS	10.9				
	FS	9.5				
	Annual	11.7				

*NQE-MA, water quality standard relating to the Maximum Admissible (MA) of the annual mean content of surface water other than inland surface waters.
**NQE-MA, water quality standard relating to the Maximum Content Admissible (MCA) of surface waters other than inland surface waters.

3.1.2.3 Seasonal biota health risks in the open waters from this ecosystem due to its metal pollution

Referring to [13-18] and [19], Cr, Cu, Fe, and Zn were not likely to have any adverse effects on the biota health of this aquatic ecosystem over the study period. However, Hg, Ni, and Pb were likely to have significant adverse effects on its biota during the same period according to these WQGs. This has been especially shown for Pb by [11-12]. Concerning to As, unlike in Cd, was likely to have significant adverse effects on its biota over the study period, according to [17,18] (Table 5). It has been the opposite if it refers to [19] (Table 6) for this trace metal.

In the whole, all the WQGs used in this case underline that the open waters from this lagoon ecosystem are likely to have significant adverse effects on its biota linked to its metal pollution, particularly by As, Hg, Ni, and Pb.

Table 5. Seasonal biota health risks due to some trace metals in the open waters from the study area according to [11,12], [13-18] and [20]

Trace metals	Threshold values for chronic effects (mg/l)	Threshold values for acute effects (mg/l)	Seasonal and mean values of the open waters from the study area [23] (mg/l)		Likely biota health risks
As	0.036 [17,18]	0.069 [17,18]	HS	0.0722	Possibility of pathogens with acute effects
			RS	0.0752	
			FS	0.0720	
			Annual	0.0730	
Cd	0.093 [14;17]	0.043 [14;17]	HS	0.0025	No adverse effects
			RS	0.0019	
			FS	0.0015	
			Annual	0.0019	
Cr	0.05 [14;17]	1.1 [14;17]	HS	0.0018	No adverse effects
			RS	0.0012	
			FS	0.0012	
			Annual	0.0014	
Cu	0.0037 [17]	0.0058 [17]	HS	0.0035	No adverse effects
			RS	0.0021	
			FS	0.0017	
			Annual	0.0024	
Fe	1.3 [20]	3.4 [20]	HS	0.0373	No adverse effects
			RS	0.0294	
			FS	0.0291	
			Annual	0.0316	
Hg	0.0011 [17]	0.021 [17]	HS	0.0097	Possibility of pathogens with acute effects
			RS	0.0073	
			FS	0.0051	
			Annual	0.0071	
Ni	0.083 [14,17]	0.075 [14;17]	HS	0.1068	Possibility of pathogens with chronic effects
			RS	0.0888	
			FS	0.0958	
			Annual	0.0970	
Pb	0.0085 [16;17]	0.22 [11,12] [16,17]	HS	0.0426	Possibility of pathogens with acute effects
			RS	0.0263	
			FS	0.0243	
			Annual	0.0304	
Zn	0.086 [15;17]	0,095 [15;17]	HS	0.0155	No adverse effects
			RS	0.0109	
			FS	0.0095	
			Annual	0.0117	

Table 6. Seasonal biota health risks due to some trace metals in the open waters from the study area obtaining according to [20]

Trace metals	Seasonal and mean values of the open waters from the study area [23] (µg/l)		Threshold values for acute effects (Criteria maximum content) (µg/l)	Threshold values for chronic effects (Criteria continuous content) (µg/l)	Likely biota health risk
As	HS	72.2	340	150	No adverse effects
	RS	75.2			
	FS	72.0			
	Annual	73.0			
Cd	HS	2.5	2.0	0.25	Likely chronic effects in RS, FS and over the study period; like acute effects in HS.
	RS	1.9			
	FS	1.5			
	Annual	1.9			
Cr	HS	1.8	Cr(VI) 16 Cr(III) 570	Cr(VI) 11 Cr(III) 74	No adverse effects
	RS	1.2			
	FS	1.2			
	Annual	1.4			
Cu	HS	3.5	13	9	No adverse effects
	RS	2.1			
	FS	1.7			
	Annual	2.4			
Fe	HS	37.3		1000	No adverse effects
	RS	29.4			
	FS	29.1			
	Annual	31.6			
Hg	HS	9.7	1.4	0.77	Likely chronic effects
	RS	7.3			
	FS	5.1			
	Annual	7.1			
Ni	HS	106.8	470	52	Likely chronic effects
	RS	88.8			
	FS	95.8			
	Annual	97.0			
Pb	HS	42.6	65	2.5	Likely chronic effects
	RS	26.3			
	FS	24.3			
	Annual	30.4			
Zn	HS	15.5	120	120	No adverse effects
	RS	10.9			
	FS	9.5			
	Annual	11.7			

3.1.2.4 Seasonal Human health risks due in the open waters from this ecosystem due to its metal pollution

Only As and Hg constitute likely serious Human health risks through the use of these water as drinking water and the ingestion of their halieutic resources, as shown in the results in Table 7.

Table 7. Seasonal Human health risks due to some trace metals in the open waters from the study area obtaining according to [20]

Trace metals	Seasonal and mean values of the open waters from the study area [23] (µg/l)		Water and organisms (µg/l)	Organisms only (µg/l))	Human health risk or no
As	HS	72.2	0.005	0.006	Likely significant adverse effects by ingestion of aquatic organisms and by the use of these waters as a drink
	RS	75.2			
	FS	72.0			
	Annual	73.0			
Fe	HS	37.3		300	No adverse effects due to ingestion of aquatic organisms only
	RS	29.4			
	FS	29.1			
	Annual	31.6			
Hg	HS	9.7	0.002	0.002	Likely significant adverse effects by ingestion of aquatic organisms and by the use of these waters as a drink
	RS	7.3			
	FS	5.1			
	Annual	7,1			
Ni	HS	106.8	160	210	No adverse effects by in ingestion of aquatic organisms and by the use of these waters as a drink
	RS	88.8			
	FS	95.8			
	Annual	97.0			

3.2 Discussion

The use of [9] for classifying the ecological quality of the open waters from the study area based on its seasonal temperatures showed their medium to very poor ability for overall biological productivity over the study period. However, these temperatures, especially that in HS, couldn't be so alarming because of the location of the study area in a tropical zone. In fact, like the whole of Ébrié system, this tropical lagoon area has a biological diversity that would be dominated by species with a high tolerance to these temperature values (eurytherms) [33]. The good quality of these waters due to their pH according to [9] in all its water seasons is essentially due to the simultaneous presence of meteorites and marine waters in one hand, and the intense biogeochemical activities taking place there, on other [23]. As for the transparency of these open waters, which aren't conducive to biological production over the study period according to [9]. This would explain by the turbid quality of the meteorites inputs and by the anarchic proliferation of aquatic plants [34, 35]. This situation is also true for the entire Ébrié system, one of its characteristics [24]. This fact, affecting autotrophic organisms and consequently the biodiversity of surface waters [35], wouldn't seem to limit biodiversity in this tropical lagoon system dominated by non-autotrophic organisms [28;36]. The intense biogeochemical phenomena would be responsible for the medium oxygenation of these open waters. This would be shown by their relative important TOC contents. These phenomena would lead to a medium suitability for biological production of these waters in RS and FS based on their dissolved oxygen and TOC contents, and in HS according to their TOC contents in accordance with [9]. In HS, the degradation of macrophytes, particularly *Eichhornia crassipes specie*, drained by Comoé river in this ecosystem in FS [23] and favored by the saline rise and the relatively high temperatures in this season [37], would lead to their relatively high deoxygenation; consequently to their poor quality for the biological activities according to [9] in this season. In the whole, these physical and chemical characteristics of these open waters can't alter the biological productivity within them, due to their specificities as tropical lagoon waters.

Embedded in Abidjan district, the lagoon area III of Ébrié system is its area most subject to strong anthropogenic pressures. So, it is the receptacle for pollutants of all kinds from all activities in different sectors such as harbor, industrial, peri-urban agricultural activities, as well as residual effluents [38,39]. Added to this are those brought by Mé and Agnéby coastal rivers and Comoé river which pass through it during their various floods to reach Atlantic Ocean. By exchanges and/or diffusion of pollutants with the open waters from the lagoon areas II and IV, the open waters from the lagoon area III partially affect their pollution level in the whole, and their metal pollution in particular. In addition to this supply of trace metals in the lagoon area II, there are those drained by Comoé and Mé rivers in this area [23]. The same is true of those from agro-industrial and mining activities, especially that of illegal gold panning [32]. So, these anthropogenic pressures on this lagoon area, less significant than those exerted on lagoon area III, would be illustrated by the low metal pollution of its open waters [23] with respect to those of the open waters from the bay of Cocody [29] and, the bays of Koumassi and Biétri [28], all belonging to the lagoon area III.

Although being subject to less significant anthropogenic pressures than those exerted on the lagoon area III, the fact remains that the lagoon area II presents a state of very significant ecological degradation, due to its metal pollution over the study period. This would have been mainly by especially by As, Cd, Hg, Ni, and Pb in all its water seasons, so over the period, as attested simultaneously by [9] and [10]. This observation would confirm the origin of the metal pollution of this lagoon area, mainly of agricultural and mining activities, as already mentioned by [23]. This situation would be accompanied by likely serious biota health risks due to Hg, Ni, and Pb, as shown by [14;16,17] and [19]. That would especially by Pb according to [11,12]. This situation is also true for As according to [17,18]. These waters present likely serious Human health risks as drinking water, but also by the ingestion of its halieutic resources, due to As and Hg according to [19]. In this case study, the likely Human health risks would be only by the ingestion of its halieutic resources, because these waters aren't used for drinking in the study area.

4. CONCLUSION

This study made it possible to highlight the biological suitability of the open waters from the lagoon area II of Ébrié system due to some physical and chemical parameters. However, these waters present an advanced degradation state due to its metal pollution, particularly by As, Cd, Hg, Ni, and Pb. So, it presents likely serious biota health risks due to As, Hg, Ni, and Pb in particular over the study period. This is the case for likely Human health risks, which are very significant and essentially due to As, Hg, and Ni over the study period. This study deserves to be completed for a complete evaluation of its state of metal pollution, particularly by studying the metal pollution of its superficial sediments and that of the metal contamination level of its biota.

ACKNOWLEDGEMENTS

The authors thank the governing authorities of National Drinking Water Office of Côte d'Ivoire (ONEP) and the techniques staff of Water Quality Analysis and Control Laboratory (LACQUE) of this institute for their invaluable help in carrying out of this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

AUTHORS' CONTRIBUTIONS

MAHI Agolé Mahi Arthur designed this study, performed the sampling and managed the analyses. He also wrote the first draft.
YAO Marcel Konan performed the statistical analysis, managed the analyses and contributed for the results and discussion.
CLAON Jean Stéphane manage the analyses and contributed for the results and discussion.
TROKOUREY Albert contributed to the results and discussion.

REFERENCES

[1] Foley M, et al. Anadromous fish as biomarkers for the combined impact of marine and freshwater heavy metal pollution. Ecotoxicology of Environment Safety. 2022;230:113153. https://doi.org/10.1016/j.ecoenv.2021.113153

[2] Polechońska L, et al. Evaluation of Nuphar lutea as bioindicator of metal pollution in freshwater ecosystems. Ecological Indicators. 2022;136:108633. https://doi.org/10.1016/j.ecolind.2022.108633

[3] Akindele EO, Ehlers SM, Koop JHE. First empirical study of freshwater microplastics in West Africa using gastropods from Nigeria as bioindicators. Limnologica. 2019;78:125708. https://doi.org/10.1016/j.limno.2019.125708

[4] Mvovo I. A comprehensive review on micro plastic pollution in African aquatic systems. Environmental Advances. 2021;5:100107. https://doi.org/10.1016/j.envadv.2021.100107

[5] N'Souvi K, et al. Fisheries and aquaculture in Togo: Overview, performance, fisheries policy, challenges and comparative study with Ghana, Mali, Niger and Senegal fisheries and aquaculture. Marine Policy. 2021;132:104681. https://doi.org/10.1016/j.marpol.2021.104681

[6] Kapelewska J, et al. Water pollution indicators and chemometric expertise for the assessment of the impact of municipal solid waste landfills on groundwater located in their area. Chemical Engineering Journal. 2021;359:790-800. https://doi.org/10.1016/j.cej.2018.11.137

[7] Uddin S, et al. Petroleum hydrocarbon pollution in sediments from the Gulf and Omani waters: Status and review. Marine Pollution Bulletin. 2021;173(Pt A):112913. DOI: 10.1016/j.marpolbul.2021.112913

[8] Melghit M. Qualité physico-chimique, pollution organique et métallique des compartiments Eau/Sédiments de l'Oued Rhumel, et des barrages Hammam Grouz et Beni

Haroun. Mémoire de Magister. Université Constantine 1, République populaire d'Algérie. 2012. French.

[9] MEDD et Agence de l'eau. Système d'Évaluation de la Qualité des Eau (SEQ-Eaux), grilles d'évaluation (version 2). 2003. French

[10] NQE DCE-UE (240/2018). Décision d'exécution (UE) 2018/840 de la Commission du 5 juin 2018 établissant une liste de vigilance relative aux substances soumises à surveillance à l'échelle de l'Union dans le domaine de la politique de l'eau en vertu de la directive 2008/105/CE du Parlement européen et du Conseil et abrogeant la décision d'exécution (UE) 2015/495 de la Commission. Journal Officiel de l'Union Européene L153. 2018;9-12. French.

[11] NYSDEC (New York State Department of Environmental Conservation). Final Report NYSDEC Niagara River Implementation Plan. January 1985 - March 1987, New York State, US. 1988.

[12] NYSDEC (New York State Department of Environmental Conservation). Final Report NYSDEC Niagara River Implementation Plan. January 1985 - March 1987, New York State, US. 1991.

[13] US-EPA (United States-Environmental Protection Agency). Ambient Water Quality Criteria for Chromium-1984. U.S.EPA, Washington, D.C. PB85-227478. 1985.

[14] US-EPA (United States-Environmental Protection Agency). Water Quality Criteria; Availability of Documents, Notice of final ambient water quality criteria documents: Chlorpyrifos, Nickel, Pentachlorophenol, Parathion, Toxaphene. Fed Regist. 1986;51(232):43665-43667.

[15] US-EPA (United States-Environmental Protection Agency). Emergency and hazardous chemical inventory forms and community right-to-know reporting requirement, final rule. Fed Regist. 1987;52(199).

[16] US-EPA (United States-Environmental -Protection Agency). Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States Compliance, Final rule. Fed Regist. 1992;57(246):60848-60917.

[17] US-EPA (United States-Environmental Protection Agency). National Recommended Water Quality Criteria; Republication, Notices. Fed Regist. 1998;63(237):68354-68364.

[18] US-EPA (United States-Environmental Protection Agency). National Recommended Water Quality Criteria. Office of Water, Office of Science and Technology. 2006.

[19] WQSSW (Water Quality Standards for Surface Waters) of Port Gamble S'Klallam tribe. Resolution No. 02-A-088 adopted August 13. 2002.

[20] SAVEX (Service des avis et des expertises). Note technique sur 9 pesticides et sur le fer. Direction du suivi de l'état de l'environnement, ministère de l'Environnement du Québec, Canada. 2000. French

[21] Bamba SB, et al. État de l'environnement lagunaire de l'île Vitré (Grand-Bassam): Aspects physique, Chimiques et biologiques. Revue Ivoirienne des Sciences et Technologies. 2008;12:77-92. French.

[22] Keumean KN, et al. Concentration en métaux lourds des sédiments de l'estuaire du fleuve Comoé à Grand-Bassam (Sud-Est de la Côte d'Ivoire). Journal of Applied Biosciences. 2013;61:4530–4539. French. DOI: 10.4314/jab.v61i0.85599

[23] Mahi AMA, et al. Seasonal dynamics of trace metals in the waters from the lagoon area II of Ébrié system (Côte d'Ivoire). Journal of Global Ecology and Environment. 2022;14(4):1-17.

[24] Durand JR, Guiral D. Hydroclimat et hydrochimie. In: Environnement et ressources aquatiques deCôte d'Ivoire. Tome II – Les milieux lagunaires. Durand J. R., Dufour Ph., Guiral D, Zabi S Eds. 1994;59-90. French.

[25] Ouattara I, et al. Processus de minéralisation des eaux souterraines et transfert de flux en milieu de socle fissuré: cas du bassin versant transfrontalier de la Comoé (Côte d'Ivoire, Burkina Faso, Ghana, Mali). International Journal of Innovation and Applied Studies. 2016;17(1):57-69. French.

[26] Yao KL. Apport du modèle 6R4J à la modélisation des bassins versants en milieu tropical humide: cas du bassin Versant de l'Agnéby à Agboville(Côte-d'Ivoire). Mémoire de Master des Sciences de l'Environnement, Université Nangui-Abrogoua, Abidjan, Côte d'Ivoire. 2016. French.

[27] Kouamé D, et al. Flore et végétation du littoral Est de la Côte d'Ivoire et potentiel de conservation de la biodiversité en zone d'activités anthropiques. REB-PASRES. 2016;01:25-34. French.

[28] CEMA. Projet d'aménagement du carrefour Akwaba dans la commune de Port-Bouët Abidjan. Étude de la qualité du milieu aquatique. 2018. French.

[29] Inza B, Yao KM. Paramètres physiques et chimiques et métaux lourds des eaux de la Lagune Ebrié (Côte d'Ivoire): influence de la marée et des effluents liquides urbaines. Journal of Materials and Environmental Science. 2015;6(5):1321-1329. French.

[30] Oura LE, et al. Spatial distribution of heavy metals in sediments of the Ivory Coastal zone (Toukouzou Hozalem-Assinie) in correlation with anthropic activities. Chemestry and Ecology. 2021;38(1):72-94. DOI: 10.1080/02757540.2021.2013475

[31] Pottier P, et al. La lagune Ébrié à l'épreuve de la pression anthropique. In book: Géographie du littoral de Côte d'Ivoire, éléments de réflexion pour une politique de gestion intégré, Géolittomer - La Clonerie Eds. 2018;165-184. French.

[32] Kouyate K, et al. Typologie de la pêche et production de *Synodontis Membranaceus* (Geoffroy Saint-Hilaire, 1809) au niveau de la rivière Bagoué (Côte d'Ivoire). European Scientific Journal. 2021;17(21):150-169. French. https://doi.org/10.19044/esj.2021.v17n21p150

[33] Guiral D. L'instabilité physique, facteur d'organisation et de structuration d'un écosystème tropical saumâtre peu profond: la lagune Ébrié. Vie et Milieu/Life & Environnement, Observatoire Océanologique - Laboratoire Arago. 1992:73-92.

[34] Amorim CA, Moura AN. Ecological impacts of freshwater algal blooms on water quality, plankton biodiversity, structure, and ecosystem functioning. Science of the Total Environment. 2021;758:143605. https://doi.org/10.1016/j.scitotenv.2020.143605

[35] Zhang R, et al. Impact of water quality variations on the microbial metagenome across coastal waters in Shenzhen, south China. Ocean & Coastal Management. 2021; 208: 105612. DOI: 10.1016/j.ocecoaman.2021.105612

[36] Villanueva MC. Biodiversité et relations trophiques dans quelques milieux estuariens et lagunaires de l’Afrique de l’ouest: Adaptations aux pressions environnementales. Thèse de l’Institut National Polytechnique de Toulouse (INPT), France. 2004. French.

[37] Yao MK. Évaluation et modélisation du phénomène d'eutrophisation dans une baie lagunaire apparenté lacustre: Cas de la baie lagunaire de Tiagba (Côte d'Ivoire), Thèse de l'Université Félix Houphouët-Boigny, Abidjan, Côte d'Ivoire. 2011. French.

[38] Yao MK, Trokourey A. Fractionation distribution and ecological risk assessment of some trace metals in artificial estuary: Vridi channel (Côte d'Ivoire). Advances in Natural and Applied Sciences. 2018a;12(6):1-6. DOI: 10.22587/anas.2018.12.6.1

[39] Yao MK, Trokourey A: Influence de l’hydroclimat sur la dynamique saisonnière de certains éléments traces métalliques dans un estuaire marin : Cas d’étude. Journal de la Société Ouest-Africaine de Chimie. 2018b;045: 31-41. French.