ijar
ISSN NO. 2320-5407

Journal Homepage: - www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/22030
DOI URL: http://dx.doi.org/10.21474/IJAR01/22030

RESEARCH ARTICLE

EVALUATION OF TRACE METAL ELEMENT LEVELS IN THE REARING WATER, SEDIMENT AND TWO FISH SPECIES (CLARIAS GARIEPINUS AND OREOCHROMIS NILOTICUS) IN TEN FISH FARMS IN THE MOUNGO DIVISION, LITTORAL REGION, CAMEROON

Safietou Mbaye[1,2], Jean Fall[2], Jenny Maiva Yango Tcoumbougnang[3], Raymond Tchabong[4], Alla Ndione[2], Dadie Lionel Binouga[4], Theophile Collins Ndjamou Yelengwe[4], Francois Tcoumbougnang[4] and Damien Banas[5]

1. Cheikh Anta Diop University of Dakar, Senegal, Faculty of Science and Technology.
2. University Institute of Fisheries and Aquaculture/Cheikh Anta Diop University Dakar-Senegal UCADII Educational Building, Ground FloorPO Box: 5005.
3. University of Bertoua, Faculty of Science, Department of Chemistry-Biology, PO Box: 652 Bertoua.
4. Universityof Douala, National Higher School of Agronomy, Halieutics and Veterinary Medicine, PO Box 7236 Douala-Cameroon.
5. University of Lorraine, INRAE, L2A, F-54500, Nancy, France.

……

Manuscript Info

Manuscript History
Received: 19 August 2025
Final Accepted: 21 September 2025
Published: October 2025

Key words:-
Clarias gariepinus, Oreochromis niloticus, metals,sediments, water.

Abstract

This study evaluated trace metal element(TME)concentrations in water, sediments, and muscle tissues of Clarias gariepinus and Oreochromis niloticus collected from ten aquaculture farms in the Moungo Division, Littoral Region, Cameroon. Sampling was conducted during the rainy season, and analyses were performed using energy-dispersive X-ray fluorescence spectrometry (Shimadzu EDX-7000). The main elements detected were Fe, Cu, Zn, Ca, K, P, S, Si, and Ti. No regulated heavy metals (Pb, Cd, Hg) were detected above the analytical limits of detection. Total arsenic, which is not regulated in fish flesh under European Union legislation,was also below detection limits.High concentrations of Fe (20.94–65.94 mg/L) and Cu (30.83–34.72 mg/L) were measured in rearing water, exceeding WHO guideline values for drinking water.These levels likely reflect local geochemical conditions, with possible additional inputs from agricultural practices or metal equipment used in farming systems. Sediments were identified as the main accumulation compartment, particularly for Fe and Si, indicating a predominantly geological origin.Fish exhibited site specific bioaccumulation patterns, especially for Fe and Ca, but levels of priority toxic metals remained low. These findings do not indicate regulatory concern but highlight the need for regular monitoring to detect potential changes in contamination levels in the context of expanding aquaculture systems.

……

Corresponding Author:- Safietou Mbaye
Address:- 1. Cheikh Anta Diop University of Dakar, Senegal, Faculty of Science and Technology. 2. University Institute of Fisheries and Aquaculture/Cheikh Anta Diop University Dakar-Senegal UCADII Educational Building, Ground FloorPO Box: 5005.

Introduction:-

Aquaculture is one of the fastest-growing food industries worldwide and plays a key role in ensuring the food and nutritional security of populations, especially in developing countries (FAO, 2022). According to FAO, the year 2022 saw global aquaculture production reach peaks, accounting for more than 50% of the overall production of marine and freshwater animals. In addition, continental aquaculture is taking an increasingly important place in the supply of animal protein (FAO, 2022b). Its development aims to reduce the growing gap between the demand for seafood and the limits of traditional fishing, which remains at a constant level. According to the FAO, aquaculture will be the world's leading source of fish supply by 2030. In this context, it appears as a strategic sector for food and nutritional security in sub-Saharan Africa, especially in Cameroon, where the production of Clarias gariepinus and Oreochromis niloticus is predominant (FAO, 2022a, 2022b). According to Temegne and Momo (2019), in Cameroon, fish constitutes nearly 40% of the protein supply of animal origin and covers 9.5% of the population's overall nutritional needs. In Cameroon, each person consumes an average of 11 kg of fish per year, offering a protein intake of 22g for every 100g of fish per individual (Kenfack et al., 2019; Temegne and Momo, 2019).

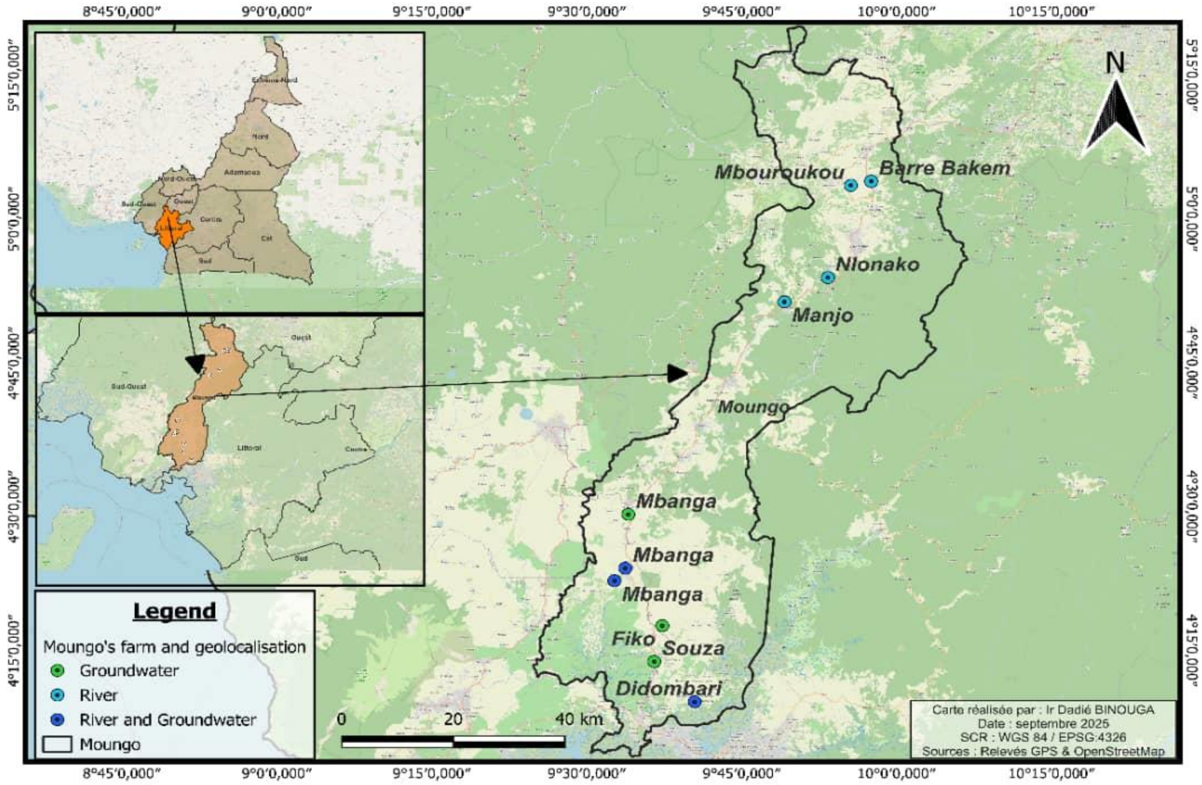
The Cameroonian population greatly values fish because of its availability and cost, which positions it at the top of meat (Kenfack et al., 2019; Pouokamet al., 2017). In 2017, the country's fish production amounted to only 181,678 tons per year, estimated at a value of 114.3 billion FCFA. In addition, less than 1000 tons per year came from fish farming activities, representing less than 0.1% of GDP (Kenfack et al., 2019; Temegne and Momo, 2019). However, the intensification of aquaculture practices, associated with sometimes inadequate management of inputs and discharges, can cause a collection of trace metals (TME) in aquatic environments (Onyena& Udensi, 2019). Contaminations, intensified by bioaccumulation and bioamplification, pose a threat to consumer health (Alloway, 2013; FAO & WHO, 2011). In Cameroon, water pollution by heavy metals represents an environmental problem of primary importance, especially in regions where industrial, mining and agricultural activity is intense. Studies on metal accumulation include the analysis of muscles, since they constitute the part consumed by human beings (Şirin et al., 2024).

Metal concentrations in water may increase due to agricultural practices (Han & Gu, 2023), wastewater discharges (Soleimani et al., 2023), mining (Lakra et al., 2019; Mishra et al., 2008), acid drainage of mines (Lebepe et al., 2020) and industrial activities (Adegbola et al., 2021). Heavy metals that are persistent in aquatic environments have the potential to accumulate in living species, leading to physiological and reproductive changes in fish. They can also pose a threat to the biological diversity and food security of riparian communities (Ali et al., 2019; Oumarou et al., 2021; FAO, 2022). Despite the notable expansion of fish farming in the Littoral region, particularly in the Mongo division, little research has focused on the evaluation of the TMEs present in the waters, sediments and fish of these farms (Troell et al., 2014). The purpose of this research is to evaluate the levels of metallic trace elements (TME) in aquaculture waters, sediments and tissues of C. gariepinus and O. niloticus from ten fish farms located in of Mongo division, in order to provide an inventory and guide sustainable management practices (FAO, 2022a). These results will make it possible to establish an assessment of local pollution and to provide crucial data for the sustainable management of these resources and health quality.

Materials and Methods:-

Sampling Sites:

The study was carried out in the Mongo Division, located in the Littoral region of Cameroon. The samples were taken from July 22 to 27, 2025 corresponding to the great rainy season in ten agro-fish farms selected through the information provided by the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA) in order to ensure the representativeness of local fish farming activity (Figure 1).The Moungo Division, located in the Littoral Region, is a major agricultural basin on the Cameroonian coast, contributing disproportionately to regional maize production and supporting important food and agro-industrial sectors (MINADER — AGRISTAT, 2023). Its favorable agro-ecological position (volcanic soils around Mount Nlonako) and the combined presence of small farms and agro-industrial enterprises explain its central role in food security and rural development in the Littoral.



Carte réalisée par : Ir Dadié BINOUGA
Date : septembre 2025
SCR : WGS 84 / EPSG:4326
Sources : Relevés GPS & OpenStreetMap

Figure 1. Map of Cameroun showing the location of the 10 aquaculture and agriculture integrated farms sampled in the Littoral region. The exact location of the ten agro-fish farms was achieved thanks to geolocation through the map coordinates.

Table 1. Coordinates and location of sampling sites.

Farm number	**Geographical coordinates**	**Littoral region/Moungo division: Specific Area**	**Water sources**
1	5°03'55.8"N 9°57'31.9"E	Barre Bakem	River (Mont Manengoumba)
2	5°03'30.4"N 9°55'33.5"E	Mbouroukou	River (Mont Manengoumba)
3	4°22'16.8"N 9°32'40.7"E	Mbanga	River and Groundwater
4	4°51'21.3"N 9°49'08.1"E	Manjo	River (Mont Manengoumba)
5	4°53'53.6"N 9°53'20.3"E	Nlonako	River (Mont Manengoumba)
6	4°29'11.7"N 9°34'01.0"E	Mbanga	Groundwater
7	4°23'34.9"N 9°33'43.2"E	Mbanga	River and Groundwater
8	4°13'50.9"N 9°36'31.2"E	Souza	Groundwater
9	4°17'35.2"N 9°37'18.6"E	Fiko	Groundwater
10	4°09'39.1"N 9°40'26.2"E	Didombari	River and Groundwater

Sampling procedure:

Samples of livestock water, sediments and fish were taken for each farm. Water samples were collected at a depth of approximately 30 cm (to avoid suspended particles), inbottles that have been previously rinsed with HNO3 because HNO3 eliminates metal traces adsorbed on the walls and prevents contamination of the sample. The samples were kept at 4°C until their analysis. The sediments were collected at five points (four corners and the center), the surface layer of sediment (around 0-5cm) was collected. For earthen ponds, a shovel was used, while for liner ponds, the collection was done by hand. After taking the five points, the whole was mixed homogeneously and a quantity of

500g was taken. The samples were then placed in bags (with a pre-wash with HNO3) sealed and labeled and then put in the cooler before being transported and put in the freezer at -18° before preparation in the laboratory. Regarding the fish, two species were sampled according to availability on each farm: tilapia (Oreochromis niloticus) and African catfish (Clarias gariepinus). Five individuals were captured by species and by farms. For a total of 5 fish per farm and 50 fish for the entire study. The fish were weighed (average weight per fish about 0.3kg or 1.5 kg per batch of samples) before being stored in coolers and then frozen at -18° before preparation in the laboratory. We sampled the Oreochromis niloticusin farms 1 and 4, while the Clarias gariepinus was taken from farms 2,3,5,6,7,8,9 and 10.

Sample preparation and analysis:

The samples were analyzed at the Laboratory of Analysis of Radiological Contaminants and Heavy Metals in Fishery Products. The water samples were filtered (filter 0.45 µm) before analysis. The sediment samples were dried in the oven between 40 °C and 60 °C for a period of 24 to 48 hours, then mixed to obtain a fine powder. For each sample, five individuals of similar size, weight and shape were grouped together to prepare a composite specimen to minimize individual variations in the determined TMEs. The fish were filleted then the muscle dried in the oven (Memmert UN55). The fish meat samples were dried in the oven at 60 °C to constant weight in accordance with the AOAC Official Method 983.18 (AOAC, 2005). Then ground (stainless steel bench ground grinder) and homogenized to have a powder ready for analysis. In this study, different categories of chemical elements were taken into account. The major elements (P, K, S) have been included as essential macronutrients commonly found in the water and tissues of fish. Essential trace metals (Fe, Cu, Zn, Mn and Cr) were also analyzed, as they play a key physiological role, but can become toxic at high concentrations.

In addition, common toxic heavy metals (Pb, Cd, Hg and As) were examined for their persistent nature, their tendency to bioaccumulation and their widely documented health hazards. For the sake of simplicity, the term « metals » is generally used throughout the article to collectively refer to these groups of elements. The analysis of metallic trace elements (TME) present in water, sediments and fish tissues was carried out using an EDXRF spectrometer (energy dispersion X fluorescence spectrometer), the SHIMADZU EDX-7000. This device allows a qualitative and quantitative analysis of the chemical elements without destroying the sample. The device has been calibrated according to the manufacturer's instructions. Certified reference materials (MRCs) were used to verify. The results were expressed in ppm or mg/L for water, and in mg/kg dry weight for fish sediments and muscle. The analytical limits of quantification (LQ) were 0.5 mg/kg dry weight for Fe, Cu, Pb, Cd and As, and 0.2 mg/kg for Ag in solid matrices (sediment and fish tissue), with corresponding values of 0.05 and 0.02 mg/L in water. For Hg, the LQ was 5 mg/kg dry weight (1.25 mg/kg wet weight), which is above the EU regulatory threshold for non-predatory fish (0.50 mg/kg wet weight). Therefore, Hg measurements by EDXRF are qualitative only and do not allow a reliable compliance assessment.

Method of analysis:-

For analysis, 5 grams of each sample of sediment, water and fish, (previously dried and crushed for sediment and fish), were transferred to adapted cups and sealed with a Mylar film. These samples were then placed in the EDXRF SHIMADZU EDX-7000 spectrometer (previously calibrated using appropriate standards). Each sample was analyzed 60 times. The results processed using the PCEDX Navi/Pro software, making it possible to obtain the concentrations of the elements in the form of ppm. Certified reference materials (CMRs) have been regularly analyzed to ensure the accuracy and of the results.

Bioaccumulation Factor (BAF):-

The bioaccumulation factor (BAF) corresponds to the ratio of the concentration of metals in an organ to that present in water or sediments (Arnot &Gobas, 2006). It measures the total bioaccumulation, i.e. the contribution of all exposure pathways (water + food + sediments).

$$\mathrm{BAF} = \frac{\mathbf{Corganism}\ \text{(concentration in fish mg/kg)}}{\mathbf{Cenvironment}\ \text{(sediment or water concentration}\ (\frac{\text{mg}}{\text{kg}}\ \text{or}\ \frac{\text{g}}{\text{l}})}$$

Statistical analysis of data:-

The data was entered into an Excel sheet, encoded, verified, and then exported to the GraphPad V8.03 software for Windows (GraphPad PRISM, California, USA). The data were presented as mean ± standard deviation (DS) in tables and figures. The one-factor orderly analysis of variance (ANOVA) and the post-hoc Duncan test were used to make comparisons of the means between the groups. The Levene variance equality test was used to verify the conditions of use of the ANOVA test. The statistical significance threshold has been set at $p < 0.05$. The data are presented as a standard average deviation (DS). The one-factor orderly analysis of variance (ANOVA) and the Duncan post-hoc test were used to make comparisons between groups. Bars with different letters are statistically significant at the threshold of $p < 0.05$.

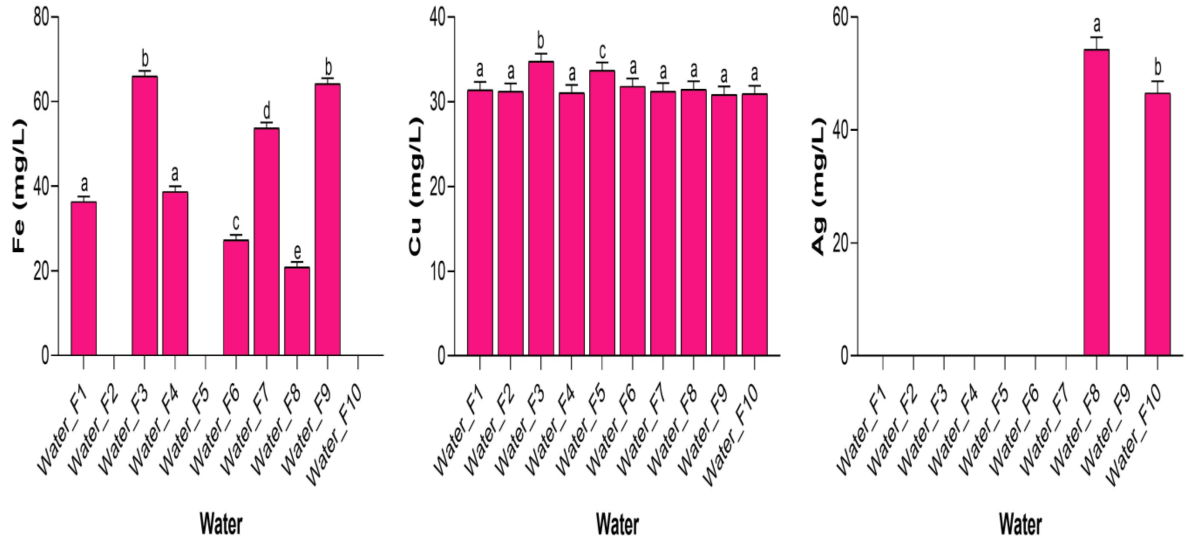
The interpretation of analytical results for regulatory comparison requires converting concentrations measured on a dry weight (d.w.) basis to a fresh weight (w.w.) basis, as regulatory thresholds for fish flesh are expressed on a fresh weight basis (European Commission, 2023). Based on published proximate composition data for fish muscle, the average water content in most freshwater fish is between 70 % and 80 % (Huss, 1995). In this study, a conversion factor of 0.25 was used, corresponding to 75 % water content. The equivalent LQ on a fresh weight basis was calculated using the following equation: $LQ_{fw} = LQ_{dw} \times (1\text{-water content})$ For example, a dry weight LQ of 0.5 mg/kg corresponds to approximately 0.125 mg/kg fresh weight (0.5×0.25). This conversion allows direct comparison between analytical capabilities and regulatory thresholds. For Hg, however, the LQ of 5 mg/kg d.w. corresponds to 1.25 mg/kg w.w., which exceeds the EU limit for non-predatory fish (0.50 mg/kg w.w.), meaning that EDXRF results for Hg are qualitative only and do not allow reliable compliance assessment.

Results:-

The results show the variation in average TME contents in fish farming waters, sediments and fish, taking into account both species: Oreochromisniloticus and Clarias gariepinus.

Change in average ETM levels in livestock water:

Metal



Number of farms

Figure 2. Variation of heavy metals according to water samples

At the level of Table 2, the farms show significant variations in terms of iron (Fe) and copper (Cu). Fe concentrations showed marked spatial variability, with peaks at F3 (65.94 mg/L) and F9 (64.17 mg/L), while the lowest level is noted at F8 (20.94 mg/L). The Cu, on the other hand, has a more uniform distribution, ranging from 30.83 to 34.72 mg/L, with peaks noted at F3 and F5 farms.

Table 2. Concentrations of metals in the breeding water of the aquaculture farms studied (average ± standard deviation)

	Water									
Metals	**Water_F1**	**Water_F2**	**Water_F3**	**Water_F4**	**Water_F5**	**Water_F6**	**Water_F7**	**Water_F8**	**Water_F9**	**Water_F10**
Fe (mg/L)	36.32 ± 1.25 ^{a}	-	65.94 ± 1.33 ^{b}	38.73 ± 1.23 ^{a}	-	27.30 ± 1.21 ^{c}	53.72 ± 1.35 ^{d}	20.94 ± 1.17 ^{e}	64.17 ± 1.34 ^{b}	-
Cu (mg/L)	31.36 ± 0.96^{a}	32.2 ± 0.96^{a}	34.72 ± 0.95^{b}	31.04 ± 0.94^{a}	33.69 ± 0.95^{b}	31.78 ± 0.96^{a}	31.21 ± 0.99^{a}	31.45 ± 0.94^{a}	30.83 ± 0.96^{c}	30.93 ± 0.95^{c}

The values of the same line bearing the letters a, b etc. in exponent show a significant difference between the metals ($p < 0.05$) compared to the farms studied.

Variation of average TME levels in sediments:

Figure 3 shows the variation of metals in the sediment

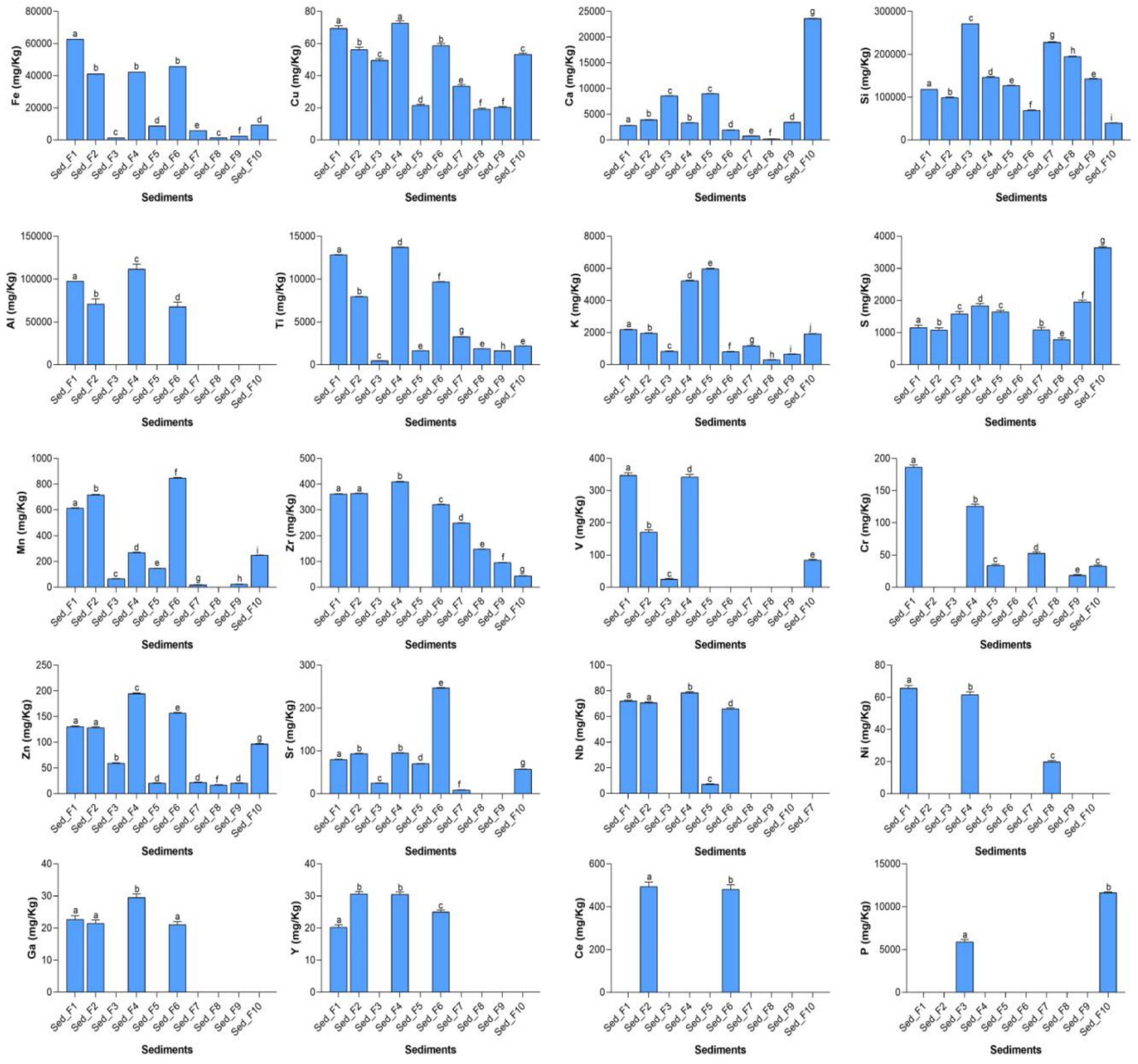


Figure 3. Variation of heavy metals across sediment samples

The analysis of the metal concentrations in the sediments of the ten aquatic farms examined shows great spatial variability (Table 3). A significant concentration of iron (Fe) is observed at F1 (62.83 mg/kg) and F6 (45.79 mg/kg), while it is considerably lower in the sediments of F3 (1.34 mg/kg) and F8 (1.48 mg/kg). Silicon (Si) is the most present element, having reached a maximum concentration at F3 (271.34 mg/kg), then at F7 (227.97 mg/kg). Calcium (Ca) reaches its maximum level at F10 (23.63 mg/kg), as opposed to rather low values observed at F7 (0.78 mg/kg) and F8 (0.20 mg/kg). The concentration of zinc (Zn) oscillates between 0.02 mg/kg (F5, F7, F8, F9) and 0.19 mg/kg (F4). Manganese (Mn) also has marked variations, reaching a peak at F6 (0.85 mg/kg), unlike a minimum concentration at F7 and F9 (0.02 mg/kg). Rather low concentrations, usually below 1 mg/kg, are often observed for other metals such as titanium (Ti), sulfur (S), vanadium (V), chromium (Cr) and strontium (Sr).

Table 3. Concentrations of metals in the sediment at the level of the aquaculture farms studied (mean ± standard deviation)

	Sediment									
Metals (x10^{3})	**Sediment_F1**	**Sediment _F2**	**Sediment _F3**	**Sediment _F4**	**Sediment _F5**	**Sediment _F6**	**Sediment _F7**	**Sediment _F8**	**Sediment _F9**	**Sediment _F10**
Fe (mg/Kg)	62.83 ± 0.04^{a}	41.18 ± 0.03^{b}	1.34 ± 0.00^{c}	43.32 ± 0.03^{b}	8.71 ± 0.00^{d}	45.79 ± 0.03^{b}	5.82 ± 0.00^{e}	1.48 ± 0.00^{c}	2.41 ± 0.00^{f}	9.25 ± 0.00^{d}
Cu (mg/Kg)	0.07±0.00^{a}	0.06±0.00^{b}	0.05±0.00^{c}	0.07±0.00^{a}	0.02±0.00^{d}	0.06±0.00^{b}	0.03±0.00^{e}	0.01±0.00^{f}	0.02±0.00^{f}	0.05±0.00^{c}
Ca (mg/Kg)	2.8±0.02^{a}	3.9±0.03^{b}	8.6±0.03^{c}	3.34±0.02^{b}	9.02±0.03^{c}	1.93±0.02^{d}	0.78±0.00^{e}	0.2±0.00^{f}	3.44±0.02^{d}	23.63±0.04^{g}
Si (mg/Kg)	118.38±1.3^{a}	99.06±1.14^{b}	271.34±0.13^{c}	146.62±1.43^{d}	126.85±0.83^{e}	69.1±0.89^{f}	227.97±1.31^{g}	194.71±1.03^{h}	142.98±0.86^{e}	39.5±0.42^{i}
Al (mg/Kg)	97.6±5.9^{a}	70.98±5.89^{b}	-	111.75±5.8^{c}	-	67.71±5.35^{d}	-	-	-	-
Zn (mg/Kg)	0.13±0.002^{a}	0.13±0.00^{a}	0.06±0.00^{b}	0.19±0.00^{c}	0.02±0.00^{d}	0.16±0.00^{e}	0.02±0.00^{d}	0.02±0.00f	0.02±0.00^{d}	0.09±0.00g
Ti (mg/Kg)	12.8±0.03^{a}	7.96±0.02^{b}	0.47±0.00^{c}	13.71±0.03^{d}	1.64±0.00^{e}	9.69±0.02^{f}	3.26±0.01^{g}	1.87±0.00^{e}	1.63±0.00^{h}	2.21±0.00^{e}
K (mg/Kg)	2.18±0.02^{a}	1.96±0.02^{b}	0.83±0.02^{c}	5.22±0.04^{d}	5.98±0.03^{e}	0.8±0.02^{f}	1.16±0.02^{g}	0.3±0.01^{h}	0.66±0.01^{i}	1.92±0.01^{j}
S (mg/Kg)	1.15±0.07^{a}	1.08±0.06^{b}	1.58±0.07^{c}	1.83±0.07^{d}	1.64±0.05^{c}	-	1.08±0.08^{b}	0.78±0.05^{e}	1.96±0.05^{f}	3.64±0.03^{g}
Mn (mg/Kg)	0.6±0.00^{a}	0.72±0.03^{b}	0.06±0.00^{c}	0.27±0.00^{d}	0.15±0.00^{e}	0.85±0.00^{f}	0.02±0.00^{g}	-	0.02±0.00^{h}	0.25±0.00^{i}
Zr (mg/Kg)	0.36±0.00^{a}	0.36±0.00^{a}	-	0.41±0.00^{b}	-	0.32±0.00^{c}	0.25±0.00^{d}	0.15±0.00^{e}	0.09±0.00^{f}	0.04±0.00^{g}
V (mg/Kg)	0.34±0.00^{a}	0.17±0.06^{b}	0.02±0.00^{b}	0.34±0.00^{c}	-	-	-	-	-	0.08±0.00^{e}

Cr (mg/Kg)	0.19 ± 0.00^{a}	-	-	0.12 ± 0.00^{b}	0.03 ± 0.00^{c}	-	0.05 ± 0.00^{d}	-	0.02 ± 0.00^{e}	0.03 ± 0.00^{c}
Sr (mg/Kg)	0.08 ± 0.00^{a}	0.09 ± 0.00^{b}	0.02 ± 0.00^{c}	0.09 ± 0.00^{b}	0.07 ± 0.00^{d}	0.25 ± 0.00^{e}	0.02 ± 0.00^{f}	-	-	0.06 ± 0.00^{g}
Nb (mg/Kg)	0.07 ± 0.00^{a}	0.07 ± 0.00^{a}	-	0.08 ± 0.00^{b}	0.00 ± 0.00^{c}	0.07 ± 0.00^{d}	-	-	-	-

Variation in average concentrations of trace metal elements in fish:

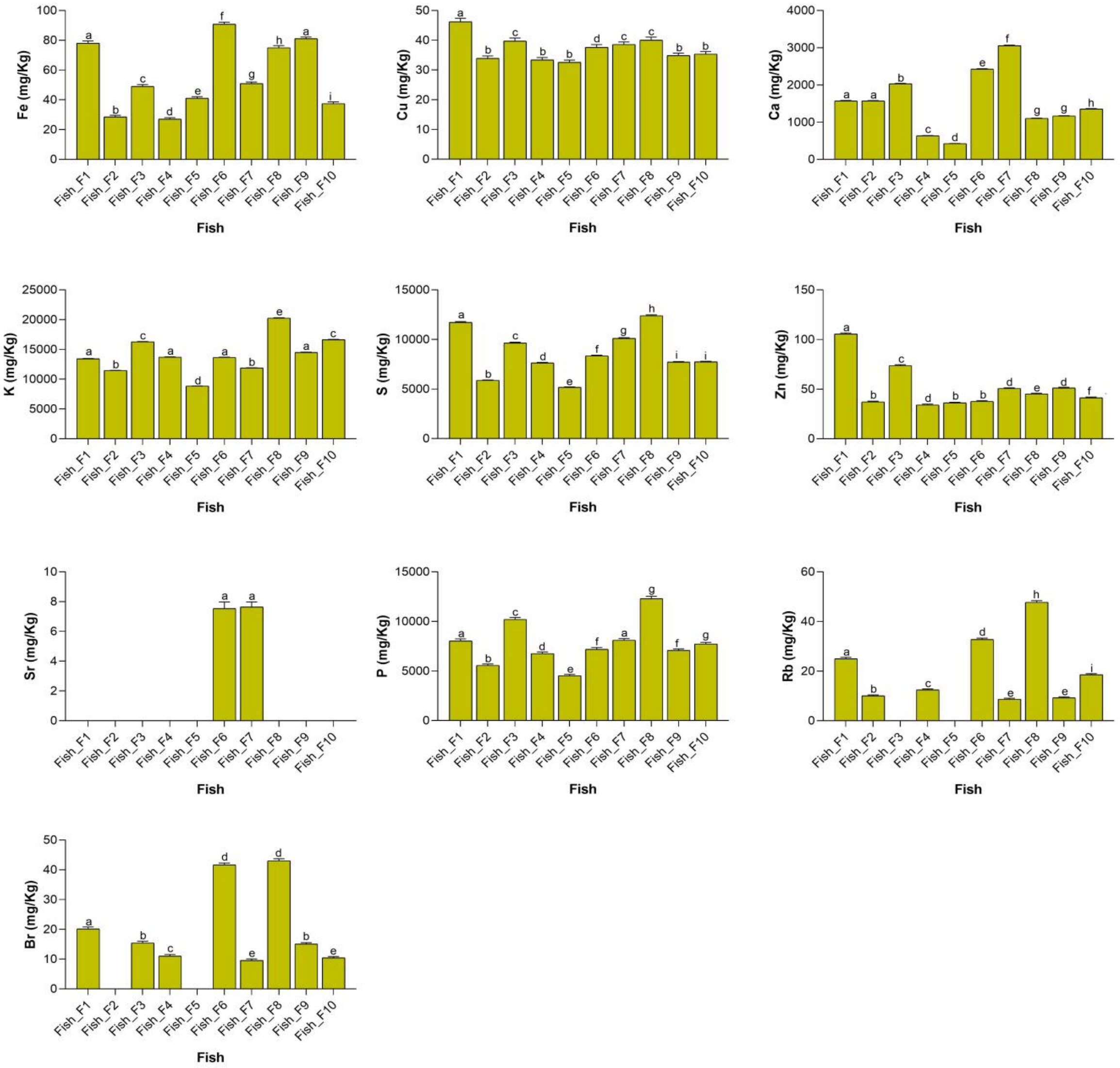


Figure 4 shows the variation of metals in fish meat

Figure 4. Variation of heavy metals according to fish samples

The data collected highlight a high variability in metal concentrations in fish tissues from the various aquaculture farms

(Table 4). Table 4. Concentrations of metals in fish meat at the level of the aquaculture farms studied (mean ± standard deviation)

	Fish									
Metals	**Fish-F1**	**Fish-F2**	**Fish-F3**	**Fish-F4**	**Fish-F5**	**Fish-F6**	**Fish-F7**	**Fish-F8**	**Fish-F9**	**Fish-F10**
Fe (mg/Kg)	78.08 ± 1.51^{a}	28.58 ± 1.06^{b}	49.01 ± 1.29^{c}	27.02 ± 1.01^{d}	41.07 ± 1.01^{e}	90.83 ± 1.36^{f}	50.91 ± 1.10^{g}	74.99 ± 1.42^{h}	81.09 ± 1.15^{a}	37.44 ± 1.13^{i}
Cu (mg/Kg)	46.22±1.13^{a}	33.92±0.82^{b}	39.74±1.01^{c}	33.37±0.82^{b}	32.56±0.79^{b}	37.61±0.94^{d}	30.6±0.83^{c}	40.01±1.05^{c}	34.88±0.8^{b}	35.35±0.84^{b}
Ca (mg/Kg)	1573.87±10.41^{a}	1572.02±8.8^{a}	2032.12±11.44^{b}	635.9±4.31^{c}	425.37±3.28^{d}	2425.59±12.79^{e}	3056.9±13.38^{f}	1103.5±6.11^{g}	1167.61±7.09^{g}	1355.6±7.66^{h}
K (mg/Kg)	13442.52±52.93^{a}	11458.59±40.68^{b}	16282.95±54.64^{c}	13707.46±44.74^{a}	8834.7±35.13^{d}	13663.31±48.66^{a}	11887.82±40.29^{b}	20255.35±63.51^{e}	14504.76±44.48^{a}	16645.12±48.8^{c}4
S (mg/Kg)	11718.21±88.8^{a}	5865.57±50.42^{b}	9639.26±74.71^{c}	7634.11±58.82^{d}	5170.94±46.62^{e}	8346.15±67.08f	10108.89±68.13^{g}	12393.15±88.04^{h}	7712.53±57.01 ^{i}	7735.9±58.82 ^{i}
Zn (mg/Kg)	105.48±1.09 ^{a}	37.14±0.71 ^{b}	73.60±0.93 ^{c}	34.17±0.7 ^{d}	36.12±0.67 ^{b}	37.59±0.85 ^{b}	50.66±0.73 ^{d}	45.1±0.9 ^{e}	51.17±0.7 ^{d}	41.25±0.73 ^{f}
P (mg/Kg)	8030.67±213.13^{a}	5566.14±149.32^{b}	10198.58±204.41 ^{c}	6764.31±155.75^{d}	4527.62±139.54 ^{e}	7187.64±182.74^{f}	8103.07±159.85^{a}	12303.87±223.74 ^{g}	7084.23±150.85^{f}	7735.15±160.4^{G}
Rb (mg/Kg)	25±0.6 ^{a}	10.04±0.39 ^{b}	-	12.45±0.4 ^{c}	-	32.76±0.51 ^{d}	8.69±0.38 ^{e}	47.78±0.6^{h}	9.28±0.37^{e}	18.53±0.41^{i}
Br (mg/Kg)	20.15±0.68^{a}	-	15.41±0.6^{b}	11.07±0.47^{c}	-	41.67±0.6^{e}	9.58±0.46^{d}	43.01±0.68^{b}	15.09±0.46^{e}	10.41±0.48^{e}

There is a significant variation in metal concentrations in fish between different farms (Table 4). Iron levels (Fe) are higher F6, F8 and F9, while the lowest values are recorded at F4 and F5. Copper (Cu) retains a certain homogeneity, displaying maximum levels at F1 and minimum levels at F7. Calcium (Ca), potassium (K) and phosphorus (P) show notable variations, with particularly high rates in F6 to F8 farms, while F5 exploitation is distinguished by low levels for most elements. Sulfur (S) reaches its peaks at F1 and F8, while zinc (Zn) reaches its peak at F1. Rubidium (Rb) and bromine (Br) have an irregular distribution depending on locations, with peaks observed at F8.

Assessment of the bioaccumulation factor:-

Figure 5 represents the bioaccumulation factors (BAF) of metals contained in fish meat in relation to the environment (water). Iron was found on almost all farms (except farms 2, 5 and 10), with BAFs ranging from 0.698 to 3.58. For copper (Cu) the values are rather uniform between the farms, located between 0.966 and 1.474. Only farm F3 showed a high concentration of calcium (Ca =5.71).

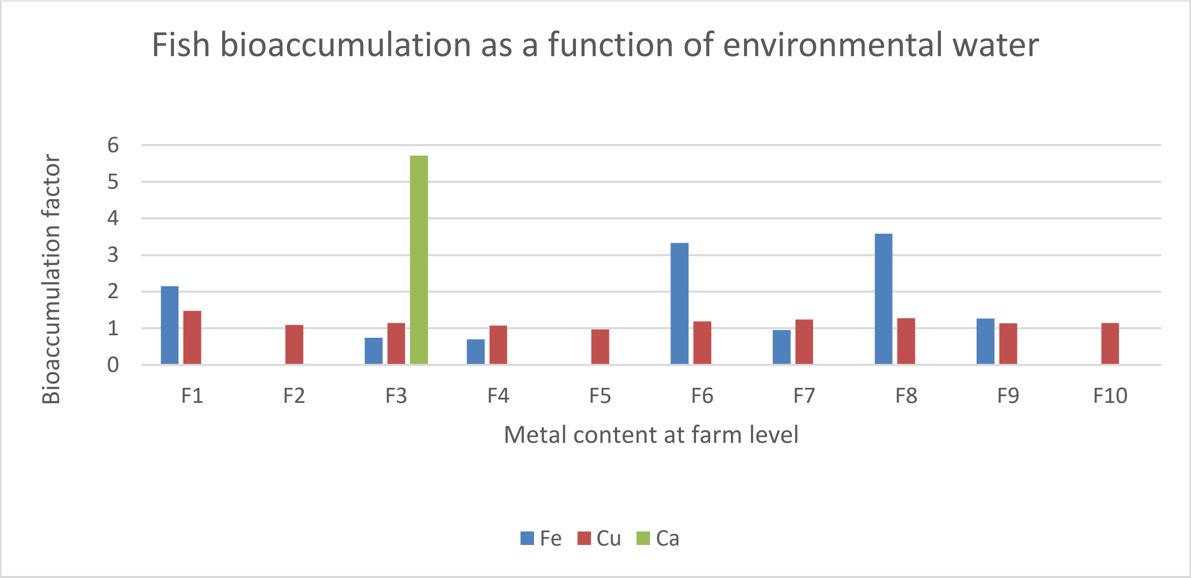


Figure 5. Bioaccumulation factor (BAF) of fish studied in relation to water

The bioaccumulation factor (BAF) in relation to sediment (Figure 6) differs from one farm to another. For iron, copper, calcium, zinc, phosphorus, bromine and strontium, BAF values remain fairly constant in all farms. With regard to potassium, it has high concentrations ranging from 1,478 to 68,001 and Suffers with a peak of 10.137 noted on farm 1.

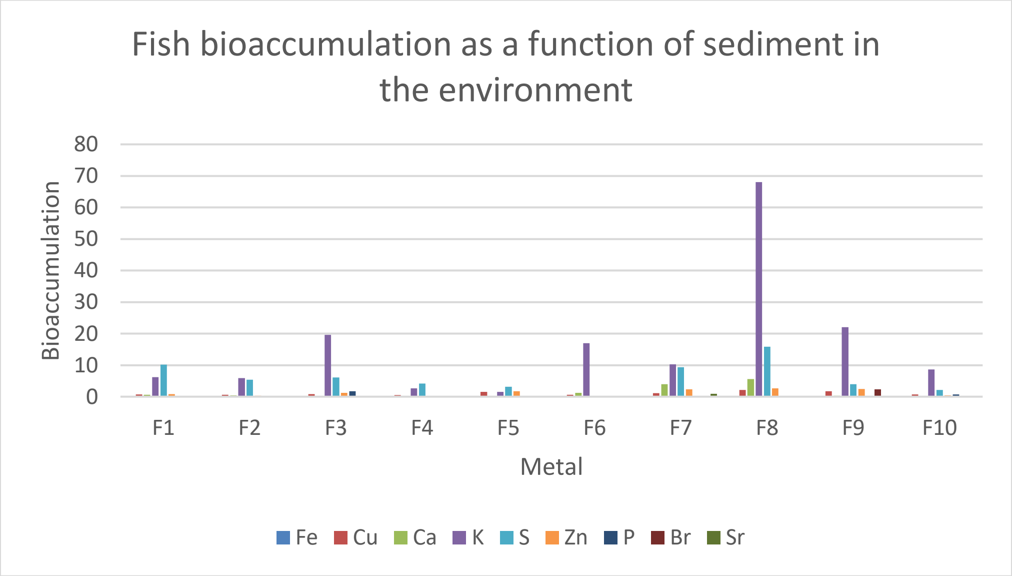


Figure 6. Bioaccumulation factor (BAF) of the fish studied in relation to the Sediment

Discussion:-

Variation in average TME contents in water:

The results obtained highlight a heterogeneity of the levels of contamination across the sites. The data collected show a high presence of iron and copper in the waters of the farms analyzed. The iron concentration, which fluctuates between 20.94 and 65.94 mg/L, far exceeds the indicative threshold of 0.3 mg/L established by the WHO for drinking water (WHO, 2017). High iron contents can result from the natural dissolution of iron-rich soils, but also from human-made emissions, such as the use of fertilizers and mining operations (Han & Gu, 2023; Lakra et al., 2019). Biologically speaking, a high concentration of iron in water can cause accumulations on the gills, thus reducing gas exchange and leading to oxidative stress in fish (Boyd, 2015). With regard to copper, the levels recorded (30.83-34.72 mg/L) also exceed the limit of 2 mg/L established by the WHO (WHO, 2017). This apparent uniformity between farms indicates a source of potentially diffuse contamination, which could be associated with the use of pesticides, agricultural discharges or the deterioration of metal equipment used in aquaculture systems (Soleimani et al., 2023; Mishra et al., 2008). Copper, at high concentration le vels, can harm aquatic beings by causing cellular damage and affecting the growth and sustainability of fish (Heath, 1995; Türkmen et al., 2021). The co-occurrence of high Fe and Cu concentrations indicates potential health risks, both for drinking water and for aquaculture. Indeed, these metals have the ability to accumulate in aquatic tissues, which can create risks to public health if contaminated fish are regularly consumed (Lebepe et al., 2020; Han & Gu, 2023).Copper concentrations measured in fish flesh, ranging from 20 to 50 mg/kg dry matter, correspond to approximately 5 to 12.5 mg/kg on a fresh basis. These levels are around or slightly above the threshold of 10 mg/kg fresh weight recommended by FAO/WHO (1989) for edible tissues. Although copper is an essential trace element involved in many physiological processes, its excessive accumulation in fish flesh may pose a potential risk to human health, particularly in cases of frequent consumption. Thus, the observed levels suggest a limited toxicological risk, but one that merits increased monitoring for samples with the highest concentrations, in accordance with food safety recommendations (FAO/WHO, 2003).

Variation in average TME contents in sediment:-

The results of this study revealed significantly higher concentrations of TMEs in sediments than in water and fish flesh. This result is in agreement with the work of Sagna and Diouf (2021) which demonstrates that sediments act as a carbon sink and a major reservoir for heavy metals in aquatic ecosystems. TMEs, once introduced into the environment, bind to suspended particles and accumulate at the bottom of the ponds. Analysis of variance (ANOVA) confirmed that iron (Fe) and zinc (Zn) concentrations in sediments differ significantly between farms ($p<0.05$), suggesting variable sources of contamination, potentially related to livestock inputs (feed) or the geochemical characteristics of local soils (Sall and Badiane, 2019). In aquatic ecosystems, most of the heavy metals that are drained there are deposited on soft bottoms, particularly sediments (Keumeanet al., 2013; Ekengeleet al., 2014). According to Dimon et al. (2014) andKamilouet al. (2014), sediments constitute a reservoir where metals accumulate. They form the most important environmental matrix which, through the phenomenon of release, constitutes an endogenous source of pollution of water and aquatic species. The levels of heavy metals present in the sediments are lower than those reported by Choutiet al.(2010), where the chromium level was 97.60 mg/kg. However, for farms F1 and F4, the concentrations were higher and were 186.43 mg/kg and 125.68 mg/kg, respectively. In addition, Kaki et al. (2011) who carried out this study in Benin and Togoreported higher copper levels than those observed in this research, with a concentration of 228.74 mg/kg for copper.

The discrepancy with the results of this study could be explained by the fact that the sediments are not identical and the collection areas differ. The nature of the sediments also plays a role in their capacity to retain metals (Soro et al., 2009). The high iron concentrations detected at some locations (F1 and F6) could be associated with the geological characteristics of the soils and human contributions, including waste from agriculture and households. Indeed, numerous researches have demonstrated that sediments represent an important source of metals, which simultaneously reflects natural and human-related contributions (Zhou et al., 2008; Singh et al., 2017). It is likely that the high Si concentration, particularly at F3 and F7, is due to the preponderance of silicate minerals in the sediments of the region. These findings confirm the work of Ajeagahet al. (2017) in Cameroon, who reported a predominance of silicon and aluminum in the sediments of aquaculture regions.

Regarding Zn and Mn, the detected levels remain below toxicity levels, however their presence, even at low concentrations, requires special vigilance because these metals have the capacity to accumulate in marine organisms and can represent a danger for the food chain (Ali et al., 2019). It is likely that the marked variations in metals (e.g., Ca at F10 or Mn at F6) reflect human contributions that vary according to location (agriculture, fish feed, livestock waste), as Oumarou et al. (2021) demonstrated in aquaculture systems in Cameroon. We identified the presence of titanium (Ti) in farm sediments. Unlike potentially toxic metals such as lead, zinc, or copper, titanium is not perceived as a problematic element for sediment quality. International sediment quality standards, such as the Canadian Sediment Quality Guidelines (CCME, 2001) and the Australian and New Zealand Sediment Quality Guidelines (ANZECC/ARMCANZ, 2000), do not set limits for Ti. This is due to its low solubility and reduced bioavailability in aquatic environments.

Variation in average TME contents in fish:-

The presence of heavy metals in fish products represents a real danger to consumer health (Youssaoet al 2011; Aina et al., 2012, Kamilouet al., 2014; Bastami et al., 2012). The variations observed in the metal levels of fish reflect the combined impact of water quality, soil type and aquaculture farming methods specific to each farm. Numerous studies have shown that the mineral composition of fish is closely linked to the physicochemical properties of their environment and the feed used (Tóth et al., 2021). It is possible that the high iron concentrations detected in some farms (F6, F8, F9) are due to contributions from iron-rich soils or human-induced emissions. This would confirm the findings of Pizarro et al. (2019), who demonstrated that iron is among the most bioaccumulated metals in terrestrial aquaculture.

Thus, the fluctuation of zinc and copper, two vital trace elements, may reflect both dietary supplementation and water pollution caused by nearby agricultural activities (Ahmed et al., 2019; Abdel-Khalek et al., 2016). Farms F6, F7, and F8 are characterized by high levels of calcium, potassium, and phosphorus, which are crucial for bone development and metabolism in fish. This supports research by Lall & Kaushik (2021), who demonstrated that these factors are directly affected by nutritional quality, particularly through the use of mineral-enriched meals. Regarding sulfur, its high concentration in some farms could be related to the presence of sulfur amino acids (methionine, cysteine) in aquaculture feeds, as reported by Gatlin et al. (2007). Finally, the variable detection of rubidium and bromine is likely a reflection of contributions associated with local geochemistry or borehole water conditions, a phenomenon already mentioned in aquaculture systems exploiting mineral-rich groundwater (Khan et al., 2022).

Bioaccumulation Factor:-

For Pb, the analytical LQ on a fresh weight basis (0.125 mg/kg) is well below the EU regulatory limit (0.30 mg/kg). The absence of detectable Pb therefore indicates that concentrations in the sampled fish are below the regulatory threshold, allowing us to reasonably exclude a risk of exceeding the standard at the time of sampling. For Cd, the analytical LQ (0.125 mg/kg w.w.) is slightly higher than the EU regulatory limit (0.05 mg/kg w.w.). As a result, non-detects cannot be interpreted as compliance, nor as exceedance. The risk of exceeding the regulatory limit cannot be formally excluded, and only more sensitive methods would allow a definitive conclusion. For Hg, the LQ of 1.25 mg/kg w.w. is more than twice the EU limit of 0.50 mg/kg w.w. for non-predatory fish. The analytical method is therefore not sensitive enough to determine compliance, and the absence of detection provides no information on the actual risk. Additional analyses using a more sensitive method would be required for regulatory assessment. This study highlights the importance of explicitly linking analytical detection limits to regulatory thresholds.

For elements where LQ values are lower than the legal limit, non-detects can reasonably be interpreted as compliance. Conversely, for elements such as Cd and Hg, where LQ values are at or above the regulatory thresholds, the absence of detection does not imply the absence of risk. Methodological sensitivity must therefore be clearly accounted for in risk assessment. The data show marked variability in the bioaccumulation factor (BAF) among metals and locations. Iron shows remarkably high levels at F6 and F8, indicating that its accumulation depends on local sediment conditions, modulated by pH, dissolved oxygen, and speciation (Alquezar et al., 2006). These differences could be explained by the tendency for moderate accumulation in fish, unlike filter-feeding organisms (Ramelowet al., 1989).

In contrast, copper exhibits fairly constant BAFs (1.0-1.3), highlighting its status as a crucial trace element and the homeostatic regulation that controls fluctuations despite environmental changes (DeForestet al., 2007; Wang & Rainbow, 2008; Rainbow, 2002). Calcium is an exception, displaying significant bioaccumulation at F4, probably associated with water hardness, high carbonate content, and the physiological requirements of fish for bone mineralization and ionic control (Flik et al., 1995; Skeaffet al., 1995). Overall, these results demonstrate that bioaccumulation is influenced by both the chemical characteristics of the elements and their biological role. Essential metals (Cu, Ca, K) are tightly regulated or functionally accumulated, while others, such as iron, are more influenced by environmental conditions (Ramelowet al., 1989). The observation of spatial variability, particularly for iron, demonstrates that risk assessment in aquaculture should take into account local sediment and water specificities, rather than relying solely on global concentrations (Linnik & Zubenko, 2000). Finally, some components are actively biologically accumulated according to physiological needs, while others are absorbed more passively depending on their presence in the environment (Rainbow, 2002).

Conclusion:-

This study highlights the importance of careful monitoring of trace metal elements (TMEs) in aquaculture systems to maintain food safety and ensure environmental sustainability. A comparative analysis conducted on ten agro-fish farms revealed heterogeneous variability in contamination levels across locations. Concentrations of iron and copper, well above WHO standards in farm waters, reflect both natural and anthropogenic pollution. Sediments were found to be significant stores of metals, playing a crucial role in pollution dynamics and representing a possible source of release into the water column and aquatic beings. Analysis of fish shows a high concentration of various metals (Fe, Cu, Ca, K, P, S), attesting to their direct exposure to environmental conditions and the quality of ingested food. Bioaccumulation factors showed significant variation depending on location and element, with notable accumulation of iron and calcium, reflecting a particular susceptibility at certain farms. From a public health perspective, although metals such as iron and zinc are essential for fish metabolism, excessively high concentrations could create a risk of nutritional imbalance that must be monitored. These results emphasize the importance of establishing periodic monitoring and follow-up in aquaculture farms. It is also advisable to conduct long-term research to measure the lasting effect of these pollutions on fish health, and consequently, on consumer health.

Acknowledgments:-

We would like to express our deep gratitude to the Inter-African Training, Research and Innovation Support Project (AFRIDI) for funding this work, which is a first in Cameroon. We would also like to thank the representatives of the Ministry of Livestock, Fisheries and Animal Industries (MINEPIA) who facilitated our task. We express our sincere thanks to the fish farmers for their warm welcome and for allowing us access to their aquaculture facilities. We also thank Dr DJOPNANG DJIMBIE Justin of the Laboratory for the Analysis of Radiological Contaminants and Heavy Metals in Fish Products for the chemicals analyses.

References:-

1. Abdel-Khalek, A. A., Elhaddad, E., Mamdouh, S., & Marie, M. A. (2016). Assessment of metal pollution around sabal drainage in River Nile and its impacts on bioaccumulation level in Oreochromis niloticus fish. Egyptian Journal of Aquatic Research, 42(4), 413–422.DOI : 10.4194/1303-2712-v16_2_02
2. Adegbola, I. P., Aborisade, B. A. & Adetutu, A. (2021). Health risk assessment and heavy metal accumulation in fish species (Clarias gariepinus and Sarotherodonmelanotheron) from industrially polluted Ogun and Eleyele Rivers, Nige ria. Toxicology Reports 81445–1460. https:// doi. org/ 10. 1016/j. toxrep. 2021. 07. 007
3. Ahmed, M. K., Baki, M. A., Islam, M. S., Kundu, G. K., Habibullah-Al-Mamun, M., & Sarkar, S. K. (2019). Human health risks from heavy metals in fish of Buriganga river, Bangladesh. Environmental Toxicology and Pharmacology, 72, 103265. DOI: 10.1186/s40064-016-3357-0
4. Aina, M. P., Degila, H., Chikou, A., Adjahatode, F. & Matejka, G. (2012). Risk of intoxication by heavy metals (Pb, Cd, Cu, Hg) connected to consumption of some halieutic species in Lake Nokoué: case of the Penaeus shrimps and the Sarotherodonmelanotheron. British Journal of Science, 5(1), 104-118.
5. Ajeagah, G. A., Tchakounté, J., Njiné, T., & Foto, S. M. (2017). Heavy metals contamination in sediments and aquatic organisms in Cameroon inland waters. International Journal of Biological and Chemical Sciences, 11(2), 832–846.
6. Ali, H., Khan, E., & Ilahi, I. (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. Journal of Chemistry, 2019, 6730305. https://doi.org/10.1155/2019/6730305
7. Alloway, B. J. (2013). Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability (3rd ed.). Springer.
8. Alquezar, R., Markich, S. J., & Booth, D. J. (2006). Effects of metals on condition and reproductive output of the smooth toadfish in Sydney estuary, southeastern Australia. Environmental Pollution, 142(1), 116–122. https://doi.org/10.1016/j.envpol.2005.09.009
9. ANZECC & ARMCANZ. (2000). Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1 : The Guidelines. Canberra : ANZECC/ARMCANZ.
10. AOAC International. (2005). Official methods of analysis of AOAC International (18th ed.). Method 983.18, Fish and other marine products. AOAC International, Gaithersburg, MD, USA.

11. Arnot, J. A., &Gobas, F. A. (2006). A review of bioconcentration factor (BCF) and bioaccumulation factor (BAF) assessments for organic chemicals in aquatic organisms. Environmental Reviews, 14(4), 257–297.https:// doi. org/ 10. 1139/ a06- 005
12. Bastami, A. A., Khoei, J. K. &Esmailian, M. (2012). Bioaccumulation of heavy metals in sediments and crab, Portunus pelagicus from Persian Gulf, Iran. Middle-East Journal of Scientific Research, 12(6), 886-892. DOI: 10.5829/idosi.mejsr.2012.12.6.661
13. Boyd, C. E. (2015). Water Quality: An Introduction. Springer, Cham.
14. Bury, N. R., Grosell, M., Wood, C. M., Hogstrand, C., & Wilson, R. W. (2001). Effects of iron and aluminum exposure on the physiology of fish. Journal of Experimental Biology, 204(1), 104–115. https://doi.org/10.1242/jeb.204.1.104
15. Bury, N. R., Walker, P. A., & Glover, C. N. (2003). Nutritive metal uptake in teleost fish. Journal of Experimental Biology, 206(1), 11–23. https://doi.org/10.1242/jeb.00068
16. CCME (Canadian Council of Ministers of the Environment). (2001). Canadian Sediment Quality Guidelines for the Protection of Aquatic Life. Ottawa: CCME.
17. Chouti, W., Mama, D., Changotade, O., Alapini, F. &Boukari, M. (2010). Study of trace metal elements contained in the sediments of the Porto-Novo lagoon (South Benin). Journal of Applied Biosciences, 34, 2186-2197.
18. DeForest, D.K., Brix, K.V., & Adams, W.J. (2007). Assessing metal bioaccumulation in aquatic environments: The inverse relationship between bioaccumulation factors, trophic transfer factors and exposure concentration. Aquatic Toxicology, 84, 236–246. https://doi.org/10.1016/j.aquatox.2007.02.022
19. Dimon, F., Dovonon, F., Adjahossou, N., Chouti, W., Mama, D., Alassane, A. & Boukari, M. (2014). Physicochemical characterization of Lake Ahémé (southern Benin) and highlighting sediment pollution by lead, zinc and arsenic. Journal of the West African Chemical Society, 37, 36-42. DOI: 10.17265/2159-5828/2019.04.002
20. Ekengele, NL, Oumar, B. & Balla, OAD (2014). Assessment of the level of heavy metal pollution in Lakes Bini and Dang, Adamawa region, Cameroon. Africa Science, 10(2), 184-198.
21. FAO (2022). The State of World Fisheries and Aquaculture 2022. Rome: Food and Agriculture Organization of the United Nations.
22. FAO. (2022a). The State of Food and Agriculture 2022. Leveraging automation in agriculture for transforming agrifood systems. Rome, FAO. https://doi.org/10.4060/cb9479fr
23. FAO. (2022b). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461fr
24. FAO. 2020. The State of Food and Agriculture 2020. Meeting the Water Challenge in Agriculture. Rome.
25. FAO/WHO. (1989). Evaluation of certain food additives and contaminants: Copper, lead, cadmium and mercury. WHO Technical Report Series 776.
26. FAO/WHO. (2003). Joint Expert Committee on Food Additives (JECFA):Summary and conclusions.
27. FAOSTAT (2019) – Statistiquesagricolesmondiales
28. Flik, G., &Verbost, P. M. (1995). Calcium transport in fish gills and intestine. Journal of Experimental Biology, 198(1), 273–281.
29. Gatlin, D. M., Barrows, F. T., Brown, P., Dabrowski, K., Gaylord, T. G., Hardy, R. W., Herman, E., Hu, G., Krogdahl, Å., Nelson, R., Overturf, K., Rust, M., Sealey, W., Skonberg, D., Souza, E. J., Stone, D., Wilson, R., & Wurtele, E. (2007). Expanding the utilization of sustainable plant products in aquafeeds: A review. Aquaculture Research, 38(6), 551-579. https://doi.org/10.1111/j.1365-2109.2007.01704.x
30. Gnandi, K., Tomety-Mensah, F., Ameyapoh, Y. &Edorh, P. (2007). Distribution, bioavailability and bioaccumulation of heavy metals in the Lomé lagoon system. Journal of Scientific Research of the University of Lomé, Series A, 9(1), 67-81.
31. Han, Y., & Gu, X. (2023). Enrichment, contamination, ecological and health risks of toxic metals in agricultural soils of an industrial city, northwestern China. Journal of Trace Elements and Minerals, 3, 100043. https://doi. org/ 10. 1016/j. jtemin. 2022. 100043
32. Hans Henrik Huss (1995). Quality and quality changes in fresh fish. FAO Fisheries Technical Paper No 348. Rome, FAO. Disponible enligne : https://www.fao.org/3/v7180e/v7180e00.htm
33. Heath, AG (1995) Water Pollution and Fish Physiology. 2nd Edition, Lewis Publisher. New York and London, 359
34. Kaki, C., Guedenon, P., Kelome, N., Edorh, PA &Adechina, R. (2011). Evaluation of heavy metals pollution of Nokoué Lake. African Journal of Environmental Science and Technology, 5(3), 255-261.

35. Kamilou, OS, Hodabalo, DS, Kissao, G., Komlan, MA & Esso, JB (2014). Assessment and health risks of heavy metal bioaccumulation in fish species in the Togolese lagoon system. VertigO - the electronic journal in environmental sciences, 14(2), 1-18.
36. Kenfack Atangana, JA, Ducarme, C., Micha, J.-C. (2019). Fish farming in Cameroon: assessment and perspectives. Int. J. Biol. Chem. Sci. 13, 1140. https://doi.org/10.4314/ijbcs.v13i2.44
37. Keumean, KN, Bamba, SB, Soro, G., Soro, N., Metongo, BS &Biemi, J. (2013). Heavy metal concentration in sediments of the Comoé River estuary in Grand-Bassam (South-Eastern Côte d'Ivoire). Journal of Applied Biosciences, 61, 4530-4539.
38. Khan, M. N., Rehman, A., Rehman, K., et al. (2022). Groundwater geochemistry and associated health risk assessment in semi-arid regions. Environmental Science and Pollution Research, 29, 4753–4769.
39. Lakra, K. C., Lal, B., & Banerjee, T. K. (2019). Coal mine effluent-led bioaccumulation of heavy metals and histo pathological changes in some tissues of the catfish Clarias batrachus. Environmental Monitoring and Assessment, 191(3), 136. https:// doi. org/ 10. 1007/ s10661- 019- 7229-2
40. Lall, S. P., & Kaushik, S. J. (2021). Nutrition and metabolism of minerals in fish. Animals, 11(10), 2711.
41. Lebepe, J., Oberholster, P. J., Ncube, I., Smit, W., & Luus Powell, W. J. (2020). Metal levels in two fish species from a waterbody impacted by metallurgic industries and acid mine drainage from coal mining in South Africa. Journal of Environmental Science and Health, Part A, 55(4), 421 432. https:// doi. org/ 10. 1080/ 10934 529. 2019. 17046 04
42. Linnik, P. M., & Zubenko, I. B. (2000). Role of bottom sediments in the secondary pollution of aquatic environments by heavy-metal compounds. Lakes & Reservoirs: Research and Management, 5(1), 11–21. https://doi.org/10.1046/j.1440-1770.2000.00094.x
43. Ministère de l'Agriculture et du Développement Rural (MINADER). (2023). AGRISTAT — Statistical yearbook / Agricultural statistics (édition 2023). PDF. Minader (document officielfournissant les statistiques de production agricole par région et par culture au Cameroun).
44. Mishra, V. K., Upadhyaya, A. R., Pandey, S. K., & Tripathi, B. D. (2008). Heavy metal pollution induced due to coal mining effluent on surrounding aquatic ecosystem and its management through naturally occurring aquatic macro phytes. Bioresource Technology, 99(5), 930–936. https:// doi. org/ 10. 1016/j. biortech. 2007. 03. 010
45. Obodai, E. A., Boamponsem, L. K., Adokoh, C. K., Essumang, D. K., Villawoe, B. O., Aheto, D. W. & Debrah, J. S. (2011). Concentrations of heavy metals in two Ghanaian lagoons. Archives of Applied Science Research, 3(3), 177-187.
46. Onyena, A. P. and Udensi, J. (2019) Evaluation of Heavy Metals Concentrations in Oreochromis niloticus and Clarias gariepinus from River and Aquaculture Systems within Owerri Metropolis, Imo State Nigeria. Journal of food science and engineering 9(4):131-138.
47. Oumarou, B., Ngassoum, M. B., & Foto, S. M. (2021). Assessment of heavy metals in aquaculture systems and implications for food safety in Cameroon. Environmental Monitoring and Assessment, 193, 134.
48. Pizarro, J., Vergara, P. M., & Ahumada, R. (2019). Bioaccumulation of trace metals in fish from aquaculture in Southern Chile. Environmental Monitoring and Assessment, 191, 94.
49. Pouokam, G.B., Foudjo, B.U.S., Samuel, C., Yamgai, P.F., Silapeux, A.K., Sando, J.T., Atonde, G.F., Frazzoli, C. (2017). Contaminants in Foods of Animal Origin in Cameroon: A One Health Vision for Risk Management "from Farm to Fork." Front. Public Health 5, 197. https://doi.org/10.3389/fpubh.2017.00197
50. Rainbow, P. S. (2002). Trace metal concentrations in aquatic invertebrates: why and so what? Environmental Pollution, 120(3), 497–507. https://doi.org/10.1016/S0269-7491(02)00238-5
51. Ramelow, G. J., Beck, J. N., Young, J. C., Callahan, J. D., & Marajh-Whittemore, P. B. (1989). Variations of heavy metals and arsenic in fish and other organisms from the Calcasieu River and Lake, Louisiana. Archives of Environmental Contamination and Toxicology, 18(6), 804–818. https://doi.org/10.1007/BF01055016
52. Sagna, J. & Diouf, M. (2021). The role of sediments in the cycling of nutrients and pollutants in aquaculture. African Journal of Marine Sciences, 18(2), 120-135.
53. Sall, F. & Badiane, B. (2019). Impact of agricultural practices on water quality in aquaculture ponds in Senegal. African Journal of Agricultural Research, 14(7), 38-49.
54. Singh, K.P., Mohan, D., Singh, V.K., & Malik, A. (2017). Studies on distribution and fractionation of heavy metals in Gomti river sediments a tributary of the Ganges, India. Journal of Hydrology, 312(1-4), 14–27.
55. Şirin, M., Bayrak, E. Y., &Baltaş, H. (2024). Human health risk assessment of heavy metals accumulation in different genders and tissues of whiting fish (Merlangius merlangus euxinus Nordmann, 1840) from Rize, Turkey. Journal of Food Composition and Analysis, 127, 105971. https:// doi. org/ 10. 1016/j. jfca. 2024. 105971

56. Skeaff, C. M., Glover, C. N., & Wood, C. M. (1995). The regulation of calcium uptake in freshwater fish. Canadian Journal of Zoology, 73(12), 2410–2419. https://doi.org/10.1139/z95-284
57. Soleimani, H., Mansouri, B., Kiani, A., Omer, A. K., Tazik, M., Ebrahimzadeh, G., & Sharafi, K. (2023). Ecological risk assessment and heavy metals accumulation in agriculture soils irrigated with treated wastewater effluent, river water, and well water combined with chemical fertilizers. Heliyon, 9(3), e14580. https:// doi. org/ 10. 1016/j. heliy on. 2023. e14580
58. Soro, G., Metongo, BS, Soro, N., Ahoussi, EK, Kouame, FK, Zade, SGP & Soro, T. (2009). Heavy metals (Cu, Cr, Mn and Zn) in surface sediments of a tropical African lagoon: case of the Ebrié lagoon (Ivory Coast). International Journal of Biological and Chemical Sciences, 3(6), 1408-1427.
59. Temegne Nono, C., Momo, NJ (2019). Review on Aquaculture Research in Cameroon: Fish Farming. Int. J. Oceanogr. Aquac. 3. https://doi.org/10.23880/ijoac-16000170
60. Tóth, G., Hermann, T., Da Silva, MR, &Montanarella, L. (2021). Heavy metals in fish and food safety in aquaculture. Science of the Total Environment, 787, 147613.
61. Troell, M., Naylor, R. L., Metian, M., Beveridge, M., Tyedmers, P. H., Folke, C., Arrow, K. J., Barrett, S., Crépin, A. S., Ehrlich, P. R., Gren, A., Kautsky, N., Levin, S. A., Nyborg, K., Österblom, H., Polasky, S., Scheffer, M., Walker, B. H., Xepapadeas, T., & de Zeeuw, A. (2014). Does aquaculture add resilience to the global food system? Proceedings of the National Academy of Sciences of the United States of America, 111(37), 13257–13263. https://doi.org/10.1073/pnas.1404067111
62. Türkmen AC, Januschowski T, Wang Y, Cemgil AT (2021) Forecasting intermittent and sparse time series: A unified probabilistic framework via deep renewal processes. PLoS ONE, 16(11): e0259764. doi:10.1371/journal.pone.0259764.
63. Wang, W. X., & Rainbow, P. S. (2008). Comparative approaches to understand metal bioaccumulation in aquatic animals. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 148(4), 315–323. https://doi.org/10.1016/j.cbpc.2008.04.003
64. WHO (World Health Organization) (2017). Guidelines for Drinking-water Quality (4th ed., incorporating the first addendum). Geneva : WHO Press.
65. Yao, K. M., Soro, M. B., Trokourey, A. &Bokra, Y. (2009). Assessment of sediments contamination by heavy metals in a tropical lagoon urban area (Ebrié Lagoon, Côte d'Ivoire). European Journal of Scientific Research, 34(2), 280-289.
66. Youssao, A., Soclo, H.H., Bonou, C., Vianou, K., Gbaguidi, M. &Dovonon, L. (2011). Evaluation of contamination of ichthyic fauna in the Nokoué–Cotonou lagoon complex by lead: cases of Sarotherondonmelanotheron, Tilapia guineensis, and Hemichromis fasciatus (Benin). International Journal of Biological and Chemical Sciences, 5(2), 595-602
67. Zhou, J., Deng, C., Cang, L., Alshawabkeh, A. N., & Zhou, D. (2008). Partitioning and fractionation of heavy metals in contaminated sediments: a review. Pedosphere, 18(4), 439–455.