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Arsenic and Trace Metal Concentrations in Tissues of Two Economically Important Fish Species (*Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron*) from Western Ebrie Lagoon, Côte d'Ivoire

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Abstract

Total concentrations of trace metals Hg, Cd, and Pb, and metalloid As were measured monthly (December 2014 to November 2015) in two fish species, *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* at five sites in the western part of the Ebrie Lagoon (Côte d'Ivoire). Results indicated that *Chrysichthys nigrodigitatus* muscle accumulated significant amount of total Hg, Cd, and As than *Sarotherodon melanotheron*, while no significant difference was found for Pb. Average total Hg and As concentrations showed opposite spatial trends, while Pb and Cd registered no spatial

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variation in *Chrysichthys nigrodigitatus*. On contrary, insignificant seasonal variation was observed for average total Hg, Cd, Pb, and As concentrations in *Sarotherodon melanotheron*. In overall, Cd and Pb concentrations in fish exceeded the safety limits set by the European Commission in 10 to 40% of the total individuals, but the maximum safe weekly consumption values of fish estimated were very high and unlikely to be reached by local communities.

1. Introduction

Trace metal pollution of aquatic systems, especially in wetlands is of great concern around the world. Exposure to metals including arsenic, mercury, lead, and cadmium may cause cancer, reproductive damage, disorders of the central nervous system, cardiovascular problems and outbreaks of deaths (Dooyema et al. 2012; Mason et al. 2014; Myong et al. 2014). Wetland habitats contain a multitude of fish species that are important sources of protein and income for local communities in many parts of the world (FAO 2003). Agriculture, industry, urbanization, and mining are the main sources of trace metals in wetland environment (Bodin et al. 2013; Chakraborty et al. 2012; 2014; Diop et al. 2014; Donkor et al. 2006; Gbogbo et al. 2015; Ngole-Jeme et al. 2017; Tang et al. 2014). High trace metals accumulation in wetlands can results in their bioaccumulation in fish at detrimental levels to wildlife and human Health. Moreover, low levels of trace metal such as mercury in the environment can expose fish to concentrations exceeding WHO limits. Therefore, studying the contamination status of fish in trace metals can help understand the risks associated with fish consumption in wetlands, but also assess the quality of waters.

Trace metal concentrations in fish have been extensively studied in different parts of the world (Aydin-Onen et al. 2015; Bosch et al. 2016; Gil-Manrique et al. 2017; Perugini et al. 2014; Subotić et al. 2013; Yi and Zhang 2012). Most of these studies focused mainly on fish muscles, but also on fish organs including the liver, kidneys, heart, gonads, bone, digestive tract and brain. This literature suggests that metal bioaccumulation in fish and subsequent distribution in organs is greatly inter-specific due to many controlling factors such as sex, age, size, reproductive cycle, swimming patterns, feeding behavior and habitat (Chouvelon et al. 2017; El-Moselhy et al. 2014; Jia et al. 2017). In Côte d'Ivoire, studies on wetland contamination in trace metals have focused on sediments (Kinimo et al. 2018; Kouassi et al. 2014; 2015; Tuo et al. 2013; Yao et al. 2009; Yao and Kouassi 2015; Yapi et al. 2012) mollusks (Bakary et al. 2015), and waters (Bakary and Yao 2015; Coulibaly et al. 2012), in proximity to the urban area of Ebrie lagoon. Only two studies on bioaccumulation of metals in fish have been carried out in lagoons around Abidjan and Adiake districts. It is was found that cadmium and lead concentrations in the fish *Sarotheron melanotheron* exceeded WHO and FAO standards (Coulibaly et al. 2012; Yapi et al. 2012). The other parts of Ebrie Lagoon are expected to be pristine. However, upstream fertilizer and pesticide uses in cash crops besides mining activities could result in trace metals contamination through land surface run-offs and river discharges.

This study aimed to determine mercury, arsenic, lead cadmium, and arsenic contamination status in two high commercial fishes (*Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron*) that occur in abundance in the western rural area of Ebrie Lagoon. To attain this objective, spatiotemporal variations were examined, and total concentrations were compared among the fish species. Finally, the health status of the fish for human consumption were investigated.

2. Material and Methods

2.1. Ethics statement

Measurements of Arsenic and trace metal concentrations in fish were performed at Centre de Recherches Oceanologiques. The field collection and laboratory fish studies were authorized and approved by Departmental Direction of Animal and fisheries resources of the Ministry of Animal and Fishery Resources (Small Scale Fishery Licence N° 00626 and Animal Health Certification N° 0002900).

2.2. Study area and fish species

The Ebrie Lagoon is the largest lagoon in West Africa, with an area of 566 km^2, and an average depth of 5 m. The lagoon has been divided in six sectors based on studies on the hydroclimate, primary and secondary production, and the fisheries (Durand and Skubich 1982). The present study focused on sectors IV and V of Ebrie Lagoon, located between 5°10’- 5°20’N and 4°07- 4°30’W, respectively, south-western Côte d’Ivoire (Figure 1).

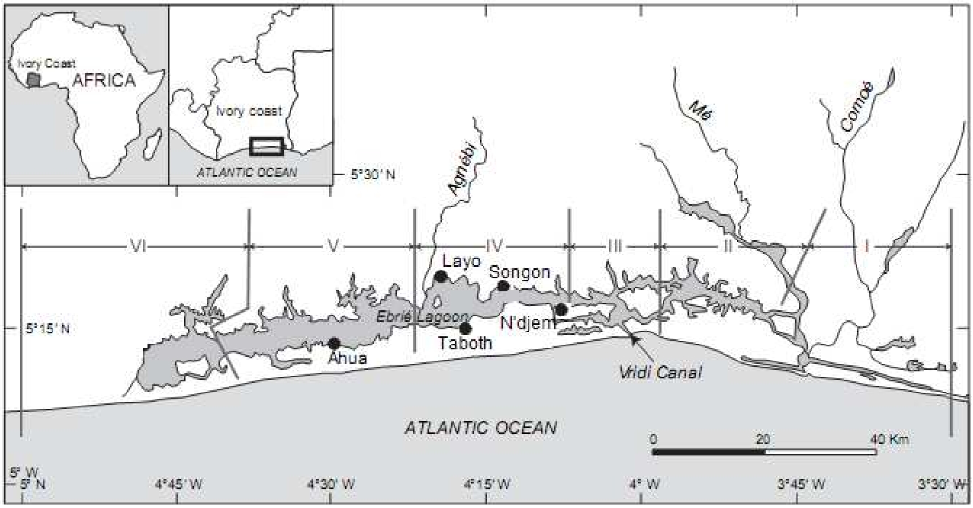

Figure 1. Location of the sampling stations along the western part of Ebrié Lagoon.

These sectors are oligohaline, stable, and homogeneous, and their total areas are 86 and 170 m^2, respectively (Durand and Guiral 1994). The drainage basin of Agneby river is the main input of the watershed in this area. Anthropogenic activities include fishing that remains the major source of income for local communities, and industrial and traditional plantations of banana and rubber. The study area is characterized by four distinct seasons, namely the low rainy season (October-November), the low dry season (August-September), the high dry season (December-March) and the high rainy season (April-July).

The samplings were carried out monthly from December 2014 to November 2015. The sampling stations comprised four stations in sector IV (Songon, N'djem, Taboh, and Layo), and one station (Ahua) in sector V (Figure 1). Two commercially important and dominant fish in biomass within African lagoons and estuaries were selected. Blackchin tilapia, *Sarotherodon melanotheron* (*S. melanotheron*) is a pelagic fish, with relative low growth rates (0.21 cm $year^{-1}$) (Ouattara et al. 2003). Adults are individuals with a total length (TL) more than 13 cm, and the highest total length for *S. melanotheron* in West Africa is 25 cm. Food items of *S. melanotheron* include phytoplankton and zooplankton (Kone and Teugels 2003).

The catfish, *Chrysichthys nigrodigitatus* (*C. nigrodigitatus*) is an omnivorious and bottom dweller fish feeding on zooplankton and insects at larval and juvenile stage. The adult individuals feed on organic detritus, fingerlings and insects larvae, decapods and fish (Risch and Vreven 2007). The maximum total length reported for wild individuals in Côte d'Ivoire lagoons is 65 cm (Legendre and Albaret 1991). Adults are individuals having at least 20 cm total length (Froese and Pauly 2017) (http://www.fishbase.org).

2.3. Sampling and chemical analysis

C. nigrodigitatus and *S. melanotheron* were monthly collected at each station by fishermen. In total 600 fishes were sampled including 300 individuals of *S. melanotheron* and 300 individuals of *Chrysichthys nigrodigitatus*. Fish were bagged and placed on ice in a cooler and transported to the laboratory (Moreau et al. 2007) where they were weighed [total weight (TW), wet weight (ww)] to the nearest mg. Both total length (TL, length at the end of the caudal fin) and standard length (SL, length from the snout to the fork) were measured and summarized in Table 1.

Table 1. Number, minimum-maximum length and weight of fish.

		Length (cm)		Weight (g)	
Species	Number	min	max	min	max
C. nigrodigitatus	300	35	206	4	809
S. melanotheron	300	7	18	13	245

The kidneys, liver, and skinless axial muscle where dissected using stainless steel scalpels and forceps which were rinsed between samples. Approximately 10 g of wet muscle tissue were taken from the dorsal musculature of each fish (sampled behind the head under the dorsal spine) (Chouvelon et al. 2017). In order to have a representative mass for analysis when fish tissues were much lower than 10 g ww, pools of organs or tissues of individuals of *S. melanotheron* and *C. nigrodigitatus* from each station (including 5 individuals per pool) were constituted, making it 60 pools for each species. Tissues were immediately weighed at 50°C to a steady mass, ground into a fine powder and stored into plastic serum tubes until chemical analyses.

All the chemicals and reagents were of the highest purity analytical reagent grade purchased from either Thermo Fischer Inc. (Massachusetts, US) or Merck (Darmstadt, Germany). Analysis of trace metals Hg, Pb, Cd, and As was performed on dried samples of fish muscle. Aliquots of 50 to 300 mg were digested with a mixture of 37% hydrochloric (9 mL) and 65% nitric acid (3 mL) in a microwave (Milestone Ethos 1 microwave, Shelton, US) following method 3051A (USEPA 2007). Cd and Pb were analyzed by graphite furnace atomic absorption spectrometry (SpectrAA100 Varian spectrophotometer, Japan), while As and Hg were analyzed by hybride generation atomic absorption spectrophotometry. Matrix blanks were analyzed with each batch of digested samples. In addition, accuracy and precision of the analytical procedures were evaluated through the analysis of certified reference materials: IAEA-407 whole fish homogenate; IAE) and DOLT-3 dogfish liver; National Research Council Canada). The measured concentrations fell within the ranges of the certified values, and the recoveries varied between 88 and 116 %.

The Wilcoxon W-test was used to compare two independent groups for the metal concentrations. A Kruskal-Wallis H test was performed when comparing more than two groups. Statistical significance was assessed at $\alpha = 0.05$. Statistical analysis were performed with the SigmaPlot 12.1 software.

3. Results

3.1. Distribution of trace elements in fish species

Spatial variations of trace metal concentrations in fish muscle at differents sampling stations for the two species are showed in Table 2.

The lowest total mercury (THg) concentration in *Chrysichthys nigrodigitatus* muscle recorded in this study was observed at N'djem (0.12 mg kg^{-1} weight weight ww) while the highest value was registered at Songon (0.14 ± 0.05 mg kg^{-1} ww). As for the Cichlidae *Sarotherodon melanotheron,* its highest muscle THg concentration was found at N'djem (0.14 ± 0.06 mg kg^{-1} ww) whereas the lowest metal levels (0.07± 0.05 mg kg^{-1} ww) was obtained at Layo. The average THg concentration in *Chrysichthys nigrodigitatus* muscle showed no significant spatial difference. On the contrary, THg concentrations in *Sarotherodon melanotheron* muscle was significantly higher in Ndjem than in Taboth, and than in Ndjem and Layo. The average Hg concentration was significantly higher in *Chrysichthys nigrodigitatus* muscle than in *Sarotherodon melanotheron.*

As for total lead (TPb), its concentration in the muscle was highest in *C. nigrodigitatus* (0.30 ± 0.23 mg kg^{-1} ww) at Taboth and lowest at Layo (0.12 ± 0.04 mg.kg^{-1} ww), and it was highest in *S. melanotheron* at Ahua (0.22 ± 0.10 mg kg^{-1} ww) and lowest at Ndjem (0.12 ± 0.02 mg kg^{-1} ww). No significant spatial difference was observed in TPb between the stations for both *C. nigrodigitatus* and *S. melanotheron*. Moreover, no significant difference was found in TPb concentrations among fish species.

Total Cd (TCd) values ranged from 0.11 ± 0.02 mg kg^{-1} ww (N'djem) to 0.04 ± 0.03 mg kg^{-1} ww (Ahua) in *C. nigrodigitatus*, and from 0.09 ± 0.17 mg kg^{-1} ww (N'djem) to 0.03 ± 0.03 mg kg^{-1} ww (Songon and Taboth) in *S. melanotheron*. No significant spatial difference was observed in Cd between the stations for both *C. nigrodigitatus* and *S. melanotheron*. Cd showed significant higher concentration for *C. nigrodigitatus* than *S. melanotheron.*

Total Arsenic concentrations (TAs) in *C. nigrodigitatus* varied between 0.21 ± 0.11 mg.kg^{-1} ww (Taboth) and 0.17 ± 0.05 mg kg^{-1} ww (N'djem). As for *S. melanotheron*, total As concentrations fluctuated between 0.33 ± 0.05 mg kg^{-1} ww (Ahua and Layo) and 0.14 ± 0.08 mg.kg^{-1} ww (N'djem). Significant spatial difference was observed in As between Songon, Ahua and N'djem, and Taboh and N'djem, and Layo and N'djem for *S. melanotheron.* No significant spatial difference was observed in As between the stations. *C. nigrodigitatus* showed significantly higher As concentrations than *S. melanotheron*.

Table 2. Average concentrations (± standard deviation) (mg kg^{-1}) and ranges of mercury, lead, cadmium and arsenic in muscle of *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron.*

Species	Location	Hg	Pb	Cd	As
Chrysichthys nigrodigitatus	Ahua	0.13 ± 0.05 (0.07-0.29)	0.16 ± .07 (0.08-0.32)	0.04 ± 0.03 (0.01-0.14)	0.20 ± 0.07 (0.07-0.34)
	Taboth	0.13 ± 0.03 (0.08-0.19)	0.30 ± 0.23 (0.1-0.7)	0.09 ± 0.07 (0.01-0.23)	0.21 ± 0.11 (0.02-0.36)
	N'djem	0.12 ± 0.3 (0.05-0.17)	0.15 ± 0.03 (0.11-0.22)	0.11 ± 0.02 (0.07-0.12)	0.17 ± 0.05 (0.11-0.32)
	Songon	0.14 ± 0.05 (0.07-0.22)	0.15 ± 0.02 (0.11-0.20)	0.07 ± 0.06 (0.01-0.18)	0.19 ± 0.09 (0.12-0.41)
	Layo	0.13 ± 0.04 (0.08-0.22)	0.12 ± 0.04 (0.02-0.19)	0.05 ± 0.05 (0.00-0.15	0.19 ± 0.10 (0.06-0.44)

Sarotherodon melanotheron	Ahua	0.10 ± 0.05	0.22 ± 0.10	0.04 ± 0.05	0.33 ± 0.05
		(0.06-0.24)	(0.07-0.37)	(0.01-0.17)	(0.25-0.41)
	Taboth	0.06 ± 0.04	0.15 ± 0.07	0.03 ± 0.02	0.31 ± 0.10
		(0.01-0.15)	(0.090.27)	(0.01-0.09)	(0.12-0.52)
	N'djem	0.14 ± 0.06	0.12 ± 0.02	0.09 ± 0.17	0.14 ± 0.08
		(0.11-0.29)	(0.09-0.14)	0.01-0.63	(0.07-0.34)
	Songon	0.08 ± 0.06	0.15 ± 0.04	0.03 ± 0.03	0.31 ± 0.10
		(0.01-0.18)	(0.10-0.21)	(0.01-0.11)	(0.13-0.43)
	Layo	0.07 ± 0.04	0.15 ± 0.12	0.06 ± 0.05	0.33 ± 0.20
		(0.01-0.12)	(0.01-0.46)	(0.01-0.15)	(0.13-0.68)

Seasonal variations

The seasonal variations of average total mercury, lead, cadmium and arsenic concentrations (± standard deviation) (mg kg^{-1}) in muscle of *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* during the sampling period are shown in Table 3. THg average concentration in *C. nigrodigitatus* remained statistically constant (Kruskal-Wallis, $p>0.05$) over the whole year with values fluctuating between 0.24 ± 0.04 mg kg^{-1} ww in the high dry season and 0.20 ± 0.04 mg kg^{-1} ww in the low dry season. The highest average THg concentration in *S. melanotheron* muscle was observed in the high dry season (0.12 ± 0.06 mg kg^{-1} ww), while the lowest was obtained during the low rainy season (0.06 ± 0.05 mg kg^{-1} ww). However, no significant difference was found between the four seasons (Kruskal-Wallis, $H = 7.33$, $P > 0.05$).

The average TPb concentration in *S. melanotheron* muscle in the high rainy season (0.20 ± 0.09 mg kg^{-1} ww) was significantly higher than in the high dry season (0.14 ± 0.09 mg.kg^{-1} ww), the low rainy season (0.12 ± 0.03 mg.kg^{-1} ww), and the low dry season (0.12 ± 0.02 mg.kg^{-1} ww), respectively. No significant seasonal variation was observed for average TPb concentrations in *C. nigrodigitatus* although the highest value was recorded in the low rainy season (0.28 ± 0.22 mg kg^{-1} ww) and the lowest in the low dry season (0.19 ± 0.05 mg kg^{-1} ww).

The highest value of average TCd concentrations in *C. nigrodigitatus* muscle was registered in the low rainy season (0.18 ± 0.11 mg kg^{-1} ww), while the lowest was observed in the high rainy season 0.12 ± 0.11 mg kg^{-1} ww. No significant difference was observed between the seasons. Average TCd concentrations in *S. melanotheron* muscle was significantly lower in the high rainy season (0.02 ± 0.00 mg kg^{-1} ww) than in the high dry season (0.07 ± 0.13 mg.kg^{-1} ww), the low rainy season (0.07 ± 0.06 mg kg^{-1} ww), and in the low dry season (0.06 ± 0.05 mg kg^{-1} ww).

In *C. nigrodigitatus*, As concentration was highest in the low rainy season (0.49 ± 0.26 mg kg^{-1} ww) and lowest in the high rainy season (0.25 ± 0.16 mg kg^{-1} ww), but no significant difference was observed between the seasons. Total As concentration in *S. melanotheron* muscle was significantly higher in the high rainy season (0.35 ± 0.18 mg kg^{-1} ww) than in the high dry season (0.23 ± 0.13 mg kg^{-1} ww), but not than in the low rainy season (0.30 ± 0.07 mg kg^{-1} ww) and in the low dry season (0.25 ± 0.05 mg kg^{-1} ww) (ANOVA, p = 0.04).

Table 3. Seasonal variations of mercury, lead, cadmium and arsenic concentrations (± standard deviation) (mg kg^{-1}) in muscle of *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* during the sampling period.

Species	Trace metals	Low rainy season	Low dry season	High rainy season	High dry season
Chrysichthys nigrodigitatus	Hg	0.13 ± 0.04^{a}	0.14 ± 0.06^{a}	0.12 ± 0.04^{a}	0.14 ± 0.04^{a}
	Pb	0.14 ± 0.02^{b}	0.13 ± 0.04^{b}	0.25 ± 0.20^{a}	0.13 ± 0.03^{b}
	Cd	0.11 ± 0.04^{a}	0.06 ± 0.04^{bc}	0.08 ± 0.07^{ab}	0.03 ± 0.02^{c}
	As	0.17 ± 0.10^{ab}	0.21 ± 0.10^{b}	0.20 ± 0.08^{b}	0.18 ± 0.09^{a}
Sarotherodon melanotheron	Hg	0.06 ± 0.05^{A}	0.08 ± 0.07^{A}	0.08 ± 0.04^{A}	0.12 ± 0.06^{A}
	Pb	0.13 ± 0.04^{A}	0.12 ± 0.02^{A}	0.20 ± 0.09^{A}	0.14 ± 0.10^{A}
	Cd	0.07 ± 0.05^{A}	0.06 ± 0.04^{A}	0.02 ± 0.01^{B}	0.07 ± 0.13^{A}
	As	0.30 ± 0.09^{A}	0.25 ± 0.05^{A}	0.35 ± 0.17^{A}	0.23 ± 0.13^{ab}

Note: *Values with the same superscript letters (i.e. a, b, …) or (A, B, …) in the same line are note significantly different (p > 0.05). Those with different letters are significantly different (p < 0.05).*

3.3. Organo tropism

The average total concentrations of Hg, Pb, Cd, and As in the kidneys, the liver, and the muscle of *C. nigrodigitatus* and *S. melanotheron* are shown in Table 4. The kidneys showed the highest concentrations, followed by the liver and the muscle regardless the fish species.

Table 4. Average concentrations (± Standard deviation) (mg kg^{-1} w.w) of Hg, Pb, Cd and As in fish tissues.

Species	Tissues	Hg	Pb	Cd	As
Chrysichthys nigrodigitatus	Muscle	0.13 ± 0.04	0.17 ± 0.13	0.06 ± 0.05	0.19 ± 0.09
	Kidney	0.36 ± 0.14	0.61 ± 0.87	0.23 ± 0.17	1.18 ± 1.63
	Liver	0.22 ± 0.07	0.23 ± 0.13	0.13 ± 0.09	0.30 ± 0.22
Sarotherodon melanotheron	Muscle	0.09 ± 0.06	0.16 ± 0.09	0.05 ± 0.09	0.28 ± 0.14
	Kidney	0.34 ± 0.23	0.38 ± 0.14	0.19 ± 0.07	0.51 ± 0.35
	Liver	0.24 ± 0.10	0.26 ± 0.10	0.16 ± 0.08	0.28 ± 0.11

4. Discussion

4.1. Distribution among the fish species and spatiotemporal variations

Metal bioaccumulation in fish is controlled by factors such as sex, age, size, reproductive cycle, swimming patterns, feeding behavior and habitat (Chouvelon et al. 2017). In the present study, the omnivorous and bottom dweller *Chrysichthys nigrodigitatus* accumulated significant amount of total Hg, Cd, and As than the pelagic and planktivores *Sarotherodon melanotheron*. This result could be explained by differences in habitat and trophic levels between the fishes. Our observation is corroborated by findings that fish feeding at a higher trophic and/ or benthic fish bioacumulate more trace metals than lower trophic level and pelagic fish (Yi and Zhang 2012). On the contrary, the two fish accumulated similar concentrations in Pb, but further investigations are needed to explain this observation.

Studies on spatial variations of trace metals accumulation in fish could provide information on water quality. This is shown by studies including fish sampling when monitoring water quality (Drevnick et al. 2015). Our data showed that the spatial variation of arsenic, lead, mercury and cadmium concentrations in the fish species is complex. The average total Hg, Pb, Cd, and As concentrations in *Chrysichthys nigrodigitatus* muscle showed no significant spatial differences. While the same trend was observed for total Pb and Cd concentrations in *Sarotherodon melanotheron* muscle, total Hg and As concentrations registered opposite signicant spatial trends between Ndjem and Taboth, and between Ndjem and Layo. Nevertheless, the observed spatial variations of arsenic and trace metal concentrations in the fish species in the present study indicate that arsenic and trace metal contamination levels in western Ebrie Lagoon may not be much different between the sites.

Seasonal variations of trace metals in fish can result from changes in metal souces in the environment, in addition to biological factors such as fish condition factor (the lipid content of the tissues), diet, reproductive cycle, and metabolic rates. Data from this study revealed that *Chrysichthys nigrodigitatus* muscle showed no significant seasonal variations in average total Hg, Cd, Pb, and As concentrations. THg concentration remained relatively constant over the whole year in *Sarotherodon melanotheron*. On the contrary, average Pb and As concentrations in *Sarotherodon melanotheron* were significantly highest during the high rainy season, while average Cd concentration was significantly lower during the high rainy season than the low rainy and the dry seasons. These observations suggest that total Hg, Cd, Pb, and As concentrations in *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* muscle could be driven by biological factors. Overall, the seasonal trends of arsenic and trace metals in data from this study are fish and metal specific. More investigations are needed to establish relations between the seasonal variations in arsenic and trace metal loads in the fishes.

A comparison of results of the present study to data from the literature (Table 5) indicated that arsenic and trace metal concentrations in fish from the werstern rural area of Ebrie Lagoon are relatively in the lowest range of the ones from other part of the world (Ouro-Sama et al. 2014; Li et al. 2015; Squadrone et al. 2012; Myrna nevarez et al. 2015; Akoto et al. 2014; Ruelas-Inzunza et al. 2015). As expected, the liver and kidneys of the fish that contain high levels of metal-binding proteins accumulated higher total Hg, Cd, Pb, and As concentrations than the muscle.

Table 5. Comparison of the heavy metal concentration in muscle from the present study with results reported elsewhere.

Species	Locations	Hg	Pb	Cd	As	References
Chrysichthys nigrodigitatus	Ebrie Lagoon/ western portion	0.13	0.17	0.06	0.19	This study
Chrysichthys nigrodigitatus	Togo lagoon systems	-	1.35	0.51	14.7	Ouro-Sama et al., 2014
Pelteobagrus fulvidraco	Nansi Lake (China)	0.213	0.249	0.023	0.083	Li et al., 2015
Silurus glanis	Italian Rivers	0.34	0.04	0.01	-	Squadrone et al., 2012
Ictalurus punctatus	Urban water reservoirs in arid areas of Northern Mexico	0.744	4.298	0.235	-	Nevarez et al., 2015
Sarotherodon melanotheron	Ebrie Lagoon/remote area	0.090	0.16	0.05	0.29	This study
Sarotherodon melanotheron	Ebrie Lagoon/Bay of Bietry	0.17	0,45	0,07	-	Coulibaly et al., 2012
Sarotherodon melanotheron	Estuarine Creek in the Niger Delta	-	6.82	0.3	-	Moslen and Miebaka, 2017
Oreochromis aureus	Sinaloa state (NW Mexico)	0.36	-	-	-	Ruelas-Inzunza et al., 2015

''-'' : Not available

4.2. Fish health status for human consumption

The safety concentrations fixed by the European Commission (EC) for elements Hg, Cd, and Pb in wet tissue weight of fish meat are 0.5, 0.05, and 0.3 mg kg^{-1} ww, respectively (European Commission 2006), while there is no international safety concentration limits set for element As in fish. Our data revealed that total Hg concentrations in all the fish collected from the western rural area of Ebrie Lagoon were below EC health guidelines. With regard to total Cd concentrations, 40% of the 300 individuals of *Chrysichthys nigrodigitatus* sampled from the study area had concentrations above the EC guidelines. Among the 300 individuals of *Sarotherodon melanotheron*, 25% had total Cd concentrations exceeding the EC guidelines. As for Pb, 30 individuals (10 %) of *Chrysichthys nigrodigitatus* and 25 individuals (nearly 8%) of *Sarotherodon melanotheron* had total Pb concentration above the safe limits (Table 5). Similarly, Coulibaly et al. (2012) and Bakary et al. (2015) reported Cd and Pb concentrations above the EC health guidelines in fish and mollusks from the urban area of Ebrie Lagoon. The western rural part of Ebrie Lagoon is considered a pristine area compared to the area of the lagoon bordering Abidjan. Therefore, the few data above the safety limits registered in this study are unexpected and constitute an alert of anthropogenic signals. These include off shore oil extrations, upstream fertilizer and pesticide uses in cash crops, and mining activities that could result in Cd and Pb contamination through land surface run-offs and river discharges in the lagoon basin.

Because *Chrysichthys nigrodigitatus* and *Sarotherodon melanotheron* are the most consumed fish by local communities and a significant part of the diet of residents of Côte d'Ivoire, we estimated the ''Maximum Safe Weekly Consumption'' (MSWC, in kg w.w. wk^{-1}) of the edible flesh of fish in the study area with regard to Hg, Cd, Pb, and As concentrations. The Joint Food and Agriculture Organization of the United Nations (FAO/WHO) Expert Committee on Food Additives (JECFA) established a provisional tolerable weekly intake (PTWI) of 0.005, 0.007, and 0.025 mg kg^{-1}bw for THg, TCd, and TPb, respectively. Our results showed that the maximum amount of fish muscle that should be eaten by a 60 kg-person over a week to reach the PTWI of Hg is 3.3 kg for *Sarotherodon melanotheron* and 2.3 kg for *Chrysichthys nigrodigitatus* (Table 5). A 60 kg-person should eat 8.4 kg of *Sarotherodon melanotheron* and 6.6 kg of *Chrysichthys nigrodigitatus* over a week to reach the PTWI of Cd. Finally, about 9.4 kg of *Sarotherodon melanotheron* and 8.7 kg of *Chrysichthys nigrodigitatus* should be eaten by a 60 kg-person over a week to reach the PTWI of Pb. These MSWC values are very high and suggest that the PTWI of THg, TCd, and TPb are unlikely to be reached by fish farmers.

The JECFA assigned a PTWI of 0.015 mg/kg bw for inorganic arsenic (in rice and derived products). It should be noted that organic arsenic makes up about 95% of the total arsenic in most fish and shellfish, and it is less toxic compared to inorganic arsenic. The committee further removed the PTWI of inorganic As because adverse effects had been reported at exposures lower than those reviewed by the JECFA (JECFA 2004). However, it was necessary to use this PTWI to provide some information with regard to arsenic effects on human health. Assuming that 10% of the total As in fish sampled in the present study is inorganic As, the maximum amount of fish muscle that should be eaten over a week by a 60 kg-person to reach the previously As PTWI is 31.6 kg for *Sarotherodon melanotheron* and 46.9 kg for *Chrysichthys nigrodigitatus* in the study areas (Table 6). These values are much higher than the 0.29 kg (15 kg over a year), i.e., the average weekly fish consumption per capita in Côte d'Ivoire estimated by FAO. Our results suggest that *Sarotherodon melanotheron* and *Chrysichthys nigrodigitatus* consumption is safe with regard to Hg, Cd, Pb and As concentrations.

Table 6. Maximum Safety Weekly Consumption (MSWC) of fish for Hg, Cd, Pb, and As calculated based on the Provisional Tolerable weekly intake (PTWI) values of the JECFA.

			Chrysichthys nigrodigitatus			*Sarotherodon melanotheron*		
Element	EC guidelines (EC, 2006)	PTWI (μg/ kg b.w.) (JECFA, 2004)	Average concentrations (mg kg^{-1})	Percentage exceeding EC guidelines	MSWC (kg w.w. wk^{-1})	Average Concentrations	Percentage exceeding EC guidelines	MSWC (kg w.w. wk^{-1})
Hg	0.50	5	0.13	0	2.3	0.09	0	3.3
Cd	0.05	7	0.06	40	6.6	0.05	25	8.4
Pb	0.30	25	0.17	2	8.7	0.16	2	9.4
As	-	15*	0.19	-	46.9	0.28	-	31.6

* The PTWI of As has been removed by the JECFA.

Conclusion

The status of trace metals mercury, arsenic, lead cadmium, and metalloid arsenic contaminations were examined in two high commercial fishes (*Chrysichthys nigrodigitatus*, *Sarotherodon melanotheron*) that occur in abundance in the western rural area of Ebrie Lagoon. Spatiotemporal variations and the health status of the fish for human consumption were also investigated, and total concentrations were compared among the fish species. Our data showed that the spatial and seasonal variations of arsenic and trace metal concentrations were fish muscle and metal specific, and complex.

Comparing arsenic and trace metal concentrations between fish species, *Chrysichthys nigrodigitatus* that feeds at a higher trophic and is benthic bioacumulated more arsenic and trace metals than the lower trophic level and pelagic fish *Sarotherodon melanotheron*.

Total cadmium and lead concentrations exceeded the European Commission safety limits at about 10-40% of the total individuals fish, making an alert of anthropogenic signals. However, the "Maximum Safe Weekly Consumption" values were far below the provisional tolerable weekly intake (PTWI) of total mercury, cadmium, and lead set by The Joint Food and Agriculture Organization of the United Nations (FAO/WHO) Expert Committee on Food Additives (JECFA). We concluded that *Sarotherodon melanotheron* and *Chrysichthys nigrodigitatus* consumption is safe with regard to mercury, cadmium, lead and arsenic concentrations. Further investigations are needed to better explain the spatial and seasonal variations of arsenic and trace metal concentrations in fish species in the western rural area of Ebrie Lagoon.

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