Egyptian Journal of Aquatic Biology & Fisheries
Zoology Department, Faculty of Science,
Ain Shams University, Cairo, Egypt.
ISSN 1110 – 6131
Vol. 25(1): 821 – 841 (2021)
www.ejabf.journals.ekb.eg

Assessment of heavy metal contamination of fish from a fish farm by bioconcentration and bioaccumulation factors

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ARTICLE INFO

Article History:
Received: June 17, 2020
Accepted: Jan. 23, 2021
Online: Feb. 25, 2021

Keywords:
Heavy metals,
water,
sediments,
farmed fish,
bioaccumulation,
bioconcentration

ABSTRACT

Fish farms are an alternative to meet human needs for fish. However, these farms are influenced by intense anthropogenic activities that can affect the quality of water, sediments and fish. This study aims to determine the concentrations of heavy metals in water and sediments in order to assess their transfer into farmed tilapia using bioconcentration and bioaccumulation factors. The results revealed very high levels of arsenic (0.050 ± 0.029 mg/L) and cadmium (0.047 ± 0.059 mg/L) in water compared to mercury (0.012 ± 0.002 mg/L) and lead (0.007 ± 0.001 mg/L). In sediments, the most accumulated metal is mercury (25.387 ± 7.728 mg/kg) while arsenic (1.455 ± 0.383 mg/kg) is the most accumulated metal in fish muscle. These arsenic levels in fish muscle are above the reference dose. Pearson's correlation showed that mercury and lead concentrations in water influence bioconcentration in fish while cadmium concentrations in sediment influence bioaccumulation. The results show that the fish muscle was contaminated with arsenic. In addition, there was bioconcentration of mercury and lead in the muscle, which is a risk for fish survival and human consumption.

INTRODUCTION

Fish is the product of the aquatic ecosystem that is most consumed by humans (**Bouhali *et al*., 2008**). It contains several essential micronutrients, vitamins (A, B and D), mineral salts (calcium, iodine, zinc, iron and selenium) and omega-3 polyunsaturated fatty acids (**FAO, 2014**). Fish play a very important role in food and nutritional security. It contributes to the protection against cardiovascular diseases, promotes the development of the brain and nervous system of the fetus and the infant (**FAO, 2016**).

Fish is a cheap source of animal protein (**Dinesh *et al.*, 2017**) which represents in many developing countries a very important source of protein of good food quality and an affordable price (**Ipungu *et al.*, 2015**). In Côte d'Ivoire, fish is the primary source of animal protein for populations (**Avit *et al.*, 2012; Failler *et al.*, 2014**). According to FAO (**FAO, 2016**), it should continue to be used mainly for consumption, and thus make a valuable nutritional contribution to diversified and healthy diets.

However, fish could become a vector of heavy metal contamination of humans through the food chain (**Das *et al.*, 2017; Ullah *et al.*, 2017**). Indeed, fish, reared in waters contaminated with heavy metals, most likely contain heavy metals in their flesh (**Benzer *et al.* 2013; Junianto *et al.*, 2017**) because they can accumulate large quantities of heavy metals (**El- Nemaki *et al.*, 2008**). Thus, when the fish's living environment is contaminated with heavy met²als, this contamination cannot only pose a threat to the fish, but also serious risks to public health (**Vieira *et al.*, 2011; Junejo *et al.*, 2019**). This therefore represents a serious threat to humans (**Shafei, 2015**).

The presence of heavy metals in the waters and sediments of fish farms comes from many sources including agricultural activities (**Garcia *et al.*, 2016)** and fish feed (**Das *et al.*, 2017**). Many studies (**Mostafa *et al.*, 2015; Sarker *et al.*, 2016; Adeyemi and Ugah, 2017; Maurya *et al.*, 2018; Junejo *et al.*, 2019**) have demonstrated anthropogenic pollution of water and sediments in fish farms by heavy metals. Moreover, the risks of toxicity to fish have been examined (**Kalantzi *et al.*, 2013**).

Although fish farming plays an important role in the production of fishery products in Côte d'Ivoire, the data on the bioaccumulation and bioconcentration of heavy metals in the tissues of farmed fish is limited. The objective of this study is therefore to determine the level of contamination in arsenic, cadmium, lead and mercury in the water and sediments of a fish farm as well as their influence on bioaccumulation and bioconcentration in farmed tilapia *Oreochromis niloticus*.

MATERIALS AND METHODS

Presentation of the study environment

The fish farm is located on the Bandama River in Taabo (Center of the Côte d'Ivoire) between latitude 6 ° 13'32.2 N and longitude 5 ° 4'55.8 W (Fig. 1) not far from the Taabo hydroelectric dam. The fish growth is done in floating cages of volume 62.5 m^3 each with a density of 2,500 fish. The farm is an intensive system with a feed based on an extruded floating granulated feed (Raanan Fish Feed) imported from Ghana. The lake Taabo on which the farm is located, is bordered by coffee, cocoa and banana plantations.

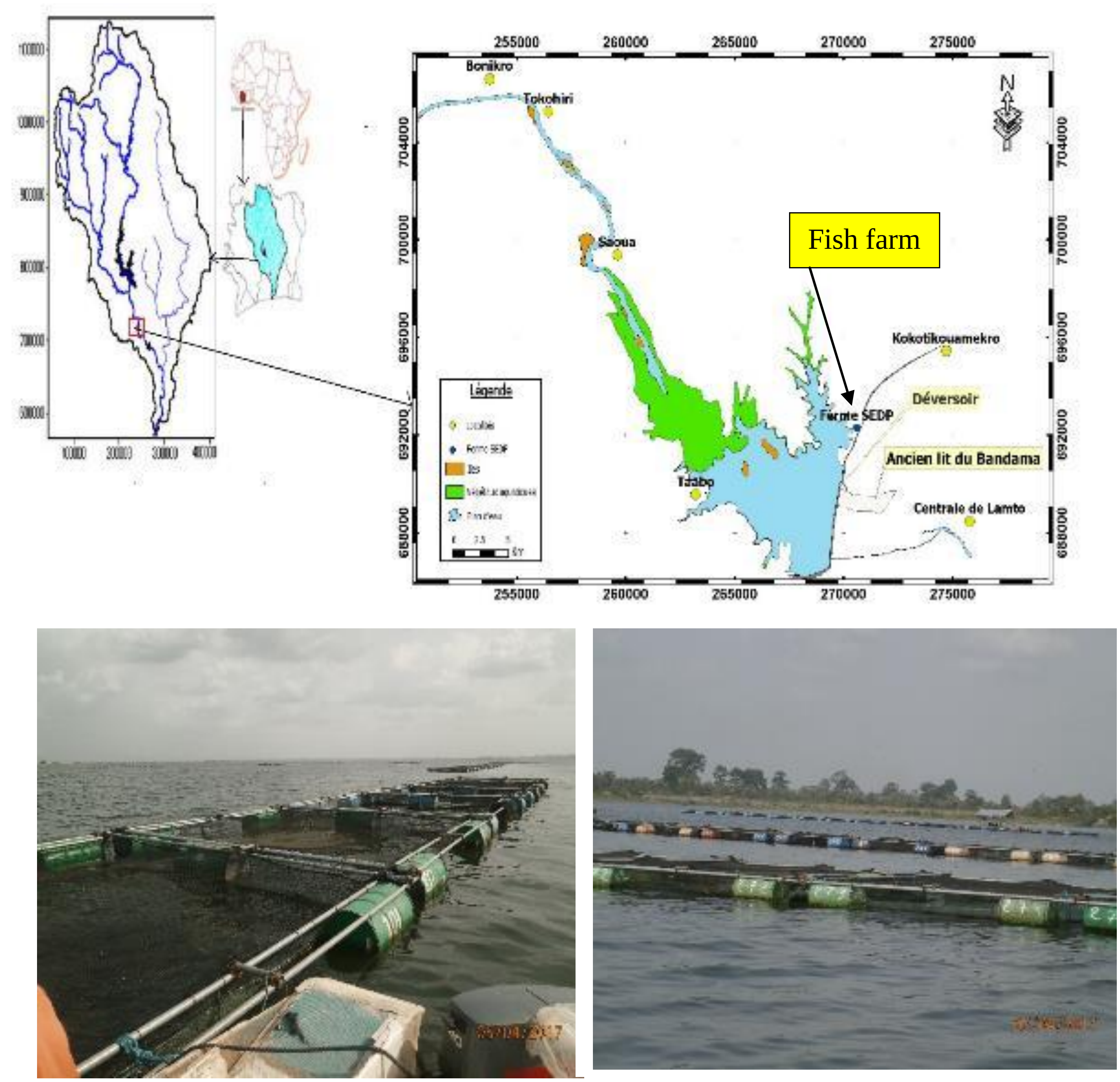

Fig. 1. Fish farm in Taabo (**Sanou, 2018**)

Collection and storage of water, sediments and fish samples

The samples were taken monthly from February to July 2017, thus covering the dry season (February - April) and the rainy season (May - July).

The water was collected using new polyethylene jars with a capacity of 1 liter previously rinsed with water from the farm. The jars are then completely immersed in the water to be sampled. Once filled, they are removed, closed, labeled and stored in a cooler at 4 °C to be transported to the laboratory.The water is then filtered under vacuum on a filtering membrane and acidified to $pH < 2$ by adding 0.5 mL of hydrochloric acid and then stored for a subsequent determination of the level of heavy metals.

Dip nets were used to sample the fish. The landing net consists of a fishing net mounted on a hoop suitable for a handle. The fish are caught alive and stored in a cooler at a temperature of 4 °C to be transported to the laboratory. Once in the laboratory, 5 g of muscle sample are weighed, stored in pill organizers and stored at -20 °C for further analysis.

The sediment sampling was carried out using a Van Veen grab. The latter is guided through the water with a rope. Once brought to the surface, the sediments are extracted from the grab, packaged in plastic bags and stored in a cooler at 4 °C. The samples are then transported to the laboratory and stored in a freezer at -20 °C (**UNEP, 2007**). After drying in an oven at 50 °C for 24 hours, the samples are pre-sieved through a 1 mm mesh sieve to remove rock debris, branches, leaves and organic debris. In order to obtain a constant mass, the fine fractions (63 µm) are retained and newly dried in an oven at 60 °C for one hour. They are then sealed in clean polyethylene bags indelibly numbered and kept individually until later use.

Determination of heavy metal levels in water, sediment and fish

The concentration of heavy metals in the samples was determined through atomic absorption spectrophotometry by using a Shimadzu spectrophotometer (Shimadzu AA 660). The determinations of cadmium (Cd), lead (Pb) and arsenic (As) are carried out by electrothermal atomic absorption spectrometry equipped with a graphite furnace. The mercury (Hg) concentration is determined by an atomic absorption spectrophotometer fitted with an AMA-254 mercury cold vapor analyzer. The assays were carried out according to **EPA** (**2007**) at wavelengths of 253.7 nm for Hg; 228.8 nm for Cd; for 283.3 nm Pb and 193.7 nm for As.

Statistical analysis

The STATISTICA 7.1 software allowed us to perform the analysis of variances (ANOVA) in order to test the significant differences between the heavy metal contents. Whenever the test result was significant, the Ducan ANOVA test was performed at $P < 0.05$ or 5% to identify groups that were particularly different from each other. Moreover, the Bravais - Pearson correlation test was used to establish a relationship between the heavy metals in water, sediments and fish.

Bioconcentration factor (BCF)

Bioconcentration is a term used in the field of aquatic toxicology. It allows to know if a substance present in a living organism has a concentration higher than that of its surrounding environment. The bioconcentration factor corresponds to a comparison expressed as a ratio between the levels of heavy metals in organisms and the levels in water. This factor is defined by the ratio of the heavy metal concentration of the organism to that of water (**Kennish, 1992**). It is expressed in L/kg and is given by the following relation (**Kennish, 1992**):

$$BCF = \frac{C_{MF}}{C_{MW}}$$

In which C_{MF} is the concentration of the heavy metal in the muscle of the fish and C_{MW} is the concentration in the water.

Biosediment Accumulation Factor (BSAF)

The bio-sediment accumulation factor or bioaccumulation factor is defined as the ratio of heavy metal concentration in the body to that in the sediment. It makes it possible to evaluate the effectiveness of the bioaccumulation of heavy metals in the organism (**Liu *et al.*, 2010; Zhao *et al.*, 2012**). It thus gives an idea of the speed of absorption and excretion of a substance by a living organism (**Coulibaly, 2013**). This factor is obtained by the following expression (**Szefer *et al.*, 1999**):

$$BSAF = \frac{C_{MF}}{C_{MS}}$$

In which C_{MF} represents the concentration of the heavy metal in the fish muscle and C_{MS} its concentration in the sediments.

Bioaccumulation is expected to occur in organisms if the value of BSAF is greater than 1 (BSAF > 1) (**Szefer *et al*. 1999**).

RESULTS

Monthly and seasonal heavy metal concentrations in fish farm water

Fig. 2 shows the monthly concentrations of cadmium, mercury, lead and arsenic measured in water. Cadmium concentrations vary between 0.018 and 0.167 mg/L. Mercury has monthly values that range between 0.011 and 0.015 mg/L. Monthly lead concentrations range from 0.006 to 0.009 mg/L. The monthly arsenic values are between 0.003 and 0.083 mg/L.

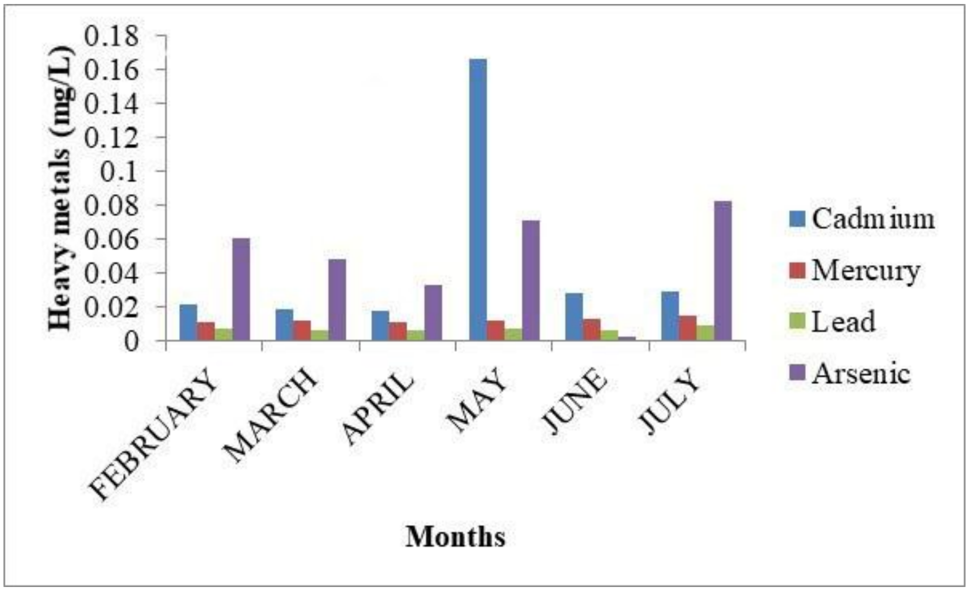

Fig. 2. Monthly variation of cadmium, mercury, lead and arsenic in the water of the fish farm from February to July 2017

Average seasonal concentrations and mean values of cadmium and mercury are above the norm for freshwater aquaculture while those of lead and arsenic are lower (Table 1). However, these values are higher in the rainy season than in the dry season for all metals. The seasonal mean cadmium concentrations show a significant difference ($P < 0.05$) between the dry season and the rainy season. Arsenic is the metal with the highest average concentration in water while lead has the lowest one. The order of heavy metals accumulation in water is As > Cd > Hg > Pb (Table 1).

Table 1. Seasonal and average values of Cadmium, Mercury, Lead and Arsenic in water (mg/L)

		Heavy metals			
		Cd	Hg	Pb	As
Dry season	Minimum	0.018	0.011	0.006	0.033
	Maximum	0.022	0.012	0.007	0.061
	Average	0.020±0.002[a]	0.011±0.001	0.006±0.001	0.047±0.014
Rainy season	Minimum	0.028	0.012	0.006	0.003
	Maximum	0.167	0.015	0.009	0.083
	Average	0.075±0.080[b]	0.013±0.002	0.007±0.002	0.052±0.043
Average value		0.047±0.059	0.012±0.002	0.007±0.001	0.050±0.029
Mélard, 1999		**0.005**	**0.0002**	**0.02**	**0.4**

The values with the letters a, b in superscript show a difference between the seasons ($p < 0.05$)

Monthly and seasonal concentrations of heavy metals in fish farm sediments

In sediments, cadmium values range from 0.117 to 0.187 mg/kg. Mercury levels vary between 16.54 and 35.23 mg/kg while monthly lead concentrations vary between 5.58 and 12.67 mg/kg. As for the monthly values of arsenic, they range from 4.01 to 7.32 mg/kg (Fig. 3).

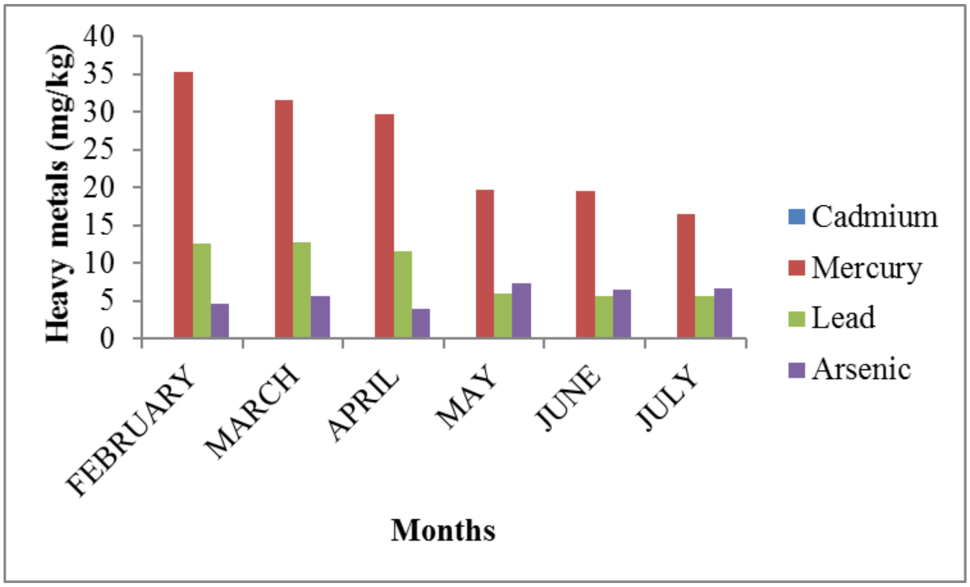

Fig. 3. Monthly variation of cadmium, mercury, lead and arsenic in the sediments from February to July 2017

Seasonal and average variations in the contents of cadmium, mercury, lead and arsenic metals in the sediments are shown in Table 2. The contents of cadmium, mercury and arsenic are higher in the sediments than in the upper continental crust mainland except for lead. With the exception of arsenic, all the other metals have higher contents in the dry season than in the rainy season. However, the concentrations of metals in the sediments were higher compared to those found in water and fish muscle. In sediments, mercury has the highest average concentrations followed by lead, arsenic and cadmium. The metals are accumulated in the sediments in the following decreasing order: Hg > Pb > As > Cd.

Table 2. Seasonal and average values of Cadmium, Mercury, Lead and Arsenic in sediments (mg/kg)

		Heavy metals			
		Cd	Hg	Pb	As
Dry season	Minimum	0.182	29.74	11.6	4.01
	Maximum	0.187	35.23	12.67	5.6
	Average	0.185±0.003	32.177±2.796	12.270±0.584	4.743±0.802
Rainy season	Minimum	0.117	16.54	5.58	6.41
	Maximum	0.157	19.68	6.01	7.32
	Average	0.135±0.020	18.597±1.782	5.757±0.225	6.770±0.484
Average value		0.160±0.030	25.387±7.728	9.013±3.589	5.757±1.258
Upper Continental Crust		**0.1**	**0.06**	**17**	**2**

The environmental quality of farm sediments was assessed by comparing their heavy metals concentrations with toxicological values. The results are presented in Table 3. The average concentrations of Cd, Pb and As in the sediments are lower than the TEL and PEL values. Mercury has a higher average concentration than TEL and PEL. However, the concentration of arsenic in 50% of the samples and that of mercury in 100% of the samples are above the corresponding TEL values. In addition, the concentration of mercury in each sample is greater than the PEL value.

Table 3. Assessment of sediment pollution by comparison of metals concentration with toxicological values

	Heavy metals			
	Cd	Hg	Pb	As
TEL* (mg/kg)	**0.596**	**0.174**	**35.000**	**5.900**
PEL* (mg/kg)	**3.530**	**0.486**	**91.300**	**17.000**
Average values (mg/kg)	0.160±0.030	25.387±7.728	9.013±3.589	5.757±1.258
% of samples < TEL	100	0	100	50
% of samples > PEL	0	100	0	0

***** TEL (Threshold Effect Level) and PEL (Probable Effect Level) according to Sediment Quality Guideline (SQG) (**MacDonald *et al*., 2000**).

Monthly and seasonal concentrations of heavy metals in fish muscles

Fig. 4 shows the monthly concentrations of cadmium, mercury, lead and arsenic found in the muscle of *Oreochromis niloticus* collected from the water of the fish farm. These values range from 0.018 to 0.026 mg/kg for cadmium; from 0.061 to 0.094 mg/kg for mercury; between 0.042 and 0.105 mg/kg for lead and between 1.070 and 1.890 mg/kg for arsenic (Fig. 4). Arsenic is the most accumulated metal in fish during the entire sampling period while cadmium remains the least accumulated. Compared to lead, mercury is the most accumulated metal during the dry season while lead is the most accumulated during the rainy season.

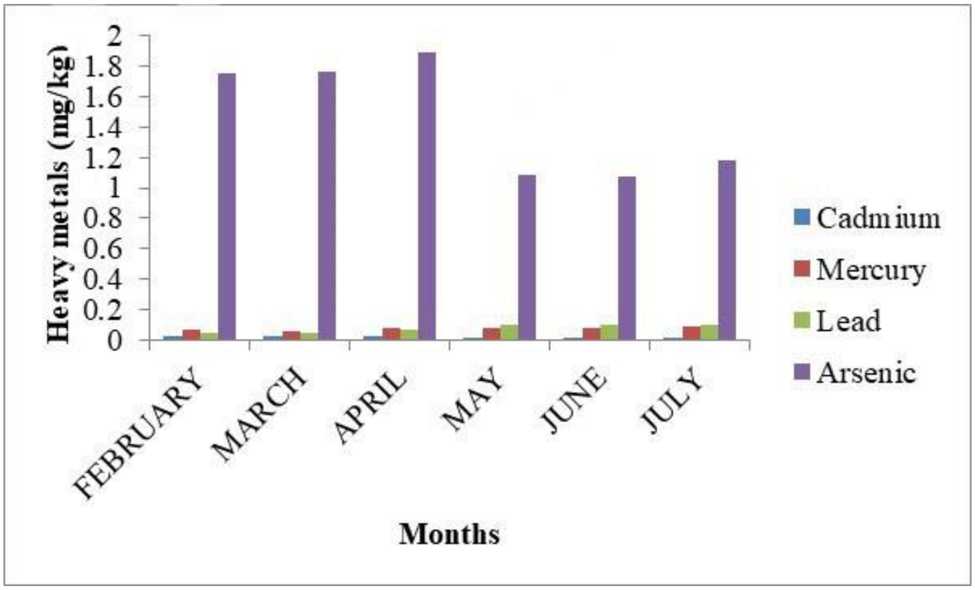

Fig. 4. Monthly variation of cadmium, mercury, lead and arsenic in *Oreochromis niloticus* muscle from February to July 2017

There is a significant difference ($p < 0.05$) in lead and arsenic values between seasons (Table 4). In the dry season, the order of heavy metal accumulation is As > Hg > Pb > Cd in fish muscle. This order of heavy metal accumulation is As > Pb > Hg > Cd in the rainy season in the organ studied. However, arsenic remains the most accumulated metal and cadmium the least accumulated metal over the two seasons. The mean contents of heavy metals in the muscle of the fish were greater than their concentrations in the fish farm water except for cadmium. The concentrations of metals in the fish muscle have been compared with the international recommendations for heavy metals in the flesh of the fish. For the metals as cadmium, mercury and lead, the average concentrations recorded in this study are lower than those indicated in international standards. Regarding arsenic, the average concentration is higher than all the referenced standards (Table 4).

Table 4. Seasonal and average values of Cadmium, Mercury, Lead and Arsenic in the muscle (mg/kg) of *Oreochromis niloticus*

		Heavy metals			
		Cd	Hg	Pb	As
Dry season	Minimum	0.021	0.061	0.042	1.75
	Maximum	0.026	0.08	0.067	1.89
	Average	0.024±0.003	0.068±0.010	0.052±0.013[a]	1.800±0.078[b]
Rainy season	Minimum	0.018	0.078	0.1	1.07
	Maximum	0.019	0.094	0.105	1.18
	Average	0.019±0.001	0.084±0.009	0.102±0.003[b]	1.110±0.061[a]
Average value		0.021±0.003	0.076±0.012	0.077±0.029	1.455±0.383
FAO/WHO (1991)		**0.05**	**0.5**	**0.3**	**0.1**
EU (2008)		**0.05**	**0.5**	**0.3**	**0.1**

The values with the letters a, b in superscript show a difference between the seasons ($p < 0.05$)

Bioconcentration of heavy metals in the muscle of *Oreochromis niloticus*

The bioconcentration factor (BCF) of heavy metals is given in Table 5. The results indicate that arsenic has the highest BCF, followed by lead, mercury and cadmium. Average BCF values are 84.787 L/kg for arsenic, 11.361 L/kg for lead, 6.170 for mercury and 0.845 L/kg for cadmium. The bioconcentration factor is higher in the rainy season except for cadmium. The metal bioconcentration factor is ranked in decreasing order according to BCF (As) > BCF (Pb) > BCF (Hg) > BCF (Cd). This order follows the order of accumulation of heavy metals in the muscle of the fish.

Table 5. Seasonal and average BCF values (L/kg)

		Heavy metals			
		Cd	Hg	Pb	As
Dry season	Minimum	1.091	5.083	6.000	28.689
	Maximum	1.667	7.273	11.167	57.273
	Average	1.209±0.143	6.028±1.126	8.389±2.605	40.876±14.750
Rainy season	Minimum	0.108	6.000	11.333	14.217
	Maximum	0.679	6.667	16.667	356.667
	Average	0.481±0.323	6.311±0.336	14.333±2.729	128.698±197.427
Average value		0.845±0.457	6.170±0.759	11.361±4.037	84.787±134.134

Bioaccumulation of heavy metals in the muscle of *Oreochromis niloticus*

The bioaccumulation factor for heavy metals in fish muscle is presented in Table 6. The results show that arsenic, cadmium, lead and mercury respectively have average bioaccumulation values of 0.276, 0.134, 0.011 and 0.004. In general, the bioaccumulation factor is higher in the rainy season except for arsenic. The bioaccumulation factor for the different metals is ranked in decreasing order according to BSAF (As) > BSAF (Cd) > BSAF (Pb) > BSAF (Hg).

Table 6. Seasonal and average values of BSAF

		Heavy metals			
		Cd	Hg	Pb	As
Dry season	Minimum	0.115	0.002	0.003	0.314
	Maximum	0.139	0.003	0.006	0.471
	Average	0.128±0.012	0.002±0.001	0.004±0.002	0.388±0.079
Rainy season	Minimum	0.121	0.004	0.017	0.148
	Maximum	0.162	0.006	0.018	0.179
	Average	0.140±0.021	0.005±0.001	0.018±0.001	0.165±0.016
Average value		0.134±0.016	0.004±0.002	0.011±0.007	0.276±0.132

Relationship between heavy metals in water, sediment and muscle of *Oreochromis niloticus*

The elementary statistical analysis was carried out between the heavy metals in the water, the sediments and the muscle of the fish. Table 7 presents the correlation matrix between the different matrices. In general, there are highly significant correlations between the concentrations of metals in the all matrices studied on the one hand and on the other hand between the concentrations of metals in water and sediments. The correlation matrix reveals a negative and significant correlation between mercury (r = - 0.84), arsenic (r = - 0.92) and lead (r = - 0.98) in sediments and their respective content in the fish muscle. However, a positive and significant correlation is observed between cadmium in sediments (r = 0.81) and cadmium in fish flesh. Besides, there is a significant positive correlation between mercury in water (r = 0.70), negative correlation between cadmium in water (r = - 0.53) and their value in fish muscle. In addition, highly significant correlations are indicated between the contents of heavy metals in water and their concentrations in sediments on the one hand: cadmium (r = - 0.51) and mercury (r = - 0.80) and on the other hand, between the concentrations of different metals in the same matrix: water (Hg / Pb: r = 0.72, Pb / As: r = 0.78) and sediments (Cd / Hg: r = 0.82, Hg / Pb: r = 0.98, Pb / As: r = - 0.83).

Table 7. Bravais – Pearson correlation coefficient between heavy metals of fish muscle, water and sediments

	Cd(w)	Hg(w)	Pb(w)	As(w)	Cd(s)	Hg(s)	Pb(s)	As(s)	Cd(f)	Hg(f)	Pb(f)	As(f)
Cd(w)	1											
Hg(w)	-0.04	1										
Pb(w)	0.12	0.72	1									
As(w)	0.36	0.27	0.78	1								
Cd(s)	-0.51	-0.44	-0.07	0.27	1							
Hg(s)	-0.42	-0.80	-0.50	-0.10	0.82	1						
Pb(s)	-0.47	-0.74	-0.47	-0.07	0.90	0.98	1					
As(s)	0.66	0.63	0.39	0.26	-0.77	-0.82	-0.83	1				
Cd(f)	-0.53	-0.47	-0.37	-0.03	0.81	0.87	0.90	-0.59	1			
Hg(f)	0.21	0.70	0.63	0.23	-0.49	-0.84	-0.76	0.42	-0.85	1		
Pb(f)	0.53	0.66	0.40	0.04	-0.87	-0.98	-0.98	0.78	-0.94	0.83	1	
As(f)	-0.54	-0.67	-0.40	-0.07	0.93	0.91	0.97	-0.92	0.79	-0.59	-0.91	1

DISCUSSION

Lead, mercury, cadmium and arsenic are major pollutants because of their toxicity, their persistence and their tendency to bioaccumulate in the food chain. They represent a risk for aquatic ecosystems and humans (**Kouamenan *et al*., 2020).** These metals are among the metals, which are the most assessed in fish farming (**Svobodova *et al*., 1993**).

Our results reveals the presence of heavy metals in the water of the fish farm. Nevertheless, lead and arsenic concentrations are below the maximum acceptable concentrations for these metals in fish farm water. This could be due to the fact that in surface waters, arsenic and lead largely accumulated in bottom sediments are higher than in water (**Svobodova *et al*., 1993**). The results showed concentrations of cadmium and mercury in water are above the recommended standards for freshwater aquaculture, which are respectively 0.005 and 0.0002 mg/L (**Mélard, 1999**). This indicates that the waters of the fish farm are contaminated with cadmium and mercury. This contamination can be attributed to the regular use of fertilizers for agricultural purposes around the farm (**Mutlu and Kurnaz, 2018**). Contaminated water could increase the content of heavy metals in fish muscle (**Qadir and Malik, 2011; Yasmeen *et al.*, 2016**) because water pollution can lead to contamination of fish (**Mensoor and Said, 2018**). According to **Moiseenko *et al*.** (**2018**), the histological analysis of liver diseases shows that different liver abnormalities have been frequently detected in fish living in waters contaminated with metals and the morbidity of the fish has progressed with the contamination of water.

The results of the study show that the sediments contain very high levels of heavy metals compared to water. This difference could be explained by the tendency of metals to accumulate in sediments and biomagnify along aquatic food chains (**Yi *et al*., 2011; Kouakou *et al*., 2016**). The Bravais - Pearson correlation matrix indicates a significantly negative correlation between mercury (r = - 0.80) and cadmium (r = - 0.51) in sediments and water. This shows that the concentrations of cadmium and mercury in sediments have no impact on their concentrations in water. Pearson's correlation coefficients show that lead is positively correlated with mercury (r = 0.72) and arsenic (r = 0.78) in water. Furthermore, mercury is positively and significantly correlated with cadmium (r = 0.82) and lead (r = 0.98) in farm sediments. According to **Suresh *et al*.** (**2011)** and **Shetaia *et al***. (**2020**), the strong correlations observed between heavy metals in the same matrix mean that they have a common source, mutual dependence and identical behavior during transport. The very low correlation coefficients observed between the other metals indicate the absence of correlation between these metals. This means that the concentrations of these heavy metals are not controlled by a single factor, but by a combination of geochemical support phases and their mixed associations (**Suresh *et al*., 2011**). The concentrations of metals in the sediments are higher than their corresponding concentration in the Upper Continental Crust, except for lead (**Wedepohl, 1995**). It turns out that the farm's sediments are polluted by cadmium, arsenic and mercury. These sediment-bound metals are likely to be released into the water column, which impact the aquatic biota (**Kouakou, 2017**); especially fish. In addition, these metals contained in the sediments can directly act on fish. Indeed, the transfer of heavy metals from sediments to aquatic organisms has been reported as an important source of metals for many species (**Rodrigue *et al*., 2016**).

In order to assess the biological and ecological effects of heavy metal pollution in farm sediments, a comparative study was carried out with the toxicological values TEL and PEL. The TEL (Threshold Effect Level) represents the concentration of the metal below which the negative effects should only occur rarely while the PEL (Probable Effect Level) indicates the concentration above which the negative effects should occur frequently (**MacDonald *et al*., 2000**). The assessment of sediment pollution by comparative analysis with TEL and PEL indicated that 50% of the samples had arsenic concentrations above the TEL value and 100% of the samples had mercury concentrations above the PEL concentration. These results indicate that the concentrations of arsenic and mercury present in the sediments could have harmful biological effects on the aquatic organisms living in the sediments of the fish farm (**MacDonald *et al*., 2000; Harikumar *et al*., 2009**).

The food intake of fish is very great importance. However, it has been shown that fish are vectors of heavy metal contamination in humans (**Usero *et al*., 2003**) to such an extent that certain species are used to assess heavy metal pollution of water (**Coulibaly, 2013; Moiseenko *et al*., 2018**). Several studies have been carried out to assess the level of heavy metals in fish organs (liver, gills, muscles, kidneys, intestine, stomach, skin, bone and spleen) (**Abdel-Baki *et al*., 2011; Chahid, 2016; Alvarado *et al*., 2019**). Nonetheless, muscle, the main edible part of fish (**Pintaeva *et al.*, 2011; El – Korashy *et al*., 2018**), remains the most analyzed organ due to the consequences of its consumption and health risks (**Chahid, 2016**). Our study reveals the presence of heavy metals in the muscle of the sampled farmed tilapia. The amounts of heavy metals accumulated in the muscle of the fish indicate that arsenic is the most accumulated metal in this organ. The high levels of arsenic observed in the flesh of *Oreochromis niloticus* could be linked to the high concentrations of this metal in the water of the fish farm. According to **Kouakou** (**2017**), heavy metals with high bioavailability could be absorbed by aquatic organisms. In addition, the accumulation of certain metals in fish organisms depends on their absorption mechanisms, which are also influenced by the availability of these metals in the aquatic environment (**Coulibaly, 2013**). Thus, the high levels of arsenic compared to other metals in fish muscle are probably due to the absorption mechanisms of this metal. In addition, this could be due to the fact that arsenic is the metal easily accumulated in tilapia compared to other farmed fish (**Jiang *et al.*, 2014**). It is known that high concentrations of heavy metals can pose a serious threat to fish (**Vilizzi and Tarkan, 2016**). These high levels of metals could alter the muscle tissue of fish. Indeed, several recent studies have indicated that the alterations in fish tissue could be due to the toxic effects of heavy metals (**Coulibaly *et al*., 2012; Abarghoei *et al*., 2016; Kouamenan *et al*., 2020**). Our results showed significantly different levels of heavy metals in fish muscle depending on the season. These seasonal variations in heavy metal concentrations in the fish flesh could result from seasonal pollution of farm water and sediments (**Kouakou *et al*., 2016**). In addition, the accumulation of metals in fish partly depends on the concentration of the metal in water and sediments (**Junejo *et al*., 2019**). The concentrations of cadmium, lead, mercury and arsenic in the muscle were compared with the limit values authorized for consumption. This comparison shows that fish muscle is heavily contaminated with arsenic, indicating a risk for human consumption (**FAO/WHO, 1991; EU, 2008**).

Yet, the levels of heavy metals in the flesh of the fish cannot only account for the effectiveness of their accumulation. For a depth assessment of the transfer of heavy metals from water and sediments to fish, the bioconcentration and bioaccumulation factors were calculated. The high bioconcentration factors (BCF > 1) of metals such as mercury, lead and arsenic show that these metals contained in water are likely to accumulate at higher and potentially toxic concentrations in fish. In addition, the contents of these metals are higher in muscle than in water, thus reflecting the phenomenon of bioconcentration. This indicates that the tilapia raised on the farm accumulates these heavy metals in its flesh through water and could be contaminated by these metals. The cadmium bioconcentration factor less than 1 (BCF < 1) indicates almost zero bioconcentration. Pearson's correlation showed that the concentration of mercury in water strongly influenced the bioconcentration of this metal in fish, while cadmium in the same matrix had no effect on its content in fish. The high level of bioconcentration factor of arsenic, lead and mercury shows that *Oreochromis niloticus* is a good bio-indicator for monitoring pollution with these heavy metals on fish farms.

All bioaccumulation factors have values less than 1 (BSAF < 1). This means that there is almost no bioaccumulation of the metals studied in fish. This could be related to the content of metals in the sediments. In fact, when the concentrations of metals in sediments are below the threshold which organisms are able to accumulate metals in their bodies, bioaccumulation is not significant (**Usero *et al*., 2005; Maha *et al*., 2008; Zhao *et al*., 2012**). Furthermore, these BSAF values < 1 could justify the strong negative and significant correlations between mercury (r = - 0.84), arsenic (r = - 0.92) and lead (r = - 0.98) in sediments and their respective concentration in fish muscle, indicating that the concentrations of these metals contained in the sediment did not influence bioaccumulation. Indeed, according to **Szefer *et al*.** (**1999**) and **Zhao *et al.*** (**2012**), bioaccumulation should occur in the body for values of BSAF > 1. The strong positive correlation observed between cadmium in sediments (r = 0.81) and fish muscle shows that the accumulation of this metal in the flesh of the tilapia increases with its concentration in the sediments. This shows that the concentration of cadmium in the sediments influences bioaccumulation in fish.

As a result, these farmed fish accumulate metals in response to their exposure to these pollutants. In fact, aquatic animals concentrate heavy metals according to their bioavailability in biota (**Kamilou *et al*., 2014**). However, this represents a risk to the health of consumers because the accumulation of metals contributes to the chronic toxicity of the fish (**Coulibaly, 2013**).

CONCLUSION

This study showed that the waters of the fish farm had high concentrations of cadmium and mercury while the sediments had high levels of cadmium, mercury and arsenic. In general, the values of metals in fish muscle are below set limits of international legislation (FAO, WHO and EU) and are safe for human consumption. However, arsenic values exceeded these limits, indicating a risk to the health of consumers. The calculation of bioconcentration factors (BCF) indicated that there was a transfer of metals (mercury, lead and arsenic) from water to fish. Furthermore, the Bravais - Pearson correlation showed a strong influence of mercury level in water on bioconcentration. The bioaccumulation factor (BSAF) indicated almost zero bioaccumulation for metals studied. However, the values of the Pearson coefficients showed that the concentration of Cd in the sediments influenced its bioaccumulation in fish muscle. The bioconcentration factors (BCF) indicating the transfer of metals from water to fish were superior to those indicating the transfer of metals from sediment to fish. This allows to conclude that the accumulation of these metals in the muscle of the fish is largely due to water. Then, these results demonstrate a high contamination of fish with arsenic, fish's ability to bioconcentrate and bioaccumulate, all of which are risk factors for the life of the fish and for human health.

FUNDING

This work was supported by the Academy of Sciences, Arts, Cultures of Africa and African Diasporas (ASCAD).

ACKNOWLEDGEMENT

We are grateful to Mr. Diallo Abou in Lycée Moderne 1 Bernard Zadi Zaourou Soubré and Mr. Sangaré Issouf in Antenne de la Pédagogie et de la Formation Continue (APFC) of Daloa for their helpful language reviews to improve draft manuscript. We are also grateful to the owner of the farm and the technical staff for their assistance during the research work.

REFERENCES

Abarghoei, S.; Hedayati, A.; Ghorbani, R.; Miandareh,H. K. and Bagheri, T. (2016). Histopathological effects of waterborne silver nanoparticles and silver salt on the gills and liver of gold fish Carassius auratus. International Journal of Environmental Science Technology,13:1753 1760.https://doi.org/10.1007/s13762-016-0972-9

Abdel-Baki, A. S.; Dkhil, M. A and Al-Quraishy, S. (2011). Bioaccumulation of some heavy metals in tilapia fish relevant to their concentration in water and sediment of Wadi Hanifah, Saudi Arabia. African Journal of Biotechnology, 10(13): 2541-2547.

Adeyemi, M. M. and Ugah, A. I. (2017). Evaluation of concentration of some heavy metals in water, soil, and fish from ponds in Lugbe, Idu and Kuje in the Federal Capital Territory (FCT), Abuja, Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology, 11(5): 39 – 43. doi:10.9790/2402-1105033943

Alvarado, C.; Ramírez, J. M.; Herrera-López, E. J.; Cortez-Valladolid, D. and Ramírez, G. (2019). Bioaccumulation of Metals in Cultured Carp (*Cyprinus carpio*) from Lake Chapala, Mexico. Biological Trace Element Research. doi:10.1007/s12011-019-01845-w

Avit, J. L. F.; Bony, K. Y.; Kouassi, N. G. C.; Konan, K. F.; Assemian O. and Allouko, J. R. (2012). Conditions écologiques de production de fingerlings de *Oreochromis niloticus* (Linné, 1758) en association avecle riz WITA 12 en étang. Journal of Applied Biosciences, 59: 4271–4285.

Benzer, S.; Arslan, H.; Uzel, N.; Gül, A. and Yilmaz, M. (2013). Concentrations of metals in water, sediment and tissues of *Cyprinuscarpio* L, 1758 from Mogan Lake (Turkey). Iranian Journal of Fisheries Sciences, 12: 45-55.

Bouhali, E. B.; Bennasser, L.; Nasri, I.; Gloaguen,V. and Mouradi A. (2008). Contamination métallique de Gambusia holbrooki auniveau du lac Fouarat et de l'estuaire Sebou dans la région du Gharb (Maroc). Afrique Science, ***4***(3) : 410 – 425.

Chahid, A. (2016). Quantification des éléments traces métalliques (cadmium, plomb et mercure total) de certains produits de la pêche débarqués dans la zone Essaouira-Dakhla : Evaluation des risques sanitaires. Thèse de Doctorat, Université Ibn Zohr-Agadir (Maroc), 191 p**p.**

Coulibaly S. (2013). Bioaccumulation des métaux lourds et effets biologiques induits chez *Saratherodon melanotheron rüppell*, 1852 pêché dans la Baie de Bietri en Lagune Ebrié (Côte d'Ivoire). Thèse de Doctorat, Université Felix Houphouët Boigny (Abidjan, Côte d'Ivoire), 214 pp.

Coulibaly, S.; Atse, B. C.; Koffi, K. M.; Sylla, S.; Konan,K. J. and Kouassi, N. J. (2012). 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. Bulletin of Environmental Contamination and Toxicology 88, 571–576. doi.:10.1007/s00128-012-0522-1

Das, P. R.; Hossain, M. K.; Sarker, B. S.; Parvin, A.; Das, S. S.; Moniruzzaman, M.;and Saha, B. (2017). Heavy Metals in Farm Sediments, Feeds and Bioaccumulation of Some Selected Heavy Metals in Various Tissues of Farmed *Pangasius hypophthalmus* in Bangladesh. Fish Aqua J, 8(3): 218. doi: 10.4172/2150-3508.1000218

Dinesh, K. G; Karthik, M. and Rajakumar R. (2017). Study of seasonal water quality assessment and fish pond conservation in Thanjavur, Tamil Nadu, India. Journal of Entomology and Zoology Studies, 5(4): 1232 – 1238.

El-Korashy, S. A.; Ali, N. A.; Al-Kenawy, D. A. and Mousa, I. M. (2018). Some heavy metals concentrations in water and tilapia (O*reochromis niloticus*) muscles of fish farms supplied by three different water sources, Abbassa International Journal of Aquaculture, 11(1): 1 – 21.

El-Nemaki, A. F.; Ali, A. N.; Zeinhom, M. M. and Radwan, A. O. (2008). Impacts of different water resources on the ecological parameters and the quality of tilapia production at El-

Abbassa fish farms in Egypt, 8th International Symposium on Tilapia in Aquaculture, 491 – 515.

European Union (EU). Commission Regulation N° 629/2008/CE of 2 July 2008. Amending regulation N° 1881/2006/CE, setting maximum levels for certain contaminants in foodstuffs. Official journal of the European Union, 173: 6 – 9.

EPA. (2007). SW-846 test methods for evaluating solid waste, physical-chemical methods, method 6010 C: inductively coupled plasma-atomic.

Failler, P.; El Ayoubi, H. and Konan A. (2014). Industrie des pêches et de l'aquaculture en Côte d'Ivoire. Rapport n°7 de la revue de l'industrie des pêches et de l'aquaculture dans la zone de la COMHAFAT, 99p. doi:10.13140/RG.2.1.2919.1843.

FAO. (2016). La situation mondiale des pêches et de l'aquaculture 2016. Contribuer à la sécurité alimentaire et à la nutrition de tous. Rome. 224 pp.

FAO. (2014). La situation mondiale des pêches et de l'aquaculture. Possibilités et défis. Rome. 275 pp.

FAO/OMS. (1991). Programme mixte FAO/OMS sur les normes alimentaires. Rapport de la vingt-troisième session du comité du codex sur les additifs alimentaires et les contaminants, 81 pp.

Garcia, G. G.; Miguel, E. J. L.; Gabriel, M. A. L. and Mingala C. N. (2016). The corollary effect of heavy metal accumulation in freshwater ponds on the hematological profile of Nile Tilapia (*Oreochromis niloticus*). Environmental and Experimental Biology, 14: 69 – 73.

Harikumar, P. S.; Nasir, U. P.; and Rahman, M. P. M. (2009). Distribution of heavy metals in the core sediments of a tropical wetland system. International Journal of Environmental Science & Technology, 6(2): 225–232. doi: 10.1007/bf03327626

Ipungu, L.; Ngoy, K.; Banze, K.; Lumfwa, K. and Kafund M. (2015). L'étude de la croissance de *Oreochromis niloticus* par la fertilisation des étangs: le cas de la ferme Naviundu Lubumbashi. Journal of Applied Biosciences, 91: 8503 – 8510.

Jiang, D. ; Hu, Z.; Liu, F.; Zhang, R.; Duo, B.; Fu, J.; Cu, Y and Li, M. (2014). Heavy metals levels in fish from aquaculture farms and risk assessment in Lhasa, Tibetan Autonomous Region of China. Ecotoxicology, 23(4): 577–583. doi: 10.1007/s10646-014-1229-3

Junejo, S. H.;Baig, J. A.; Kazi, T. G. and Afridi, H. I. (2019). Cadmium and Lead Hazardous Impact Assessment of Pond Fish Species. Biological Trace Element Research, 191: 502–511.doi: 10.1007/s12011-018-1628-z.

Junianto A., Zahidah H. &Apriliani I.M. (2017). Evaluation of heavy metal contamination in various fish meat from Cirata Dam, West Java. Indonesia. Aquaculture, Aquarium, Conservation & Legislation-International Journal of the Bioflux Society, 10(2):241-246.

Kalantzi, I.; Shimmield, T. M.; Pergantis, S. A.; Papageorgiou, N.; Black, K. D. and Karakassis, I. (2013). Heavy metals, trace elements and sediment geochemistry at four Mediterranean fish farms, Science of the Total Environment, 444: 128–137.

Kamilou, O-S.; Hodabalo, D. S.; Kissao, G.; Komlan, M. A. and Essô J. B. (2014). Évaluation et risques sanitaires de la bioaccumulation de métaux lourds chez des espèces halieutiques du système lagunaire togolais, VertigO - la revue électronique en sciences de l'environnement [Online], 14(2): http://journals.openedition.org/vertigo/15093 ; DOI : 10.4000/vertigo.15093 (Referd on 13/09/2019)

Kennish, M. J. (1992). Ecology of estuaries: Anthropogenic effects. Institute of marine and costal science fisheries and aquaculture, rutgers University New Brunswick, New Jersey, pp. 1-6.

Kouakou A. R. (2017). Evaluation de la spéciation, de la biodisponibilité et de la toxicité potentielle des métaux cadmium, cuivre, plomb et zinc dans les sédiments du canal de Vridi (Côte d'Ivoire). Thèse de Doctorat, Université Félix Houphouët Boigny, 180 p.

Kouakou, A. R.; N`Guessan, L. B. K.; Yao, K. B.; Trokourey, A. and Adouby, K. (2016). Heavy Metals in Sediments and Their Transfer to Edible Mollusc. Journal of Applied Sciences, 16: 534-541.

Kouamenan, N. M.; Coulibaly, S.; Atse, B. C. and Goore, B. G. (2020). Human Health Risk Assessment and Effects some Heavy Metals in the Tissue of Two Species of Cichlidae (*Hemichromis fasciatus* and *Tilapia zillii* × *Tilapia guineensis*) from the Western Part of the Ebrie Lagoon, Côte D'Ivoire, International Journal of Science and Research, 9(4): 160 – 167.

Liu, H. B.; Yang, J. and Gan, J. L. (2010). Trace element accumulation in bivalve mussels Anodonta woodiana from Taihu Lake, China. Archives of Environmental Contamination and Toxicology, 59:593–601.

MacDonald, D. D.; Ingersoll, C. G. and Berger, T. A. (2000). Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Fresh Water Ecosystems, Archives of Environmental Contamination and Toxicology, 39: 20-31.

Maha, A. M.; Abdallah, A. and Abdallah, A. A. (2008). Biomonitoring study of heavy metals in biota and sediments in the South Eastern coast of Mediterranean sea, Egypt. Environmental Monitoring and Assessment, 146: 139–145.

Maurya, A.; Negi, T. and Negi, R. K. (2018). Seasonal assessment of heavy metal pollution in water and sediment of fish pond at Bhagwanpur, Roorkee (U.K.), India. Asian Journal of Animal Sciences, 12: 16-22.

Mélard C. (1999)**.** Bases biologiques de l'aquaculture: Notes de cours. Université de Liège (Belgique): Centre de Formation et de Recherche en Aquaculture, 238 p.

Mensoor, M. and Said, A. (2018). Determination of Heavy Metals in Freshwater Fishes of the Tigris River in Baghdad. Fishes, 3(2), 23. Doi: 10.3390/fishes3020023

Moiseenko, T. I.; Morgunov, B. A.; Gashkina, N. A.;MegorskiyV. V. and Pesiakova, A. A. (2018). Ecosystem and human health assessment in relation to aquatic environment pollution by heavy metals: case study of the Murmansk region, northwest of the Kola Peninsula, Russia, Environmental Research Letters 13 (6): 14p.

Mostafa, M. E.; Rabie, S. F.; Aida, A. D. and Mohammad F. (2015). Assessment of heavy metals concentration in water and edible tissues of nile tilapia (*Oreochromis niloticus*) from two fish farms irrigated with different water sources, Egypt. International Journal of Environment, 4(1): 108 – 115.

Mutlu, E. and Kurnaz A. (2018). Assessment of physicochemical parameters and heavy metals in Celte Pond water. Indian Journal of Geo Marine Sciences, 47 (06): 1185 – 1192.

Qadir, A and Malik, R. N. (2011). Heavy metals in eight edible fish species from two polluted tributaries (Aik and Palkhu) of the River Chenab, Pakistan. Biological Trace Element Research, 143(3): 1524–1540.

Rodrigue, K. A.; Yao, B.; Trokourey, A. and Kopoin, A. (2016). Assessment of Heavy Metals Contamination in Sediments of the Vridi Canal (Côte d'Ivoire), Journal of Geoscience and Environment Protection, 4(10): 65-73.

Sanou, A. (2018). Détermination du niveau de contamination métallique des eaux et des sédiments de trois fermes piscicoles en Côte d'Ivoire. Mémoire de Master, Université Jean Lorougnon Guédé Daloa (Côte d'Ivoire). 100 pp.

Sarker, J. Md.; Kanungo, I.; Tanmay, M. H. and Patwary, S. A. Md. (2016). A study on the determination of heavy metals in sediment of fish farms in Bangladesh. Fisheries and Aquaculture Journal, 7(1): 159. doi:10.4172/2150-3508.1000159.

Shafei, H. M. E. L. (2015). Some heavy metals concentration in water, muscles and gills of Tilapia Niloticus as biological indicator of Manzala Lake Pollution. Journal of Aquaculture Research and Development, 6(9): 358. doi:10.4172/2155-9546.1000358.

Shetaia, S. A.; Abu Khatita, A. M.; Abdelhafez, N. A.;Shaker, I. M. and El Kafrawy S. B. (2020). Evaluation of Potential Health Risk, Heavy Metal Pollution Indicesand Water Quality of Edku Lagoon- Egypt, Egyptian Journal of Aquatic Biology & Fisheries, 24(2): 265 – 290.

Suresh, G.; Ramasamy, V.; Meenakshisundaram, V.; Venkatachalapathy, R. and Ponnusamy, V. (2011). Influence of mineralogical and heavy metal composition on natural radionuclide concentrations in the river sediments. Applied Radiation and Isotopes, 69(10): 1466-1474. doi:10.1016/j.apradiso.2011.05.020

Svobodova, Z.; Lloy, R.; Machova, J. and Vykusova, B. (1993). Water quality and fish health. EIFAC, technical paper 54, FAO, Rome, p. 71. (Consulté le 14/4/2020)

Szefer, P.; Ali, A. A.; Ba-Haroon, A. A.; Rajeh, A. A.; Gełdon, J. and Nabrzyski, M. (1999). Distribution and relationships of selected trace metals in molluscs and associated sediments from the Gulf of Aden, Yemen. Environmental Pollution, 106(3): 299–314. doi: 10.1016/s0269-7491(99)00108-6

Ullah, A. K. M. A.; Maksud, M. A.; Khan S. R.; Lutfa, L. N. and Quraishi S. B. (2017). Dietary intake of heavy metals from eight highly consumed species of cultured fish and possible human health risk implications in Bangladesh. Toxicology Reports, 4: 574–579. doi:10.1016/j.toxrep.2017.10.002

UNEP (2007). Manuel d'échantillonnage et d'analyse des sédiments. UNEP (DEPI)/MED WG.321/Inf., 26 pp.

Usero, J.; Morillo, J. and Gracia I. (2005). Heavy metal concentrations in molluscs from the Atlantic coast of southern Spain. Chemosphere, 59: 1175–1181.

Usero, J.; Izquierdo, C.; Morillo, J. and Gracia, I. (2003). Heavy metals in fish (Solea vulgaris, Anguilla anguilla and Liza aurata) from salt marshes on the southern Atlantic coast of Spain. Environment International, 29: 949–956.

Vilizzi, L. and Tarkan, A. S. (2016). Bioaccumulation of metals in common carp (Cyprinuscarpio L.) from water bodies of Anatolia (Turkey): a review with implications for fisheries and human food consumption. Environmental Monitoring and Assessment, 188(4), 24 p. doi: 10.1007/s10661-016-5248-9

Vieira, C.; Morais, S.; Ramos, S.; Delerue-Matos, C. and Oliveira M. (2011). Mercury, cadmium, lead and arsenic levels in three pelagic fish species from the Atlantic Ocean: intra-and inter-specific variability and human health risks for consumption. Food and Chemical Toxicology, 49(4): 923 – 932.

Wedepohl K.H. (1995). The composition of continental crust, Goechimica and Cocmochimica Acta, 59(7): 1217-1232.

Yasmeen, K.; Mirza, M. A.; Khan, N. A.; Kausar, N.; Rehman, A-U. and Hanif M (2016). Trace metals health risk appraisal in fish species of Arabian Sea. Springer Plus 5 (1): 859, 7 p. doi: 10.1186/s40064-016-2436-6

Yi, Y.; Yang, Z. and Zhang, S. (2011). Ecological risk assessment of heavy metals in sediment and human health risk assessment of heavy metals in fishes in the middle and lower reaches of the Yangtze River basin. Environmental Pollution, 159(10): 2575–2585.

Zhao, L.; Yang, F.; Yan, X.; Huo, Z. and Zhang G. (2012). Heavy Metal Concentrations in Surface Sediments and Manila Clams (*Ruditapes philippinarum*) from the Dalian Coast, China after the Dalian Port Oil Spill. Biological Trace Element Research, 149(2): 241–247. doi:10.1007/s12011-012-9412-y