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Original Research Article

Consumption of the Silver Catfish *Chrysichthys nigrodigitatus* Lacépède, 1803 from the Lake Togo-Lagoon of Aného Hydrosystem (Southern Togo): Risks to Human Health With Reference To Trace Elements

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Abstract

The Silver Catfish *Chrysichthys nigrodigitatus* from the hydrosystem Lake Togo-Lagoon of Aného contributes to the socio-economic well-being and food security of local populations. However, this ecosystem is known to be threatened by trace elements contamination. This study aims to assess the human health risk associated with exposure to trace elements via the consumption of Silver Catfish. The study method followed four main steps as described by USEPA after measuring trace element concentrations in *C. nigrodigitatus* tissues. The results showed that some values greater than 1 were obtained in the dry season, for As in adults (THQ = 1.17) and children (THQ = 1.80) and for Cr in children (THQ = 1.11) and in the rainy season for As in children (THQ = 1.36). Regarding the consumption of whole fish organs analyzed, the THQ recorded in the dry season for Cd, Pb, Cr and As in adults and children and for Hg in children are all greater than 1. In addition, in the rainy season, the THQ obtained for Cd and As in adults and Cd, Pb, Cr, Hg and As in children, are also greater than 1. The total target hazard quotient (TTHQ) are all greater than 1 for muscles and for all the combined fish organs studied. The CR values of Cr and As obtained in the muscles and the combined fish organs are all unacceptable (CR > 10^{-4}) in both adults and children during both seasons. Children are more exposed than adults and the consumption of all the organs studied is found to be more dangerous than muscles alone. Therefore, the consumption of vital fish organs such as gills, kidneys and liver should be avoided since they are the favorite sites for most pollutant concentration.

Keywords: *Chrysichthys nigrodigitatus*, Health risk, Lake Togo, Lagoon of Aného, Target hazard quotient.

INTRODUCTION

The environmental pollution issues known to be caused by anthropogenic activities are a main subject of national sustainable development policies [1] For several decades, full consideration has been given to pollutants dispersion in the environment by the scientific community. Trace elements are one of the main environmental pollutants, because of their high toxicity, their accumulation in living organisms such as fish, their persistence and their wide dispersion in the environment [2-4].

Although trace elements are normal constituents of rocks in the earth's crust, anthropogenic and natural processes can release significant amounts of these elements leading to their enrichment above natural background concentrations [5-7]. In aquatic environments, trace elements pollution can result from atmospheric deposition, waste disposal, smelter tacks, geological weathering or from the discharge of agricultural, urban run-off, residential or industrial waste, spillage of petroleum products etc. [7, 8]. Trace elements have the capacity to be bioaccumulated in aquatic organisms and biomagnified along aquatic food chains. This threatens both ecosystem balance and human health [9, 10]. Consequently, toxic trace elements accumulation in fish can negatively affect, not only the health and productivity of fish but also human health because of fish consumption by humans. Although, fishes have important nutritional benefits on human's physiology, they constitute the main pathway (90%) of human exposure to environmental pollutants such as trace elements, leading to serious public health issues [11-14]. Several methods based on non-cancer risk and cancer risk calculations have been proposed and used to assess potential human health risks from exposure to trace elements via food consumption [11, 13, 15-17].

In Togo, Silver Catfish *Chrysichthys nigrodigitatus* from the hydrosystem Lake Togo-Lagoon of Aného is very appreciated in food and contributes to socio-economic well-being and food security of local populations who are mainly fishermen. This species has an important ecological role in the ecosystem and presents valuable economical and nutritional interests [18-20]. However, waters, sediments and some biota of this hydrosystem are known to be contaminated by trace elements [17, 21-24]. This study aims to assess the human health risk associated with the exposure to trace elements via contaminated Silver Catfish consumption.

MATERIALS AND METHODS

Study area

The study area is represented by the hydrosystem Lake Togo-Lagoon of Aného (Figure 1). It is a continuous body of water along Togolese coast between the phosphorite mining area in the North and the phosphorite processing plant on the beach in the south. It is located between the North latitudes (6° 17' 37"; 6° 14' 38") and the East longitudes (1° 23' 33"; 1° 37' 38") and is composed of three lagoons: Lake Togo (46 km^2), located between the village of Dékpo in the North and Agbodrafo in the South, is 13 km long in its larger diagonal (NW-SE) and 6 km in its smaller diagonal (NE-SW), the Togoville lagoon (13 km long and 150 to 900 m wide) which is parallel to the coast between the villages of Togoville and Zalivé and the lagoon of Aného which is a network of narrow channels from Zalivé to the mouth at Aného [25].

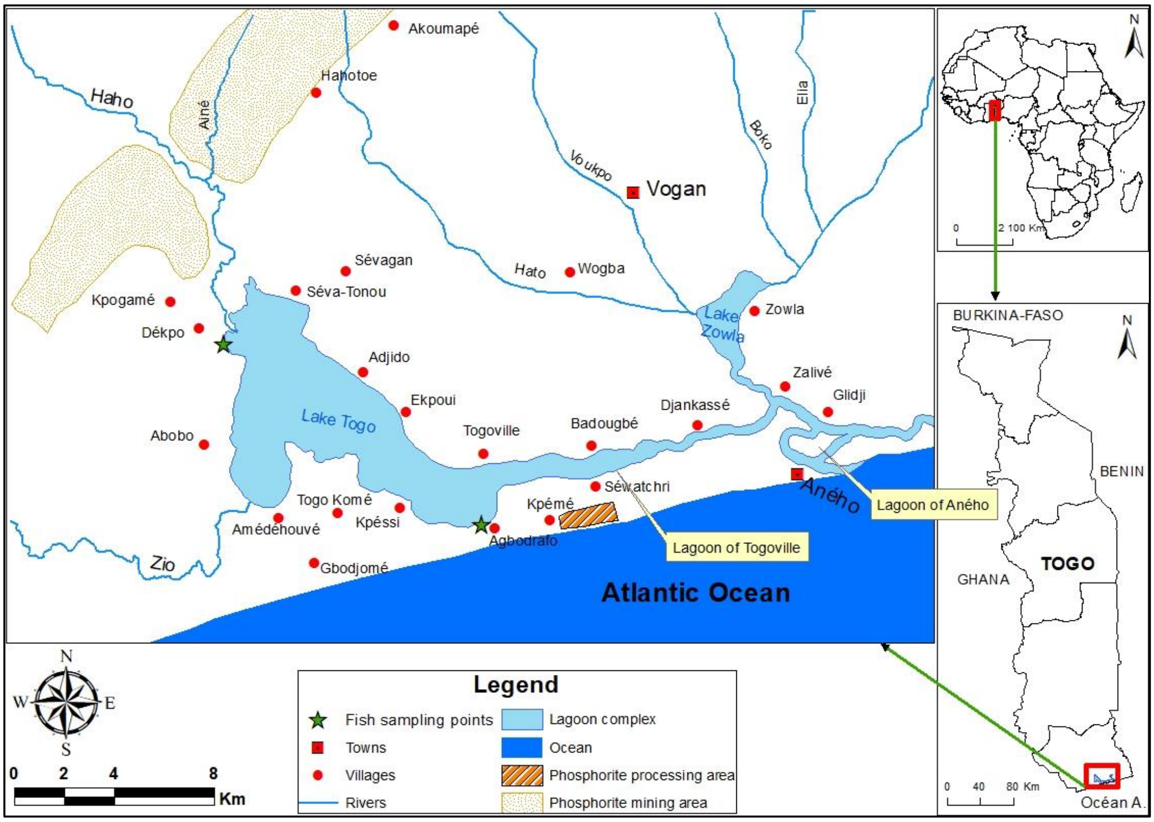

Figure 1: Location map of the study area and sampling points

Sampling and laboratory analysis

C. nigrodigitatus were sampled from two (2) sites in dry season and in rainy season in collaboration with the fishermen of the hydrosystem and individually wrapped in plastic foil. Then, they were packaged in coolers containing ice packs and transported to the laboratory where they were frozen at -20 °C for further processing. In the laboratory, the organs (gill, liver, kidney, muscle) were removed using stainless dissection equipment. Then, they were dried in an oven at 65 °C and ground in an agate mortar before storing in a dry place until analyzes [26-29]. The mortar, pestle and dissection material had been thoroughly cleaned with 10% nitric acid (HNO_3) solution and rinsed with distilled water before and after each sample. Masses varying from 0.1 to 3 g of organs were digested in borosilicate glass vials at 90 °C using corresponding volumes of a mixture of 30 % hydrogen peroxide and 67% nitric acid (4 to 6 ml) in the proportions of 1 H_2O_2: 3 HNO_3. Digestion is carried out until almost complete evaporation of the reagents without calcining the residues. The solutions are then kept at room temperature for cooling [28, 30, 31]. For the determination of mercury, samples were digested using the same reagents but without heating (room temperature) for 72-96 hours. They were regularly stirred in order to allow good digestion of the samples. Simultaneously, the blanks were prepared and processed under in the same conditions for the two series of samples but without samples. Then, each solution from the digestion was filtered, completed to 20 ml with distilled water and stored at room temperature for analyzes. These solutions were analyzed for trace elements using flame atomic absorption spectrometer (AAS) for Cd, Pb, Cr, Ni, Cu, Zn, Mn and by the AAS coupled to the hydride and cold vapour generator with flame for As and without flame for Hg.

Accuracy and quality control

The quality of the analytical methods has been verified by internal control. A procedural blank was prepared with the same reagents and under the same experimental conditions as the main samples. The blank allowed zeroing the device and was analyzed after each 10 samples batch during the analysis. This allowed to determine possible contaminations and eliminate quantization errors. The standard solutions prepared for each trace element were also analyzed at regular intervals in order to verify the accuracy of the results. In addition, the repeatability of the results was checked by the analysis of duplicates which were randomly incorporated among the samples.

Health risk assessment method

It followed four main steps in accordance with the methods described by the United State Environmental Protection Agency (USEPA) (https://www.epa.gov/risk/human-health-risk-assessment): hazard identification, dose-response assessment, exposure assessment and risk characterization.

Hazard identification involves identifying the substances to be studied, the toxic effects they are able to cause in humans and determining their concentrations in the exposure material studied. In this study, this was done by literature research and trace elements analysis in *C. nigrodigitatus* tissues.

Dose-response indicates the relationship between the level of exposure to toxic substances and the severity of the effects. This leads to the determination of toxicological reference values (TRV) for non-carcinogenic effects and for carcinogenic effects. In the present study, the TRV were selected from the databases of the Office of Environmental Health Hazard Assessment (OEHHA) and United States Environmental Protection Agency (USEPA). This selection was made by considering only the lowest values from epidemiological studies in humans and the most recent values [32].

Exposure assessment involves determining the way, frequency, duration and extent of exposure. This leads to the determination of the estimated daily intake (EDI) [11, 16, 17, 33]. In the present study, only the oral and chronic exposure way via consumption of *C. nigrodigitatus* was considered. The quantities and frequencies of fish consumption were determined around the hydrosystem by survey using "focus groups" method. The average quantities of fish ingested per day were calculated according to the following equation [11]:

$$Q = \frac{\sum[quantity \times \%\,(adult\ or\ children)]}{100}$$

Where Q = average quantity of fish consumed per day; quantity (g): minimum quantity of fish consumed per day; % (Adult or Child): percentage of adults or children corresponding to the different quantities; 100: number of individuals surveyed.

In order to determine the estimated daily intake (EDI), two categories of target populations were considered according to age: adults and children. The EDI were expressed for each trace element according to the following equation [34-37]:

$$\mathrm{EDI} = \frac{\mathrm{C} \times \mathrm{Q} \times \mathrm{F}}{\mathrm{W}}$$

Where EDI = Estimated Daily Intake (mg/kg/d); C = trace element concentration (mg/kg); Q = daily quantity of fish ingested (kg/d); F = frequency of exposure (d/year); W = body weight (kg). The average body weight of the riparian population are 67.64 kg in adults aged 22-60 and 29.40 kg in children aged 3-16 [38, 39]. In order to favor the most maximalist assumptions in the exposure scenarios, the frequency of fish consumption was considered to be equal to 365 days/year.

Risk characterization

For non-carcinogenic effects the target hazard quotient (THQ) was determined for each trace element using the following relationship [15, 16, 40, 41] :

$$\mathrm{THQ} = \frac{\mathrm{EDI}}{\mathrm{RfD_o}}$$

Where RfDo is the oral reference dose (mg/kg/d), set by USEPA; If THQ < 1, the occurrence of a toxic effect is very unlikely; If THQ > 1, the occurrence of a toxic effect cannot be excluded. It is reported by Hallenbeck [42] that exposure to several pollutants results in additive and/or iterative effects. Thus, the total THQ (TTHQ) taking into account all the trace elements, was calculated by adding the individual THQ according to the following equation [9, 13, 40]:

$$TTHQ = THQ_1 + THQ_2 + \cdots + THQ_n$$

For carcinogenic effects the cancer risk (CR) was calculated. It represents the lifetime probability of developing cancer associated with the substance according to exposure scenario. It is expressed for each trace element according to the following equation [13, 15, 16]:

$$CR = \frac{C \times Q \times F \times T \times CSF_o}{W \times T_m} = EDI \times CSF_o \frac{T}{T_m}$$

Where CSFo is the oral Cancer Slope Factor $(mg/kg/d)^{-1}$; T: Duration of exposure (year); Tm: Average period of entire life (year). For carcinogenic effects, the duration of exposure (T) is equal to 30 years and the average period of entire life (Tm) is equal to 70 years [16]. The carcinogenic risks were calculated only for Pb, Cr and As according to the availability of CSFo. $CR < 10^{-6}$ is negligible; $10^{-6} < CR < 10^{-4}$ is acceptable and $CR > 10^{-4}$ is unacceptable [13, 15, 43, 44]:

RESULTS

Danger related to trace elements in *C. nigrodigitatus* tissues

The health risk assessment focused on the 9 trace elements (Cd, Pb, Cr, Ni, Cu, Hg, As, Zn and Mn) analyzed in various *C. nigrodigitatus* organs of the hydrosystem Lake Togo-Lagoon of Aného. All these trace elements have average concentrations above the permissible limits (standards) for fishery products intended for human consumption except for Hg in muscles. Table 1 shows the seasonal average of trace element concentrations in muscles and combined organs (muscle, gill, liver and kidney).

Table 1: Average levels of trace elements in muscles and the combined organs

TE (mg/kg)	Muscles		Combined organs (muscle, gills, liver and kidney)		Standards
	DS	RS	DS	RS	
Cd	0.23±0.12	0.12±0.06	3.92±1.65	3.27±1.40	0.05
Pb	3.05±1.81	0.93±0.47	5.46±1.25	3.67±2.0	0.2
Cr	2.51±1.54	1.35±0.47	7.15±2.16	3.80±2.02	0.5
Ni	1.08±0.85	0.70±0.91	6.61±1.77	3.43±2.46	0.5
Cu	1.16±0.18	0.90±0.09	6.32±2.26	5.58±1.89	0.5
Hg	0.005±0.002	0.007±0.003	0.103±0.033	0.099±0.068	0.05
As	0.45±0.33	0.34±0.19	1.61±0.45	1.13±0.47	0.1
Zn	19.82±8.28	35.90±5.97	78.86±30.59	131.66±59.77	30
Mn	6±6.76	4.23±2.78	21.80±7.62	15.01±7.53	0.5

Note: TE: Trace elements; DS: Dry season; RS: Rainy season

Except Hg average concentrations during the two seasons and Zn in the dry season, all other average concentrations in muscles are above the standards for fish consumption. The average concentrations of trace elements recorded in the combined organs are all higher than the permissible limits for human consumption. These concentrations are at least twice the standards for all trace elements except Hg in the rainy season. In addition, trace element contents of the combined organs are considerably higher than those of the muscles alone during the two seasons. Thus, the consumption of these contaminated fishes could expose the population to trace elements and lead to acute or chronic toxicities for consumers.

Toxicological reference values selected (TRV)

Toxicological reference values (TRV) used for health risk assessment are from the United States Environmental Protection Agency (USEPA) and the Canadian Office of Environmental Health and Hazard Assessment (OEHHA). All the RfDo (oral Reference Dose) are from the USEPA database whereas oral Cancer Slope Factors (CSFo) are from the OEHHA database for Cd and Pb and USEPA database for As. In order to maximize the level of risk prevention, the values used are depicted in Table 2.

Table 2: RfDo for non-carcinogenic effects and CSFo for carcinogenic effects

Trace elements	RfDo for non-carcinogenic effects (mg/kg/d)		CSFo for carcinogenic effects $(mg/kg/d)^{-1}$	
	Values	Agency and years	Values	Agency and years
Cd	$1x10^{-3}$	US EPA / 2009	-	-
Pb	$4x10^{-3}$	US EPA / 2009	$8.5x10^{-3}$	OEHHA / 2005
Cr	$3x10^{-3}$	US EPA / 2015	0.42	OEHHA / 2005
Ni	$1x10^{-2}$	US EPA / 2015	-	-
Cu	$4x10^{-2}$	US EPA / 2015	-	-
Hg	$1x10^{-4}$	US EPA / 2015	-	-
As	$3x10^{-4}$	US EPA / 2015	1.5	US EPA / 2010
Zn	$3x10^{-1}$	US EPA / 2015	-	-
Mn	$1.4x10^{-1}$	US EPA / 1996	-	-

Human exposure to trace elements via fish consumption

Exposure scenarios

The fishes from the hydrosystem are a significant source of animal protein. They contribute to food security and the livelihoods of local populations. These fishes are caught and consumed by local fishermen and/or sold to other local or foreign consumers. Therefore, the only way of contamination considered in this study is the consumption of fishes from the hydrosystem. Local populations, and particularly fishermen and their families, are the most exposed to trace elements through the consumption of fish. Indeed, fishermen and their families consume fish at least once a day. This study therefore considers the oral route of exposure and concerns chronic exposure only. Thus, the results from the survey regarding the frequency and quantities of fish consumed by adults and children are shown in Table 3.

Table 3: Frequency and quantity of fish ingested by adults and children

Frequency of consumption (F)	Adults		Children	
	Rate (%)	Quantity (g/d)	Rate (%)	Quantity (g/d)
	0	25	6	25
	2	50	16	50
	5	75	10	75
	3	100	21	100
At least once a day	7	125	8	125
	26	150	14	150
	23	200	10	200
	13	225	9	225
	8	250	5	250
	10	275	1	275
	3	300	0	300
Average quantity (g/d ww)		166.75		110.25
Average quantity (g/d dw)		53.18		35.36

Notes: ww = wet weight; dw = dry weight

Table 3 indicates that the average quantities of fish ingested per day by the target population were 53.18 g/d of dry weight for adults and 35.36 g/d of dry weight for children. It was observed that the residents surveyed consume fish at least once a day.

Estimated daily intakes (EDI)

Table 4 shows that the estimated daily intake (EDI) calculated for muscles are mostly lower than the reference doses (RfDo) of the US EPA with the exception of those of Cr (EDI = $3.22x10^{-3}$ mg/kg/d) in children and As in adults ($3.52x10^{-4}$ mg/kg/d) and children ($5.39x10^{-4}$ mg/kg/d) in the dry season. During the rainy season, only the EDI for As ($4.07x10^{-4}$) is higher than the RfDo. Regarding all the organs combined during the dry season, the EDI obtained for Cd, Pb, Cr and As in adults and those recorded for Cd, Pb, Cr, Hg and As in children, are higher than the oral reference doses (RfDo). In the rainy season, the EDI of Cd and As in adults are higher than the RfDo while in children, it is the EDI of Cd, Pb, Cr, Hg and As which are higher than the respective RfDo. It has been observed that the highest EDI are recorded during the dry season, on the one hand, and in children, on the other hand. In addition, the EDI obtained for the muscles alone are always lower than those obtained for all the organs combined. The EDI of Hg are the lowest while the EDI of Zn are the highest.

Table 4: EDI in adults and children during the two seasons

Trace elements	Dry season		Rainy season		RfDo (mg/kg/d)
	Adults	Children	Adults	Children	
Muscles					
Cd	$1.84x10^{-4}$	$2.82x10^{-4}$	$9.79x10^{-5}$	$1.50x10^{-4}$	1.10^{-3}
Pb	$2.40x10^{-3}$	$3.67x10^{-3}$	$7.28x10^{-4}$	$1.11x10^{-3}$	4.10^{-3}
Cr	$1.97x10^{-3}$	$\mathbf{3.22x10^{-3}}$	$1.06x10^{-3}$	$1.62x10^{-3}$	3.10^{-3}
Ni	$8.48x10^{-4}$	$1.30x10^{-3}$	$5.53x10^{-4}$	$8.46x10^{-4}$	1.10^{-2}
Cu	$9.10x10^{-4}$	$1.39x10^{-3}$	$7.08x10^{-4}$	$1.08x10^{-3}$	4.10^{-2}
Hg	$4.22x10^{-6}$	$6.45x10^{-6}$	$5.68x10^{-6}$	$8.69x10^{-6}$	1.10^{-4}
As	$\mathbf{3.52x10^{-4}}$	$\mathbf{5.39x10^{-4}}$	$2.66x10^{-4}$	$\mathbf{4.07x10^{-4}}$	3.10^{-4}
Zn	$1.56x10^{-2}$	$2.38x10^{-2}$	$2.82x10^{-2}$	$4.32x10^{-2}$	3.10^{-1}
Mn	$4.72x10^{-3}$	$7.22x10^{-3}$	$3.32x10^{-3}$	$5.08x10^{-3}$	$1.4x10^{-1}$

Combined organs					
Cd	**$3.08x10^{-3}$**	**$4.71x10^{-3}$**	**$2.57x10^{-3}$**	**$3.93x10^{-3}$**	1.10^{-3}
Pb	**$4.29x10^{-3}$**	**$6.57x10^{-3}$**	$2.89x10^{-3}$	**$4.42x10^{-3}$**	4.10^{-3}
Cr	**$5.63x10^{-3}$**	**$8.60x10^{-3}$**	$2.98x10^{-3}$	**$4.57x10^{-3}$**	3.10^{-3}
Ni	$5.20x10^{-3}$	$7.95x10^{-3}$	$2.69x10^{-3}$	$4.12x10^{-3}$	1.10^{-2}
Cu	$4.97x10^{-3}$	$7.60x10^{-3}$	$4.39x10^{-3}$	$6.71x10^{-3}$	4.10^{-2}
Hg	$8.08x10^{-5}$	**$1.24x10^{-4}$**	$7.80x10^{-5}$	**$1.19x10^{-4}$**	1.10^{-4}
As	**$1.27x10^{-3}$**	**$1.94x10^{-3}$**	**$8.90x10^{-4}$**	**$1.36x10^{-3}$**	3.10^{-4}
Zn	$6.20x10^{-2}$	$9.48x10^{-2}$	$1.04x10^{-1}$	$1.58x10^{-1}$	3.10^{-1}
Mn	$1.71x10^{-2}$	$2.62x10^{-2}$	$1.18x10^{-2}$	$1.81x10^{-2}$	$1.4x10^{-1}$

Thus, the EDI calculated for the muscles decrease as follows for each season: Zn > Mn > Pb > Cr > Cu > Ni > As > Cd > Hg in the dry season and Zn > Mn > Cr > Pb > Cu > Ni > As > Cd > Hg in the rainy season. For all organs combined, the EDI decrease as follows for each season: Zn > Mn > Cr > Ni > Cu > Pb > Cd > As > Hg in the dry season and Zn > Mn > Cu > Cr > Pb > Ni > Cd > As > Hg in the rainy season.

Risk of poisoning

Target Hazard Quotients (THQ)

It appears in Table 5 that the majority of the THQ obtained for the muscles are less than 1, in both adults and children during both seasons. However, values greater than 1 were obtained in the dry season, for As in adults (THQ = 1.17) and children (THQ = 1.80) and for Cr in children (THQ = 1.11) and in the rainy season for As in children (THQ = 1.36). At the level of all organs combined, the THQ recorded in the dry season for Cd, Pb, Cr and As in adults and children and for Hg in children are all greater than 1. In addition, in the rainy season, the THQ obtained for Cd and As in adults and Cd, Pb, Cr, Hg and As in children, are also greater than 1. The total THQ (TTHQ) which characterize the risks caused by the combined effect of all the trace elements studied are all greater than 1 for muscles as well as for all organs combined.

Table 5: Target Hazard Quotients for adults and children during the two seasons

THQ	Muscles				Combined fish organs			
	Dry season		Rainy season		Dry season		Rainy season	
	Adults	**Children**	**Adults**	**Children**	**Adults**	**Cildren**	**Adults**	**Children**
Cd	0.18	0.28	0.10	0.15	**3.08**	**4.71**	**2.57**	**3.93**
Pb	0.60	0.92	0.18	0.28	**1.07**	**1.64**	0.72	**1.10**
Cr	0.66	**1.11**	0.35	0.54	**1.88**	**2.87**	0.99	**1.52**
Ni	0.08	0.13	0.06	0.08	0.52	0.80	0.27	0.41
Cu	0.02	0.03	0.02	0.03	0.12	0.19	0.11	0.17
Hg	0.04	0.06	0.06	0.09	0.81	**1.24**	0.78	**1.19**
As	**1.17**	**1.80**	0.89	**1.36**	**4.22**	**6.46**	**2.97**	**4.54**
Zn	0.05	0.08	0.09	0.14	0.21	0.32	0.35	0.53
Mn	0.03	0.05	0.02	0.04	0.12	0.19	0.08	0.13
TTHQ	2.85	4.36	1.77	2.71	12.03	18.40	8.84	13.53

In muscles, they vary from 1.77 in adults in the rainy season to 4.36 in children in the dry season. The TTHQ obtained for all the organs combined are much greater than 1 and are between 8.84 in adults in the rainy season and 18.40 in children in the dry season. Also, it was noted for the muscles and all the organs combined that the values of THQ and TTHQ of children are always higher than those for adults. In addition, the THQ and TTHQ values observed in dry season are mostly higher than those obtained in rainy season and those of the muscles are always lower than those of the organs combined. The THQ of trace elements for the muscles decrease as follows in dry season: As > Cr > Pb > Cd > Ni > Zn > Hg > Mn > Cu and in rainy season: As > Cr > Pb > Cd > Zn > Hg > Ni> Mn > Cu. As for the combined organs, their THQ for trace elements decrease as follows: As > Cd > Cr > Pb > Hg > Ni > Zn > Cu > Mn in the dry season and As > Cd > Cr > Hg > Pb > Zn > Ni > Cu > Mn in the rainy season.

Cancer risk (CR)

Table 6 shows that the CR of Pb for the muscles vary from $2.7x10^{-6}$ in adults in rainy season to $1.3x10^{-5}$ in children in dry season, while for the organs combined, they oscillate between $1.1x10^{-5}$ in adults in rainy season and $2.4x10^{-5}$ in children in dry season. All of these values are acceptable (10^{-6} < CR <10^{-4}) for the probability of lifetime cancer risk in the present conditions of exposure. However, the CR values of Cr and As in muscles and organs combined are all unacceptable (CR > 10^{-4}) in both adults and children whatever the season.

Table 6: The CR in adults and children during the both seasons

CR	Dry season		Rainy season	
	Adults	Children	Adults	Children
Muscles				
Pb	$8.7x10^{-6}$	$1.3x10^{-5}$	$2.7x10^{-6}$	$4.1x10^{-6}$
Cr	$3.6x10^{-4}$	$5.4x10^{-4}$	$1.9x10^{-4}$	$2.9x10^{-4}$
As	$2.3x10^{-4}$	$3.5x10^{-4}$	$1.7x10^{-4}$	$2.6x10^{-4}$
Combined organs				
Pb	$1.6x10^{-5}$	$2.4x10^{-5}$	$1.1x10^{-5}$	$1.6x10^{-5}$
Cr	$1.0x10^{-3}$	$1.5x10^{-3}$	$5.4x10^{-4}$	$8.2x10^{-4}$
As	$8.1x10^{-4}$	$1.2x10^{-3}$	$5.7x10^{-4}$	$8.8x10^{-4}$

The decreasing order of CR in muscles is Cr > As > Pb regardless of the season and the groups of people exposed. For the combined organs, the order is: Cr > As > Pb in the dry season and: As > Cr > Pb in the rainy season, regardless of the group of people exposed.

DISCUSSION

Consumption of muscles alone or all organs of *C. nigrodigitatus* from the hydrosystem Lake Togo-Lagoon of Aného may constitute a danger to human health according to European, Nigerian and WHO standards. In fact, with the exception of Hg during both seasons and Zn in the dry season, all other concentrations do not comply with quality standards [45-49]. These fishes are the main source of animal protein for residents and other consumers. However, it is known that the consumption of fish represents an important route of exposure to chemical pollutants such as trace elements [11, 30, 50].

The risk of toxicity of a trace element is determined by its concentration in the source of exposure and the quantity of this source consumed [51]. The results obtained on the levels and frequencies of fish consumption by local residents seem to corroborate those obtained by Laré [52] across the country. According to this author, the average consumption of fish in Togo is around 15.60 kg per person per year. These data recalculated on the basis of the maxima showed that fish are more frequently (9 times/person/week) consumed in the Maritime Region with an average quantity of 2.65 kg per/person/week. This frequency is not too far from that obtained in the present study (at least once/day). However, the amount of fish ingested is much higher than that of the present study. This may be related to the fact that this study focused on one species of fish. Thus, it turns out to be more judicious to use the amounts obtained from the present study for the calculation of the estimated daily intakes.

According to the reference doses (RfDo) accepted by the USEPA [53], consumption of *C. nigrodigitatus* muscle is likely to cause toxic effects related to As in adults and children and Cr in children in the dry season. During the rainy season, only children are exposed to the toxic effects of As. However, consuming all organs (muscle, gill, liver and kidney) exposes consumers to toxic effects of more trace elements than muscle alone. These toxic effects generally concern Cd, Pb, Cr, Hg and As [53, 54]. This is confirmed by the respective THQ of these trace elements which are greater than 1, indicating a potential health risk. It is noted that the THQ of As are higher than those of other trace elements for each source of exposure (muscles and combined organs) and regardless of the season and the group of people exposed. These high values observed for As could be due to its low RfDo values ($3x10^{-4}$ mg/kg/d) [55]. However, these values do not represent great danger to consumers as these calculations are based on the total arsenic present in fish tissues. However, it is known that the arsenic accumulated in fish species is largely in the organic form with very low toxicity. In fact, the proportion of toxic inorganic As in fish is generally less than 10% [56]. Marine organisms can have high arsenic concentrations in the order of 100 mg/kg wet weight, but in its organic form [57]. These higher values of As THQ were also observed by Monferran *et al.* [13] in the Cordoba region (Argentina). In addition, possible As related toxic effects were noted for *C. nigrodigitatus* from the Weija Dam on the Densu River in Ghana with exposure scenarios similar to those of the present study [14]. Also, other studies in Benin have shown that the frequent and abundant consumption of fishery products from the lakeside village of Ganvié [11] and from the Lake Nokoué [3] may cause toxic effects and health risks for consumers related to trace elements (Cd and Pb).

This study indicates that certain trace elements are not dangerous for health (THQ < 1) following consumption of muscles or all organs combined by adults or children. However, it should be noted that the combined effect of all the trace elements studied can be very toxic to consumers (TTHQ > 1). Indeed, it has been reported that exposure to two or more pollutants can lead to additive and/or iterative effects [42]. Thus, one can expect toxic effects resulting from the combination of several trace elements with THQ less than 1. This toxic character resulting from the combination of trace elements has also been reported by other studies [13, 30, 58].

The increased levels of health risks during the dry season for each exposed group and source of exposure is directly related to the increase in trace element concentrations in fish tissues in the dry season. These results are in agreement with those obtained by Monferran *et al*., [13] in Lake San Roque in Argentina showing higher TTHQ in the dry season (TTHQ = 1.61-5.75) than in the rainy season (TTHQ = 1.13 to 4.21). In addition, it is noted that the consumption of all organs combined has a higher risk of toxicity than muscles alone. This is due to the high contamination of these organs. Indeed, these organs are very involved in the metabolic activities of fish [4, 59, 60]. Thus, the consumption of fishes with their organs may be more dangerous because of their often high pollutant contents. It appears, according to the values of the EDI and THQ, that children remain the most exposed to the toxic effects of trace elements. This is due to their low body weight, their physiological predisposition and the fragility of their organism. In fact, contaminants are more easily absorbed in the body of children [61]. However, they remain unable to eliminate them as easily as adults because their excretion systems are less developed [11, 61]. These results are consistent with those obtained by Hounkpatin *et al*., [11] in Lake Ganvié in Benin and by Ouro-Sama *et al*., [17] in Lake Togo. Also, Aina *et al*., [3] note the vulnerability of children to the risks of metal toxicity. In addition, the health risk assessment of urban soils in Anshan (China), contaminated with trace elements, showed that THQ and TTHQ are higher in children than in adults, especially through oral and inhalation routes [44]. This vulnerability of children is reflected in the effect of fluoride pollution in the phosphorite mining area in Togo, which is more visible in children through the deposition of fluoride on their teeth [62, 63].

The risk of developing cancer linked to Pb following the consumption of *C. nigrodigitatus*, from the hydrosystem, according to the exposure scenarios of the present study is acceptable for human health. However, the risk of developing Cr and As related cancer in the general population following the same exposure scenarios is likely to be high and should not be overlooked. Indeed, at least one in 10.000 people will develop cancer linked to the toxic effects of Cr and As. Children are especially more exposed with risks reaching 5.4 times the reference (10^{-4}) for the consumption of muscles and 8.8 times the reference for the consumption of all combined organs [13, 16, 43]. The risk of developing cancer linked to As has also been reported by Monferran *et al*. [13].

The absorption of trace elements through food is a source of several diseases following acute or chronic poisoning because they are rapidly distributed to the various systems. These trace elements have the ability to unite specific groups of certain proteins, inhibiting the enzymatic activity of certain biochemical processes [64]. The brain of adults and particularly, that of developing fetuses, is very sensitive to the neurotoxic effects of Hg [65].

This study only concerned oral and chronic exposure through the consumption of fish. However, there are other sources of exposure such as the consumption of other contaminated food (animal or vegetable origin) [66, 67], contaminated groundwater and surface water [68] and inhalation of phosphorite dust that contains high concentrations of trace elements [38]. It is therefore important to regularly monitor this ecosystem in order to prevent any public health issues.

CONCLUSION

This study indicated that the consumption of *C. nigrodigitatus* according to the exposure scenarios of the present study is likely to cause toxic effects in consumers since total THQ (TTHQ) are all greater than 1 whatever the season and group exposed. The values of cancer risk (CR) showed that the risk of developing cancer linked to Cr and As following the consumption of *C. nigrodigitatus* according to the same exposure scenarios cannot be excluded (CR > 10^{-4}). This cancer can therefore be developed in at least 1/10000 of the exposed population. It is noted that children are more exposed than adults and consumption of all organs indiscriminately is found to be more dangerous than muscles alone. It is therefore essential to avoid the consumption of vital fish organs such as gills, kidneys and livers as they are favorite places for the concentration of most pollutants.

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Conflict of Interest

The authors declare that there is no potential conflict of interest with this research or and in the publication.

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