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Trace Metals Accumulation in *Oreochromis niloticus* Inhabiting Chari River along the Banda Township in Chad

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study was undertaken to evaluate the trace metals in the fish *Oreochromis niloticus* inhabiting water of the Chari river, along the Banda township in the middle-Chari Province (Chad). Fishes were sampled at three sites along the river. Trace metals in fish meat were assessed through atomic absorption spectrophotometry. Results indicated that fish meat contents in Pb, Cd, Fe, Cr, Cu and Zn were ranged respectively from 0.482, 0.144, 0.632, 1.110, 1.479 and 4.465 mg/Kg in the dry season, compared to 0.545, 0.179, 0.624, 0.946, 2.917 and 1.813 mg/Kg in the wet season. The bioconcentration factor (BCF) of Pb, Cd, Cr, Cu and Zn was higher than 1, indicating that these heavy metals were indeed accumulated in *Oreochromis niloticus*. Copper was the most accumulated metal in fish meat during both campaigns. The source of accumulation of these trace metals in fishes was undoubtly from water, and was thought to originate either from the abusive utilization of phytosanitary inputs in agriculture or from nearby wastewater's factories thrown into the Chari river. It is suggested appropriate controlled measures to be taken to decrease the trace metals pollution of the Chari river, and thereof that of the inhabiting fishes.

Keywords: Pollution; trace metals; Oreochromis niloticus; Chari river; Chad.

1. INTRODUCTION

The contamination of water by heavy metals continue to become a serious concern, not only because it limits the water utilization for domestic usages, but also due to damages it inflicts to aquatic organisms [1]. In Chad, surface water resources are essentially constituted of rivers that originated from neighboring countries. Water plays a fundamental role in agriculture, industries, energy production, or several domestic usages [2]. Chad is known as one of the several worldwide countries where rivers, very rich in fishes are not only subjected to effects of climate changes, but also serve as industrial waste deposits [3]. Recent researches carried out on water quality of the Chari and Logone rivers have shown their profound modifications attributed to repeated industrial activities [4,5]. The Chari river receives urban and industrial wastewater from the boaders with the Central Africa republic to Lake Chad [3]. The main micro-pollutants present in water and involved in chemical pollution phenomenon are heavy metals such as Plomb, Cadmium, Manganese, Zinc, Copper, Chrome and Nickel [6]. In recent years, the consumption of halieutic resources, especially fishes, is at the front line, as far as benefic elements provided to human health, such as essential fatty acids, proteins, vitamins A, D and E, as well as mineral elements are concerned [7]. However, fishes are also exposed to toxic contaminants, namely Trace Metals, particularly Cd and Pb among others, which are accumulated in their different tissues and could be transferred within the food web up to human [8]. Opposed to numerous organic pollutants, heavy metals are not eliminated through biological routes, and this favor their cumulative effects within diverse ecosystem components like water, sediments, fauna and flora [9]. The problematic of trace metals contaminants transfer in the environment towards the food web is risky, and is subjected to several researches worldwide [10]. Considering the exposition of the population to pollution and its derived-health risks, it is a pre-requisite to evaluate the pollution in trace elements of water from the Chari river, and its impact on inhabiting fishes (*Oreochromis niloticus*), the most consumed species in the Middle-Chari province in the south of Chad. *Oreochromis niloticus* was chosen based on the facilities it has to colonize very polluted environments, its easy and daily capture by fishermen, and its consideration as specific nutrient for the population of the study zone. In the present study, the accumulation of trace metals by *Oreochromis niloticus* from Chari river is assessed and discussed.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The study was conducted on the Chari river, along the Banda township, which is located upstream from the Maïmana village to the Rônier village in the Est of Sarh town, and within the department of Bahr Kôh in the south of Chad. It is located at between 08°55' and 9°11' North latitudes, between the 18°35' and 18°22' Est longitudes, and at 365 m altitude in average. The Global Position system (GPS) coordinates of the three sampling sites are summarized in (Table 1). The rainfall data which vary form 900 mm to 1200 mm yearly, largely influence the agricultural production systems. The average mean temperature is 27.6°C, with maxima at between 25°C and 32°C [11]. The maximum atmospheric humidity at Banda is fixed in August at 82%, against 33% as minimum in February. The soil is of ferruginous tropical type, leached or ferralitic, thus oriented to sylvo-pastoral activities, and adapted for cultivation of cotton, cereals, oleaginous and proteaginous crops.

2.2 Samples Collection

Fish and water samples were collected in February (dry season) and July (wet season) 2023. Fishes were captured through artisanal meshes by fishermen working on the Chari river, along the Banda township (Sarh-Chad). Collected *Oreochromis niloticus* (Fig. 1) were stored in sterile labelled plastic bags, and conserved in coolers containing ice, before their transportation in the laboratory for the assessment of the biometric parameters (weight, height), and the analysis of metal elements.

2.3 Preparation of Fish Samples

In the laboratory the size of each fish was measured and its weight taken, using a 0.01 electronic balance. Fishes were then scaled and dissected before a portion of muscle was sampled and dried for 24h at 105°C until a constant weight was obtained. After cooling into a dessicator, the mortar bearing the dried muscle was also weighted.

2.4 Determination of Ash Content in the Dried Matter

The dry muscle was transformed into powder using a porcelain mortar and stored in a plastic bag. A 10g powder sample was weighted twice in the mortar, then dried again in the oven until a constant weight was obtained. After cooling into a dessicator, the mortar containing the powder was placed into a muffle furnace and dried for 24h at 550°C. Cooled samples for 1h were again weighted and the ash content for 100g of dry matter was assessed using the following formular:

$$\text{Ash content (\%)} = \frac{(P3-P1)\times 100}{P2-P1}$$

where, P_1: mass of the empty mortar; P_2 : mass of the mortar containing the powder from the oven; P_3 : mass of the mortar containing the ash from muffle furnace.

Table 1. Geographical coordinates of sampling points sites

Site names	GPS coordinates	Altitudes (m)	Villages nearby the sampling sites
ChS1	N 08°55'49.19" E 18°35'21.45"	320	Mindinwol (Maïmana)
ChS2	N 09°00'00.6" E 18°30'16.03"	358	Mallah
ChS4	N 09°11'17.72" E 18°22'05.24"	364	Rônier

Fig. 1. A sample of fish (*Oreochromis niloticus*)

2.5 Extraction of Heavy Metals from Ashes

Extracts were prepared by submitting the ashes to chlorhydric acid attack to liberate mineral elements. Ashes contained trace metals were present in the form of phosphate and sulfate salts, or non-volatilized chlorures after combustion. The principle consisted of dissolving ashes into chlorhydric acid, where heavy metals were drained into the solution, while insoluble residues were separated from the solution by filtration [12]. To achieve this, 0.10 g of ash of each sample was introduced into a 100 mL beaker calibrated to zero, then 5mL concentrated chlorhydric acid was added before 20 mL distilled water. The solution mixed was worm to ebullition on an electric plate until one third of the solution was obtained. After cooling, the solution was filtered through a N°1 Whatman paper into a 50 mL flask. The flask was then filled to the volume with distilled water, before the ash solution was vacuum filtered through a 0.45µm diameter mesh cellulose membrane to exclude suspended particles. Samples were stored at 4°C in a closed container for further uses.

2.6 Determination of Trace Metals Contents in Fish Meat

The trace metals (Pb, Cd, Fe, Cr, Cu, Zn) in fish meats were determined through a DR 2400 spectrophotometer, which measures the absorbance in solutions at between 400-880nm at 0-40°C temperature range. The principle is that when a monochromatic particle light beam of λ wave length of Io intensity crosses a solution to be analyzed, it is subjected to an absorption, and then, gets out with a reduced intensity I. This decreased intensity is due to the absorption of one or many frequencies by the crossed solution. From the proportion of the light intensity absorbed by the solution, the concentration C (mg/L) of the absorbed substance is determined from the Beer-Lamber equation:

$$D = \log Io/I = aLC, \text{ where,}$$

a is molar absorption coefficient;
L, is optical distance crossed by radiation through the solution
C, is the concentration of the solution

The inorganic components in solution are in contact with specific reagents, and the intensity of the produced color is measured, representing the concentration in inorganic ions to analyze. For each assay, a blanc made up of distilled water and reagents was performed.

2.7 Assessment of the Bioconcentration Factor (BCF)

The transfer of trace metals from water to fishes expressed as the Bioconcentration Factor (BCF) was calculated based on water [13], compared to the total fraction of sediments and the bioavailable fraction as follows.

$$FBC = C_{tissue}/C_{\text{water}}$$

where, C_{tissue} represents the concentration of a trace metals in fish tissue and C_{water} that of the contaminant in water.

2.8 Data Analysis

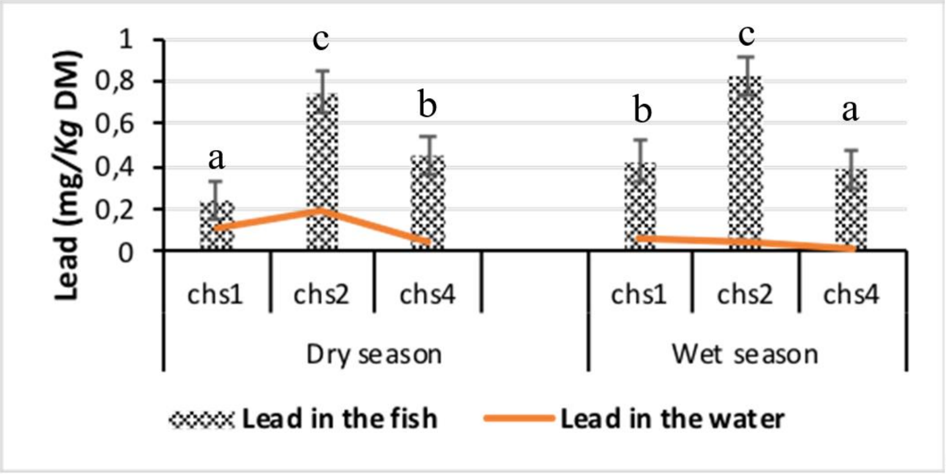
Data were statistically analyzed using Statgraphics 16.1 software, and the Analysis of Variance (ANOVA) was used to discriminate means of trace metals in water and fish meat between the sampling sites. The Student test was applied to compare means of trace metals at sites ChS1, ChS2, ChS4 between the dry and wet seasons. Differences between sites or seasons were considered significant for p-values < 0.05.

3. RESULTS AND DISCUSSION

The results of this study express the trace metals contents in fish meats (mg/Kg.DM) as compared to that of water (mg/L). Iron and zinc were the most concentrated trace metals in water at sites ChS1 and CHS2 in the wet season, whereas in the dry season it is instead Cd and Fe that were the most found in water (Table 2). Apart from Cr and Cu in the wet season, Cu and Zn in the dry season, the concentrations of Fe, Cd and Pb in water were above the limit concentration set by WHO [14]. For each trace metal in water, the concentration was significantly different (p = 0.0001) between sampling sites both in the dry and wet seasons.

Lead (Pb): The average water concentration in Pb of the Chari river was irregularly distributed from one sampling site to another. Lead water concentration was significantly (p = 0.0001) greater at site ChS4 than that of sites ChS1 and ChS2 during the dry season (Fig. 2a), whereas in the wet season it was instead more elevated at site ChS1 than the other two sites (Fig. 2b). The increased Pb water concentration from site ChS1 was suggested to be provided by running water containing chemical-fertilizers residues supplied by the Moussafoyo factory located at 12 Km from the ChS1 site. These results differ from those of Naoura et al. [15], who revealed bad quality surface water sampled from sites downstream suspected to be exposed to pollution.

The levels of chemical distribution in surface waters influence the diversity of life present or adapted to the water column. Lead is a potent hazardous element that is bioaccumulated in aquatic organisms through water feed [16]. Lead water concentration measured was generally weak in the wet than the dry season, due to dilution effect by rainfall water, and was considered lower compared to those reported by Tchoroun et al. [17] in Logone and Chari water within N'Djamena town, thus attributed to the little influence of the anthropic activities in the study zone. Pb content measured in fish meat indicated elevated values registered at sites ChS2 (0.74 mg/Kg) and (0.82 mg/Kg), respectively during the dry and the wet season, against the lowest values obtained at site ChS1 (0.24 mg/Kg) during the dry season, and site ChS4 (0.38 mg/Kg) during the wet season. This bioaccumulation of Pb (0.249 mg/Kg) in fish meat of the genus *Oreochromis niloticus* was also recently reported in samples from Congo river, but only at a concentration of 0.05 mg/Kg [7]. Lead is accumulated in different fish organs including liver, kidney, gills, spleens and even digestive system [18]. Once in fish, Pb negatively affects the growth and feed utilization of fish by reducing weight gain, specifically growth rate and feed intake [19].



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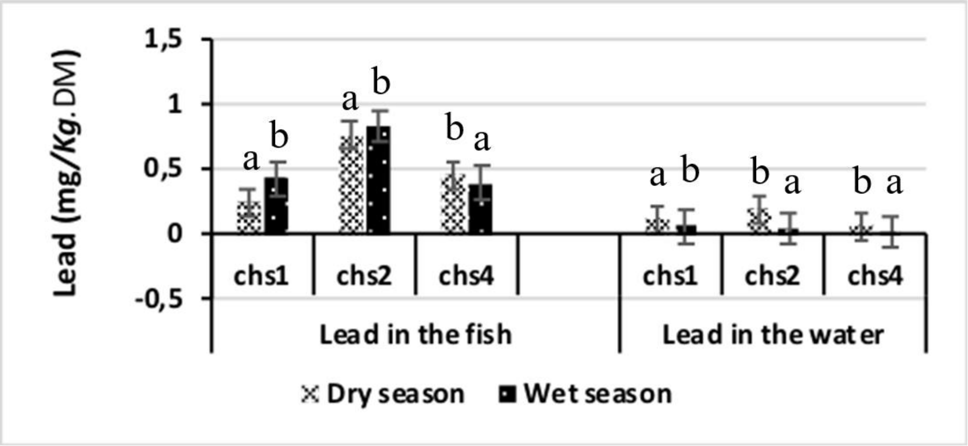


(b)

Fig. 2. Variation of lead water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

Table 2. Differences in water trace metals contents between sampling sites along the Chari River (mg/L)

	Wet season (July)				
Sampling sites	**ChS1**	**ChS2**	**ChS4**	**p-values**	**WHO standard (2011)**
Trace metals	**Treatments**				
Lead	0.057±0.001c	0.041±0.001b	0.015±0.013a	0.0001	0.01
Cadmium	0.012±0.0005a	0.105±0.001c	0.07±0.001b	0.0001	0.003
Iron	1.57±0.001c	0.681±0.001a	1.12±0.001b	0.0001	0.3
Chromium	0.03±0.001b	0.021±0.0005a	0.03±0.001b	0.0002	0.05
Copper	0.111±0.001c	0.011±0.0005a	0.08±0.0005b	0.0001	2.0
Zinc	1.301±0.001a	1.701±0.001c	0.501±0.001a	0.0001	0.1
Dry season (February)					
Lead	0.000±0.0a	0.000±0.0a	0.056±0.005c	0.0001	0.01
Cadmium	1.117±0.02b	2.33±0.0c	0.009±0.003a	0.0001	0.003
Iron	0.6±0.0b	1.00±1.00c	1.22±0.006b	0.0001	0.3
Chromium	0.017±0.005a	0.030±0.0b	0.38±0.0c	0.0203	0.05
Copper	0.086±0.01c	0.005±0.0a	0.013±0.005b	0.0001	2.0
Zinc	0.043±0.001b	0.033±0.002a	0.041±0.004a	0.0001	0.1

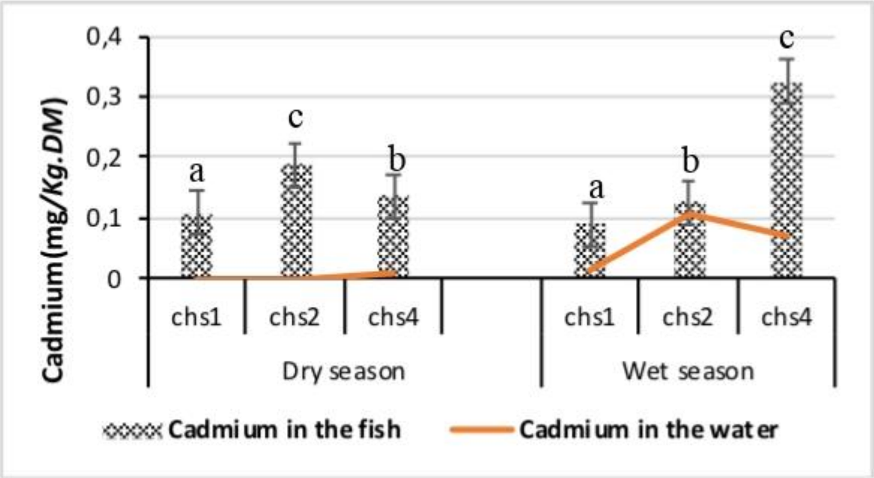
For each season and for each trace metal, values on a row affected by the same letter are not significantly different between sites

Cadmium (Cd): Cadmium was only present in water sample from site ChS4 in the dry season at a concentration of 0.009 mg/L. During the wet season, Cd was detected in water sampled at 0.011 mg/L and 0.105 mg/L, respectively from sites ChS1 and ChS2 (Fig. 3), thus different from those pointed out by Tchoroun et al. [17] in Logone water at Moundou, but were above the requested standard value of 0.005 mg/L set by WHO [14]. Cadmium was more concentrated from the upstream at site ChS1 to the downstream (site ChS4) of Chari river.

Elevated Cd concentration in Chari river water could be attributed to running off of sulfate, nitrate and urea as fertilizers applied in agriculture [16]. The seasonal variation of Cd concentrations indicated weak values in the dry season 0.10, 0.18 and 0.13 mg/kg.DM, respectively in fish meat sampled at sites ChS1, ChS2 and ChS4, compared to elevated values of 0.42, 0.82 and 0.38 mg/kg.DM at the same sites during the wet season. Cadmium concentrations in fish was greater in sample from the upstream (site ChS1) than the downstream (site ChS4) during the dry season. The presence of Cd in fish meat from sites ChS1 and ChS2 in the dry season (February) although it was absent in water could be justified by the mobility of fish from polluted to non-polluted sites. Fishes of the genus *Oreochromis niloticus* were reported to accumulate Cd to up to 0.173 mg/kg at Kingabwa within the Malebo Pool of the Congo river [7]. According to Priyanka et al. [20], elevated concentrations of Cd were found in muscles of tree fish species, and in carp meat [21]. In this study, Cd was present at high concentrations in the dry than the wet season, opposite to decreased concentrations revealed by Coulibaly et al. [22] in Ivory Coast during the same seasonal period. In the reverse, Cd content in *Oreochromis niloticus* meat was stated to be below the norm values recommended by WHO [14], thus was not at a risk for human health [23]. However, Cd is very toxic to organisms, but has no biological known function. Cd toxicity has been reported to induce production of free radicals, causing oxidative deterioration of lipids, proteins and DNA, and in fishes, it particularly induces severe oxidative damages to liver and gills [24], or affect the physiology of fish and hamper their growth [25].

Iron (Fe): Iron was present in water from all sampling sites at concentration more elevated in the dry season than the wet season, and above the standard value fixed at 0.30mg/L (Fig. 4).

The greatest iron concentration was found in water sample from site ChS2 in the dry season, compared to 1.570 mg/L at site ChS1 in the wet season (1.001 mg/L). The presence of iron in all water samples could be explained by leaching of ferralitic soils upstream along the Chari river. Similar to that of water, iron was found in *Oreochromis niloticus* meat sampled at site ChS2 in the dry season at concentration of 0.96



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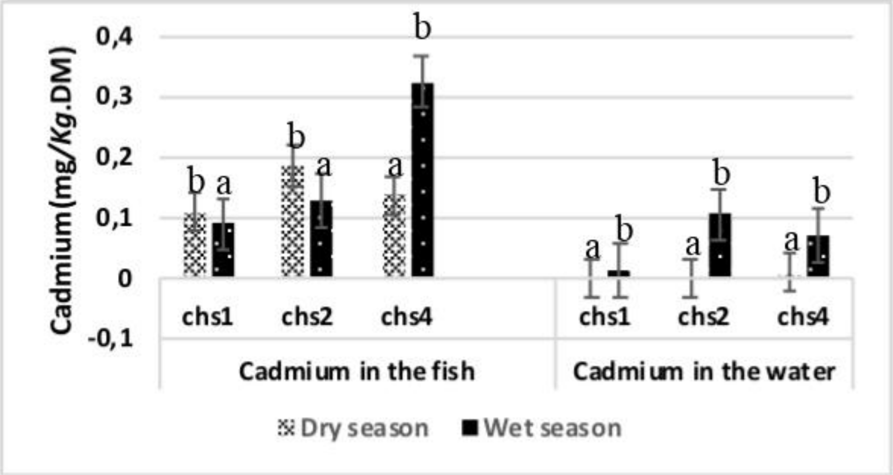


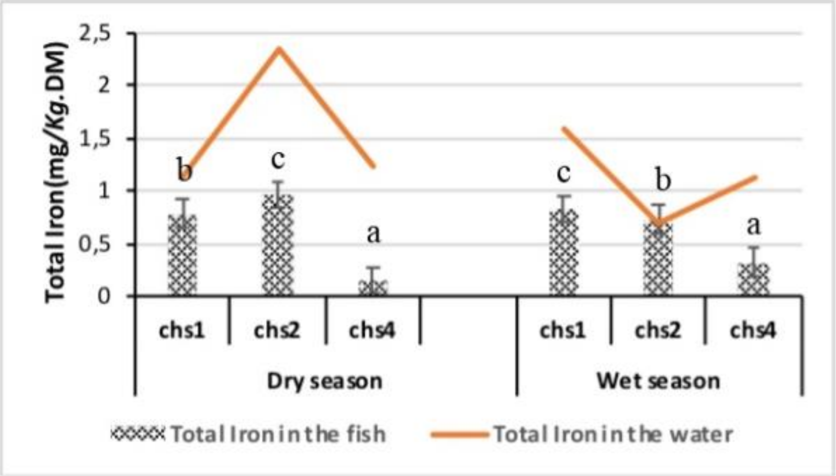
(B)

Fig. 3. Variation of Cadmium water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

mg/kg.DM, against 0.82 mg/kg.DM. At site ChS1 in the wet season, in agreement with previous reported results [15], who suggested it to be attributed to ingestion of iron from anthropogenic activities and domestic wastewater from domestic usages.

Chromium (Cr): The greatest Cr concentration in water sampled in the dry season at site ChS2 was 1.001 mg/L instead of 0.030 mg/L at site ChS1 measured in the wet season. In all the sampling sites, Cr concentrations were always more elevated in the dry than in the wet due to dilution effect by rainfall. In fact, the greatest Cr content in the wet season corresponds to the lowest concentration in the dry season (Fig. 5a). In *Oreochromis niloticus* meat, Cr was detected at concentrations of 1.020, 1.497 and 0.813 mg/Kg.DM, respectively from samples at sites ChS1and ChS4 in the dry season, compared to 0.895 and 1.020 and 0.924 mg/Kg.DM in samples of respective sites during the wet season (Fig. 5b). Heavy metals contents such as that of Cr were revealed to be higher than the relative standard due to artisanal activities in towns and uncontrolled liquid wastes residues [26,15]. In small, middle and big carp fish meats, the variations of Cr concentrations were found to be respectively 26.55, 28.11 and 51.93 mg/Kg.DM [21]. Selcuk et al. [27] have pointed out significantly decreased growth and feed utilization of several fish species at high Cr levels in fish diets.



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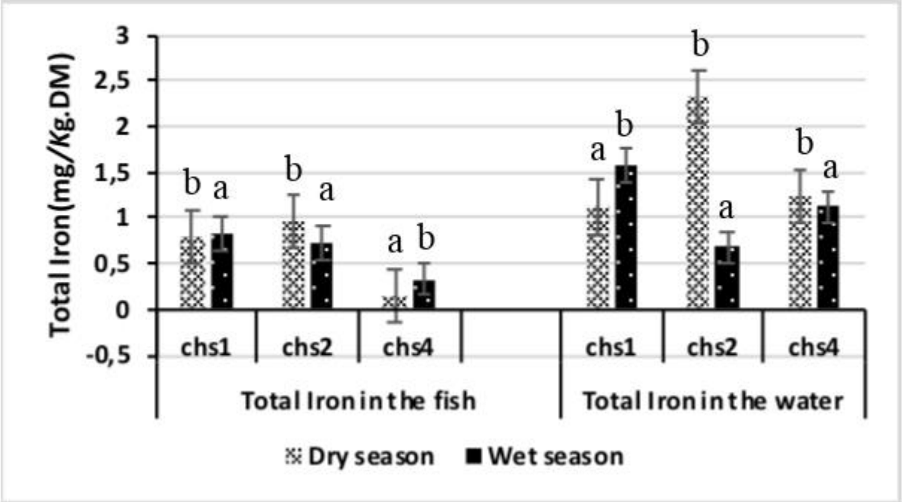
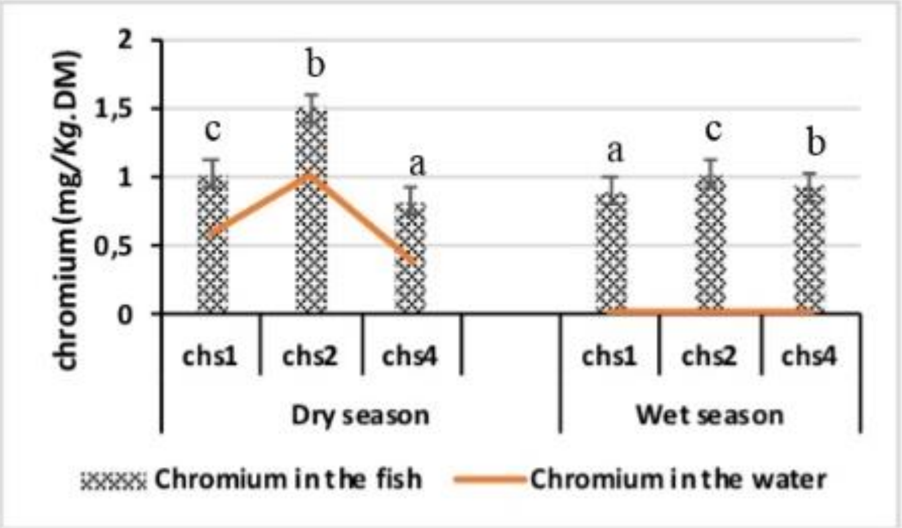


(B)

Fig. 4. Differences in iron water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

Copper (Cu): Copper is a major contaminant of aquatic systems that results in stressful conditions for aquatic organisms and is significantly involved in the reduction of fish growth and physiology [28]. Copper concentrations in Chari river water fluctuated from 0.013 at site ChS4 to 0.030 mg/L at site ChS2 (Fig. 6a) in the dry season, but were revealed at concentrations of 0.080 and 0.111 mg/L, respectively at the same sites during the wet season (Fig. 6b). This was thought to be attributed to throwing of running wastewater from agricultural activities into the Chari river. *Oreochromis niloticus* meat sampled at sites ChS4 and ChS2 was concentrated in Cu at respectively 0.203 and 3.700 mg/Kg.DM) in the dry season, against 2.011 and 3.619 mg/Kg.DM in the wet season. Cu content was heterogenous in the dry season and homogenous in the wet season between sites. In addition to their eventual anthropic activities' origin, heavy metal was reported to have a geological origin, from which hydroclimatic erosion might have drained them into water [15]. Even if this trace metal is essential for the organism, it becomes toxic at high concentration [29]. Excess Cu in the fish diet is known to reduce its appetite, thus negatively affects its growth and feed utilization [30].



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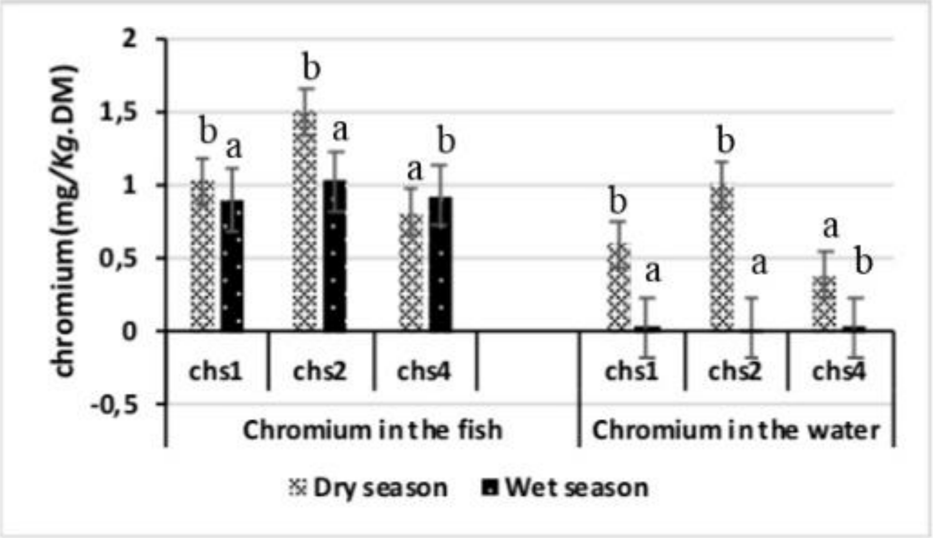
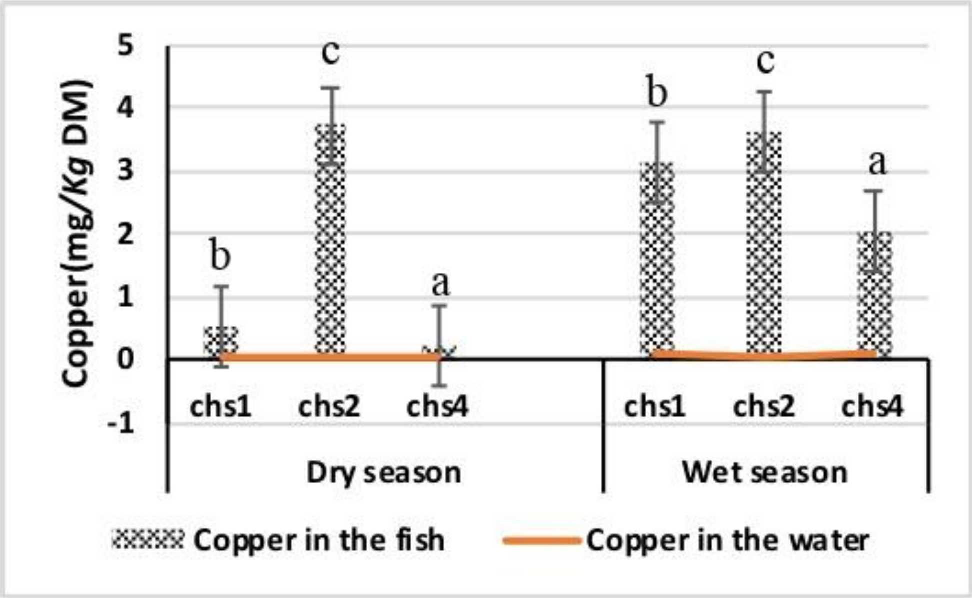


(B)

Fig. 5. Changes in chrome water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

Zinc (Zn): Zinc is an essential micronutrient that plays a significant role in the growth and reproduction of fish [31]. The concentrations of Zn varied from 0.005 to 0.08 mg/L in water sampled at sites ChS2 and ChS1, respectively in the dry season, and were lower than those of the wet season, comprised between 0.501 mg/L at site ChS1, and 1.700 mg/L at site ChS2 (Fig. 7a). In *Oreochromis niloticus* meat, Zn was accumulated at concentrations of between 3.80 mg/kg.DM at site ChS4, 5.16 mg/kg.DM at site ChS2 in the dry season, compared to 0.99 and 3.22 mg/kg.DM at the same sites during the wet season. These values were lower than other previous reported results of between 6.36 to 13.31 mg/kg.DM in fish meat [32]. Fish meat sampled from site ChS2 was heavily concentrated in Zn compared to that of other sites. The concentration of fish meat in Zn was more important in the dry season (Fig. 7b), attributed to the low water level that increases the Zinc content in water inhabiting fishes. Zinc toxicity has been reported to affect the growth, feed intake [33], and reproduction [34] of fish.



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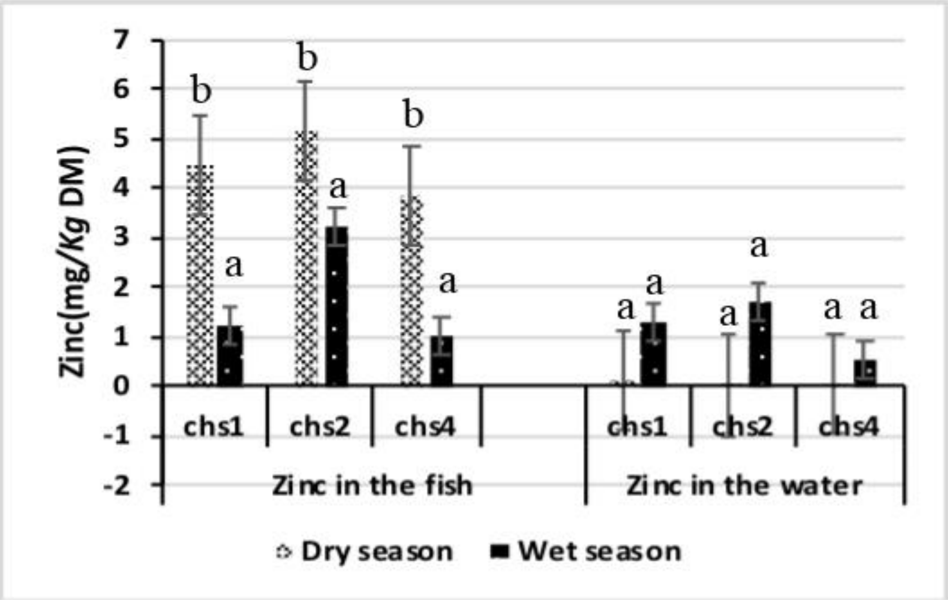

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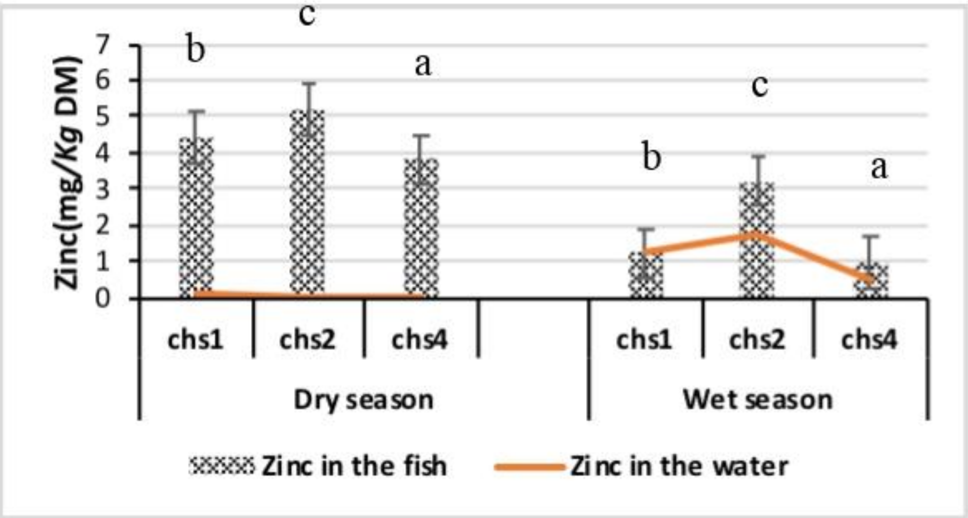
Fig. 6. Variation in copper water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

Table 3. Order of concentrations of metallic trace elements *Oreochromis niloticus* meat in the dry and wet seasons

Sites	Dry season	Wet season
ChS1	Zn > Cr > Fe > Cu > Pb > Cd	Cu > Zn > Cr > Fe > Pb > Cd
ChS2	Zn > Cu > Cr > Fe > Pb > Cd	Cu > Zn > Cr > Pb > Fe > Cd
ChS4	Zn > Cr > Pb > Cu > Fe > Cd	Cu > Zn > Cr > Pb > Fe = Cd



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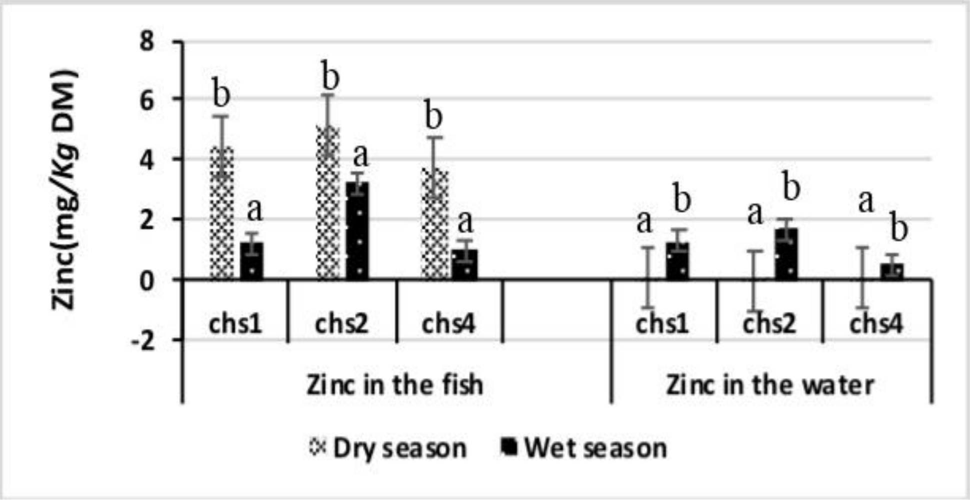

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Fig. 7. Differences in iron water and fish meat concentrations in samples during the dry (a) and the wet season (b)

(a) For each season, bars affected with the same letter are not significantly different between sampling sites; (b) In fish or water, bars affected with the same letter are not significantly different in sampling site between seasons

Table 4. Bioconcentration Factor (BCF) values of metallic trace elements *Oreochromis niloticus* meats in the dry and wet seasons

			Dry season			
Trace metals	**Pb**	**Cd**	**Fe**	**Cr**	**Cu**	**Zn**
Water (mg/L)	0.044	0,003	1.555	0.660	0.020	0.042
Fish meat (mg/Kg.DM)	0.482	0.144	0.632	1.110	1.479	4.465
BCF	10.947	48.000	0.406	1.682	73.933	106.302
	Wet season					
Water (mg/L)	0.038	0,061	1.123	0.027	0.034	1.167
Fish meat (mg/Kg.DM)	0.545	0.179	0.624	0.946	2.917	1.813
BCF	14.342	2.934	0.556	35.037	85.794	1.554

Bioconcentration Factor (BCF) linked to *Oreochromis niloticus* meat pollution: From Table 3 illustrating the concentrations of trace metals in *Oreochromis niloticus* meat from the Chari river, Zn was the best accumulated element in the three sampling sites, whereas Cr was the best accumulated at sites ChS1 and ChS4. This consistent accumulation of Zn was previously revealed by several authors [20,35]. In the wet season, it was instead Cu and Zn in this order that were the most accumulated in fish meats. Boohene and Agbasah [36] reported elevated levels of heavy metals (Cr, Cd, Cu, Pb, Zn, Fe and Ni) in surface waters, sediments and tissues of *Oreochromis niloticus* in Afram River, Ghana.

In environmental assessment, bioaccumulation factor is one of the ecological tools for estimating contaminant levels in living organisms. In this study, BCF values were calculated as the concentration of heavy metals in fishes over their concentration in water. A BCF value greater than 1 is an indication of efficient uptake of a contaminant. In this study, BCF values were higher than 1 for all trace metals, which indicated high uptake of heavy metals from Chari river (Table 4). The increased uptake of metals reported in the fishes' tissues and the high BCF values are a warning signal for the anthropogenic activities along the Logone and Chari rivers in Chad and could be introducing pollutants, including metals into the food web. The levels of heavy metals reported in the fishes' tissues were higher than that reported in surface waters. This is an indication of the potentials of *Oreochromis niloticus* to accumulate and biomagnify heavy metals across the food web. Apart from iron (Fe) the bioconcentration factor (BCF) of each trace metals accumulated in *Oreochromis niloticus* meat was above 1, suggesting that the fish has indeed accumulated Pb, Cd, Cr, Cu and Zn in their tissues (Table 4). These results line with elevated concentration in surface waters of iron, nickel and zinc that were above recommended limit [37], and consequently increased uptake of these metals reported in sediments and tissues of three fish species [38]. Copper was the most accumulated pollutant in the wet season, while zinc and cadmium were the most accumulated during the dry season. This accumulation has been reported to affect the la normal physiology and reduce the behavior and the reproduction of fishes [39]. Waste water factories that has not undergone treatment, when thrown into surface water contains trace metals, as well as residues of several chemical products involved in the extraction or separation processes, or in the refining process [40]. These pollutants once solubilized become toxic, destroy aquatic life downstream the discharge points at several kilometers away, and are metabolized within the whole food web, thus, constitute a health risk to neighboring population [40].

4. CONCLUSION

The outcomes of this research are that the concentration of trace metals in the Chari river was more important in the wet than in the dry season. Some of the toxic metals such as Pb, Cd, Zn, and Cr were highly accumulated in the fish meat of *Oreochromis niloticus* inhabiting the Chari river, more than the stipulated limits fixed by WHO [14], with a bioaccumulation factor higher than 1, except for iron. Copper was the most accumulated trace metal in the fish meat, both in the wet and dry season, while zinc and cadmium were mostly found in fish only in the dry season. On the basis of these findings, there is a risk contamination of human through the food wed due to bioaccumulation of trace metals by fish he consumes. Hence, continuous water monitoring measures of the Chari river are necessary to avert possible public health implications of these toxic metals on consumers of water and seafood from the study area.

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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