

Evaluation of Metal Contamination in Water, Sediments, and *Crassostrea rhizophorae* from Water Bodies in Southern Benin

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How to cite this paper: Hounsa, J., Hounkpatin, A.S.Y., Sakirigui, A., Gnamy, R.S., Houndeton, D.A.G. and Hounsou, S. (2025) Evaluation of Metal Contamination in Water, Sediments, and *Crassostrea rhizophorae* from Water Bodies in Southern Benin. *Journal of Environmental Protection*, 16, 965-978.

<https://doi.org/10.4236/jep.2025.169051>

Received: August 19, 2025

Accepted: September 27, 2025

Published: September 30, 2025

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Abstract

Wetlands, particularly the lagoon complex “Lake Nokoué-Lagune de Porto-Novo”, are under severe threat from anthropogenic activities, notably the use of agricultural chemicals. To assess pollution in these ecosystems, a sampling campaign was conducted, involving the collection and analysis of 36 water, sediment and oyster samples. The study focused on three trace metals: lead (Pb), cadmium (Cd) and mercury (Hg), analyzed by atomic absorption spectrometry at the Environmental Geochemistry Laboratory of the University of Lomé, using the flame technique (SAA iCE 3000 SERIES THERMO FISHER) for lead (Pb) and cadmium (Cd) and the flameless technique (SAA iCE 3000 SERIES + VP100) for mercury (Hg). The average concentrations recorded are concerning, exceeding accepted standards. The mean concentrations of cadmium, lead and mercury were 0.0047 mg/L (Cd), 0.390 mg/L (Pb) and 0.0535 µg/L (Hg) in water; 0.2415 mg/L (Cd), 46.439 mg/L (Pb) and 0.2498 µg/L (Hg) in sediments; and 2.329 mg/L (Cd), 3.850 mg/L (Pb) and 0.0479 µg/L (Hg) in oysters from the Ouémé, all significantly above the permissible limits. The stations in Littoral and Atlantic show high concentrations of lead and mercury in water, reaching 0.3775 mg/L (Pb) and 0.0405 µg/L (Hg) in Littoral and 0.110 mg/L (Pb) and 0.1356 µg/L (Hg) in the Atlantic. Sediments are less contaminated, but oysters exhibit elevated levels of cadmium and lead, 2.374 mg/L (Cd) and 3.845 mg/L (Pb) respectively. These results indicate alarming contamination, particularly in oysters, posing a risk to human health and the eco-

logical balance of the lagoon complex.

Keywords

Heavy Metals, Aquatic Ecosystem, Oysters, Benin

1. Introduction

Contamination of ecosystems by trace elements remains a serious and increasingly concerning environmental issue. Surface waters occupy the largest part of the Earth, with approximately 98% being marine waters and the remaining 2% constituting continental waters, represented by rivers, lakes and ponds [1]. In the context of the current population explosion, human activities represent one of the main causes of the degradation of aquatic ecosystems. Worldwide, many water bodies have been irreversibly damaged by point and diffuse pollution.

Trace metals are chemical substances naturally found in the environment in negligible concentrations (less than 100 parts per million or 100 µg/g) [2]. Rivers receive significant amounts of material from their watersheds [3]. The degradation of water quality in aquatic ecosystems is an increasingly important issue in Benin, as elsewhere in the world, particularly in the context of climate change, where water resources are limited, fragile and threatened [4]. Water quality is defined according to its intended use [5] [6].

A healthy aquatic ecosystem is essential for the sustainability of fishery products and for ensuring safe food for the population [7] [8]. It is evident that the health status of Beninese surface waters continues to be influenced by pollution accumulated in sediments by trace elements. Sediments serve as habitats and breeding grounds for numerous aquatic organisms and store a wide variety of pollutants, including heavy metals and polycyclic aromatic hydrocarbons. These pollutants can affect water quality for long periods, compromising the survival of aquatic organisms, disrupting their hormonal or immune systems, altering their genetic makeup, or causing tumors [9] [10].

Numerous studies have highlighted sediment contamination by trace elements. Among the main lake pollutants, heavy metals such as Al, Fe, Mn, Ni, Zn, Cu, As, Cr, Cd, Pb and Hg are often found, with some (Cd, Pb, Mg, As and Cr) being highly toxic even at low doses [11]. Studies evaluating chemical pollution of the Mékrou River by trace elements reveal high cadmium concentrations, whereas zinc, copper and lead levels remain relatively below the permissible limits [11], [12].

Furthermore, several studies have been conducted on water bodies in southern Benin to evaluate the impact of heavy metals on ecosystems, particularly surface waters, agricultural products, sediments and fishery species [7] [13] [14], as well as their bioaccumulation in aquatic animal species [14]. In Benin, oysters (*Crassostrea rhizophorae*), commonly called “Adakpin” in Fongbé and “Atcha”

in Aizo, are consumed and marketed by local populations and are exploited in Lake Nokoué [15], where increasing human activities lead to trace element pollution in aquatic ecosystems [16].

Little is known about the quality of this species consumed by the population, and documentation is limited. Therefore, this study was conducted to assess the ecology and quality of the water bodies in the Lake Nokoué-Lagune de Porto-Novo complex regarding heavy metals (Cd, Pb and Hg) in southern Benin, aiming to establish a baseline database on these xenobiotics.

2. Materials and Methods

Study Area (Figure 1)

The Lake Nokoué-Lagune de Porto-Novo complex is located in southeastern Benin, between latitudes 6° 25' and 6° 30' N and longitudes 2° 20' and 2° 40' E. Lake Nokoué covers an area of 160 km², while the Porto-Novo lagoon spans 20 km². This complex represents the largest brackish water area in Benin. Lake Nokoué has a depth ranging from 0.4 to 3.5 m and is directly connected to the Atlantic Ocean via the Cotonou channel or lagoon, which is approximately 4.5 km long and 300 m wide.

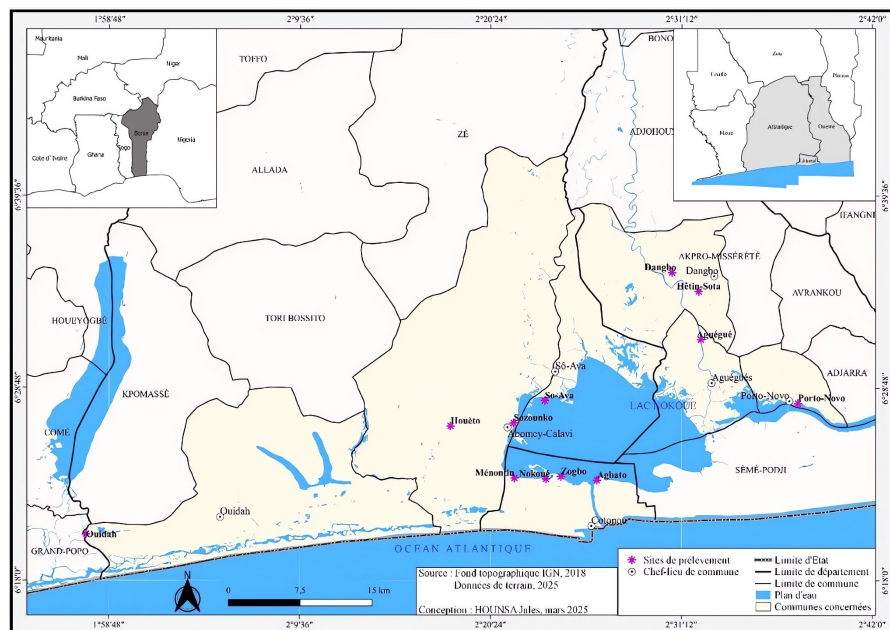


Figure 1. Map showing the Sampling Points. Source: Field Data, March 2025.

The Lake Nokoué-Lagune de Porto-Novo complex receives freshwater from the Ouémé River and the So River, which contribute to water level increases. The Porto-Novo lagoon, much smaller (35 km²), is largely connected to the west with Lake Nokoué through the Totchè canal, which is about 5 km long and 200 - 300 m wide and to the east with the Lagos lagoon via a canal nearly 100 km long and 20 - 50 m wide [17]. The Ouémé River delta separates the two lagoons.

The Lake Nokoué-Lagune de Porto-Novo complex experiences a subequatorial climate characteristic of southern Benin, with two dry seasons and two rainy seasons. The hydrological regime is characterized by a flood period, theoretically extending from September to December and a low-water period from December to July [17]. The duration of floods varies depending on whether the Cotonou channel is closed or open and on the amount of rainfall [17].

Sampling and Analysis

The three matrices (water, sediments and oysters) were sampled in three zones, with four sampling stations per zone: Atlantic (Gbezoumè, So-Ava, So-Zounko and Houéto); Littoral (Zogbo, Mènantin, Agbato, Nokoué) and Ouémé (Dangbo, Aguégué, Hêtin).

Samples were taken early in the morning using a canoe. A total of 36 samples were collected, consisting of 4 samples from each matrix at four different sites within the department, i.e. 12 samples per component in the 3 departments. Composite samples of each matrix were taken at each site during sampling. The water was collected in sterilized 1.5L plastic bottles, the sediments were packaged in 500mL polyethylene bags and the oysters were wrapped in aluminum foil. Each sample was labeled and then stored at 4°C using accumulators in a cooler, before being transported to the laboratory for analysis.

The treatment was carried out at the Waste Management, Treatment and Recovery Laboratory (GTVD) of the University of Lomé (Togo), Lead and cadmium were analyzed by Atomic Absorption Spectrophotometry (Thermo Orion assisted by Solaar S2 software). As for mercury, the analysis was done by the Molecular Absorption Spectrophotometer according to the HACH method (HACH-LANGE DR 2800) after mineralization and extraction by cold steam.

Oyster tissues and sediments were recovered, air-dried in the laboratory away from dust, ground and sieved through a 63 µm mesh [18]. They were then mineralized in Teflon tubes at 120°C using a diacid digestion (nitric acid and hydrochloric acid in a 1:3 volume ratio) on a hot plate. After cooling to ambient temperature, the mineralized solution was diluted with distilled water and filtered into a polypropylene tube.

The concentrations of trace elements (Cd, Pb, Hg) in water, sediments, and oysters were determined from the mineralized solution using Atomic Absorption Spectrophotometry (AAS). Flame AAS (iCE 3000 SERIES THERMO FISHER) was used for cadmium (Cd) and lead (Pb), while cold vapor AAS (iCE 3000 SERIES+VP100) was employed for mercury (Hg) at the Environmental Geochemistry Analysis Laboratory (AGE) of the University of Lomé, following the method described by [19]. Analytical validity was ensured through internal quality control using procedural blanks and standard solutions.

Data Processing and Analysis

The data were entered and processed using R software for statistical analysis. Means and standard deviations were calculated as descriptive statistics. Compliance tests were conducted using Student's t-test at a 5% significance level. Subse-

quently, the obtained means were compared with Beninese and WHO standards for water and oysters and with Environmental Quality Standards (EQS) for sediments.

The data from the heavy metal analysis were entered using Excel 2016. After data cleaning, they were imported into R software version 3.6.1. The variables were standardized (centered and scaled) in order to eliminate the influence of differences in measurement units. The PCA was performed on the correlation matrix using R 3.6.1. The principal components retained were those with eigenvalues greater than 1 and that cumulatively explained more than 70% of the total variance. The factorial maps were then generated and interpreted to identify relationships among variables and groupings of samples.

3. Results and Discussion

Table 1 shows the mean concentrations of the trace elements (Cd, Pb and Hg) measured in water samples from the sampling stations.

Table 1. Mean concentrations (\pm standard deviation) of trace elements (TEs) in water sampling stations.

Contents	Sites			P
	Atlantic	Littoral	Ouémé	
Cd (mg/L)	0.0010 ^b \pm 0.0008	0.0007 ^b \pm 0.0001	0.0047 ^a \pm 0.0002	0.008
Water Pb (mg/L)	0.1100 ^b \pm 0.0967	0.3775 ^a \pm 0.0236	0.3900 ^a \pm 0.0408	0.018
Hg (μ g/L)	0.1356 ^a \pm 0.0001	0.0405 ^b \pm 0.0001	0.0535 ^c \pm 0.0001	0.001

Source: Hounsa, 2024.

The analysis of **Table 1** shows that the water samples from the three sites—Atlantic, Littoral, and Ouémé contain higher levels of Pb compared to Cd and Hg. The average metal concentrations in the water samples from the three sites follow the order: Pb > Hg > Cd. The highest average concentration of Cadmium is observed in the Ouémé samples (Cd = 0.0047 mg/L). In contrast, the average concentrations of Pb and Hg in the water samples from the Atlantic (Pb = 0.11 mg/L; Hg = 0.1356 μ g/L), Littoral (Pb = 0.3775 mg/L; Hg = 0.0405 μ g/L), and Ouémé (Pb = 0.3900 mg/L; Hg = 0.0535 μ g/L) exceed 0.01. **Figure 2** presents a comparison of the trace element concentrations relative to the accepted threshold values.

Through the analysis of this figure, except for the average Cadmium (Cd) concentration in water samples from the Atlantic and Littoral sites, the mean Cadmium level in samples from the Ouémé site far exceeds the WHO threshold of 0.003 mg/L. The average concentrations of Lead (Pb) and Mercury (Hg) in water from all three sampling sites—Atlantic, Littoral and Ouémé, are significantly higher than the WHO thresholds of 0.01 mg/L for Pb and 0.006 mg/L for Hg.

Regarding sediments, the average metal concentrations in sediment samples collected from the different sites are presented in **Table 2**.

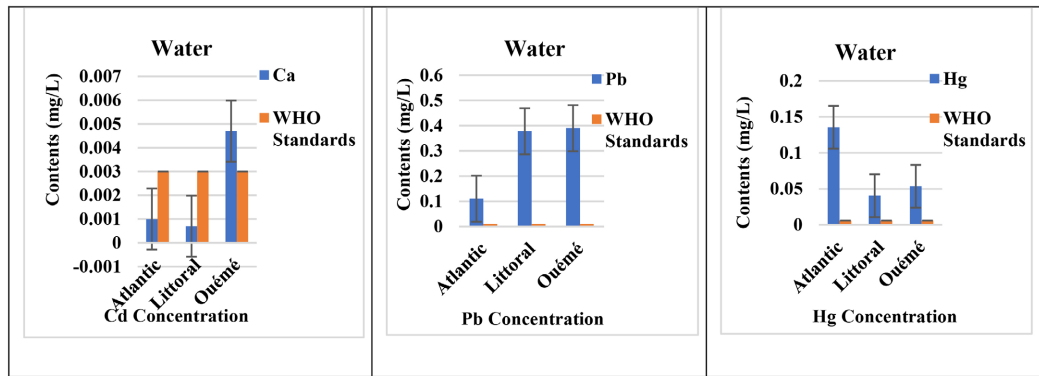


Figure 2. Distribution of trace element concentrations in water samples relative to the accepted thresholds. Source: Hounsa, 2024.

Table 2. Average concentrations (\pm standard deviation) of trace elements in sediment sampling stations.

Teneurs	Sites			P
	Atlantique	Littoral	Ouémé	
Cd (mg/L)	0.1523 ^a \pm 0.1119	0.1998 ^b \pm 0.0135	0.2415 ^c \pm 0.0043	0.001
Sediments Pb (mg/L)	20.637 ^a \pm 0.515	24.362 ^b \pm 0.635	46.439 ^c \pm 0.358	0.001
Hg (μ g/L)	0.0053 ^a \pm 0.0001	0.1245 ^b \pm 0.0202	0.2498 ^c \pm 0.0185	0.001

Source: Hounsa, 2024.

Table 2 shows that the highest concentrations of Cd, Pb and Hg in sediment samples 0.2415 mg/L, 46.439 mg/L and 0.2498 μ g/L, respectively—are found at the Ouémé site stations. Furthermore, the concentrations of Pb and Cd, 46.439 mg/L and 0.2415 mg/L respectively, are more than twice as high as those observed at the Littoral and Atlantic sites. Except for the Atlantic site, which records a very low Hg concentration (0.0053 μ g/L), there is a significant difference between the Ouémé (0.2498 μ g/L) and Littoral (0.1245 μ g/L) sites.

Figure 3 presents a comparison of the distribution of trace metal concentrations in sediments relative to the permissible thresholds.

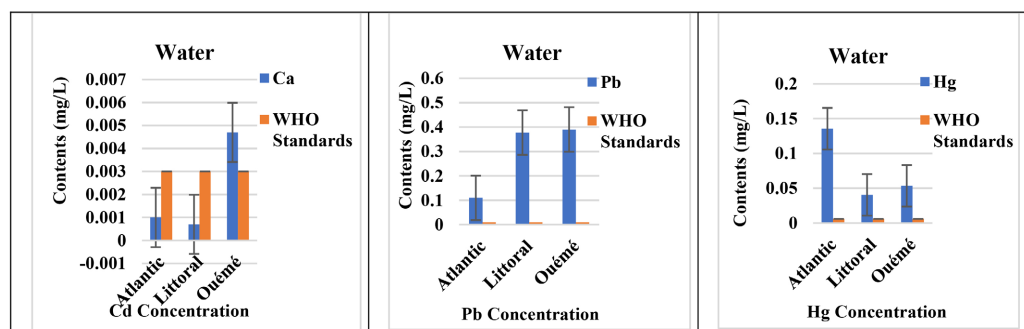


Figure 3. Distribution of trace metal concentrations in sediments relative to the permissible limits. Source: Hounsa, 2024.

Based on **Figure 3**, the measured concentrations are below the NQE standards across the three sampling sites: Atlantic, Littoral and Ouémé. The cadmium (Cd) levels in the sediments comply with the environmental quality standards (Cd = 0.6 mg/L), suggesting no significant cadmium pollution at these sites. Lead (Pb) concentrations are slightly below or close to the NQE standard (Pb = 35 mg/L), with a slightly higher concentration observed at the Ouémé sites, indicating anthropogenic pressure from urban or industrial activities. Mercury (Hg) concentrations are slightly above the NQE standard (Hg = 0.17 mg/L) at the Littoral and Ouémé sites, while slightly below at the Atlantic site, which could pose ecotoxicological risks and requires environmental monitoring. **Table 3** presents the average concentrations of trace metals in oyster samples collected from the different sites.

Table 3. Average concentrations (\pm standard deviation) of trace metals in oyster sampling stations.

Contents	Sites			P
	Atlantique	Littoral	Ouémé	
Oysters Cd (mg/L)	2.374 \pm 0.126	2.027 \pm 0.0867	2.329 \pm 0.183	0.208
Oysters Pb (mg/L)	3.845 \pm 0.971	3.770 \pm 0.450	3.850 \pm 0.238	0.995
Oysters Hg (μ g/L)	0.0221 ^b \pm 0.0016	0.0961 ^a \pm 0.0015	0.0479 ^b \pm 0.0140	0.001

Source: Hounsa, 2024.

Figure 4 below illustrates the comparison with the accepted standards.

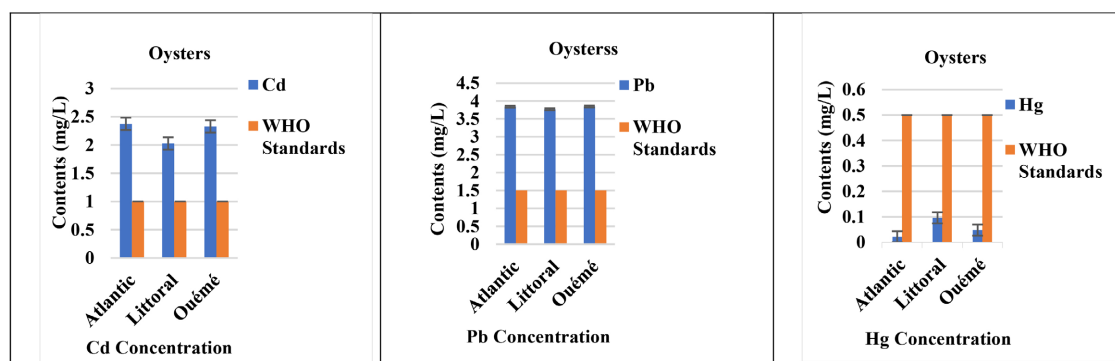


Figure 4. Distribution of trace element contents in oysters compared to the permissible limits. Source: Hounsa, 2024.

The concentrations of Cd and Pb in all three sites are well above the WHO standards. The Cd levels show a significant deviation from the recommended limit (1 mg/L). Similarly, Pb exhibits a deviation of 2.82 mg/L from the recommended value (1.5 mg/L). This indicates a potential health risk associated with the consumption of oysters by the local population.

In contrast to Cd and Pb, Hg concentrations in the samples from the Atlantic (0.0221 μ g/L), Littoral (0.0961 μ g/L) and Ouémé (0.0479 μ g/L) are significantly

below the WHO recommended limit (0.5 µg/L).

Figure 5 presents the Principal Component Analysis (PCA) of trace element distribution in water, sediments, and oysters.

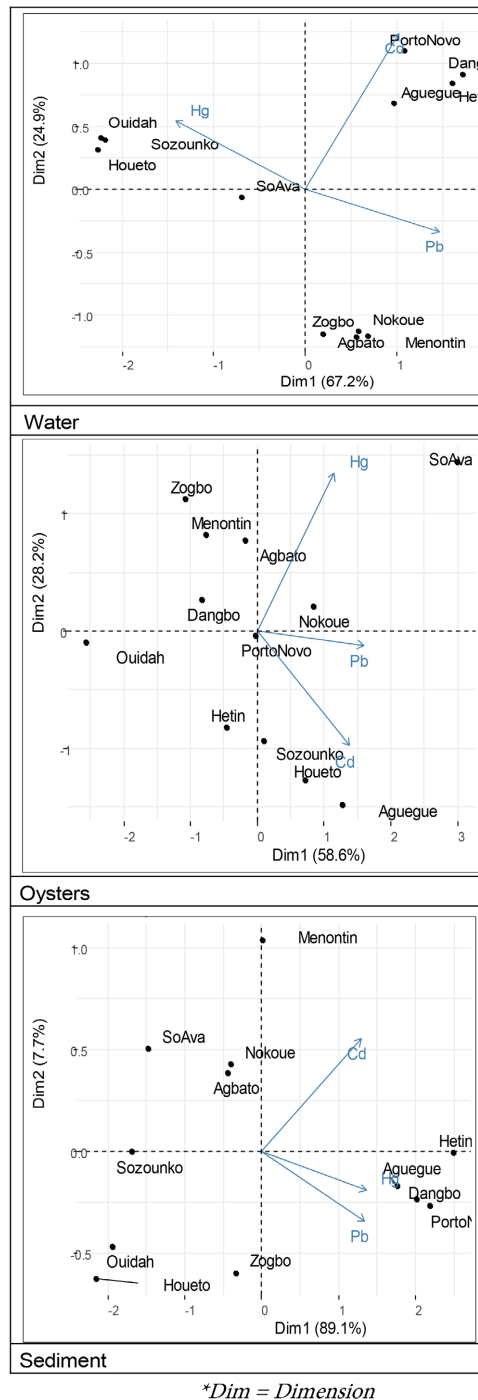


Figure 5. Principal Component Analysis (PCA) of Trace Element Distribution. Source: Hounsa, 2024.

The results of the Principal Component Analysis show that the first two prin-

principal components explain 92.10%, 86.80% and 96.80% of the data variability for water, oysters, and sediments, respectively.

For water, Cd and Pb are strongly represented (at least 60%) and positively correlated with the first principal component, while Hg is negatively correlated with this component. The stations of Porto-Novo, Dangbo, and Hêtin are characterized by high Cd concentrations. Stations of Sozounko, Ouidah, and Houèto are characterized by high Hg values and low Pb values. Stations of Zogbo, Agbato, Nokoué, and Menontin show low Hg concentrations.

For sediments, all metals are strongly and positively correlated with the first principal component. Stations of Ouidah, Sozounko, So-Ava, and Houèto are characterized by low Hg, Cd and Pb values, while Porto-Novo, Dangbo, Hêtin, and Aguégué stand out with high Pb, Hg and Cd levels. Zogbo and Menontin show intermediate values.

Similarly, for oysters, all metals are strongly and positively correlated with the first principal component. The Ouidah station shows low Pb values, whereas Aguégué is distinguished by high Cd concentrations. So-Ava station is characterized by high Hg content.

4. Discussion

The contamination of water bodies with a wide range of pollutants has become a major concern over the past decades. Except for Cd, the concentrations of Pb and Hg in the sampling stations of the Atlantic (Pb = 0.11 mg/L; Hg = 0.1356 µg/L) and Littoral (Pb = 0.3775 mg/L; Hg = 0.0405 µg/L) sites are high and significantly above the accepted standards (Cd = 0.003 mg/L, Pb = 0.01 mg/L and Hg = 0.006 mg/L) [20]. Comparing these results with previous studies, they are similar to those reported by [1] [12], et [21] in the Mékrou and Houeyiho rivers, respectively.

The study of trace metal elements in water reveals contamination by Cd (0.0085 mg/L) and Pb (4.8 mg/kg), with concentrations exceeding European standards (Cd = 0.003 mg/L, Pb = 0.01 mg/L et Hg = 0.006 mg/L). Similarly, studies on the spatio-temporal variations of pollution in the Porto-Novo lagoon confirm high concentrations of Fe, Cd, Pb, Hg, Cr and Mn, with average values of 3.56 mg/L, 0.10 mg/L, 2.35 mg/L, 4.99 mg/L, 4.16 mg/L and 3.42 mg/L, respectively [22].

The presence of these concentrations could be explained by poor management or the discharge of untreated domestic and industrial wastewater into water bodies. The average concentrations of cadmium (0.0047 mg/L), lead (0.39 mg/L) and mercury (0.0535 µg/L) observed in water samples from the Ouémé stations are significantly above the recommended limits [20], consistent with results obtained by [23] in the same lake and by [24] in their assessment of agricultural contamination of surface waters in the upper Ouémé. Water quality degradation in these water bodies may be linked to the extensive use of chemical fertilizers [25] [26].

The results of heavy metal analysis in sediments, except for cadmium (0.2415 mg/L), show that the average concentrations of lead (46.439 mg/L) and mercury

(0.2498 µg/L) in Ouémé stations are significantly higher than those reported in Lake Ahémé (Pb: 21.316 mg/kg) [27] and in Lake Nokoué [28] [29]. Anthropogenic activities release chemicals into the environment, which can penetrate aquatic ecosystems and integrate into suspended matter. Heavy metals in sediments arise from wastewater discharges, runoff from agricultural dumps near lagoon systems, road transport and the trafficking of adulterated fuels [10] [28]. Over time, these particles settle on the bottom materials and contaminants may accumulate. Sediments can therefore act as an endogenous source of water pollution through remobilization.

Low average heavy metal concentrations in sediments were recorded in the Atlantic samples (Cd: 0.15 mg/L; Pb: 20.637 mg/L; Hg: 0.0053 µg/L) and Littoral samples (Cd: 0.1998 mg/L; Pb: 24.362 mg/L; Hg: 0.1245 µg/L) and these values are below the environmental quality standards (NQE) (Cd = 0.6 mg/L; Pb = 35 mg/L; Hg = 0.17 mg/L). Furthermore, these concentrations are lower than those reported by [14] [24] at Aguigadji (rainy season: Cd 3.02; Pb 265.96; Hg 0.25; dry season: Cd 2.32; Pb 255.38; Hg 0.04), Ahlan (rainy season: Cd 3.00; Pb 235.70; Hg 0.46; dry season: Cd 2.12; Pb 231.48; Hg 0.08), Sele (rainy season: Cd 2.10; Pb 209.05; Hg 0.43; dry season: Cd 1.97; Pb 188.67; Hg 0.03) and Toho (rainy season: Cd nd; Pb 0.43; Hg nd; dry season: Cd 0.06; Pb 0.24; Hg nd). These concentration levels recorded in Lake Nokoué could be linked to sanitation efforts along the lake's shoreline. Indeed, the presence of trace metals at high concentrations in the environment can pose a significant risk to human health through the consumption of fishery products from polluted ecosystems [20].

The average cadmium and lead concentrations in oyster (*Crassostrea rhizophorae*) samples collected from the three sites (Atlantic, Littoral and Ouémé) reveal concerning results. Cadmium (Cd) concentrations are very high, reaching 2.374 ± 0.126 mg/L at Atlantic, 2.027 ± 0.0867 mg/L at Littoral and 2.329 ± 0.183 mg/L at Ouémé, which is more than twice the WHO standard of 1 mg/L. Similarly, lead (Pb) levels are alarming, with respective values of 3.845 ± 0.971 mg/L (Atlantic), 3.770 ± 0.450 mg/L (Littoral) and 3.850 ± 0.238 mg/L (Ouémé), greatly exceeding the WHO limit of 1.5 mg/L. These concentrations identify Cd and Pb as the main health risk factors, as both metals are toxic, bioaccumulative and responsible for serious human health effects, including renal, neurological, skeletal damage and carcinogenic risks. These values are higher than those reported by [29] in their assessment of the risk of food poisoning related to the consumption of fishery products from Lake Nokoué and by [30] on snails in the Ouémé Valley [7] [25]. In boiled snails, average cadmium and lead concentrations range from 0 - 0.046 mg/kg and 0.035 - 0.096 mg/kg in *Archachatina marginata* and 0 - 0.422 mg/kg and 0.016 - 1.024 mg/kg in *Limicolaria* spp. In fried snails, average cadmium and lead concentrations range from 0.003 - 0.067 mg/kg and 0.023 - 0.062 mg/kg in *Archachatina marginata* and 0 - 0.769 mg/kg and 0 - 0.275 mg/kg in *Limicolaria* spp. Similarly, in Lake Ahémé, crabs showed high contamination by trace elements. Lead, zinc and copper concentrations (respectively 20.944 ± 11.237 ; 30.565

± 5.954 ; and 59.915 ± 12.597) recorded during both low- and high-water seasons were well above the standards (0.1, 5 and 1 mg/L, respectively).

In contrast, mercury (Hg) levels in the oysters remain relatively low, with 0.0221 $\mu\text{g/L}$ in the Atlantic, 0.0961 $\mu\text{g/L}$ in the Littoral and 0.0479 $\mu\text{g/L}$ in Ouémé, values well below the WHO limit of 0.5 mg/kg. However, even though mercury does not pose an immediate threat due to its low concentrations, the combined presence of the three heavy metals, particularly the critical levels of Cd and Pb, results in significant contamination of the oysters. This simultaneous accumulation increases the risk of chronic toxicity in consumers due to the synergistic and cumulative effects of heavy metals in the body and also the phenomenon of bioaccumulation.

Oysters (*Crassostrea rhizophorae*), as filter-feeding bivalves, ingest particulate matter, including organic matter and phytoplankton. Their high heavy metal concentrations likely reflect environmental pollution, enabling them to bioaccumulate substantial amounts of metals. Because oysters appear at specific times throughout the year, the data in this study come from a single sampling campaign and may not reflect seasonal variations in pollution levels.

5. Conclusion

The results of trace metal analysis in water, sediments and oysters (*Crassostrea rhizophorae*) from Lake Nokoué and the Porto-Novo lagoon indicate contamination by heavy metals such as Cd, Pb and Hg. The concentrations of heavy metals in oysters exceeded regulatory limits, posing a health risk to consumers and threatening the sustainability of aquatic species. It is urgent to repeat the research on several campaigns in order to find suitable solutions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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