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Contamination Level of Arsenic and Cadmium in the Water and Sediments of a Fish Farm: Application of Contamination Indices

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Abstract: Fish farming is widely practiced around the world. Fish is an important source of protein and contributes to the supply of highly nutritious animal protein in Côte d'Ivoire. Pollution of fish farms by toxic metals can lead to contamination of farmed fish. This study evaluates the content of trace metallic elements (TME), which are arsenic (As) and cadmium (Cd) in the water and sediments of a pond farm located in Abengourou in the east of Côte d'Ivoire. Water and sediment samples were collected from a dam and three ponds on the farm in September and October 2020. These samples were analyzed using an atomic absorption spectrophotometer. All data was processed using STATISTICA 7.1 and was used to calculate Metal Pollution Index (MPI), Ratio Sediment/Water ($R_{S/W}$), Contamination Factor (CF), the pollution load index (PLI), the individual potential risk index (Er) and the ecological risk index (PERI) in order to assess the level of metal contamination of the fish farm. The mean concentrations of metallic trace elements are higher in the sediments (As: 0.2045±0.218496 - 0.3950±0.1103 mg/kg; Cd: 0.0565±0.0148 - 0.0880±0.0212 mg/kg) than in water (As: $(0.1837±0.0148) \times 10^{-2}$ - $(0.2296±0.0300) \times 10^{-2}$ mg/L; Cd: $(0,1150±0.0129) \times 10^{-2}$ - $(0.1250±0.0076) \times 10^{-2}$ mg/L). Sediments also have the highest overall metal contents. However, MPI<1 in both sediment and water. The CF (As=0.102±0.109 - 0.198±0.055; Cd=0.565±0.148 - 0.880±0.212) showed that the sediments were not contaminated. The PLI (0.253±0.062 - 0.335±0.090) indicated that the sediments on the fish farm were not polluted. In addition, Er (As: 1.02±1.09 - 1.98±0.55; Cd: 16.95±4.44 - 26.40±6.36) and PERI (18.93±4.99 - 27.59±7.57) showed that the sediments do not pose an ecological risk to farmed fish. However, $R_{S/W}>1$ showed strong mobility of TMEs from water to farm sediments. The concentrations of trace metal elements assayed in the samples were below the recommended standard for freshwater aquaculture. The CF, PLI, Er and PERI indices indicate a low degree of contamination, pollution and a low ecological risk. However, $R_{S/W}$ indicate high mobility of TME from water to sediment.

Keywords: Trace Metal Elements, Fish Pond, Water, Sediment, Pollution, Côte d'Ivoire

1. Introduction

Aquaculture contributes to increase food availability and provide highly nutritious animal protein. Fish farms therefore constitute an alternative source to fish production for the satisfaction of increasingly growing human needs [1].

However, these fish farms are subject to environmental pollution. Pollutants such as trace metallic elements (TME) are found in the aquatic environment by human action, atmospheric transport and erosion due to rain [2]. Certain metallic trace elements including lead, cadmium, mercury and arsenic are major pollutants because of their toxicity. In addition, they are persistent and tend to bioaccumulate in the food chain posing a risk to humans and ecosystems [3].

Several studies have highlighted the metallic contamination of the water and sediments of fish farms [4-10]. This metal pollution is responsible for fish mortality causing to lower productivity and sometimes the abandonment of aquaculture farms [11].

Metallic trace elements, once in the aquatic ecosystem, can remain in dissolved form or be removed from the water column by sedimentation [12]. In these aquaculture systems such as fish ponds, sediments play a role as an indicator of contamination because of their capacity to bind pollutants, in particular trace metal elements [13]. They then constitute a reservoir and then a potential source of contaminants for water and farmed fish [9]. Sediments can also behave as endogenous sources of contamination by resuspension or by changes in the speciation of metallic trace elements, which will affect their bioavailability [14].

Studies carried out in Ivorian fish farms have revealed the presence of trace metal elements in the sediments [7, 9, 10]. But, these metal contents in the sediments do not give sufficient information on the level of contamination of the sediments, so we need to assess their level of contamination by applying contamination indices.

The present study proposes to use contamination indices to assess the level of pollution of a fish farm in ponds.

2. Materials and Methods

2.1. Study Zone

The fish farm is located in the department of Abengourou in the east of the Côte d'Ivoire between longitude 3°62'53" W and latitude 6°71'66" N (Figure 1). It is a continental farm where the fish tilapia *Oreochromis niloticus* and catfish *Clarias gariepinus* are reared in ponds. The farm has five ponds with areas between 400 and 500 m^2, which are supplied by a 12,000 m^2 dam. They have an open pipe system completed by polyvinyl chloride pipes, which provide water to the various livestock structures. The dam is fed by a tributary of the Comoé River. Rubber plantations and food crops border the farm.

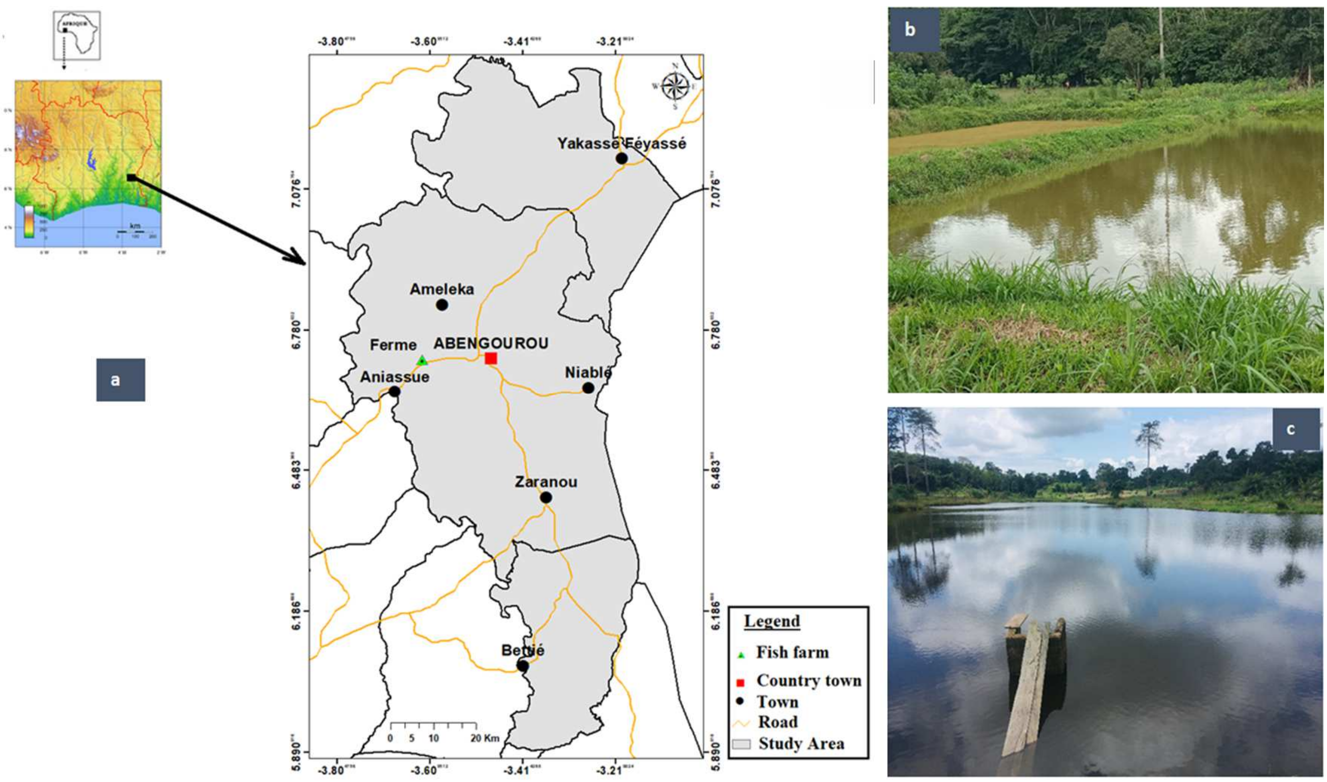

Figure 1. *Fish farm in Dramanekro (Abengourou); a: Location map; b: Farm ponds; c: Farm dam [14].*

2.2. Sampling and Preservation of Samples

The analysis protocol used in this work is based on the NF T90-101 standard of AFNOR [15] and EPA [16].

The water was collected using polyethylene jars with a capacity of 300 mL. Each jar is rinsed three times with water from the fish farm before being introduced to the desired depth. Once filled, the jar is removed from the water and immediately closed. For the analyzes to be carried out in the laboratory, the water is stored at a temperature of 4°C in a cooler containing cooling packs.

The sediments were sampled using a Van Veen type stainless steel bucket with a surface area of 250 cm^2 and a mass of 12 kg. The sediment samples were then packaged in new plastic packaging and then placed in a cooler (4°C) before being transported to the laboratory. In the laboratory, the sediments are dried in an oven at 50°C for 24 hours. After drying, the samples are pre-sieved through a 1 mm mesh sieve to remove rock debris, branches, leaves and organic debris before being sieved again to obtain a fraction<63 µm. In order to obtain a constant mass, the fraction (<63 µm) is retained and newly dried in an oven at 60°C for one hour. The samples are subsequently stored in polyethylene pill containers and are packaged in polyethylene bags. The whole is placed in a freezer (-20°C) [17].

2.3. Measurement of the Physico-chemical Parameters of Water

The physicochemical parameters of the water namely temperature, pH, dissolved oxygen, conductivity, total dissolved solids and transparency were measured *in situ*. Transparency was determined by using the Secchi disk. The other parameters were measured by using a portable multi-parameter of the HANNA HI 9829 type. The suspended matters (SM) were determined in the laboratory according to the method described by Aminot and Chaussepied [18].

2.4. Determination of the Content of Metallic Trace Elements

The determination of traces of metals in water and sediments was carried out using a Shimadzu Atomic Absorption spectrophotometer (Shimadzu AA 660). The determination of cadmium (Cd) was carried out by Atomic Absorption Spectrometry with a graphite furnace. The arsenic (As) assay was performed by flame spectrometry. Cd and As assays were respectively performed at wavelengths 228.8 nm and 193.7 nm according to the EPA method [16] in water and sediment samples.

2.5. Statistical Analyzes

One-way analysis of variance (ANOVA) was used to test for significant differences between the means by comparing the variances. Therefore, the difference between the supply dam and the ponds; between sediment and water and between arsenic and cadmium was determined. Whenever the test result was significant, ANOVA's Tukey test was performed at $P < 0.05$ to identify groups that were particularly different from each other. All treatments were performed using STATISTICA 7.1 software.

2.6. Evaluation of the Level of Metal Contamination

2.6.1. Metal Pollution Index

The Metal Pollution Index (MPI) allows the comparison of the total content of metallic trace elements among study sites. To compare the total metal content in water and sediment on the farm, the MPI was calculated with the following equation [19]:

$$MPI = (C_1 \times C_2 \times \ldots \times C_n)^{1/n}$$

In which C is the concentration of metal in the sample and n is the total number of trace metal elements measured in the sample.

2.6.2. Ratio Sediment/Water

The Ratio Sediment/Water ($R_{S/W}$) is the ratio of the concentration of metal in sediment to the concentration of the same metal in water. If the ratio is superior to 1, so the concentration of the metal in the sediment is greater than the concentration of the metal in the water. The Ratio Sediment/Water shows how many times the concentrations of trace metal elements in water are multiplied to obtain those in sediment. Its expression is given by the following mathematical formula:

$$R_{S/W} = \frac{C_S}{C_W}$$

With: $R_{S/W}$: Ratio Sediment/Water; C_S: concentration of metal in the sediment; C_W: concentration of metal in water.

2.6.3. Contamination Factor (CF)

The contamination factor helps to highlight contamination or an absence of contamination of the sediments by metallic trace elements and gives the level of contamination [20]. The CF is defined by the ratio of the concentration of a given metallic element to the geochemical background of this same metallic element taken as a normalizing factor. The reference values used in this study are the crustal concentrations (Upper Continental Crust) of the different metals studied: Cd = 0.10 mg/kg and As = 2.00 mg/kg [21]. This contamination factor is calculated by the following formula [22]:

$$CF = \frac{C_S}{B_g}$$

With: Cs: content measured for a metallic element in sediment; Bg: geochemical background for a metallic element.

The four (4) contamination classes for CF are reported in Table 1.

Table 1. *Contamination factor classes [22, 23].*

Class	Value	Contamination
1	CF < 1	Low degree
2	1 ≤ CF < 3	Medium degree
3	3 ≤ CF < 6	Considerable degree
4	CF ≥ 6	Very high degree

2.6.4. Pollution Load Index (PLI)

The pollution load index indicates the number of times the metal content in the sediment exceeds the background concentration. It provides comprehensive information on the toxicity of trace metal elements in a sample [24]. The PLI is evaluated using the following mathematical relation [25]:

$$PLI = (CF_1 \times CF_2 \times \ldots \times CF_n)^{1/n}$$

With CF the contamination factor and n the number of metallic trace elements measured in the sample.

According to Barakat et al. [26]., the values of PLI < 1 indicate an absence of pollution while the values of PLI > 1 show pollution of the sediments.

2.6.5. Individual Potential Risk Index

The individual potential risk index is defined as the coefficient of potential ecological risk of a single metal [27]. It is the product of the contamination factor (CF) of the metal by its toxicity coefficient (Tr) [22]:

$$E_r = CF \times T_r$$

With: CF: Metal contamination factor; Tr: Toxicity coefficient of the metal.

The toxicity coefficient assigned to the trace elements Cd and As used in the calculation of the individual risk index is respectively 30 and 10 [28]. For the classification of individual risks of metallic trace elements in sediments, five (5) classes have been defined (Table 2).

Table 2. *Classes of the individual risk index (Er) [24].*

Class	Value	Ecological risk
1	Er ≤ 40	Low ecological risk
2	40 < Er ≤ 80	Moderate ecological risk
3	80 < Er ≤ 160	Considerable ecological risk
4	160 < Er ≤ 320	High ecological risk
5	Er > 320	Very high ecological risk

2.6.6. Ecological Risk Index

The Potential Ecological Risk Index (PERI) takes into account several environmental effects, such as toxicology, environmental chemistry and ecology [29]. It also helps to assess the ecological risks caused by metallic trace elements in sediments [29, 30]. The PERI takes into account the content of the metal, the type of metal, the toxicity of the metal and the sensitivity of the water to contamination by metallic trace elements in the sediments [27]. It is obtained using the following formula [22]:

$$PERI = \sum E_r$$

With: Er: individual risk of the metal.

The classification of the potential ecological risk index is given in Table 3.

Table 3. *Potential Ecological Risk Index (PERI) classes [24].*

Class	Value	Potential Ecological Risk
1	PERI ≤ 150	Low ecological risk
2	150 < PERI ≤ 300	Moderate ecological risk
3	300 < PERI ≤ 600	Considerable ecological risk
4	PERI > 600	Very high ecological risk

3. Results and Discussion

3.1. Results

3.1.1. Physico-chemical Parameters of Fish Farm Water

The average values of the physico-chemical parameters of the water in the ponds and the dam of the fish farm are presented in Table 4. The average temperature is high in all the farming structures. It varies from 28.89±0.86 to 30.10±0.14°C. The highest temperature is recorded in Pond 3 and the lowest in the dam. Average pH values fluctuate between 6.94±0.54 and 8.11±0.09 during this study. These pH values show that the waters of the dam (7.60±0.66) and of pond 3 (8.11±0.09) have a basic character while those of pond 1 (6.94±0.54) and pond 2 (6.97±1.08) have an acidic one. The waters of all breeding structures are oxygenated throughout the sampling period. Nevertheless, low values (5.98±0.26 - 6.02±0.24 mg/L) were noted in the three ponds compared to the dam (6.35±0.80 mg/L). However, no significant difference (*P>0.05*) was observed among rearing structures for temperature, pH and dissolved oxygen. The average conductivity ranges from 37.50±7.77 to 92.50±12.02 µS/cm. Its minimum value (37.50±7.77 µS/cm) is noted at pond 2 while pond 3 records the maximum value (92.50±12.02 µS/cm). The level of dissolved solids changes in all structures in the same way as the conductivity. The concentrations are low in pond 2 (23.00±2.82 mg/L) and pond 1 (29.50±3.53 mg/L) but high in the dam (35.00±5.65 mg/L) and pond 3 (40.50±2.12 mg/L). Statistical analysis (ANOVA) shows that there is a significant difference (*p<0.05*) among structures for conductivity and TDS. The average transparency is low in ponds (25.47±0.67 - 28.18±0.25 cm) but high in the dam (43.30±0.42 cm). Contrary to transparency, the rate of suspended matters is higher in the water of the ponds (135.39±5.89 - 148.80±1.10 mg/L) than in those of the dam (103.07±1.95 mg/L). The transparency is high in the waters of pond 2 compared to those of ponds 1 and 3. On the other hand, the waters of ponds 1 and 3 contain more suspended matter. One-way statistical analysis (ANOVA) shows that there is a significant difference (*p<0.05*) between the dam and all three ponds for transparency and suspended solids values. For these two parameters, there is also a significant difference between pond 2 and the other two ponds (1 and 3).

Table 4. *Average values of the physico-chemical parameters of the water in the ponds and the dam of the fish farm from September to October 2020.*

Parameters	Structures	Pond 1	Pond 2	Pond 3
	Dam			
Temperature (°C)	28.89±0.86	29.80±1.51	29.70±0.78	30.10±0.14
pH	7.60±0.66	6.94±0.54	6.97±1.08	8.11±0.09
O_2 (mg/L)	6.35±0.80	6.02±0.24	5.89±0.86	5.98±0.26
Conductivity (µS/cm)	66.00±5.65^b	59.50±4.94^a	37.50±7.77^a	92.50±12.02^c
TDS (mg/L)	35.00±5.65^b	29.50±3.53^a	23.00±2.82^a	40.50±2.12^b
Trans (cm)	43.30±0.42^b	25.47±0.67^a	28.18±0.25^c	26.27±0.38^a
SM (mg/L)	103.07±1.95^a	147.79±0.14^c	135.39±5.89^b	148.80±1.10^c

The values of the same line bearing the letters a, b, c in superscript show a significant difference between the breeding structures ($p<0.05$).

3.1.2. Average Concentrations of Metallic Trace Elements and the Ratio S/W

The average concentrations of cadmium (Cd) and arsenic (As) in water (mg/L) and in sediment (mg/kg) as well as the ratio sediment/water (L/kg) are shown in Table 5. The values of the metallic trace elements in the different structures of the farm show a significant difference ($p<0.05$) between water and sediment for all the studied metals. Average Cd concentrations vary between (0.1150±0.0129) × 10^{-2} mg/L and (0.1250±0.0076) × 10^{-2} mg/L in water and between 0.0565±0.0148mg/kg and 0.0880±0.0212mg/kg in sediment. The highest values for this metal in water are recorded in pond 3 and in sediments in pond 1. The Ratio S/W is higher in Pond 1 (70.63) and Pond 2 (63.91) than in Dam (47.84) and Pond 3 (50.00). The mean concentrations of As vary from (0.1837±0.0148) × 10^{-2} mg/L to (0.2296±0.0300) × 10^{-2} mg/L in water and from 0, 2045±0.218496 mg/kg to 0.3950±0.1103 mg/kg in sediment. The highest values for this metal are recorded in the water of the dam in the sediment of pond 1. The Ratio S/W is higher in Dam (172.04) than in Pond 1 (111.29), Pond 2 (118.91) and Pond 3 (111.32).

Table 5. *Average concentrations of metallic trace elements in water (× 10^{-2} mg/L) and sediments (mg/kg) and ratios sediment/water ($R_{S/W}$, in L/kg).*

TME	Matrices	Livestock structures	Pond 1	Pond 2	Pond 3
		Dam			
Cd	Water	0.1181±0.0042^a	0.1246±0.0071^a	0.1150±0.0129^a	0.1250±0.0076^a
	Sediments	0.0565±0.0148^b	0.0880±0.0212^b	0.0735±0.0050^b	0.0625±0.0035^b
	$R_{S/W}$	47.84	70.63	63.91	50.00
As	Water	0.2296±0.0300^a	0.2143±0.0477^a	0.1909±0.0063^a	0.1837±0.0148^a
	Sediments	0.3950±0.1103^b	0.2385±0.2411^b	0.2270±0.0750^b	0.2045±0.2185^b
	$R_{S/W}$	172.04	111.29	118.91	111.32

Values in the same column with letters a, b in superscript show a significant difference between matrices ($p < 0.05$) for a given metal.

3.1.3. Metal Pollution Index (MPI)

The overall content of trace metal elements in water and sediment was calculated using the Metal Pollution Index. The results are given in Table 6. The mean values of the metal pollution index oscillate between (0.1482±0.0090) × 10-2 and (0.1647±0.1122) × 10^{-2} for water while they vary from 0.1131±0.0277 to 0.1494±0.0404 for sediments. The obtained values indicate a higher overall contamination in sediments than in water (MPI Sediments >MPI Water). The average MPI values in the different breeding structures are in the following decreasing order: Dam > Pond 1 > Pond 3 > Pond 2 and Dam > Pond 1 > Pond 2 > Pond 3 respectively for water and sediment.

Table 6. *Average values of MPI in water and sediment on the farm.*

	Matrices	Livestock structures			
		Dam	Pond 1	Pond 2	Pond 3
MPI	Water (× 10^{-2})	0,1647±0,1122	0,1634±0,0184	0,1482±0,0090	0,1515±0,1061
	Sediments	0,1494±0,0404	0,1449±0,0715	0,1292±0,0194	0,1131±0,0277

3.1.4. Assessment of Contamination and Pollution in Sediments

The Contamination Factor (CF) and the Pollution Load Index (PLI) of Cadmium and Arsenic in the sediments of the ponds and dam of the fish farm are presented in Table 7. The contamination factor shows values less than 1 for all structures. The CF values vary from 0.565±0.148 to 0.880±0.212 for Cd and from 0.102±0.109 to 0.198±0.055 for As. The highest contamination factor is recorded in the dam (CF = 0.198±0.055) for as and for Cd in pond 1 (CF = 0.880±0.212). The pollution load index has values between 0.253±0.062 in Pond 3 and 0.335±0.090 in the dam.

Table 7. *Average values of CF and PLI in farm sediments.*

	Contamination factor (CF)		Pollution load index (PLI)
	Arsenic	Cadmium	
Dam	0.198±0.055	0.565±0.148	0.335±0.090
Pond 1	0.119±0.121	0.880±0.212	0.324±0.160
Pond 2	0.114±0.038	0.735±0.050	0.289±0.044
Pond 3	0.102±0.109	0.625±0.035	0.253±0.062

3.1.5. Evaluation of the Potential and Ecological Risk of Sediments

The individual risk index (Er) and the potential ecological risk index (PERI) of cadmium and arsenic in the sediments of the ponds and farm dam are presented in Table 8. The risk index individual (Er) is higher for Cd compared to the one of As in all structures. For Cd, it varies from 16.95±4.44 to 26.40±6.36 and the highest value is noted in pond 1. For As, it varies from 1.02±1.09 to 1.98±0.55 and the highest value is recorded in the dam level. The values of the index of potential ecological risk (PERI) are between 18.93±4.99 and 27.59±7.57. The highest values are observed in the ponds.

Table 8. *Average values of Er and PERI in farm sediments.*

	Individual potential risk index (Er)		Ecological risk index (PERI)
	Arsenic	Cadmium	
Dam	1.98±0.55	16.95±4.44	18.93±4.99
Pond 1	1.19±1.21	26.40±6.36	27.59±7.57
Pond 2	1.14±0.38	22.05±1.50	23.19±1.88
Pond 3	1.02±1.09	18.75±1.05	19.77±2.14

3.2. Discussion

The measurement of the physico-chemical parameters of the water gives a first estimate of its quality [31]. Our study revealed that the water temperature remains high in all farm structures, particularly in Pond 3 (30.10±0.14°C). The waters of the dam (7.60±0.66) and of the pond 3 (8.11±0.09) have a basic character while the waters of the pond1 (6.94±0.54) and Pond 2 (6.97±1.08) are slightly acidic. In addition, the waters of all the facilities on the farm have very good oxygenation rates (5.89±0.86 - 6.35±0.80) throughout the sampling period. Besides, the electrical conductivity and total dissolved solids are low varying from 37.50±7.77 to 92.50±12.02 µS/cm and from 29.50±3.53 to 40.50±2,12 mg/L, respectively. Our results also showed that the transparency is low in all the ponds (25.47±0.67 - 28.18±0.25 cm) compared to the values obtained in the dam (43.30±0.42 cm). On the other hand, the levels of suspended solids are high in the ponds (135.39±5.89 - 148.80±1.10 mg/L) compared to the dam (103.07±1.95 mg/L). In general, the physicochemical parameters evaluated on the fish farm have values that comply with the range recommended for optimum productivity in fish farming, particularly for the rearing of tilapia *Oreochromis niloticus* and catfish *Clarias gariepinus* (Table 9). Nonetheless, the electrical conductivity and transparency are not compliant with the recommended standard. The obtained SS concentrations were greater than the maximum value accepted for good productivity of *Oreochromis niloticus* to but below the threshold recommended for *Clarias gariepinus*.

Table 9. *Some physicochemical parameters for optimal growth of Oreochromis niloticus (O. niloticus) and Clarias gariepinus (C. gariepinus).*

Parameters	Units	Species	Standards	References
Temperature (T)	°C	*O. niloticus*	26 - 30	[32]
		C. gariepinus	20 - 30	[33]
Potential hydrogen (pH)	–	*O. niloticus*	6,5 – 9	[32]
		C. gariepinus	6,5 – 8	[33]
Dissolved oxygen (O_2)	mg/L	*O. niloticus*	>3,5	[32]
		C. gariepinus	≥ 3,0	[33]
Electric conductivity (EC)	µS/cm	*O. niloticus*	150 – 450	[34]
		C. gariepinus	–	
Transparency (Trans)	cm	*O. niloticus*	30 – 60	[35]
		C. gariepinus	25 – 50	[33]
Suspended Matters (SM)	mg/L	*O. niloticus*	25 – 80	[32]
	g/L	*C. gariepinus*	≤ 100	
Total dissolved Solids (TDS)	mg/L	*O. niloticus*	<200	[36]
		C. gariepinus	–	

This study reveals the presence of metallic trace elements in the water of all the structures of the farm. This presence of cadmium and arsenic in the water can be explained by the regular use of herbicides and pesticides in the plantations around the farm [37]. Arsenic has higher concentrations than cadmium in all structures. This difference could be related to environmental conditions. Indeed, the solubility and mobility of heavy metals in water are partly influenced by the physico-chemical parameters of the water and the properties of each metal [31, 38]. The study also indicated that there is no significant difference between farm structures for any metallic trace elements. This could be explained by an identical source of contamination of the waters of the different livestock structures that were studied. In fact, the farm is close to rubber tree plantations, a probable source of toxic metals with the use of fertilizers and phytosanitary products [39]. Our results for cadmium are lower than those obtained by [6, 9]. These authors respectively recorded values between 0.0121 and 0.0409 mg/L and varying from 0.023±0.01 to 0.074±0.08 mg/L. However, the obtained cadmium contents are higher than those (0.00022±0.00001 - 0.00027±0.00003 mg/L) recorded by [4] in fish farms in Egypt. But, our values remain below the standard required for freshwater aquaculture, which is 0.005 mg/L of cadmium [32]. Concerning arsenic, our values are lower than those recorded by [9, 10]. Indeed, these authors noted concentrations respectively varying from 0.043±0.04 to 0.044±0.02 mg/L and from 0.047±0.014 to 0.052±0.043 mg/L. Futhermore, the arsenic values recorded during the study period are well below the recommended standard for freshwater aquaculture which is 0.4 mg/L [32]. Nevertheless, the consistent presence of metals in water could harm fish through the phenomenon of bioconcentration. In fact, fish can accumulate heavy metals in their bodies by directly absorbing water through the gills [40].

Our results showed the presence of TME (As, Cd) in the sediments of the structures of the fish farm. These sediments have higher metal contents compared to their concentration in water. This difference is believed to be due to the fact that in aquatic environments, metals tend to accumulate in the sediments [41]. Indeed, sediments are considered to be the most important reservoirs of metallic trace elements [1]. These large amounts of metals accumulated in the sediments represent real dangers for the aquatic environment, such as the death of benthic organisms reducing the availability of food for fish, inhibiting fish growth and bioaccumulation as well as biomagnification of metallic trace elements in fish [9]. Our cadmium values (0.0565±0.0148– 0.0880±0.0212mg/kg) are lower than those (2.04±0.02 mg/kg) of [42] in sediments from El – Shikh pond in Egypt and those (0.121±0.00 - 0.174±0.01 mg/kg) by [9] in a farm in a pond, located in Offoumpo in the department of Agboville in the Côte d'Ivoire. Our arsenic results (0.2045±0.218496 - 0.3950±0.1103 mg/kg) are lower than those recorded by [10] which evolve from 4.743±0.802 to 5.757±1.258 mg/kg.

The ratio sediment/water ($R_{S/W}$) was used to assess the mobility of metallic trace elements from water to sediments as well as their accumulation in these sediments. This ratio is well above 1 ($R_{S/W}>1$) for all metals, thus showing their high mobility from water to sediments [9, 43]. The high values of the ratios recorded for the studied metals also indicate a strong accumulation of metals contained in the water by the sediments of the farm. This confirms that the sediments of the different rearing structures constitute a reservoir of metallic trace elements for the water column [1]. Arsenic (111.29 - 172.08) has higher ratios than cadmium (47.84 - 70.63) on the farm. These high values of the $R_{S/W}$ of arsenic would result from the physicochemical properties of the aquatic environment. In fact, in aquatic environments, the physicochemical parameters partly control the behavior and mobility of contaminants among the different compartments [44]. The high mobility of TMEs towards the sediments as well as their accumulation lead to an increase in metals levels in the sediments [45]. Sedimentary particles have the capacity to fix pollutants thanks to clays and humic compounds and consequently they are hardly carried away by leaching [46]. This explains why the TME are often highly concentred in soils and sediments [47].

The overall content of trace metal elements in water and sediment was assessed using the Metal Pollution Index. The recorded values indicate a higher overall contamination in sediment (0.1131±0.0277 - 0.1494±0.0404) than in water ((0.1482±0.0090) × 10^{-2} - (0.1647±0.1122) × 10^{-2}). This could be attributed to higher concentrations of metallic trace elements in the sediments. However, these values are less than 1 (MPI<1). This means that all of the TMEs (Cd and As) contained in the water and sediment of the fish farm are safe for Oreochromis niloticus and Clarias gariepinus fish [48].

However, the crude concentrations of metallic trace elements in the sediments do not provide sufficient information on the level of contamination of the sediments. This is why the level of contamination of the sediments was assessed with indices. The contamination factor has values between 0.102±0.109 and 0.198±0.055 for arsenic and between 0.565±0.148 and 0.880±0.212 for cadmium. These values being less than 1 (CF < 1), point out a low degree of contamination of the sediments with arsenic and cadmium [22]. But, sediments pose a greater risk of cadmium contamination than arsenic ($CF_{Cd} > CF_{As}$). This order of contamination has the same tendency as the content of metals in sediment and the ratio S/W. The overall toxicity status of TMEs in the sediments of the fish farm was assessed with the pollution load index. The PLI indicates the result of the contribution of the different metals. The average values of the pollution load index obtained are between 0.253±0.062 and 0.335±0.090 confirming an absence of pollution of the sediments of the fish farm (PLI < 1) [26]. The PLI is a powerful tool in the assessment of pollution by trace metal elements [49]. It helps to assess the impact of human activities on the quality of the sediments on the farm. In fact, according to [48], a PLI > 1 means a contribution from anthropogenic sources; pointing out a gradual deterioration in the quality of the sediments.

The ecological risk associated with each metal was assessed with the individual potential risk index (Er). The values of the individual potential risk are less than 40 (Er<40) for all metals (As: 1.02±1.09 to 1.98±0.55 and Cd: 16.95±4.44 to 26, 40±6.36) and in all structures. This shows a low ecological risk for the metals studied. Indeed, according to the classification of individual potential risks, Er ≤ 40 belong to Class 1, which indicates a low ecological risk [24]. To assess the ecological risks caused by all metals, the potential ecological risk (PERI) was determined. The obtained values (18.93±4.99 - 27.59±7.57) are all less than 150 (PERI<150). They indicate that farm sediments pose a low ecological risk [24].

4. Conclusion

The present study consisted of determining the environmental quality of water and sediments from a pond fish farm in order to assess the risk of exposure of farmed fish to arsenic and cadmium. The study found that the waters of the various structures on the farm generally have high temperatures. The waters of the dam are basic while those of the ponds are acidic. Conductivity and total dissolved solids evolve in all structures in the same way and are higher in the dam. The waters of the various farm facilities are well oxygenated. However, they are loaded with suspended matter with low transparency. Almost all of the structures on the farm have physicochemical parameters in accordance with the water quality guidelines for rearing Oreochromis niloticus and catfish Clarias gariepinus. Analysis of the water and sediments of the farm structures showed the presence of metallic trace elements (arsenic and cadmium) in these two compartments. Arsenic has higher concentrations than cadmium in all the structures. The study indicated that there is no significant difference among the farm structures for the two metals. The concentrations of trace metal elements in sediments are significantly higher than those in water. Moreover, the overall contamination of metallic trace elements is higher in sediment than in water. The study also indicated that the values of the contamination factor, the individual potential risk index and the ecological risk index point out a low level of contamination of the farm's sediments with arsenic and cadmium and a low ecological risk. However, the Sediment/Water Ratios for cadmium and arsenic which are high in all the farm structures show, that the sediments are true sinks of trace metal elements. These large quantities of metals accumulated in the sediments represent real dangers for all living species in this environment. The danger of these high metal concentrations in the sediments lies in the resuspension of these metals during the control of fisheries, which can disrupt the biological balance and increase the risk of contamination of farmed fish.

We recommend fish farmers to:

1. Clean out the ponds after each production cycle and dispose of sediment away from the ponds;
2. Develop dykes around the ponds to slow down the entry of runoff water into the ponds;
3. Avoid the use of phytosanitary products on the farm to dry weeds.

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