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# Assessment of Lead and Cadmium Bioaccumulation by Tilapia, *Sarotherodon melanotheron* (Rüppell 1852), from the Lake Nokoué Lagoon of Porto-Novo Complex, Benin Republic

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## ABSTRACT

Lake Nokoué-lagoon of Porto-Novo complex, as a surface water body, is exposed to heavy pollution whose intensity varies across seasons. The present study aimed to assess the bioaccumulation of lead and cadmium levels by Sarotherodon melanotheron fish, one of the most populated fish in this complex. To this end, fish (muscle, gills, female gonads), water, and sediment were sampled during high-water and low-water. Lead and cadmium were quantified from different samples using flame atomic absorption spectrometry. The health risk associated with fish consumption was estimated. In the water samples, lead concentration was higher during high water (0.106 ± 0.116 $mg.L^{-1}$), and cadmium was higher during low water (0,010 ± 0,001 $mg.L^{-1}$). In the sediment samples, lead was higher during high water (13.94 ± 20.79 $mg.kg^{-1}$), cadmium was higher during low water (0,2 ± 0,06 $mg.kg^{-1}$). On the other hand, high concentrations of lead and cadmium in fish were found during low water, respectively 27.66 $mg.kg^{-1}$ and 0.22 $mg.kg^{-1}$ in the muscle. Cadmium accumulation in fish is influenced by dissolved oxygen and the pH of the water. Consumption of 400 g of Sarotherodon melanotheron fish from this complex per week constitutes a health risk for anyone weighing between 0 and 90 kg.

## INTRODUCTION

The Lake Nokoué lagoon of Porto-Novo complex, later referred to as "the Complex," is one of the most important fishing areas in West Africa (Lalèyè et al. 1995) and accounts for more than half of continental fish production in Benin (65-70%) (Lalèyè et al. 2004). However, this Complex is surrounded by Benin's most densely populated municipalities, with around 2 million inhabitants living around it (INSAE 2015), and the majority of Benin's industries are located near the Complex (Elegbede Manou et al. 2020). Therefore, the Complex constitutes a receptacle for industrial discharges, which are the major source of heavy metals and all the solid and liquid wastes of neighboring populations. The Complex is also the main route for petroleum products, particularly leaded petrol, from Nigeria to Benin (Dovonou 2019). All this exposes the Complex to heavy pollution from human activities. Various wastes generated by the surrounding population, including domestic, hospital and industrial wastes, and petroleum products, are the main sources of heavy metals (Rossi 2009). Heavy metals with a density greater than 5 $g.cm^{-3}$, such as cadmium and lead, are classified as toxic (Cuniasse & Glass 2020). The presence of these toxic metals in an ecosystem exposes it to a high risk of degradation. Studies have shown the capacity for bioaccumulation and biomagnification of these toxic metals in aquatic fauna, particularly fish, due to their lipophilic nature, and top links are the most vulnerable (Başyiğit & Tekin-özan 2013). Most of these heavy metals are also endocrine disruptors for fish (Barbier 2011) and have carcinogenic effects on human health. Despite previous studies that focused on this Complex (Agbandou et al. 2018, Elegbede Manou et al. 2020, Agbohessi et al. 2023a), the seasonal pollution level, the bioaccumulation across various organs in the fish, and the health risk assessment relative to the consumption of Sarotherodon melanotheron from the Complex remain largely unknown. Therefore, this study was undertaken to fill this gap in knowledge to stimulate the public and decision-makers' awareness of the destruction of biodiversity and the health risk for the population.

## MATERIALS AND METHODS

The study was carried out during the high-water and low-water seasons, in March 2023 and October 2024. To this end, sampling sites were selected, samples were collected, lead and cadmium levels were determined, and the data were statistically processed.

### Sampling Sites

The complex is located in south-east Benin (West Africa) and covers an area of 180 km2 at low water (Fig. 1). Lake Nokoué (160 km2 at low water) and the Porto-Novo lagoon (20 km2 at low water) are a brackish water complex located between parallels 6°25'and 6°30' North and meridians 2°20'and 2°40' East, linked by the Totché channel (Colleuil & Texier, 1987). Fed by freshwater from the Ouémé river, the Sô river, rainfall and run-off, Lake Nokoué is connected to the Atlantic Ocean by the Cotonou channel over a length of 4.5 km and a width of around 300 m (Lalèyè et al. 1995).

Fifteen (15) sites were identified on the complex for sampling (Fig. 1). These sites were identified for the following reasons:

Proximity to housing (Proximity to human activities like markets, leisure facilities, fishing areas, etc. and Proximity to hospitals.

### Sample Collection

During sampling, a number of physico-chemical parameters, such as temperature, dissolved oxygen, pH and salinity, were measured at each site in order to provide a general characteristic of the Complex. These physico-chemical parameters were taken in the morning from 7 am to 9 am and in the evening from 4 pm to 6 pm at all sites to a depth of 30 cm. Water samples were taken in 1-litre bottles, and sediment samples were taken in jars using a sampling bucket at each of the identified sites. Specimens of Sarotherodon

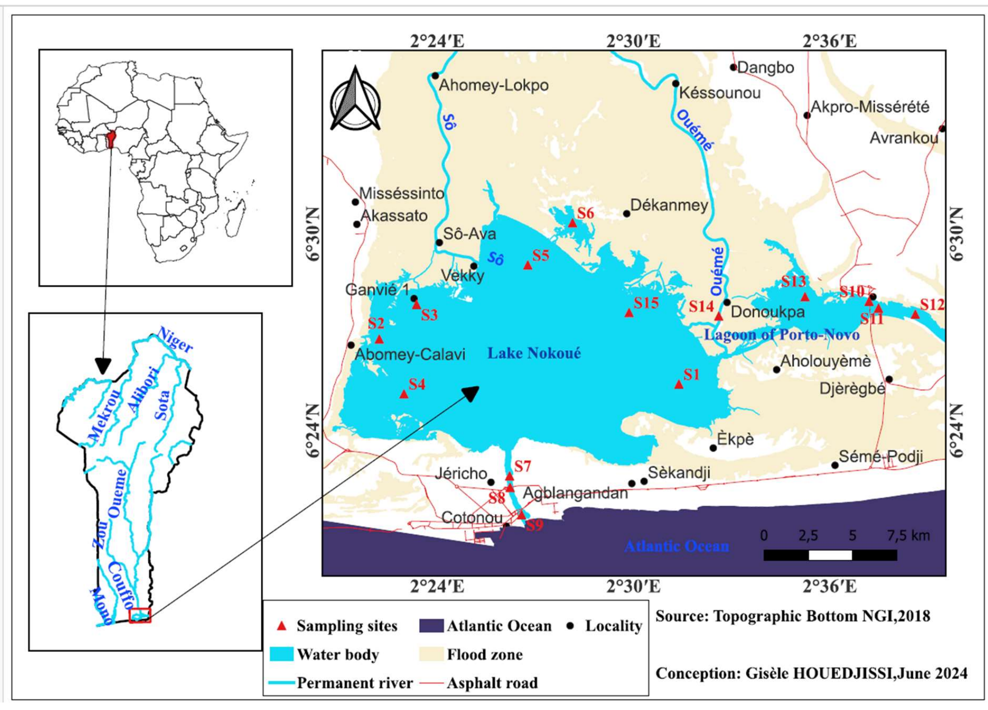


Fig. 1: Representation of sampling sites.

melanotheron at various sites to collect muscle, gonads and gills for metal assays. Eighty (80) fish were collected during each season, making a total of 160 fish. Samples are stored in an isothermal cooler containing ice in the field. In the laboratory, water samples were acidified with nitric acid. Sediment, female gonads, gills, and muscle were oven-dried at 99°C for lead and cadmium determination.

### Lead and Cadmium Analysis

Sample preparation: lead and cadmium in water were determined using the atomic absorption method described above (Rodier et al. 2009). Water samples were filtered at 0.45 µm, acidified to 1% with $HNO_3$ and stored at room temperature until analysis.

For sediment, the acid-etch mineralization method (a mixture of hydrochloric acid and nitric acid) was used. One gram (1g) of sediment was mixed with 3mL of 37% hydrochloric acid and 1mL of 65% nitric acid at 110-150°C. The mixture is then filtered to obtain the filtrate, which will be used for the determination of these metals.

For fish organ samples, 1g of organ was immersed in 10mL of 9% hydrogen peroxide ($H_2O_2$) for 24 hours. Then 4mL of 65% nitric acid was added, heated to 150°C for 2 minutes, and filtered to obtain the filtrate.

Determination of concentration: A flame atomic absorption spectrometer (SAA Ice 3000 SERIES THERMO FISCHER) was used for the determination of lead and cadmium in the previously prepared filtrates. After establishing the calibration curve from the standards, the “optical densities” were read to obtain the concentrations of the elements in the filtrates, and then related to the mass of sediment or fish. These concentrations were determined under the following experimental conditions (Table 1). The spectrometer displays the concentration of the element studied in the samples directly to the computer. These concentrations are expressed in $mg.L^{-1}$. However, the actual concentrations (C) of the elements measured in solid samples are expressed in $mg.Kg^{-1}$ of dry weight.

### Bioaccumulation Factor

An estimate of the bioaccumulation factor (Bf) of toxic metals was made in order to see at what rate these metals are accumulated in fish in proportion to the water concentration.

Table 1: Summary of experimental conditions for the analysis of each element.

| Element analyzed | Wavelength (nm) | Width of slot | Type of flame |
|---|---|---|---|
| Cadmium | 228,8 | 0,5 | Air-Acetylene |
| Lead | 217,0 | 0,5 | Air-Acetylene |

The formula used is as follows:

$$Bf = CMF/CMW$$

Bf being the bioaccumulation factor, CMF the concentration of metals in fish in $mg.kg^{-1}$ and CMW the concentration of metals in water in $mg.L^{-1}$.

### Assessment of the Health Risk Associated with Fish Consumption

According to information gathered in the study area, a resident may consume two to three Sarotherodon melanotheron fish per week, estimated at around 400g per week per person. This information was used to calculate Weekly Exposure Doses (WED) for lead and cadmium using the method used by Elegbede Manou et al. (2020) compared with the Maximum Tolerable Weekly Intake (MTHI) according to the World Health Organisation.

$$WED = (Q \times C)/W$$

Q being the Quantity of fish consumed per week by one inhabitant in kg, C the concentration of lead or cadmium in one Kg in the fish sample in $mg.kg^{-1}$ and W the weight of one inhabitant in kg.

### Statistical Analysis

The data was entered into the Excel 2016 spreadsheet and processed using XLstat statistical software. The experimental units are water, sediment and fish, and the factor is the high and low-water seasons. The Ryan-Joiner test and the Levene test were used to assess the normality and homoscedasticity of the data, respectively. Data that does not follow a normal distribution is transformed into log(x+1). Results are expressed as mean ± standard deviation of the mean. The differences between the means were evaluated using a test based on one-factor analysis of variance (ANOVA) according to the effect studied. Average values were compared between seasons. Duncan’s test was used to show a significant difference between the data. A correlation matrix was drawn up between the variables used. For the analyses, a difference was considered statistically significant if the p-value was less than 0.05.

## RESULTS AND DISCUSSION

### Physico-Chemical Characteristics

The average values of the physico-chemical parameters of the Lake Nokoué-Porto-Novo lagoon complex are presented in Table 2. The average temperature was higher during low water (33.41 and 32.87°C) in the Lake Nokoué-Porto-Novo lagoon complex than during high water. The same observations were made for dissolved oxygen, pH

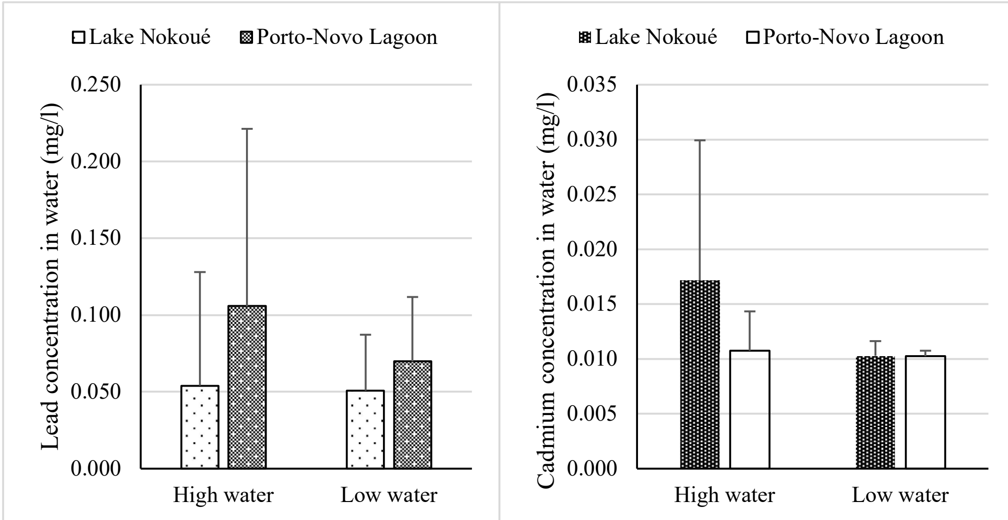


Fig. 2: Lead and cadmium concentrations in water.

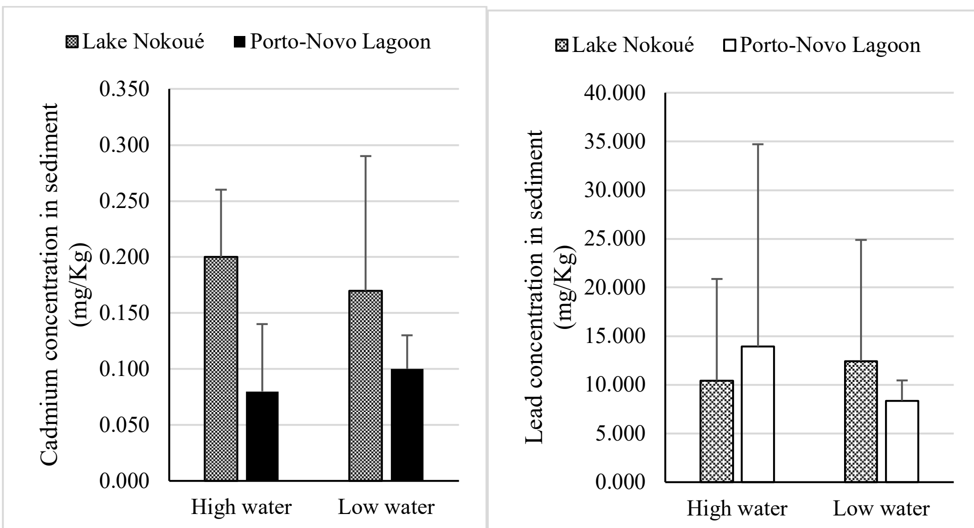


Fig. 3: Concentration of lead and cadmium in sediment.

Table 2: Physico-chemical parameters.

| Physico-chemical parameters | Seasons | Lake Nokoué | Porto-Novo Lagoon |
|---|---|---|---|
| Water temperature [℃] | High water | 29,02 ± 6,27 | 30,13 ± 0,48 |
| | Low water | 33,41 ± 0,74 | 32,87 ± 0,15 |
| Dissolved oxygen [$mg.L^{-1}$] | High water | 3,74 ± 6,84 | 2,11 ± 1,40 |
| | Low water | 5,38 ± 1,45 | 2,18 ± 1,86 |
| pH | High water | 6,52 ± 0,24 | 6,21 ± 0,12 |
| | Low water | 8,63 ± 0,54 | 7,42 ± 0,49 |
| Salinity [$g.L^{-1}$] | High water | 0,49 ± 0,70 | 0,68 ± 0,49 |
| | Low water | 19,64 ± 10,77 | 4,83 ± 0,71 |

and salinity. Dissolved oxygen recorded in the Porto-Novo lagoon during both seasons was also low (2.11 and 2.18, respectively, during flood and low water).

## Lead and Cadmium Concentrations in Water and Sediment

The concentration of lead and cadmium in water and sediment was expressed as the mean plus or minus standard deviation (mean ± SD, Figs. 2, 3 and 4). The high concentration of lead recorded in the water during the flood was 0.106 ± 0.116 $mg.L^{-1}$, and that in the sediment was 13.94 ± 20.79 $mg.kg^{-1}$ during the flood. The high concentration of cadmium in the water was 0.017 ± 0.013 $mg.L^{-1}$ during the high water event, and that in the sediment was 0.20 ± 0.12 $mg.kg^{-1}$ during the high water event. The highest concentrations of lead were recorded in the Porto-Novo lagoon and cadmium in Lake Nokoué during the high water.

## Lead and Cadmium Concentrations in Sarotherodon Melanotheron Fish

The mean concentration of lead and cadmium in the muscle, gills and female gonads of Sarotherodon melanotheron is shown in Fig. 4. High lead concentrations in muscle, gills and female gonads are 16.41 ± 15.91 $mg.kg^{-1}$, 7.93 ± 3.43 $mg.kg^{-1}$ and 5.277 ± 1.30 $mg.kg^{-1}$, respectively. Cadmium levels in female muscle, gills and gonads are 0.148 ± 0.11 $mg.kg^{-1}$, 0.22 ± 0.04 $mg.kg^{-1}$ and 0.174 ± 0.05 $mg.kg^{-1}$, respectively. Of the two toxic metals, lead concentrations are very high in all three organs of the complex during low water.

As for the sum of lead and cadmium concentrations in the various fish organs (Fig. 5), it should be noted that lead was significantly higher during low water than during high water (p= 0.014), and fish are more polluted with lead than with cadmium. Results at the water level show that the concentration was higher in water during high water, whereas these pollutants are more concentrated in fish during low water.

## The Bioaccumulation Factor for Lead and Cadmium in Fish

The bioaccumulation factor for lead and cadmium in Sarotherodon melanotheron fish is presented in Table 3. The concentration of lead in fish was 14.71 to 382.56 times higher than in water, and the concentration of

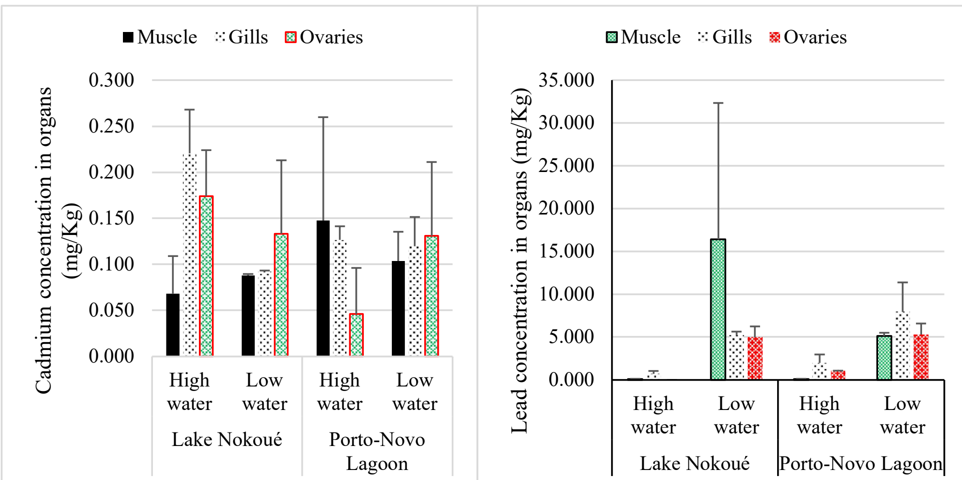


Fig. 4: Concentration of lead and cadmium in fish organs.

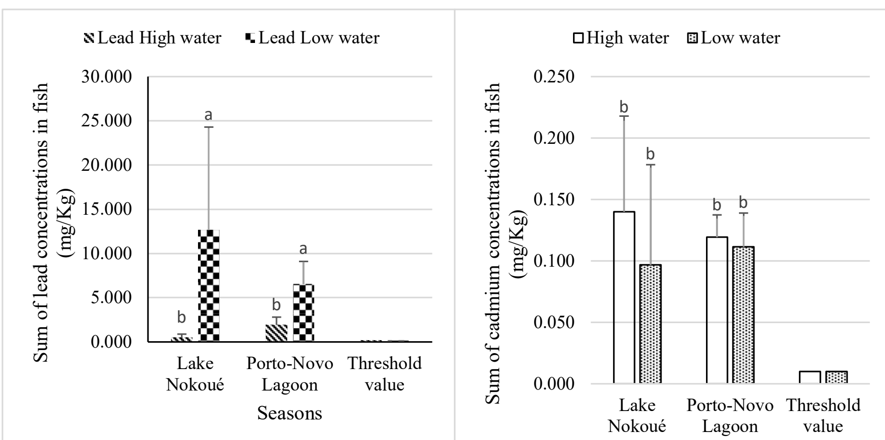


Fig. 5: Sum of lead and cadmium concentrations in whole fish [$mg.Kg^{-1}$].

Table 3: Bioaccumulation factor for lead and cadmium in whole fish.

| Sites | Seasons | Heavy metals | Water concentration | Bioaccumulation factor |
|---|---|---|---|---|
| Lake Nokoué | High water | Cadmium | 0,017 ± 0,01 | 26,93 ± 7,23 |
| | | Lead | 0,054 ± 0,07 | 14,71 ± 6,72 |
| | Low water | Cadmium | 0,010 ± 0,001 | 31,35 ± 0,71 |
| | | Lead | 0,070 ± 0,04 | 382,56 ± 240,12 |
| Porto-Novo Lagoon | High water | Cadmium | 0,011 ± 0,003 | 29,75 ± 13,33 |
| | | Lead | 0,141 ± 0,11 | 28,78 ± 13,08 |
| | Low water | Cadmium | 0,010 ± 0,0005 | 34,52 ± 11 |
| | | Lead | 0,070 ± 0,04 | 262,79 ± 65,5 |

Table 4: Correlation matrix between lead and cadmium in fish and physico-chemical parameters.

| Variables | r et p | Salinity | Dissolved oxygen [mg.L$^{-1}$] | T°C | pH | Lead in fish | Cadmium in fish |
|---|---|---|---|---|---|---|---|
| Salinity | r | 1 | | | | | |
| | p | 0 | | | | | |
| Dissolved oxygen [mg.L$^{-1}$] | r | -0,13 | **1** | | | | |
| | p | 0,79 | **0** | | | | |
| T °C | r | 0,68 | -0,285 | **1** | | | |
| | p | 0,13 | 0,584 | **0** | | | |
| pH | r | 0,07 | **0,864** | -0,385 | **1** | | |
| | p | 0,88 | **0,026** | 0,451 | **0** | | |
| Lead in fish | r | 0,59 | 0,170 | 0,506 | 0,089 | **1** | |
| | p | 0,21 | 0,747 | 0,305 | 0,867 | **0** | |
| Cadmium fish | r | 0,46 | **-0,820** | 0,620 | **-0,816** | 0,361 | 1 |
| | p | 0,35 | **0,046** | 0,189 | **0,047** | 0,482 | 0 |

"r" represents the coefficients of determination, and 'p' represents p-values

cadmium in fish was 26.93 to 34.52 times higher than in water.

## Correlation Matrix Between Lead, Cadmium in Whole Fish and Physico-Chemical Parameters

The correlation coefficients between physico-chemical parameters and toxic metals in whole fish (Table 4) show that cadmium is strongly negatively correlated with dissolved oxygen and pH. Oxygen and pH are also positively correlated. But there is no correlation between lead in fish and the physico-chemical parameters measured.

## Health Risks Associated with Eating the Fish

The Weekly Exposure Doses (WED) were assessed 15 to 90 kg using the reference of the World Health Organisation (WHO), which is 0.025 for lead and 0.007 for cadmium. The WED of the lowest weight up to 90 kg exceeded the Weekly Maximum Tolerable Dose (WMTD) set by the WHO for lead. This reveals that anyone weighing between 0 and 90 kg who consumes around 400 g of this fish per week is exposed to a major health risk linked to lead. As for cadmium, the WED up to 9 kg was exactly at the limit of the MLD given by the WHO (Fig. 6). This shows that the

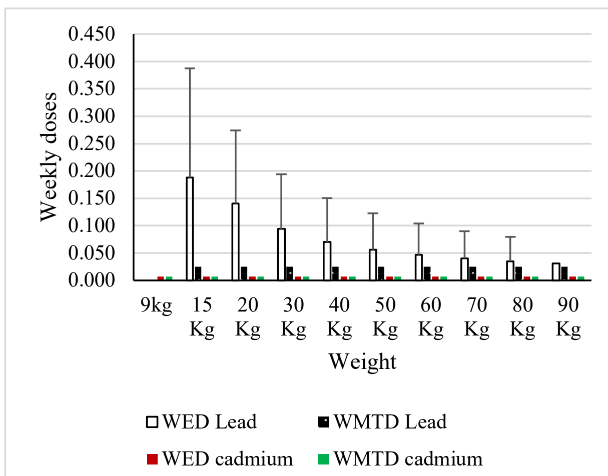


Fig. 6: Weekly Exposure Dose to lead and cadmium.

health risk for eating this fish associated with cadmium is lower.

## DISCUSSION

### Physico-Chemical Characteristics

The physico-chemical parameters of an aquatic environment are crucial for the survival and growth of aquatic organisms (Zandagba et al. 2016). The lowest mean temperature recorded was 29.02 ± 6.27 °C during the high-water period, while the highest reached 33.41 ± 0.74 °C during low water. These readings are higher than those reported by Capo-Chichi et al. (2022), who observed 26.80 °C and 32.40 °C, as well as the values recorded by Agbohessi et al. (2023b) and Lalèyè et al. (2022) in Lake Nokoué–Lagune at Porto-Novo. Moreover, they exceed the standards set by the Water Quality Evaluation System (SEQ-Eau 2003). This variation may be attributed to several factors, including increased organic pollution within the ecosystem and particularly at the sampling sites (Capo-Chichi et al. 2022). Rising global temperatures could also explain the observed increase in water temperature. Hani et al. (2019) demonstrated that elevated temperatures in aquatic environments can reduce fish reproductive capacity, a finding supported by Agius & Robert (2003).

Dissolved oxygen levels range from 2.11 to 5.38 $mg.L^{-1}$, below the value set by SEQ-Eau (2003) for very good water quality. This value (2.11 $mg.L^{-1}$) is below the values obtained by Capo-Chichi et al. (2022) in Lake Nokoué. Dissolved oxygen in aquatic environments ensures fish respiration. A decrease in the oxygen content of an aquatic environment can be due to a rise in temperature, decomposition of organic matter and low water flow (Stantec 2015). The high temperature recorded for this study may support this low oxygen level. The complex also faces heavy pollution of all kinds, even organic (Agbandou et al. 2018), with the Acadja practice occupying 60% of the surface area of Lake Nokoué, which requires excessive use of wood that is then abandoned in the water. This helps reduce the flow of water in the complex, which also reduces oxygen levels. A drop in oxygen levels could cause mortality or reduce fish growth. The pH ranges from 6.21 to 8.62. These values are close to those found by several other authors on Lake Nokoué (Capo-chichi et al. 2022, Agbohessi et al. 2023b). These values are also within the standards set by SEQ-Eau (2003).

### Heavy Metals in Water and Sediment

The average concentration of lead recorded in the water over the two seasons exceeded the standards set by the SEQ-Eau, which is 30 $\mu g.L^{-1}$ (SEQ-Eau 2003). These values are close to those found by several authors on the Lake Nokoué-Porto-Novo lagoon complex (Kaki et al. 2011, Agbandou et al. 2018, Elegbede Manou et al. 2020, Agbohessi et al. 2023c). The same observations were made for the concentration in the sediment and that of cadmium found in the water and sediment. Exposure of fish to cadmium induces histopathological alterations in the liver, gills and kidney (Pantung et al. 2008) and many other molecular and biological alterations. This high concentration is due to the activities carried out around and on the complex. Benin's largest brewing industry, which produces and stores alcoholic beverages, is located near Lake Nokoué. The high concentration of lead can also be explained by the proximity of these industries, which are also sources of lead (Kayalto & Mbofung 2013). The results of these studies revealed that the concentration of both heavy metals is highest in water and sediments during floods. The same observations were made by Babalola & Fiogbe (2016) in the same ecosystem, particularly in the Porto-Novo lagoon. The high water levels correspond to the most intense rainy seasons of the year, and the complex is fed by several tributaries from northern Benin (Colleuil & Texier 1987). In addition, Lake Nokoué receives all the rainwater runoff from the surrounding towns, the town's industries, numerous household waste disposal sites, and the many markets in the area due to its geographical location. Around 80% of Benin's industries are located along this waterway (Agbandou et al. 2018). Industrial discharges are a potential source of heavy metals, particularly lead and cadmium (Angerville 2009, Kayalto & Mbofung 2013, Cuniasse & Glass 2020). During rainfall, this complex also receives all urban discharges from the rainwater collectors of Cotonou and Abomey-Calavi (the most populated and industrialized cities in Benin) (Mama 2010) which are a major source of heavy metals (lead and cadmium) at concentrations 7 to 26 times higher than in their areas of origin (Verge & Petit 2009). The Lake Nokoué-Porto-Novo lagoon complex is also Benin's main transport route for petroleum products, particularly gasoline, and receives these products on a daily basis (Dovonou 2019). These products are sources of lead (Loustau Cazalet 2012). The high rain season is a period when the transport of petroleum products on the complex is more difficult, as high water and strong currents cause the boats transporting these products to capsize. These petroleum products are more likely to be spilled in the complex during the rainy season because they are sold not only on the shore but also in the lagoon complex, particularly in lakeside villages such as Ganvié, Sô-ava, Dékanmey, and Houédogbadji. They are sometimes accidentally spilled into the ecosystem due to leaks or explosions of cans during transport, or deliberately spilled by transporters to ensure the balance of boats or to escape customs or security checks (Agbohessi et al. 2023). All this explains the high concentrations of lead and cadmium recorded during high water in this ecosystem.

**Heavy Metal Contamination of Ichthyological Fauna**

The heavy metals present in this aquatic environment are more concentrated in fish than in water and sediment. Fish receive a large proportion of the heavy metals drained into this ecosystem. The calculated bioaccumulation factor shows that the amount accumulated by fish is as high as 382.56 in water, mainly in low water. Studies conducted by Babalola (2015) in the same ecosystem in 2014 and 2015 showed that the species Sarotherodon melanotheron exhibited bioaccumulation of lead and cadmium 214.92 times and 23.18 times higher than their concentration in water, respectively. According to several studies conducted on the ecosystem between 2001 and 2023, an increase in lead and cadmium concentrations has been observed, and these heavy metals are the most studied in the environment (Chouti et al. 2010, Kaki et al. 2011, Hounkpatin et al. 2012, Yehouenou et al. 2013, Babalola & Fiogbe 2016, Chouti et al. 2017, 2020, Vodougnon et al. 2018, Azon et al. 2021, Agbohessi et al. 2023b). This shows that the ecosystem is chronically exposed to these heavy metals. This explains the high bioaccumulation of lead in this species in 2024. Studies conducted by Agbohessi et al. (2023b) have also shown that the liver tissue of this species sampled in the same ecosystem exhibits severe histopathological alterations, particularly cellular necrosis. This could explain why their livers can't get rid of the heavy metals that have built up, which is why we've seen these pollutants accumulate. In the Lagos Lagoon in Nigeria, despite the fact that the concentration of heavy metals assessed was low and below standards in the water, Sarotherodon melanotheron fish caught in this lagoon accumulated these heavy metals in concentrations exceeding those found in the water and the recommended standards (Omoregham Jumoke & Okeke Ebele 2025). Studies have also shown that the bioaccumulation factor for lead assessed in certain fish species (Tilapia zillii, Chrysichthys nigrodigitatus, Synodontis membranaceus) in the lower Volta basin in Ghana exceeded several hundred to over 1,000, indicating active and worrying bioaccumulation (Biney 1991). Similarly, in the Ogun River in Nigeria, studies on Clarias gariepinus revealed very high concentrations of lead in the muscles (17.45 $mg.kg^{-1}$) (Adeboyejo et al. 2015). This shows that in ecosystems polluted with heavy metals, lead also appears to have a high capacity for bioaccumulation in fish muscle tissue. Lake Nokoué, a lagoon in Porto-Novo, appears to be one of the most lead-polluted aquatic ecosystems in West Africa.

Toxic metals are endocrine disruptors; they can cause feminization, decrease the production of 17 beta-estradiol (E2), inhibit the synthesis of estradiol, and inhibit the effects of androgens (Scholz & Mayer 2008). According to ecotoxicological studies, cadmium negatively affects the hypothalamic-pituitary-gonadal-hepatic axis, estradiol, and vitellogenin, even at very low concentrations of cadmium in water (5-10 $\mu g.L^{-1}$) (Hachfi 2013). Exposure of fish to low concentrations of lead nitrate (0.1, 1, 3, and 10 $\mu g.L^{-1}$) for 24 h resulted in inhibition of steroid production (Singh et al. 2008). While the concentrations observed in the water of this ecosystem exceed those reported in these studies. These metals also cause histopathological alterations and malformations in embryos (Osman et al. 2007). They also affect the biochemical functions of the kidneys and liver of fish (Elarabany & Bahnasawy 2019).

The muscles, gills, and gonads are the parts of the fish that are consumed. These organs have accumulated up to 16.41 $mg.kg^{-1}$ of metals, whereas the limit set by the FAO/WHO in "CODEX STAN 193-1995" and Seventy-third meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) (JECFA 2011) is 0.2 $mg.kg^{-1}$ for lead and 0.01 $mg.kg^{-1}$ for cadmium. The study revealed that during the dry season, when water levels are low, the concentration of heavy metals in fish is significantly higher, whereas the concentration in water is high during high water. This clearly explains the phenomenon of bioaccumulation. After pollutants are released into the ecosystem during high water, it takes some time for fish to accumulate them, and this accumulation becomes apparent during periods of low water. This absorption occurs directly through the respiratory system via the gills (Omoregham Jumoke & Okeke Ebele 2025), which shows a high concentration in the gills. Absorption also occurs through the food chain when aquatic plants and micro- and macro-invertebrates that come into contact with the sediment are consumed (Soltani et al. 2019). This concentration found in fish exceeds that obtained by several authors on the same fish species in the same ecosystem (Youssao et al. 2011, Goussanou et al. 2018, Elegbede Manou et al. 2020, Agbohessi et al. 2023b). This complex is more polluted with lead than the Anambra River in Nigeria, where Clarias gariepinus and Oreochromis niloticus fish are believed to be contaminated with toxic metals, with accumulated lead concentrations of 1,062 ppm (Ogbuene et al. 2024). Appropriate measures must be taken to limit sources of pollution and consider a plan to clean up this ecosystem.

The Weekly Exposure Doses (WED) assessed for lead show that anyone weighing between 0 and 90 kg and consuming around 400 g of this fish per week is at high risk of lead poisoning. As for cadmium, WED up to 9 kg is exactly at the limit of the Maximum Tolerable Weekly

Dose (MTHWD) given by the WHO It was shown that consumption of 150 g of fish from Lake Nokoué per day presented a lead poisoning risk for a 30 kg child (Elegbede Manou et al. 2020). Whereas in the present study, the lead-related poisoning dose assessed is less than half that found by this author for a weight range of 0 to 90 Kg. This shows that the level of pollution in this complex is very high, and the population is exposed to great danger. The population needs to be aware of the risk of poisoning linked to the consumption of fish from the complex. A toxicology study is needed to assess the health status of all fish products from this ecosystem destined for consumption. Chronic exposure of the human body to lead has numerous health drawbacks, such as reproductive disruption, cancer, hypertension, renal failure, neuropathy and hematological effects, etc. (Bismuth et al. 2002). A study on the treatment of urban discharges from stormwater collectors in the communes that this ecosystem serves should be considered. It is also necessary to consider decontaminating this watercourse to save the population that depends on it.

### The Influence of Physico-Chemical Parameters on the Bioaccumulation of Heavy Metals

Cadmium concentrations in fish are negatively correlated with pH and dissolved oxygen. This negative correlation shows that cadmium is more mobile to accumulates in fish when pH and dissolved oxygen are low. According to the Canadian Environmental Protection Act, cadmium is more toxic and mobile in low pH ecosystems (LCPE 2009). The Lake Nokoué-Porto-Novo lagoon complex is exposed to organic and chemical pollution (Agbohessi et al. 2023c), affecting physico-chemical parameters (Capo-Chichi et al. 2022). In the present work, the recorded oxygen level was low, and the pH was also low at several sites. This could facilitate cadmium accumulation in fish and cause more damage to the species' physiology. All these phenomena expose the ecosystem to imminent degradation if no solution is envisaged.

A study of the physiological state and, above all, the reproductive system of the fish is needed to determine the damage this pollution would have caused to the physiology and sustainability of the aquatic fauna.

## CONCLUSIONS

Our study confirmed that the complex is polluted with heavy metals, in particular lead and cadmium, through their accumulation in water, sediment and aquatic fauna. This poses a risk of metal poisoning when the general public consumes these fish. Appropriate measures to limit sources of pollutants must be taken. Consider an alternative route for transporting petroleum products, or opt for a safer means of transport, which is also a major source of lead.

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