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Seasonal Accumulations of Some Heavy Metal in Water, Sediment and Tissues of Black-Chinned Tilapia *Sarotherodon melanotheron* from Biétri Bay in Ebrié Lagoon, Ivory Coast

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Abstract The seasonal accumulation of cadmium, copper, lead, mercury and zinc was determined in sediments, water, and black-chinned tilapia (*Sarotherodon melanotheron*; muscle, brain, kidney and liver tissues) collected monthly from Biétri Bay. The mean water concentration of metals (in mg L^{-1}) ranged from 0.01 to 0.30 (mercury), 0.02–0.26 (cadmium), 2.40–4.80 (lead), 9.05–9.68 (copper), and 12.05–19.87 (zinc). The seasonal variations showed a significant difference in the levels of mercury, cadmium and lead among season. The highest mercury (0.30 ± 0.02 µg L^{-1}), cadmium (0.26 ± 0.02 mg L^{-1}) and lead (4.80 ± 1.03 mg L^{-1}) levels were observed during dry season, while the lowest levels (0.21 ± 0.01, 0.02 ± 0.01 and 2.40 ± 0.02 mg L^{-1}, respectively mercury, cadmium and lead) were measured during rainy season. The average cadmium (0.58 ± 0.36 mg L^{-1}), copper (42.15 ± 19.40 mg L^{-1}), lead (58.47 ± 38.10 mg kg^{-1}), mercury (0.79 ± 0.47 µg kg^{-1}) and zinc (187.58 ± 76.99 mg kg^{-1}) concentrations determined in Biétri Bay sediments showed a similar trend as in water. The seasonal variations of mercury, cadmium and lead in tissues revealed that these metals were higher concentrated during dry and swelling seasons. The levels of zinc and copper followed by lead were higher in the tissues. The order of tissues metals concentrations was: kidney > liver > brain > muscle.

Keywords Metals · Accumulation · *Sarotherodon melanotheron* · Tissues · Biétri Bay

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In recent years there has been growing environmental concern, especially regarding the use and discharge of toxic substances. Hence there is a growing need to monitor organic pollutants in environmental studies and to control the quality of food (Brondi et al. 2011). Estuaries and coastal area exhibit a wide array of human impact that can compromise their ecological integrity, because of rapid population growth and uncontrolled development in many coastal region worlds wide (Kulikova et al. 1985). Estuaries, coastal area and bay receive significant anthropogenic inputs from both point and non-point upstream sources and from metropolitan areas, tourism and industries located along the estuarine edges. Pollution has been very damaging to aquatic ecosystems, and may consist of agricultural, urban, and industrial wastes containing contaminants that have proven to be very damaging to aquatic habitats and species (EPA 2009).

According to Olufemi et al. (2008) aquatic organisms are constantly exposed to metals from geochemical processes and anthropogenic activities. Metals exist in a variety of physical and chemical forms in the water column and the bottom sediments (Sri 2006). The ingestion of these contaminants may affect not only the productivity and reproductive capacibilities of these organisms, but ultimately affect the health of man that depends on these organisms as a major source of protein. The United States Environment Protection Agency has classified some metals such as lead, cadmium and mercury as priority pollutants because of their toxicity (EPA 2009). The amount of these metals in our environment increases as a result of industrialization (Igwe et al. 2005). The determination of the metals in food and environmental samples is very important due to the risks that these compounds offer to human health, besides their persistence in the environment and their tendency to bioaccumulation. Some studies have shown the presence of metal in fish species (Ling et al. 2009). The fact that toxic metals are present in high concentrations in fish is of particular importance in relations to the FAO (1983) standards for heavy metals toxicity. In Ivory Coast, the assessment of level of metals of the products of fishing is limited.

Black-chinned Tilapia *Sarotherodon melanotheron* (Rüppell 1853) is an important commercial species and is also one of the most consumed fish in Ivory Coast. Due to their wide abundance and distribution in the Ebrié lagoon, it is important to focus on the use of black-chinned Tilapia as indicators of environmental quality in order to assess the potential risks to which the populations are exposed through the consumption of this species.

The aim of the present study was to determine seasonal accumulations of metals in water, sediments and different tissues of *S. melanotheron* collected from the Biétri Bay which is one of the principal bays of Ebrié Lagoon draining an important discharge from industrial factories. Moreover, due to heavy industrial activities and some other small factories in the region, the Biétri Bay receives large quantities of untreated industrial and domestic sewage. Therefore, it is one of the most polluted coastal waters of Ivory Coast. Meanwhile the Biétri Bay has an economical importance for fishery. Thus, contamination in the Bay is an important issue regarding the health of the aquatic animals and in turn health of the seafood consumers.

Materials and Methods

All samples of sediments, water and fish were collected monthly in Biétri Bay (05°16′N–03°58′W, Fig. 1) from February 2008 until January 2009. The surface sediments were collected using a Van Veen snapper in 5 points of the bay (Fig. 1) during the same journey near to the outlets of the main industrial effluents and the drainage and sewage systems of Biétri City. All samples were dried at 50°C. Large rock debris; mollusk skeletons and organic debris were removed before sieving. The fraction smaller than 1 mm was ground to a fine powder (<63 µm) in an agate mortar. The pulverized samples were newly dried at 60°C until obtaining a constant weight. The water was preserved in plastic bottles by the addition of few drops of nitric acid. Each month, five *S. melanotheron* caught by fishermen's nets were sampled, total length measured, weighed. Approximately 5 g of muscle on the surface of the fish (epaxial muscle of dorsal side), entire liver, kidney and brain from each fish were dissected, washed with distilled water, packed in polyethylene bags and stored at −20°C until chemical analysis.

Chemical analyses of sediments, water and fish tissues were done in accordance with standard procedures established by the EPA (2007). Dried sediments samples were prepared and analyzed using a mixture of hot nitric and hydrochloric acids, followed by ICP-Atomic Emission Spectrometry according to EPA Method 200.2 (EPA 2007). Water samples were digested according to the method described in APHA (1992), while fish tissues were digested after drying according to AOAC (1995) methods. A sample of 1 g of each tissue sample was digested using 1:5:1 mixture of 70% perchloric acid, concentrated nitric and sulphuric acids in fume chamber until colorless liquid was obtained. Lead (Pb) and zinc (Zn) analyses were carried out using an atomic absorption spectrophotometer (Varian SAA Pb), cadmium (Cd) and copper (Cu) (air-acetylene flame). Wavelengths for Pb, Cd, Cu, and Zn were 283.3, 228.8, 324.7, and 213.9 nm respectively. Determination of mercury (Hg) was atomic absorption spectrophotometer (Shimadzu AA 660) equipped with a continuous cold vapor generator connected to an electrically heated quartz tube atomizer, at absorbance resonance line of 253.7 nm. All extractions were carried out in triplicate and blanks were processed as the samples. Results are expressed as mg L^{-1} for water, mg kg^{-1} wet weight for fish and mg kg^{-1} dry weight for sediments.

ANOVA was used to evaluate the effect of season or type of tissues over the metal accumulation in water, sediment or tissues. Then, Duncan multiple range test was performed if significant difference found in ANOVA. Differences were considered significant at p values < 0.05. Statistical analyses were carried out with Statistica 7.1 software.

Results and Discussion

The physicochemical parameters determined in the Biétri Bay were given in Table 1.

Our results on metals concentrations in water show that Zn content was the highest and that of Cd was the lowest in water (Table 2). The order of metals concentrations in water was Zn > Cu > Pb > Hg > Cd. Seasonal variations in the levels of metals (Hg, Cd, Pb, Cu and Zn) in water are given in Table 2. There are significant differences ($p < 0.05$) in the levels of Hg, Cd and Pb among seasons. In contrast, no significant differences ($p > 0.05$) were observed in the levels of Cu and Zn among dry, rainy and swelling seasons. The highest Hg, Cd and Pb levels were

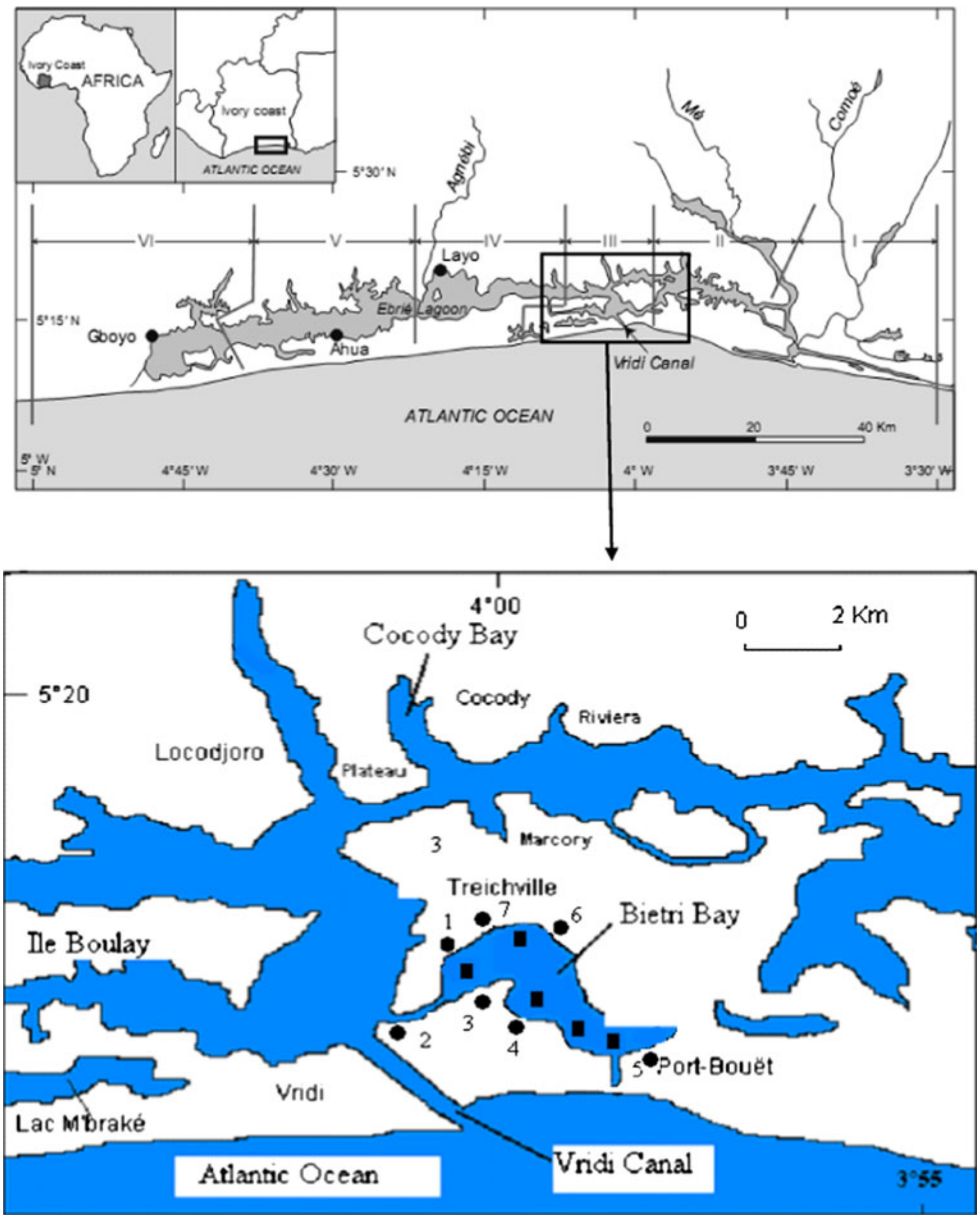

Fig. 1 Location of sampling sites (*square*) in Biétri Bay, Ebrié Lagoon, Ivory Coast (*circle*) Industrial factories (1 Unilever; 2 SHELL; 3 Village of fishermen; 4 SIR; 5 Slaughterhouse; 6 SIVOA; 7 Marina)

Table 1 Physicochemical parameters measured in the sample sites of Biétri Bay

Parameters	Annual	Season		
		Dry	Rainy	Swelling
Temperature T(°C)	29.26 ± 1.53	30.49 ± 1.56	28.12 ± 1.70	29.18 ± 1.35
pH	7.88 ± 0.68	7.46 ± 0.53	8.17 ± 0.71	8.01 ± 0.82
Salinity (%)	16.70 ± 1.92	28.10 ± 2.18[c]	13.49 ± 2.30[b]	8.51 ± 1.30[a]
O_2 (mg L^{-1})	6.10 ± 0.54	5.10 ± 0.18	6.60 ± 0.36	6.62 ± 1.09
Transparency (m)	0.69 ± 0.23	0.64 ± 0.25	0.71 ± 0.24	0.72 ± 0.22
MES (mg L^{-1})	38.08 ± 17.79	45.23 ± 20.30[b]	46.84 ± 24.68[b]	22.18 ± 8.40[a]

pH Hydrogen potential; O_2 Dissolved oxygen; MES Suspended matter

Letters in the same row show differences among seasons ($p < 0.05$)

observed during dry season, while the lowest levels were measured during rainy season. The average Hg, Cd, Pb, Cu and Zn concentrations determined in Biétri Bay sediments are given in Table 2. Hg, Pb, Cu and Zn concentrations showed maximum in dry and swelling seasons, and Cd concentration is practically uniform in all studied seasons.

Table 2 Annual and seasonal heavy metal concentrations (mean ± SD, n = 60) in water (mg L^{-1}) and surface sediments (mg kg^{-1} dry weight, except Hg (μg kg^{-1})) of Biétri Bay

Metal	Sample type	Annual	Season		
			Dry	Rainy	Swelling
Hg	Water	0.20 ± 0.01	0.30 ± 0.02^{c}	0.21 ± 0.01^{b}	0.01 ± 0.00^{a}
	Sediments	0.79 ± 0.47	0.88 ± 0.46^{b}	0.68 ± 0.33^{a}	0.81 ± 0.52^{b}
Cd	Water	0.10 ± 0.01	0.26 ± 0.02^{b}	0.02 ± 0.01^{a}	0.04 ± 0.01^{a}
	Sediments	0.58 ± 0.36	0.59 ± 0.39	0.47 ± 0.13	0.68 ± 0.57
Pb	Water	3.53 ± 0.69	4.80 ± 1.03^{b}	2.40 ± 0.02^{a}	3.39 ± 1.03^{b}
	Sediments	58.47 ± 38.10	56.83 ± 37.67^{ab}	45.30 ± 29.87^{a}	73.29 ± 46.76^{a}
Cu	Water	9.43 ± 2.30	9.56 ± 2.03	9.05 ± 1.85	9.68 ± 3.02
	Sediments	42.15 ± 19.40	53.94 ± 32.27^{b}	25.45 ± 4.33^{a}	47.07 ± 21.61^{b}
Zn	Water	17.04 ± 1.47	19.22 ± 1.08^{b}	12.05 ± 1.32^{a}	19.87 ± 2.01^{b}
	Sediments	187.58 ± 76.99	198.70 ± 86.09^{b}	152.76 ± 46.44^{a}	211.27 ± 98.46^{b}

Letters in the same row show differences among seasons ($p < 0.05$)

As in water, the Zn levels were the highest and that of Cd the lowest in the sediments (Table 2).

The concentrations of metals in fish tissues are given in Table 3. Seasonal variations were observed in the levels of Hg in all tissues; the Hg levels were higher ($p < 0.05$) in dry season. However, the difference in Hg levels between dry and swelling seasons was statistically insignificant in brain and liver tissues. The Cd levels were significantly different ($p < 0.05$) between seasons in all of the tissues examined except in the liver. The highest Cd levels in muscle were found in dry season whereas the Cd concentrations in brain and kidney tissues were slightly higher in swelling season. There were no significant differences ($p > 0.05$) between seasons for Pb concentrations in the brain, kidney and liver; for Cu and Zn concentrations in all of the tissues examined except the muscle in which the highest level of Pb was observed in dry season. The results of the annual mean concentrations show that metal accumulation was highest in kidney and liver while it was lower in brain and muscle (Table 3). The highest mean concentrations of Hg were found in the kidney and liver, Cd and Pb in the liver, and Cu and Zn in the kidney. The order of tissues metals concentrations was: kidney > liver > brain > muscle.

Table 3 Annual and seasonal heavy metal concentrations (mean ± SD, n = 60, mg kg^{-1} wet weight) in tissues of *S. melanotheron* collected from Biétri Bay

Metal	Tissue	Annual	Season		
			Dry	Rainy	Swelling
Hg	Muscle	0.17 ± 0.11$^{(1)}$	0.19 ± 0.13^{b}	0.04 ± 0.04^{a}	0.33 ± 0.15^{a}
	Brain	0.25 ± 0.21$^{(1,2)}$	0.33 ± 0.21^{b}	0.14 ± 0.13^{a}	0.32 ± 0.24^{b}
	Kidney	0.33 ± 0.24$^{(2)}$	0.61 ± 0.40^{b}	0.22 ± 0.15^{a}	0.19 ± 0.16^{a}
	Liver	0.34 ± 0.29$^{(2)}$	0.43 ± 0.39^{b}	0.20 ± 0.16^{a}	0.44 ± 0.33^{b}
Cd	Muscle	0.07 ± 0.05$^{(1)}$	0.10 ± 0.09^{b}	0.05 ± 0.01^{a}	0.06 ± 0.04^{a}
	Brain	0.24 ± 0.21$^{(2)}$	0.26 ± 0.24^{ab}	0.17 ± 0.11^{a}	0.32 ± 0.25^{b}
	Kidney	0.64 ± 0.52$^{(3)}$	0.71 ± 0.68^{b}	0.46 ± 0.20^{a}	0.80 ± 0.69^{b}
	Liver	1.34 ± 0.63$^{(4)}$	1.35 ± 0.79	1.28 ± 0.56	1.39 ± 0.54
Pb	Muscle	0.45 ± 0.41$^{(1)}$	0.69 ± 0.57^{b}	0.34 ± 0.23^{a}	0.35 ± 0.28^{a}
	Brain	0.76 ± 0.52$^{(1)}$	0.84 ± 0.47	0.67 ± 0.48	0.79 ± 0.61
	Kidney	4.78 ± 2.38$^{(2)}$	4.66 ± 2.33	4.84 ± 2.35	4.82 ± 2.50
	Liver	6.34 ± 2.74$^{(3)}$	5.99 ± 2.48	6.15 ± 2.65	6.94 ± 3.05
Cu	Muscle	5.52 ± 3.13$^{(1)}$	6.05 ± 2.89	5.63 ± 2.67	4.85 ± 3.80
	Brain	11.98 ± 6.95$^{(2)}$	12.42 ± 7.23	12.41 ± 7.78	10.96 ± 5.30
	Kidney	19.33 ± 13.58$^{(3)}$	21.25 ± 15.47	19.41 ± 13.10	17.27 ± 11.99
	Liver	9.92 ± 3.29$^{(2)}$	9.19 ± 3.29	10.15 ± 3.08	10.34 ± 3.49
Zn	Muscle	11.70 ± 3.40$^{(2)}$	12.00 ± 3.30	11.13 ± 3.60	12.15 ± 3.19
	Brain	13.00 ± 4.33$^{(2)}$	13.42 ± 4.18	13.44 ± 4.65	11.97 ± 3.92
	Kidney	26.72 ± 9.66$^{(3)}$	25.33 ± 8.89	26.92 ± 11.08	27.86 ± 8.27
	Liver	7.63 ± 2.79$^{(1)}$	7.37 ± 2.99	7.39 ± 2.59	8.22 ± 2.8

Letters in the same row show differences among seasons ($p < 0.05$)

Superscript numbers in brackets in the column show differences among tissues ($p < 0.05$)

There are significant differences in the concentrations of Pb, Hg and Cd in the water and the sediments among seasons. Seasonal metal means recorded in both water and sediments (Table 2) showed higher dry season levels than the rainy season levels, except Cu. The higher dry season levels of Hg, Pb, Cd and Zn may be attributed to the fact that heavy metal accumulation in water is dependent upon the physical and chemical properties of water, such as pH, temperature, salinity, conductivity and dissolved oxygen levels (Wong et al. 2000). The water pH, the nature and concentration of organic ligands, oxidation state and redox conditions within the environment could influence metal solubility (Lalah et al. 2008). The higher dry season metal levels could be attributed to more bioaccumulation due to metal concentration arising from reduced water volume during the dry season. The higher swelling season metal levels are probably due to penetration of inland waters in the Biétri Bay during the swelling season. While, the lower rainy season metal levels could be attributed to the decrease in temperature and salinity due to precipitations. This study revealed that the sediment from Biétri Bay contained very high significant amounts of metals when compared with their concentration in water. Sediments act as the most important reservoir or sink of metals and other pollutants in the aquatic environment (Abdel-Baki et al. 2011).

Seasonal changes of metal concentrations in fish may result from intrinsic factors such as growth cycle and reproductive cycle and from changes in water temperature (Dural et al. 2010). Additionally, the differences noted in the metal concentrations in different tissues between seasons could have been the result of seasonal pollution in water and sediments (Table 2). Our results show that the tissues were generally richest in Zn and Cu, and lowest in Hg, Cd and Pb. This different accumulation patterns between Zn and Cu on the hand and Hg, Cd and Pb on the other hand may be related to the fact that Zn and Cu are essential for metabolic activities (Rejomon et al. 2010). The higher levels of Pb than Hg and Cd levels in tissues were probably due to the motor oil nearly and to the concentrated fishery activities carried out in the region. Our results are important in terms of understanding metal uptake and accumulation in fish tissues. The amount of metals accumulated in the different tissues investigated suggests that kidney accumulated the highest concentration of metals while muscle accumulated the lowest. The high accumulation of Cu and Zn in the kidney corroborated the results obtained by Abdel-Baki et al. (2011). Also, Malik et al. (2010) reported that the kidney was the major site for heavy metals accumulation. The physiological role of the tissue in fish metabolism influences the concentration of metals. Some tissues such as the kidney, the liver and the gills are metabolically active, as compared to low-metabolism tissues like muscle (Ploetz et al. 2007). The absorption of metals is to a large extent a function of their chemical forms and properties. Pulmonary intake causes the most rapid absorption and distribution through the body via the circulatory system. Absorption through the intestinal tract is influenced by pH, rate of movement through the tract and presence of other materials. Combinations of these factors can either increase or decrease absorption (Adeosun et al. 2010). Although, fish is the main source of Hg in human diet (Malik et al. 2010). Hg was found to be the least accumulating metal during this study. Muscle is the main edible part of fish and can directly influence human health. The levels of Cd and Cu in fish muscle were higher than the WHO and FAO recommended maximum allowable standards in food fish, while those of Hg, Pb and Zn were lower than the standards (FAO 1983).

The concentration of metals in fish tissues, along with those in water and sediments in the present study, calls for caution as cumulative effects might constitute health hazards to aquatic life including humans who consume fish.

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