Evaluation of the contamination of four Metal Trace Elements (ETM) of Tilapia fish (*Oreochromis niloticus*) from two types of fish ponds in an aquaculture production center in Côte d'Ivoire

ABSTRACT

Trace Metal Element (ETMs) pollution in fish farming is becoming a concern due to difficult production conditions. This study investigated the level of contamination by four trace metals: lead (Pb), mercury (Hg), arsenic (As) and cadmium (Cd). ETM research focused on *Oreochromis niloticus* from two types of fish ponds in the Haut-Sassandra region of Côte d'Ivoire. The health risk associated with tilapia consumption in this major production area was assessed. The concentration of Trace Metal Elements in fish was measured using a Perkin Elmer argon plasma emission spectrometer, Optima 3000 DV model. The physicochemical parameters of pond water were taken in situ with a multi-parameter. The physicochemical characteristics show that the Haut-Sassandra region is an area favorable to fish farming activity with a neutral pH, an average temperature of 30°C and a conductivity less than 300. As for ETMs, Low concentrations ranging from 0 to 0.040 mg/kg for tilapia, from 0 to 3.0147 mg/kg for sediments and from 0 to 0.3262 mg/kg for ponds water were observed in the matrices studied. Mercury and arsenic were found to be absent in Tilapia. The statistical analyzes carried out showed that the average concentrations of these ETMs are lower than the standards recommended by FAO and European Union. However, bioconcentration factors between 2 and 6 indicate that chemical pollutants in pond water and sediments have a negative impact on *Oreochromis niloticus* production, As for dam ponds / retentions basins, values less than 1 were obtained. This study reveals that the consumption of Tilapia from fish ponds in the Haut-Sassandra region could presents a low risk. The work has also shown that tilapia from bypass ponds / diversion basin are the most vulnerable to the ETMs studied.

Keywords: *Oreochromis niloticus*, Chemical pollutants, ETM Exposure, Health risk.

Introduction

Population growth is accompanied by the development of major human activities, resulting in enormous environmental pollution (Adam et al., 2010; Smatti-Hamza., 2019; Ye et al., 2020). Chemical pollutants, including trace metals (TMEs) (Traore et al., 2014 ; Traore et al., 2015 ; Smatti-Hamza., 2019) are recognized for their negative impact on the environment. They enter the environment, particularly the aquatic environment, through atmospheric deposition, erosion of the geological matrix and human activities. In addition, the discharge of industrial effluents, domestic wastewater, mining waste and the use of pesticides and inorganic fertilizers (Martin and Lefèvre, 2019) gradually accentuate this pollution.

These heavy metals can have harmful effects on aquatic life. ETMs such as Lead, Mercury and Cadmium are worrying pollutants that can accumulate in aquatic organisms. They are then transmitted to humans through the consumption of contaminated fish products, which can lead to serious health damage (Smatti-Hamza., 2019; Boko et al., 2022).

In recent years, the consumption of fishery resources, particularly fish, has been at the heart of concerns due to the benefits they bring to human health (Diop et al., 2919; Nakweti et al., 2021 ; N'Doua et al ., 2023). However, exposure of fish to trace metal elements raises major public health concerns, especially in regions where fish farming is crucial for the food security and income of local communities.

In the Haut-Sassandra region, an area with high aquaculture production in Côte d'Ivoire, the species *Oreochromis niloticus*, commonly called Tilapia, is widely cultivated in ponds, in two types of ponds (Ehui et al., 2024). While this practice is beneficial for food safety, it also raises growing concerns about contamination with Trace Metal Elements (ETMs) (Dupont et al., 2020). Previous studies have highlighted alarming levels of contamination in various water bodies in Côte d'Ivoire, suggesting that fish from these environments could have ETMs levels exceeding recommended thresholds (Kouadio et al., 2021).

Regular consumption of contaminated fish can therefore lead to adverse effects on human health, including neurological disorders, kidney problems and cardiovascular diseases (Soro and N'Guessan, 2022). Moreover, communities that depend on fish as their main source of protein and income are particularly vulnerable to the effects of this contamination.

In Haut-Sassandra, very few studies have been carried out on the contamination of fish by Metallic Trace Elements, even though this region is an emblematic center of aquaculture production in Côte d'Ivoire (Adingra et al., 2010).

In this context, it is essential to assess the level of contamination by Lead (Pb), Mercury (Hg), Arsenic (As) and Cadmium (Cd) in Tilapia, water and sediments from two types of fish ponds in the Haut-Sassandra region. This study will provide an overview of likely health risks, in order to make effective suggestions to producers for sustainable management of aquatic resources.

MATERIALS AND METHODS

1. Study area and sampling site

This study was carried out in the Haut-Sassandra region, an area with high aquaculture production in Ivory Coast. This region is located in the west center of Côte d'Ivoire and has 4 departments including the departments of Daloa, Issia, Vavoua and Zoukougbeu. There are six fish cooperative societies.

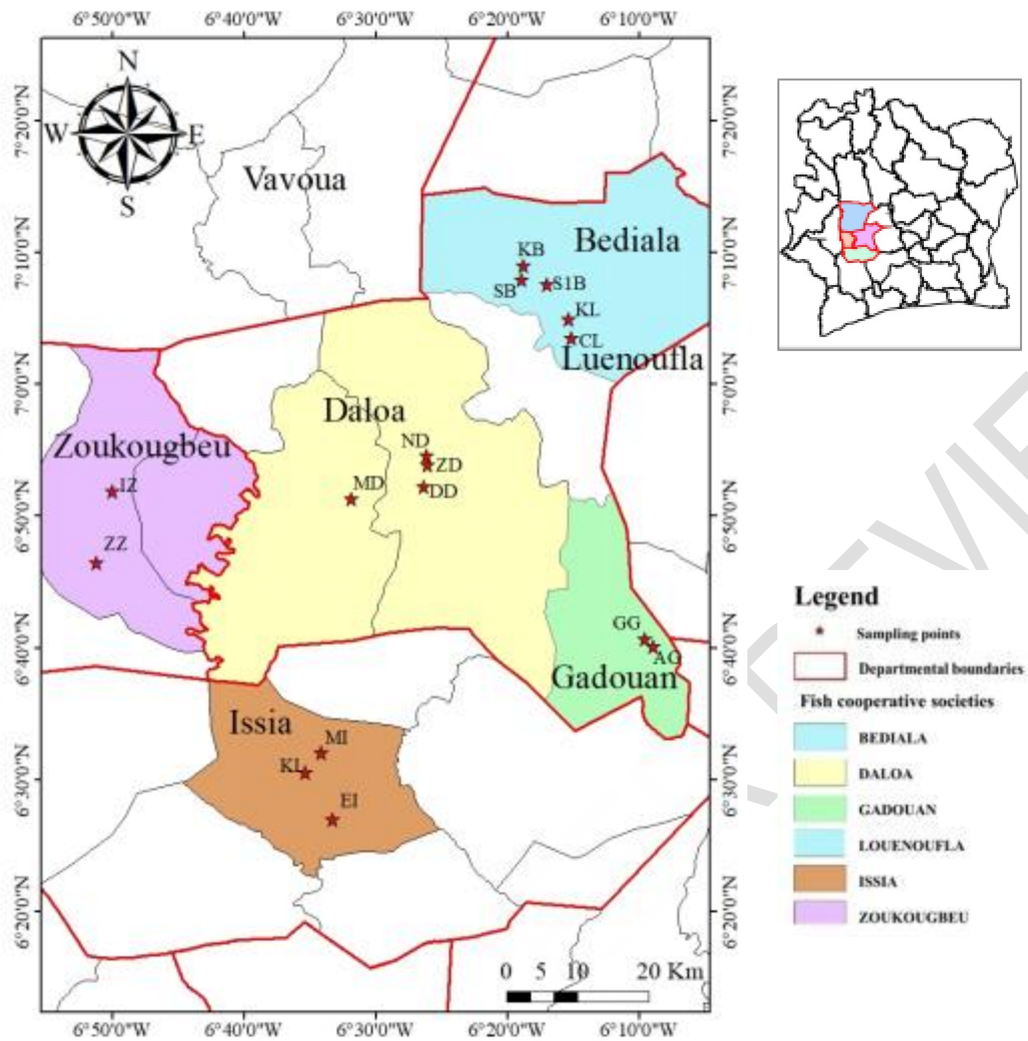

Figure 1: mapping of sampling sites

2. Materials

The biological material used in this study is mature Tilapia fish (*Oreochromis niloticus*), sediment and pond water (Figure 2).

Oreochromis niloticus Ponds sediments Fish ponds water

Figure 2: Different biological study materials

2. Methods

3.1. Sampling

Stratified sampling was carried out in this study. The type of ponds, associated and surrounding activities, and the production system are the stratification criteria used. A total of 16 farms were selected, including eight (08) farms with dam ponds and eight (08) others with diversion ponds. On each farm, three ponds were studied, one upstream, one in the middle and the last downstream.

3.2. Sample collection

3.3.1. Pond water

The pond water was sampled using the method of the Canadian Council of Ministers of the Environment (2011). The pond water was sampled by plunging the jar to a depth of approximately 50 cm. pond water. The jar is hermetically closed, leaving an air space of at least 2.5 cm between the water and the closure of the bottle, then labeled and coded. Composite sampling was carried out. A sample consists of five (04) bottles of 250 mL of water taken from the four (04) points of the ponds. All of the samples are put in a cooler containing cold accumulators and sent directly to the laboratory for analysis. In sum, 2 samples were retained per farm. A total of 32 samples of water from 16 fish ponds in the Haut Sassandra region were analyzed.

3.3.2. Pond sediments

The sediment samples were collected according to the ISO 5567-12 standard and the method of (Lionard et al., 2015). The sediments are collected by scraping the first cm (< 5 cm) from the bottom of the ponds using a stainless steel shovel beforehand and placed in bags. The bags are tightly closed, labeled and then coded. Composite sampling was carried out. A sample consists of five (04) bags of 250 g of sediment taken from the four (04) points of the ponds. The entire sample is put into coolers containing ice and taken directly to the laboratory for analysis. Two (02) samples will be taken per farm according to the same criteria as water. Two sediment samples will be retained for each farm. A total of 32 sediment samples from a few fish ponds in the Haut Sassandra region will be analyzed.

3.3.3. Pond fish

Tilapia fish were collected according to the method used by (Coulibaly., 2018). They were captured under usual fishing conditions using a net. After fishing, eight mature Tilapia of at least 250 g each are collected at random and placed in a Stomacher bag. A fish sample consists of eight (08) mature fish (Tilapia). Three (03) samples are retained per operation. A total of 48 fish samples were collected and placed in Stomacher bags, carefully labeled then placed in coolers containing ice and transported directly to the laboratory for analysis.

3.3. Determination of heavy metals

3.3.1. Mineralization of samples

Solid samples (Tilapia and sediment) were partially thawed at room temperature. Approximately 5 g of each wet sample is collected in a plastic cup. The samples taken are dried in an oven at 103°C ± 5°C for 48 hours. After drying, they are weighed and transferred to a dry mortar with a smooth surface previously cleaned with Extran 300 soap and rinsed with diluted nitric acid and ultra-pure water then dried. The mortar is cleaned between two samples. The samples were subsequently ground until homogeneous. 300 mg of the powder obtained is taken and placed in a Teflon container fitted with a lid. 5 mL of concentrated HNO_3 is added and left to rest for approximately 30 minutes under the hood without closing the lid tightly. The Teflon containers are lowered, without their lids, into a sand bath and heated to approximately 150 °C ± 10 °C until the volume reaches approximately 0.5 to 1.0 mL. 2 mL of 30% H2O2 is added and allowed to evaporate (approximately 30 minutes) by half without drying. 2 mL of concentrated HNO3 and 1 mL of concentrated HCl are added and the gas is allowed to escape for a few minutes with gentle stirring. The container is tightly closed and placed in the sand bath and allowed to heat for 1 hour. After about 30 minutes, the lid is gently opened to relieve the pressure in the container and allow the gas to escape. The whole is heated for 1 hour then the Teflon is immersed in cold water for 10 to 15 minutes to reduce the pressure. The contents of the telfon are transferred into a 50 mL polypropylene tube. The telfon is rinsed with several volumes of water to reach an exact volume of 30 mL in the tube. The tube is closed and shake vigorously to make it homogeneous.

3.3.2. Dosage

The samples are measured using a Perkin Elmer argon plasma emission spectrometer, Optima 3000 DV model. The Cyclonic Spray Chamber and Burgener Peek Mira Mist Nebulizer are used. If necessary, samples are diluted to meet the upper limits of the instrument. The metals sought are as follows: Cd; Pb; Hg; Ace.

3.4. Data processing and statistical analysis

3.4.1. Estimation of the intensity of contamination

The intensity of contamination of Tilapia, water and sediments is estimated from the comparison between the values of trace elements determined and the reference values of the maximum concentration limits recommended by the Commission of the European Communities No. 1881/2006 and revised in 2023 and *Codex Alimentarius* 193-1995 (FAO/WHO, 2023).

3.4.2. Calculation of the bioconcentration factor (BCF)

The BCF is a parameter used to describe the transfer of trace metal elements (TME) from the biotope (water and sediments) to organisms. It comes from the ratio between the concentration of a trace metal element in an organism in a state of equilibrium and its concentration in the biotope (Traore et al., 2014) as indicated by equation 1 :

$$BCF = \frac{\text{Concentration of ETM in animals}}{\text{Concentration of ETM in water or sediment}} \qquad (1)$$

BCF < 1: means that there is no bioconcentration of the trace element in Tilapia. The fish eliminates the pollutant faster than it absorbs it.

BCF > 1: means that there is a bioconcentration of the trace element in the fish. The pollutant is therefore absorbed by the fish at a higher rate than it is eliminated.

3.4.3. Statistical analyzes

The analysis of the results was carried out using STATISTICA version 7.1 software. Descriptive statistics was performed to calculate the mean concentrations and standard deviation. The t comparison test made it possible to compare the average concentrations with the recommended standards.

4. RESULTS AND DISCUSSION

4.1. Results

4.2. Physico-chemical characteristics of pond water

The following table presents the average values of the physicochemical characteristics of water from diversion and dam ponds. The statistical analyzes carried out show a statistical difference between the values collected and the recommended standards. The average temperature values of the two types of ponds are between 29°C and 31°C and that of neutral pH. The conductivity is less than 300 mg/L.

Table 1: Average values of physicochemical parameters measured on the two types of ponds

Type of ponds		Temperature (°C)	pH	Conductivity (mg/L)
DP	Average ± SD	29,98±2,69	7.19±0,8	82.34 ±10,69
	Test-t	16,80 ; -7,37	8.166 ; -14,18	-57.601

	p	< 0,001	< 0,001	< 0,001
PD	Average ± SD	31,18±1,29	6.99±0,5	87.58±10,66
	Test-t	37,618 ; -12,72	11.38 ; -22.91	-56.371
	p	< 0,001	< 0,001	< 0,001
	Standards	14-37	5-11	< 300

DP: Dam Ponds; PD: Ponds in Diversion: SD: Standard of Diversion; p: probability; p <0.05: indicates a significant difference between the compared values

4.2.1. Contaminant contents of Tilapia fish from different fish ponds by Metal Trace Elements (MTE)

The table below presents the average concentrations of ETMs studied in Tilapia, pond water and sediments, depending on the types of ponds. The analyzes carried out showed no trace of Mercury and arsenic in Tilapia regardless of the type of pond considered. Cadmium and lead were present in very low concentrations in Tilapia. Of the two ponds considered, Tilapia from diversion ponds are the most contaminated.

At the sediment level, the analyzes revealed the presence of the four ETM studied with an absence of arsenic in dam ponds. Mercury, cadmium and arsenic are present at low concentrations of 0.0292 mg/L, 0.7682 mg/L and 0.0182 mg/L respectively in the dam ponds and 0.011 mg/L, 0. 7682 mg/L. Lead is present in high concentrations in both types of ponds.

Pond waters are present at lower concentrations than sediments. However, the highest concentration of Mercury was observed in water from dam ponds.

Table 2: Average concentration in mg/kg of ETMs in Tilapia, water and sediments

Pond type	Matrix	ETM	N	**Minimum**	**Mean ± SD**	**Maximum**
Diversion ponds	Tilapia	**[Hg]**	8	0,0000	0±0	0,0000
		[Cd]	8	0,0481	0,040± 0,006	0,0555
		[Pb]	8	0,0355	0,02306±0,007	0,0466
		[As]	8	0,0000	0±0	0,0000
	Sediment	**[Hg]**	8	0,0470	0,0292±0,0127	0,0622
		[Cd]	8	0,8681	0,7682± 0,0732	0,9768

		[Pb]	8	3,7282	3,0147±0,4124	4,5074
		[As]	8	0,0214	0,0182±0,0028	0,0264
	Pond water	**[Hg]**	8	0,0028	0±0,0038	0,0080
		[Cd]	8	0,0129	0,0125±0,0002	0,0132
		[Pb]	8	0,2820	0,19288±0,0459	0,3127
		[As]	8	0,0316	0,0179±0,0239	0,0722
Dam ponds	Tilapia	**[Hg]**	8	0	0±0	0
		[Cd]	8	0,001	0±0,0010	0,001
		[Pb]	8	0,020	0,0020±0,012	0,035
		[As]	8	0	0±0	0
	Sediment	**[Hg]**	8	0,0174	0,011±0,0056	0,0240
		[Cd]	8	0,9348	0,7682±0,0834	1,0246
		[Pb]	8	3,3967	3,3567±0,0993	3,6422
		[As]	8	0,0120	0±0,0105	0,0250
	Pond water	**[Hg]**	8	0,1346	0±0,3699	1,0500
		[Cd]	8	0,0395	0,0126±0,0170	0,0531
		[Pb]	8	0,3328	0,3262±0,0030	0,3355
		[As]	8	0,0524	0,014±0,0245	0,0740

ETM: Metal Trace Elements; N: Number of samples; SD: Standard deviation

4.2.2. Compliance with standards for Metallic Trace Elements of Tilapia fish

The statistical analyzes carried out indicate a significant difference between the concentrations detected and the standards recommended by the EU and the FAO/WHO. The concentrations of mercury, lead, cadmium and arsenic are statistically lower than the respective standards of 0.5 mg/kg, 0.05 mg/kg, 0.3 mg/kg and 0.1 mg/kg FAO/WHO. (2023) This difference is as well marked in dam ponds as in diversion ponds.

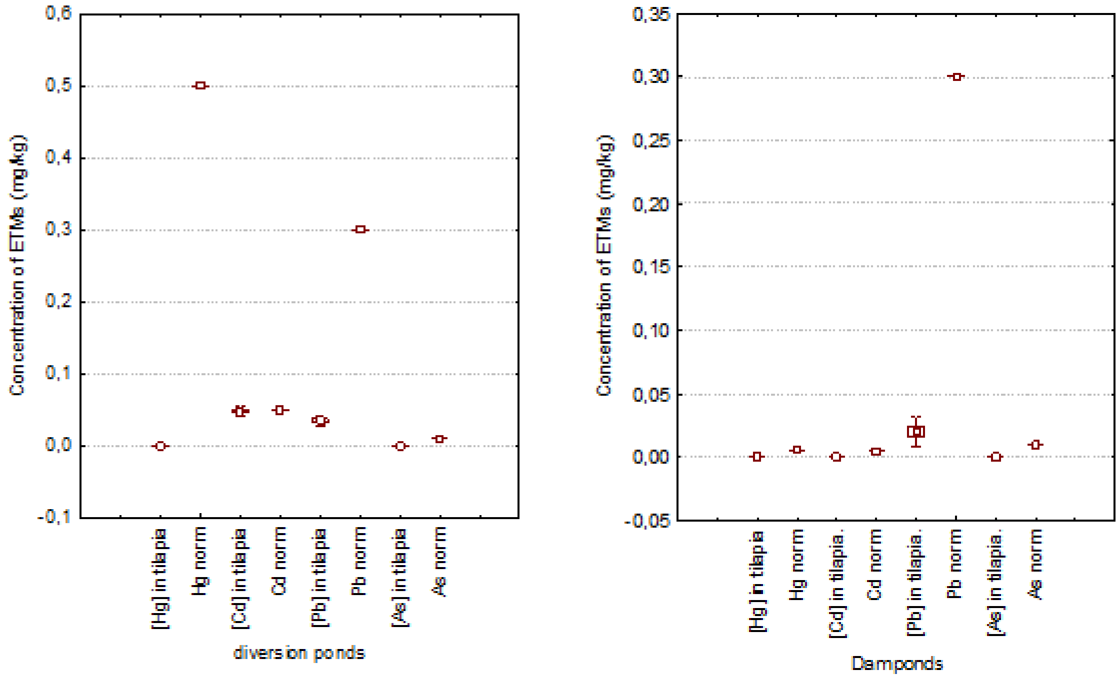

Figure 3: The conformity study of ETMs in Tilapia from the two the types of ponds

4.2.3. Compliance with standards for Metallic Trace Elements of pond sediments

The following figure shows the differences between the concentrations of ETMs present in sediments and the standards. Cadmium and lead are present with respective average concentrations of 0.7682 mg/kg and 3.014 mg/kg for diversion ponds and 0.7682 mg/kg and 3.3567 mg/kg for dam ponds. These different concentrations are higher than the standards recommended by FAO/WHO. (2023). These standards are 3.5 mg/kg, 10 mg/kg, 100 mg/kg and 19 mg/kg respectively for Mercury, Cadmium, Lead and Arsenic.

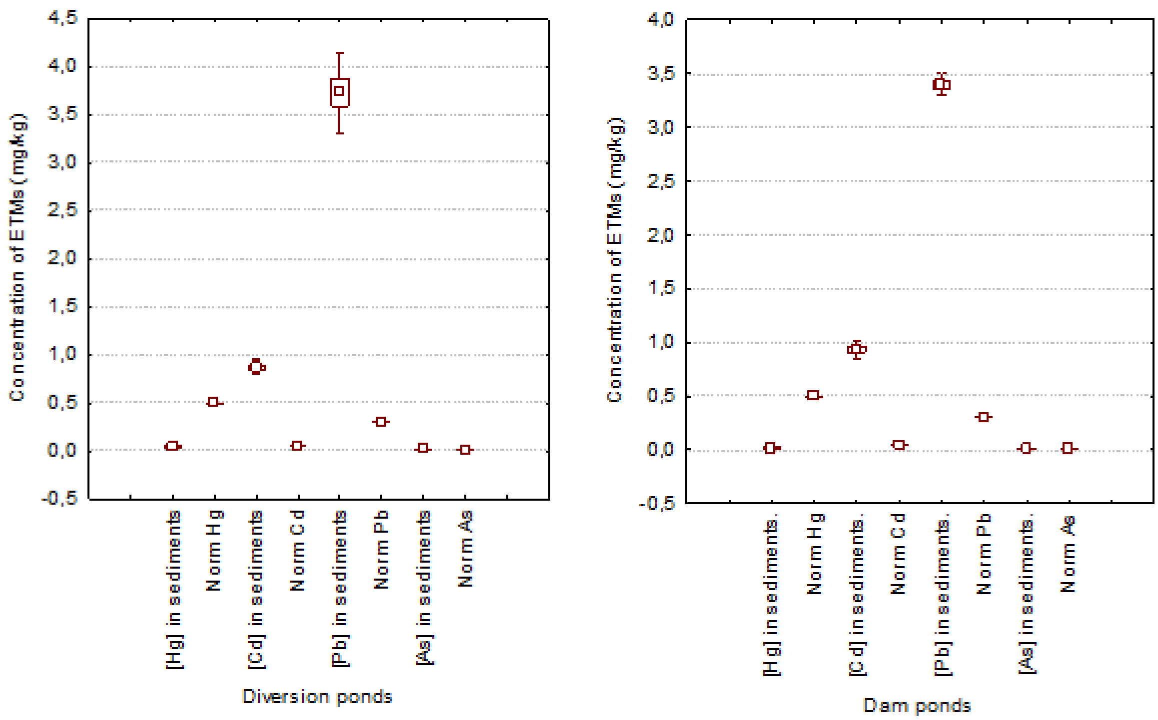

Figure 4: The conformity study of ETMs in sediments from the two the types of ponds

4.2.4. Compliance with standards for Metallic Trace Elements of pond water

The following boxplots show the conformity of Metal Trace Elements in pond waters. All the ETMs studied are present in pond water with concentrations below standards. These standards are 3.5 mg/kg, 10 mg/kg, 100 mg/kg and 19 mg/kg for Hg, Cd, Pb and As respectively FAO/WHO. (2023).

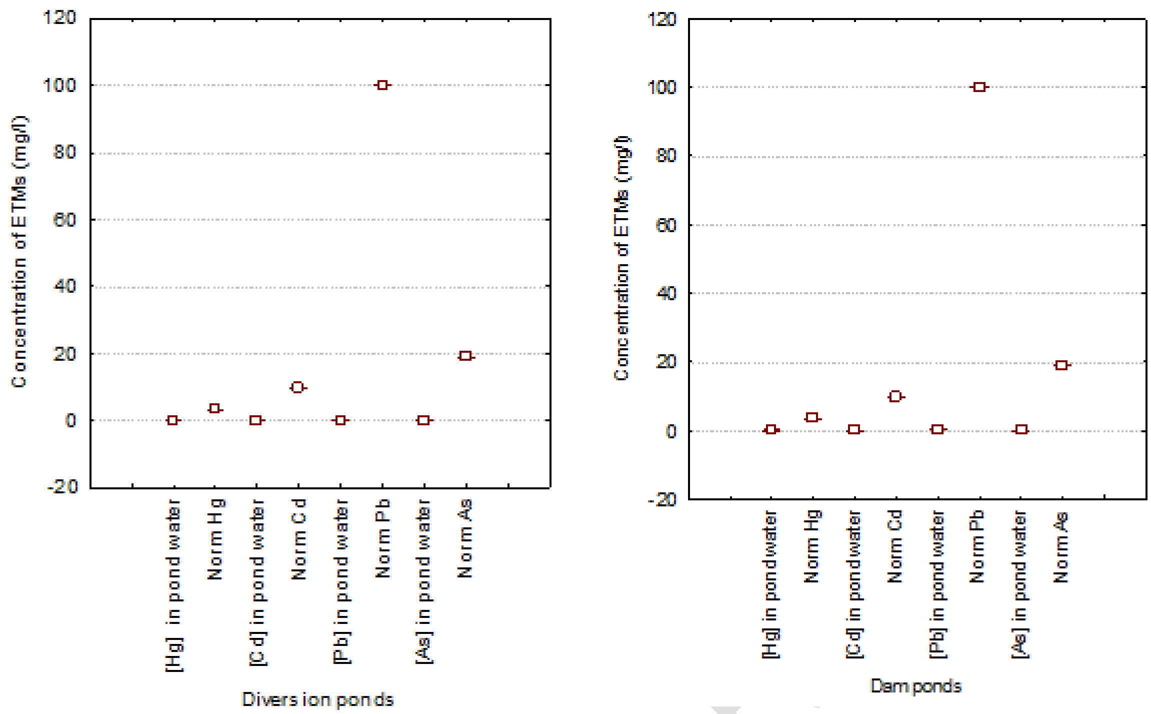

Figure 5: The conformity study of ETMs in water from the two the types of ponds

4.3.Accumulation of Trace Metal Elements in Tilapia in fish ponds

4.3.1. bioconcentration factors of ETMs in relation to pond water (BCFe) and fish

The effect of trace metal elements contained in water on Tilapia is presented in Tables 3. The calculated bioaccumulation factors give zero values for mercury and arsenic in both types of ponds. For cadmium, only the diversion basins had values greater than 1 for BCFe. As for lead, the BCFe are greater than 1 in both types of ponds.

Table 3: bioconcentration factors of ETMs in relation to pond water (BCFe) and fish

Pond type		Mercury (Hg)	Cadmium (Cd)	Lead (Pb)	Arsenic (As)
Diversion ponds	BCFe	0,000	4,667	6,800	0,000
Dam ponds	BCFe	0,000	0,875	4,400	0,000

4.3.2. bioconcentration factors of ETMs in relation to sediment (BCFs) and fish

The effect of trace metal elements contained in the sediments on Oreochromis niloticus is presented in Tables 4. The calculated bioaccumulation factors give zero values for mercury and arsenic in both types of ponds. For cadmium, only the diversion basins had values greater than 1 for BCFe. As for lead, the BCFs are all less than 1 in both types of basins.

Table 4: bioconcentration factors of ETMs in relation to fish and sediment (BCFs)

Pond type		Mercury (Hg)	Cadmium (Cd)	Lead (Pb)	Arsenic (As)
Diversion ponds	BCFs	0,000	2,333	0,120	0,000
Dam ponds	BCFs	0,000	0,200	0,067	0,000

4.3. DISCUSSION

The analysis of the average values of the physicochemical parameters of the diversion and dam ponds reveals significant results which deserve to be put into perspective with previous work. The measured temperatures, between 29° C and 31° C, are consistent with the studies of Dupont et al., 2020). This research shows similar temperatures in ponds, indicating thermal stability favorable to aquatic biodiversity. Regarding pH, values ranging from 5 to 11 show wide variability. This observation is supported by the research of Martin and Lefèvre (2019), who noticed pH fluctuations in similar aquatic systems, highlighting the importance of environmental factors A pH that is too acidic can harm sensitive species, while a high pH can encourage harmful algal blooms, as the work of Gauthier (2021) suggests. Conductivity, less than 300 mg/L, is a crucial indicator of water quality. The results obtained are in agreement with those of (Boucher et al., 2022), who reported similar conductivity levels in unpolluted ponds. However, these values should be interpreted with caution. High conductivity could indicate pollution by salts or nutrients, which could have harmful consequences on aquatic flora and fauna. The statistical analyzes show a significant difference between the collected values and the recommended standards, which is in line with the conclusions of Lemoine (2020), who also observed worrying deviations in other aquatic systems. These differences Underline the need for regular monitoring and proactive management of water resources to maintain the health of aquatic ecosystem.

Analysis of average ETMs concentrations in Tilapia, pond water and sediment reveals interesting results that deserve to be examined in detail. First of all, the absence of mercury and arsenic in Tilapia, whatever the type of pond, is a positive point which suggests a low contamination of these metals in the aquatic ecosystems studied. This observation is consistent with the work of (Tremblay et al., 2018), who also noticed significant levels of these metals in other fish species in similar environments. However, the presence of cadmium and lead, even at very low concentrations in Tilapia is a cause for concern. This presence of cadmium and lead in Tilapia can be explained by the persistence of these elements in the environment (water and sediment). This idea is supported by (Adam et al., 2010) during their study on the search for ETMs in four species of fish consumed by the fishing families of Jacqueville. Tilapia from diversion ponds show higher levels of contamination, which could indicate diffuse pollution in these systems. This trend is corroborated by (Adam et al., 2010 ; Kouadio et al., 2021), who observed similar concentrations of cadmium in fish from aquatic environments influenced by agriculture and urbanization. More worrying results were obtained by (Ouro-Sama., 2014 ; Akan et al., 2012) respectively in Congo and Togo. This autor obtained very high concentrations in the same matrices and in *Claria gariepinus* and *Chrysichthys nigrodigitatu*. The presence of cadmium and lead underline potential risk to human health. Cadmium is associated with adverse effects on the kidneys and bone system (Renner et al., 2011). while lead can cause neurological disorders, particularly in childhood (Lanphear, 2005). As for the absence of mercury and arsenic, this could be attributed to the nature of the foods. The unavailability of these elements linked to their nature and fish ability to eliminate them (Traore et al., 2015 ; Nakweti et al., 2021).

According to sediments study, with an absence of arsenic was notied in dam ponds. The importance of monitoring these environmental matrices. The presence of mercury, cadmium and lead at low concentrations in dam ponds is of concern (0.0292 mg/L, 0.7682 mg/L and 0.0182 mg/L respectively) and in diversion ponds (0.011 mg/L for mercury and 0.7682 mg/L for cadmium). These levels, although low, can accumulate in the food chain, as research by (Nguyen et al., 2020). Lead concentrations, meanwhile, are high in both types of ponds, which could be attributed to anthropogenic sources such as industry or pesticide use. This situation is alarming, because lead is recognized for its harmful effects on human and animal health (Bouchard et al., 2019). Finally, the presence of mercury at higher concentrations in the waters of dam ponds compared to sediments is surprising. This could indicate bioaccumulation dynamics or recent inputs of mercury into these systems. Previous studies, such as those by (Friedman et al., 2021), demonstrated that surface waters can often be temporary reservoirs of contaminants before their sedimentation.

The statistical analyzes carried out Distinguish a significant difference between the concentrations of ETMs detected in Tilapia, sediment and water and the standards established by (FAO/OMS, 2011). These different pollutants and contaminants are present at concentrations below standards. This situation would be all the more worrying for the regular consumption of these fish, because chronic exposure to these different ETMs can lead to neurological disorders, behavioral problems and learning deficits (Lanphear et al., 2018). These results diverge from those of (Nakweti et al., 2021; Sama et al., 2024). The results also reveal variations in heavy metal concentrations depending on the type of pond. In diversion ponds, the increasing order of concentrations is in this order: Cadmium (Cd) < Lead (Pb) < Mercury (Hg) = Arsenic (As). This indicates that although cadmium is present at lower levels, lead appears to be the metal of greatest concern in these environments. On the other hand, for dam ponds, the order is: Lead (Pb) < Cadmium (Cd) < Mercury (Hg) = Arsenic (As). This difference can be attributed to several factors, including the nature of human activities, which can influence water contamination (Zhang et al., 2020). The results also suggest that diversion ponds may be more vulnerable to pollution, possibly due to insufficient drainage or an accumulation of contaminants from surrounding land (Akan et al., 2012). On the other hand, dam ponds, which could benefit from better water circulation, seem to present more varied levels of contamination. This situation Spotlight the importance of adequate management of aquatic resources to minimize the risk of contamination. These results illuminate the need for continued monitoring of fish contamination levels in these ponds, in order to protect the health of fish as well as consumers. Concerning the effect of environmental contaminants on fish, interesting results were observed, notably with zero values for the bioaccumulation factors (BCF) of mercury and arsenic in both types of ponds. These results corroborate those of (Baker et al., 2019), who also observed an absence of significant bioaccumulation of mercury in fish from uncontaminated areas. This suggests that mercury and arsenic levels in these aquatic ecosystems are low enough to not cause food safety concerns.

Nevertheless, the results regarding cadmium are concerning. In our study, only diversion ponds showed BCFs greater than 1, indicating notable bioaccumulation. This is in agreement with the work of (Nguyen et al., 2020), who also reported high levels of cadmium in fish from agricultural areas. This suggests that human activities may contribute to the contamination of sediments and their accumulation in the food chain. This bioaccumulation highlights the importance of effective management of water resources. Regarding lead, BCFs greater than 1 in both types of ponds are worrying. This result is similar to those of (Kouadio et al., 2021), who found lead levels of concern in fish samples from urban and industrial areas. The presence of lead in our results indicates that even in environments considered relatively healthy, there may be risks of accumulation.

Conclusion

The analysis of physicochemical parameters and ETMs concentrations in the ponds revealed significant results which underline the importance of environmental monitoring.The physicochemical parameters studied indicate favorable conditions for aquatic biodiversity. The absence of mercury and arsenic in Tilapia is a positive point. yet, the presence of cadmium and lead, even at low concentrations, raises food safety concerns.The results also show that diversion ponds are more vulnerable to contamination, likely due to surrounding human activities. The significant differences between measured concentrations and standards established by FAO/WHO Emphasize the need for proactive management of water resources. Although contamination levels are below standards, chronic exposure to these metals can have adverse effects on human health. Bioconcentration factors also reveal the negative impact of water and sediment. These results highlight the importance of continuous assessment of the risks associated with the consumption of fish from these ponds. Also, the need for sustainable management of the aquatic ecosystem. In perspective, studies should focus on identifying sources of contamination and implementing appropriate management strategies to minimize environmental impacts.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Références

1. Adam S., Edorh P.A., Totin H., Koumolou L., Amoussou E., Aklikokou K. and Boko M. (2010). Pesticides and heavy metals in drinking water, soils and sediments of the cotton belt of Gogounou, Kandi and Banikoara (Benin). International Journal of Biological and Chemical Sciences, 4(4): 1170-1179

2. Adingra A., Gore bi T., Ble M. and Dosso M. (2010). Evaluation of the bacterial load in Tilapia Oreochromis niloticus (Linnaeus 1758) sold on the markets of Abidjan (Ivory Coast). African Agronomy 22 (3): 217 – 225.

3. Akan J. C., Afolabi, O. A. and Olayemi, J. A. (2012). Heavy metals in fish from the River Niger, Nigeria. Environmental Monitoring and Assessment, 184(3), 1871-1881. https://doi.org/10.1007/s10661-011-2020-5

4. Bamba I. and Traoré M. (2023). Food security and health risks related to aquaculture. Journal of Nutrition and Health.

5. Boko L.F., Musibono D.E., Matand A., Ngelikoto P. and Iketsh L.B. (2022). Contribution to the study of contamination with trace metal elements (Mn, Co, Cu, Pb, Hg, Ni, Zn) of Oreochromis niloticus and Clarias gariepinus of the Yolo River (KINSHASA, DRC), International Journal of Advanced Research. 10(07), 871-884

6. Cohen J. T., Bellinger D. C. and McGeehin M. A. (2009). "Health effects of mercury exposure." Environmental Health Perspectives, 117(6), 1006-1014.

7. Diop C., Diatta A., Ndiaye A., Cabral M., Toure A. and Fall M. (2019). Trace metal levels in water and fish from five ponds in Dakar and risks to human health. Journal of Applied Biosciences 137:13931–13939

8. Dupont J., Martin P. and Lefèvre S. (2020). Impact of aquaculture on public health. Journal of Aquatic Biology, 15(2), 123 135

9. Ehui E.J.F., Kouassi K.C., Kouassi K.A. and Ehouman A.G.S. (2024). "Specific Diversity of Fish Ponds in the Haut-sassandra and Risks of Contamination by Potential Pathogens among Oreochromis niloticus (Tilapia)", Asian Journal of Fisheries and Aquatic Research 26, no. 3 (2024): 76-86, https// doi: 10.9734/AJFAR/2024/v26i3748

10. FAO/WHO (2011). Food Standards: Codex Alimentarius. Joint FAO/WHO Food Standards Programme.

11. Kouadio K., Bamba I. and N'Guessan, A. (2021). Study of Oreochromis niloticus in the ponds of Haut-Sassandra. Bulletin of Aquatic Sciences.

12. Lanphear B. P., Hornung R., Khoury J., Yolton K. and Matte T. (2005). Health effects of lead exposure. Environmental Health Perspectives, 113(7), 1001-1006.

13. Lanphear B. P., Hornung R., Khoury J., Yolton K., Hohman Z. and Nevin R. (2018). "Low-level lead exposure and mortality in US adults: a population-based cohort study." The Lancet Public Health, 3(4):177-184.

14. Martin P. and Lefèvre, S. (2019). Trace metal elements in fish: risks and implications. Journal of Environmental Health.

15. N'Doua A. D.Y.S., Ayi M. N. M., Adjessan D. and Koffi K.M. (2023). Determination of the Level of Metal Contamination (Arsenic, Cadmium, Mercury and Lead) of Four Fish

Species Consumed by Fishing Families in Jacqueville. ESI Preprints. https://doi.org/10.19044/esipreprint.10.2023.p737

16. Nakweti K.J., Lusasi S.W. and Tembeni M.J. (2021). Assessment of Trace Metal Element (Cadmium and Lead) Levels in Water, Sediments and Two Fish Species Clarias Gariepinus (Burchell, 1822) and Oreochromis Niloticus (Linnaeus, 1758) in the Malebo Pool (Congo River), DR Congo. European Scientific Journal, 17(25): 174.

17. Ouro-Sama K., Solitoke H. D., Gnandi K., Afiademanyo K. M. and Bowessidjaou, E. J. (2014). Assessment and health risks of heavy metal bioaccumulation in fish species of the Togolese lagoon system. VertigO, 14(2)

18. Renner L., Schwabe A., Döll S., Höltershinken M. and Dänicke S. (2011). Effect of rare earth elements on beef cattle growth performance, blood clinical chemical parameters and mitogen stimulated proliferation of bovine peripheral blood mononuclear cells in vitro and ex vivo. Toxicology Letters, 201 (3): 277-284

19. Smatti-Hamza I., Afri-Mehennaoui F-Z., Keddari D. and Mehennaoui S. (2019). Level of contamination by the trace metal elements cadmium, cobalt, copper and zinc of two cyprinids and sediments of the Koudiet Medouar dam (Batna, Algeria). Journal of Applied Biosciences, 143: 14606 – 14622

20. Soro, A. and N'Guessan A. (2022). Water Contamination and Public Health in Côte d'Ivoire. Annales de l'Environnement.

21. Traore A., Ake-assi Y., Ahoussi K.E. and Soro N. (2015). Assessment of the Concentration of Trace Elements (Pb, Cu, Zn, Fe, Cd and Hg) in Shrimp (Macrobrachium vollenhovenii) from the Aghien and Potou Lagoons (South-Eastern Côte d'Ivoire). Larhyss Journal, 24: 129-142

22. Traore A., Soro G., Ahoussi K.E., Bamba B.S., Soro N. and Biemi J. (2014). Heavy metal contamination level of sediments in a tropical lagoon: the Aghien lagoon (South-East of Côte d'Ivoire). Afrique SCIENCE, 10(3) 73 - 88

23. Ye L ., Lompo D.J.P., Sako A. and Nacro H.B. (2020). Assessment of trace metal element contents in soils subjected to the input of urban solid waste. International Journal of Biological and Chemical Sciences, 14(9): 3361-3371

24. Zhang Y., Wang X., He Y., Liu Y. and Zhang H. (2020). "Impact of anthropogenic activities on water quality in urban rivers: A case study of the Yangtze River." Science of The Total Environment, 738

25. Dupont J., Martin S. and Lefèvre T. (2020). Study of thermal variations in aquatic ponds. Journal of Aquatic Ecology, 15(3), 123-135.

26. Martin S. and Lefèvre T. (2019). pH fluctuations in aquatic systems: Impact on biodiversity. Journal of Water Sciences, 32(2), 45-58.

27. Gauthier R. (2021). Algal blooms and water quality: A comparative study. Aquatic Research Bulletin, 8(1), 67-79.

28. Boucher A., Dupuis C. and Moreau P. (2022). Conductivity and pollution in ponds: A data analysis. Annals of the Aquatic Environment, 10(4), 201-215.

29. Lemoine V. (2020). Water quality monitoring in aquatic ecosystems: Gaps and concerns. Journal of Environmental Sciences, 27(5), 88-102.

30. Sharma M, Kant R, Sharma AK, Sharma AK. Exploring the impact of heavy metals toxicity in the aquatic ecosystem. International Journal of Energy and Water Resources. 2024 Apr 12:1-4.

31. Goura SO, Gouissi FM, Hounkpatin AS, Yessoufou WB, Biaou TS, Fassinou NM. Evaluation of Agricultural Contamination Level by Heavy Metals and Pesticides in Sediments of Rivers and Water Bodies for Shrimp Fishing in the Lower Ouémé: Case of the Aguigadji, Ahlan and Sele Stations in Benin. Advances in Materials Physics and Chemistry. 2024 Feb 5;14(02):25-46.

32. Onyena AP, Folorunso OM, Nwanganga N, Udom GJ, Ekhator OC, Frazzoli C, Ruggieri F, Bocca B, Orisakwe OE. Engaging one health in heavy metal pollution in some selected Nigerian Niger delta cities. A Systematic review of pervasiveness, bioaccumulation and subduing environmental health challenges. Biological Trace Element Research. 2024 Apr;202(4):1356-89.

33. Farzadkia M, Yavary Nia M, Yavari Nia M, Shacheri F, Nourali Z, Torkashvand J. Reduction of the environmental and health consequences of cigarette butt recycling by removal of toxic and carcinogenic compounds from its leachate. Environmental Science and Pollution Research. 2024 Apr;31(16):23942-50.

34. Kumar A, Kumar V, Bakshi P, Parihar RD, Radziemska M, Kumar R. Mercury in the natural environment: Biogeochemical cycles and associated health risks. Journal of Geochemical Exploration. 2024 Sep 25:107594.