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Study of the Risk Associated with Fish Ingestion in the Volta Grande of the Xingu River - Brazilian Amazon Region

Estudo do Risco Associado à Ingestão de Peixe na Volta Grande do Rio Xingu - Região da Amazônia Brasileira

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Mining activity in the Amazon region has brought, over the years, environmental impacts and impacts on the health of traditional peoples such as indigenous and riverside peoples. The implementation of large projects in the region, such as hydroelectric plants, has changed the conditions of water bodies, adding potentially toxic metals to the environment that can be harmful to flora, fauna, and human beings. The objective of this research was to study the risk associated with local populations of ingestion of fish species captured in the Volta Grande region of the Xingu River, located in the Brazilian Amazon region. Sixty specimens of pacu (*Piaractus mesopotamicus*), pescada (*Plagioscion spp.*), piranha (*Serrasalmus spp.*), and tucunaré (*Cichla spp.*) fish were collected in two different regions of Volta Grande (middle and lower portions). For the determination of the elements Al, Mn, and Zn, an optical emission spectrometer with inductively coupled plasma was used, and for the Hg analysis, direct analysis with gold amalgamation was used. Statistical comparison tests and the use of indices were applied to assess the associated health risk, such as the Target Hazard Quotient (THQ) and Total Target Hazard Quotient (TTHQ) indicators and the risk of consuming food contaminated by Potentially Toxic Metals. The results showed that the elements Al, Mn, and Zn are the most susceptible to bioconcentration in fish, with the most affected species being *Piaractus mesopotamicus* and *Serrasalmus spp.* above safety limits.
Keywords: Amazon fish, potentially toxic metals, human health.

A Mineração na Amazônia trouxe impactos socioambientais aos povos indígenas e ribeirinhos. A implantação de hidrelétricas altera as condições dos rios com adição metais potencialmente tóxicos, trazendo danos ao ecossistema e humanos. A investigação visa diagnosticar risco associado às populações locais pela ingestão de pescados consumidos na região da Volta Grande do rio Xingu, na Amazônica. Foram 60 exemplares das espécies pacu (*Piaractus mesopotamicus*), pescada (*Plagioscion spp.*), piranha (*Serrasalmus spp.*) e tucunaré (*Cichla spp.*) em duas regiões da Volta Grande (porção média e inferior). Os metaloides Al, Mn e Zn foram quantificados pelo Espectrômetro de Emissão Ótica com Plasma Acoplado e o Hg utilizou-se Análise Direta com Amalgamação de Ouro. Foram aplicados índices que avaliaram o risco à saúde associado como Target Hazard Quotient (THQ) and Total Target Hazard Quotient (TTHQ) e o risco do consumo de alimentos com Metais Potencialmente Tóxicos. Os resultados mostraram que Al, Mn e o Zn são mais suscetíveis à bioconcentração em peixes, com destaque para *Piaractus mesopotamicus* e *Serrasalmus spp*., trazendo riscos à saúde da população pelo seu consumo.
Palavras-chave: peixes amazônicos, metais potencialmente tóxicos, saúde humana.

1. INTRODUCTION

Currently, one of the main risks to human health is associated with food safety and the presence of chemical contaminants in food emerges as one of the most urgent problems [1]. The direct and indirect intrusion of chemical products, through punctual or diffuse effluents, provides a considerable advance in the index of metals and metalloids in the aquatic environment, with emphasis on elements such as Al, Hg, Mn, and Zn. When at high levels, they can potentially cause several changes in the aquatic ecosystem due to their easy integration into the food chain of the species and their high cumulative power due to non-degradability [2].

From this perspective, it is suggest that to assess the content of Metals with Toxic Potential (MPT) in water bodies, it is necessary to analyze the level of absorption in the species of the local ecosystem and fish emerge as the best analytical viability since they participate in all stages of the aquatic food chain [3].

In the Amazon, gold mining is one of the main extractive processes present in the region, it is explained that to perform metal isolation, the amalgam must be heated to separate the various associated metals that will consequently evaporate or solubilize in water bodies, especially Hg [4]. This situation ends up affecting the entire aquatic ecosystem, as the processes of bioaccumulation and trophic expansion allow the mobility of metals along the food chain, especially for carnivorous fish species [5]. Carnivorous species are favored due to their economic and commercial importance as a fishing resource in the Amazon region. It is featured in local cuisine and is a source of food for riverside fishermen and indigenous communities [3].

Once the presence of TPM is identified, the need to assess the environment is imperative [6]. Analytical strategies such as biomonitoring studies of native species can be used to outline contamination profiles and impacts on the health of animals and humans residing in the study region. Ribeiro et al. (2017) [7] corroborate the need to evaluate these effects in species from specific environments with very peculiar characteristics such as the Amazon, where they can directly influence the bioavailability of contaminants.

As the Amazon region presents great complexity regarding the biochemical processes that occur in ecosystems in general, the addition of chemical elements with high toxicity promotes in this a miscellany of chemical and biological interactions that can significantly interfere with the environmental balance and consequently in human health [8]. Along these lines, researchers such as Milačič et al. (2019) [9] agree with the importance of monitoring toxic metal concentrations, given the need to ensure compliance with food safety and consumer protection standards, in addition to preventing the extinction of native species.

The region of Volta Grande do Xingu in the municipality of Altamira, state of Pará, in the Brazilian Amazon is the subject of several environmental discussions over time mainly due to the recent implementation of the third largest hydroelectric complex in the world and the implications for the aquatic ecosystem that has not yet been is well characterized [10]. Authors such as Ribeiro et al. (2017) [7] state in research carried out in the region under study that mineral exploration activities cause several impacts, mainly due to the presence of Metals with Toxic Potential (MTP) both in water and in fish species.

Mendes et al. (2021) [11] report that this region has a diverse and rich biome of fauna and flora. It is a consensus that the region also stands out for the diversity of traditional communities such as example, indigenous and riverside peoples, with a social, economic, and cultural reality rooted in habits and customs inherited from generations.

Mayer et al. (2021) [12] report that the presence of numerous anthropic exploration activities directly affects the traditional peoples of the Xingu region, since they are dependent on local natural resources, such as fish consumption and the consultative use of water from rio. The authors point out that the most affected are the local populations due to the presence of several potentially toxic chemical substances.

In this context, the research focused on diagnosing the dietary risk to which riverside communities in the Volta Grande do Xingu region is subjected, using as an analytical and guiding instrument the main exposure indexes used in recent research on the subject.

2. METHODOLOGY

2.1 Study area

The Xingu River has a basin with an area of 531,250 km^2, its sources are located at altitudes of 600 m, at the junction of the Roncador mountain range with the Formosa mountain range, and has an elongated shape with about 350 km of average width and 1,450 km of length. The region called Volta Grande of the Xingu River begins after the city of Altamira (3º12'12.6" S; 52º12'22.3" W), a 100 km region where the Belo Monte hydroelectric plant is located and where the Juruna and Arara indigenous peoples [13]. In this region, of great biodiversity, historically, manual extraction of gold with the use of Hg takes place in places like Fazenda and Ressaca, the same region where a Canadian company is seeking the installation of the Belo Sun project of mechanized gold exploration using cyanide.

2.2 Sample collection

Sampling consisted of capturing 60 specimens of fish from four species most consumed by the local population. Fish specimens were collected in the area called the middle and lower portions of the Volta Grande of the Xingu River (Figure 1) in October 2022 through a single campaign that lasted five days to reach the entire extent of the researched area.

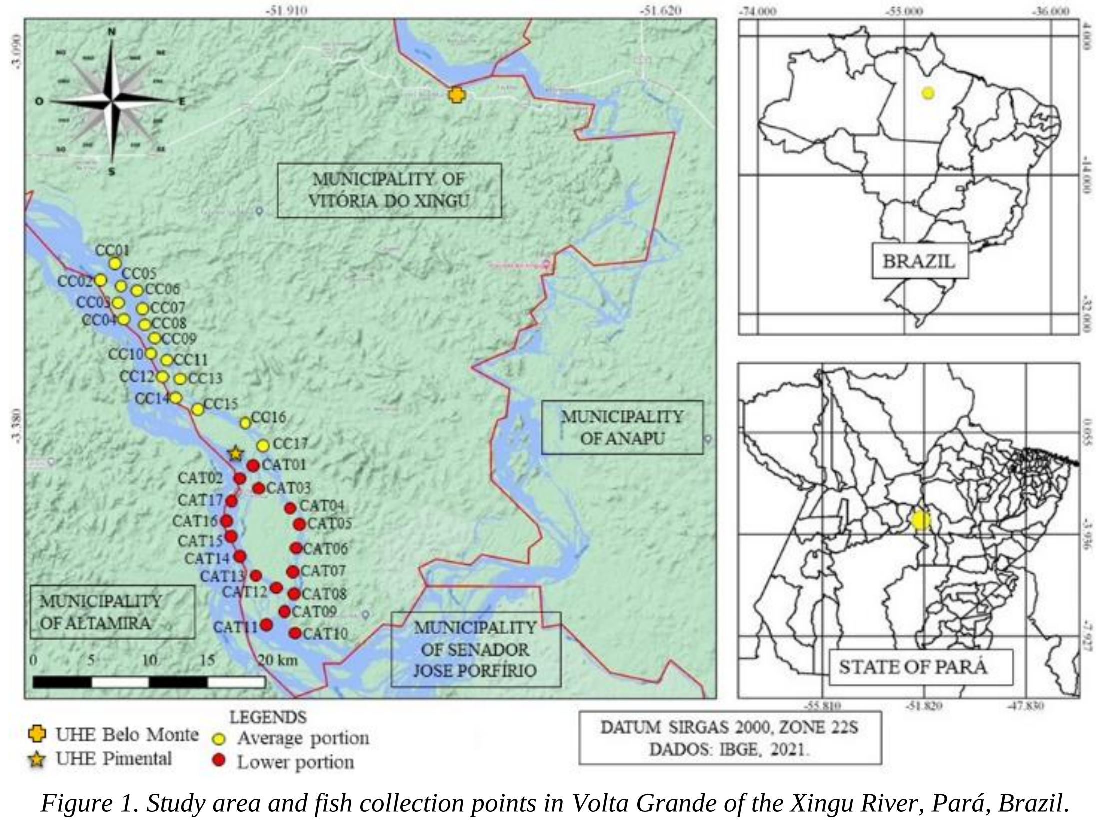

Figure 1. Study area and fish collection points in Volta Grande of the Xingu River, Pará, Brazil.

Fishing nets 1.1 m high and 12 m long were used to remove the fish muscles, with meshes varying between 3 cm and 15 cm, to optimize the capture of the species under study. The capture procedure followed that recommended by Albuquerque et al. (2020) [8]. The analyzed characteristics of the fish species are shown in Table 1. All samples were stored in identified frozen polyethylene bags and transported on ice to the laboratory. In the laboratory, they were stored in a freezer at -20 °C until analysis.

Table 1: Classification, habitat and food category of fish species collected.

Popular name	Scientific name	Family	Habitat	Dietary category
Pacu	*Piaractus mesopotamicus*	Characidae	Riverbeds with calmer waters.	Carnivore
Pescada	*Plagioscion* spp.	Sciaenidae	Large agglomerations in the central portion of lakes, ponds and reservoirs.	Carnivore
Piranha	*Serrasalmus* spp.	Characidae	Riverbeds, lakes and streams.	Carnivore
Tucunaré	*Cichla* spp.	Cichlidae	Marginal lagoons and igapó.	Carnivore

Source: Adapted from da Silva et al. (2021) [14].

2.3 Pre-treatment and opening of samples

The entire analytical procedure was developed as suggested by [8, 11, 14] with adaptations. The muscle of the captured specimens was removed and washed, dehydrated by lyophilization, ground, weighed, and solubilized by wet digestion with the aid of microwaves Provecto brand and model DGT 100 Plus.

2.4 Determination of metals and Hg

The entire analytical procedure was developed at the Laboratory of Analytical and Environmental Chemistry (LAQUANAM) localized at the Federal University of Pará (UFPA). For the determination of metals Al, Mn, and Zn, an optical emission spectrometer with inductively coupled plasma (ICP-OES) from Varian, Vista-Pro, was used. This step was developed based on the EPA method 6010D [15].

Hg was determined by atomic absorption spectrophotometry with preliminary thermal decomposition and gold amalgamation, using Direct Mercury Analyzer equipment, Brand DMA-80 (Milestone, Inc., Sheldon, Conn) [16].

2.5 Analytical quality

The analytical quality of the results was guaranteed in the studies of accuracy and precision using reference materials for fish DORM 4 (Canada), with recoveries of 93.9 % Al, 98.7 % Mn, 99.4 % Zn, and 91.8 % of Hg.

2.6 Statistical treatment

The analytical results were treated statistically using the SPSS® software version 21 for Windows®. To ensure the accuracy of the results, the sample set was subjected to the normality test to verify the predominant type of distribution.

2.7 Limits and Consumption Rates

The indices were based on studies performed by Saha et al. (2016) [17] and Miri et al. (2017) [18], which show the determination of the Percentage of Tolerable Weekly Intake (% PTWI) by humans of non-carcinogenic metals. To determine this factor Miri et al. (2017) [18] suggest using Equation 1.

$$\% PTWI = \frac{EWI}{PTWI} \times 100 \qquad \text{Equation 1}$$

Where:
EWI = Estimated Weekly Metal Intake (mg kg-1 body weight (bw)/week)
PTWI = Provisional Tolerable Weekly Intake (mg kg-1 body weight (bw)/week).
% PTWI = Percent Tolerable Weekly Intake (%).

Concerning the Provisional Tolerable Weekly Intake (PTWI), the metal levels adopted as a reference were those determined by Serrão et al. (2014) [19]: Al = 2.0 µg L^{-1}, Hg = 1.6 µg L^{-1}; for Mn = 7.0 µg L^{-1}; for Zn = 7.0 µg L^{-1}. Regarding the method of interpretation of the % PTWI results, it is suggested that the results be organized on a descending scale, as in this way, it is possible to classify the absorption rate taking into account the weekly fish intake [17, 18].

It is also suggested by Saha et al. (2016) [17] and Miri et al. (2017) [18] the determination of the Estimated Daily Intake Index (EDI), which evaluates the absorption of metals taking into account the daily consumption of fish. Equation 2 corresponds to the description for determining the EDI.

$$EDI = \frac{EF \times DE \times DFCR \times CF \times CM}{WAB \times AT} \times 10^{-3} \quad \text{Equation 2}$$

Where:
CF[1] = Conversion factor to convert fresh weight to dry weight.
CM = Concentration of metals in fish muscle.
EF[2] = Exposure frequency.
DE[3] = Duration of exposure.
DFCR[3] = Daily Fish Consumption Rate.
AT[4] = Average time of exposure to Potentially Toxic Metals (PTMs)
WAB[5] = Average body weight for adults.

2.8 Health risk assessment

In the Risk Assessment (RA), the Target Hazard Quotient (THQ) and Total Target Hazard Quotient (TTHQ) indices were used, both recommended by the United States Environmental Protection Agency [20] and widely used by authors such as Varol and Sünbül (2020) [21], Vieira et al. (2021) [22], and Nurulnadia et al. (2021) [23]. These results were obtained through equations 3 and 4.

$$THQ = \frac{CM \times DFCR \times 10^{-3} \times EF \times DE}{RFR \times WAB \times ATN} \quad \text{Equation 3}$$

$$TTHQ = \sum_{j=1}^{n} THQn \quad \text{Equation 4}$$

Where:
ATN = Average time of PTMs
RFR[6] = Oral Reference Dose for Metal Absorption.

Legend of numeric indexes:
[1] In the research, the moisture content determined in the fish samples was equal to 79%, which according to Saha et al. (2016) [17] corresponds to a factor equal to 0.208.
[2] 365 days $year^{-1}$.
[3] Value extracted from Mendes et al. (2021) [24], Viana et al. (2023) [25], and Viana et al. (2024) [26].
[4] Equal to EF × DE [17].
[5] 60 kg, as suggested by da Silva et al. (2019) [27] and Custódio et al. (2020) [28] in research developed in the studied region.
[6] Al = 1.0 µg L^{-1} day^{-1}; Hg = 0.1 µg L^{-1} day^{-1}; Mn = 0.14 µg L^{-1} day^{-1}; Zn = 0.3 µg L^{-1} day^{-1} [20].

The THQ is an index that assesses the potential risk of each metal with or without carcinogenic potential. Kwaansa-Ansah et al. (2019) [29] indicate that the interpretation should be as follows: when THQ is > 1, there is a probability of occurrence of potentially harmful effects, while when THQ ≤ 1, there is no probability of unfavorable effects. For the TTHQ, the interpretation of this indicator is directed towards an assessment of the risk associated with the addition of all metals with or without carcinogenic potential. The analysis follows the same pattern as for THQ: TTHQ > 1, probability of risk associated with ingestion, and TTHQ ≤ 1, no associated risk.

3. RESULTS AND DISCUSSION

3.1 Descriptive Exploratory Analysis

Table 2 describes the experimental results and adopted reference standards. Al was identified with the highest levels and the predominant species were: *Piaractus mesopotamicus*, *Plagioscion* spp., and *Serrasalmus* spp., with values above the limit indicated by Meche et al. (2010) [30].

This analysis shows that, among the studied species, the one that deserves more attention and concern is *Piaractus mesopotamicus*, as it presents Al, Mn, and Zn values above the levels considered in this research as safe for human consumption. In relation to the other species, the average concentration was below the established limits.

Regarding the variability of the analytical results, two behaviors that differ from each other were found. The first involved the species *Plagioscion spp.* and *Serrasalmus spp.* which did not show sample variability, indicating a homogeneous distribution of analytical results. The second involved the species *Piaractus mesopotamicus* and *Cichla spp.* which indicated a dispersion of the analyzed values, characterizing a heterogeneous distribution. This variability may be related to biometric factors. Avigliano et al. (2019) [31] report that most of the metals found in fish in South America have a heterogeneous distribution of analytical results.

Table 2. Descriptive analysis of metals in each analyzed fish species (μg g^{-1}).

Element	Species	Experimental					Mean	References
		Min.	Max.	Mean	SD	CV (%)		
Al	*Piaractus mesopotamicus*	3.44	42.0	**10.3**	7.91	76.8	2.83	[30]
	Plagioscion spp	5.54	10.3	**8.11**	1.65	20.3	6.61	[30]
	Serrasalmus spp	6.51	10.7	**9.03**	1.10	12.2	8.11	[30]
	Cichla spp	3.30	16.5	8.13	2.99	36.8	46.1	[32]
Hg	*Piaractus mesopotamicus*	0.05	0.18	0.11	0.03	27.3	1.00	[33]
	Plagioscion spp	0.14	0.28	0.23	0.03	13.0	0.50	[34]
	Serrasalmus spp	0.10	0.53	0.23	0.11	47.8	0.27	[35]
	Cichla spp	0.12	0.29	0.21	0.04	19.0	0.41	[8]
Mn	*Piaractus mesopotamicus*	0.31	1.44	**0.53**	0.29	54.7	0.10	[30]
	Plagioscion spp	0.09	0.44	0.35	0.11	31.4	0.36	[30]
	Serrasalmus spp	0.09	0.51	0.36	0.10	27.8	1.67	[30]
	Cichla spp	0.13	0.50	**0.40**	0.08	20.0	0.12	[8]
Zn	*Piaractus mesopotamicus*	2.27	10.6	**5.13**	1.88	36.6	4.48	[30]
	Plagioscion spp	3.32	5.89	4.81	0.71	14.8	9.00	[36]
	Serrasalmus spp	4.20	8.11	5.91	1.09	18.4	8.00	[36, 37]
	Cichla spp	3.24	5.85	4.58	0.71	15.5	6.00	[36]

Min.: Minimum; Max.: Maximum; SD: Standard Deviation; CV: Coefficient of Variation. In bold the values above the average of the references.

Regarding the concentration of Mn above the safety limit established in the research, the species that need more attention are *Piaractus mesopotamicus* and *Cichla spp.*, as high levels of this metal in the human body can affect the Central Nervous System (CNS) if the absorption is continuous [8, 30].

Regarding Zn, the only species that presented an average value above the established safety limit was *Piaractus mesopotamicus*. The statistical results indicate a significant variability of the analytical results, affecting the average value determined. According to Gutiérrez-Mosquera et al. (2021) [38], this variability is common in Amazonian fish species and may be a consequence of the diet to which they are submitted. They reiterate that the presence of anthropic activities such as mining and industry and the release of effluents into water bodies contribute significantly to the alteration of the aquatic ecosystem, mainly due to the intrusion of Toxic Chemical Substances (TCS).

Regarding Hg, discrepant results were not identified in the average levels, to the point of being reported with greater emphasis, although the presence of Hg in the analyzed samples serves as a warning regarding the carcinogenic risk that this metal can cause.

From a socio-environmental point of view, the results point to a risk associated with the consumption of these species that are part of the diet of the communities researched. The presence of metals, such as Zn, in the analyzed species highlights the need to correlate environmental factors and health problems of riverside populations, as this has characteristics of an essential element for the organism, although when in high concentrations it can cause anemia and alterations in the immune system [39]. The recommendation of the Maximum Daily Intake for the element is 7 mg kg^{-1} $week^{-1}$ [33].

The high levels of Al diagnosed in the analyzed fish species may be related to the geochemistry of the Amazonian soils where the presence of this metal is favored [7]. Meche et al. (2010) [30] report that the acidity of water bodies resulting from the presence of humic acids facilitates the bioavailability of this metal at trophic levels and in the food chain.

3.2 Bivariate correlation

The results of the statistical tests showed the existence of direct and indirect linear correlations between the set of metallic variables and biometric factors (Table 3). The direct relationships highlight the Hg and the weight of the fish collected and the indirect relationship has the following pairs: Al, Mn, and Zn with the length of the fish and Zn with the width of the fish.

Table 3. Correlation between metals and biometric factors.

Elements	Correlation	Mass (g)	Length (cm)	Width (cm)
Al	PC	-0.16	**-0.25***	-0.21
	Sig	0.19	0.04	0.10
Hg	PC	**0.48****	0.18	-0.18
	Sig	0.05	0.15	0.15
Mn	PC	-0.16	**-0.24***	-0.10
	Sig	0.21	0.04	0.42
Zn	PC	-0.24	**-0.27***	**-0.27***
	Sig	0.06	0.03	0.03

PC: Pearson correlation coefficient; Sig: Significance; *The correlation is significant at the 0.05 level (two floating points); **The correlation is significant at the 0.01 level (two floating points).

Based on the results, it is possible to infer that the biometric factors influence the absorption of metals in the researched species. In the case of Hg, the average levels determined below the established safety limit are directly due to the weight of the fish collected and for the metals Al, Mn, and Zn, the length and width of the fish become preponderant factors for its bioaccumulation, corroborating the results of Avigliano et al. (2019) [31].

By correlating the results of the applied statistical tests, the species *Piaractus mesopotamicus* as being the most susceptible to pre-concentration of metals Al, Mn, and Zn, becoming the fish with the highest risk of contamination when consumed. This predisposition is associated with the weight, length, and width of the fish. The species *Plagioscion spp.* and *Serrasalmus spp.* are the most susceptible to Al absorption in a situation inversely proportional to the length of the fish. This situation is repeated with the species *Cichla spp.* for the Mn.

Regarding Hg, despite not presenting significant results, it is directly correlated with the weight of the fish, indicating a condition of proportionality in the sense that the greater its weight, the greater the concentration of the metal. Among the studied species, *Plagioscion spp.* and *Serrasalmus spp.* showed the highest mean levels of Hg, although with mean values lower than those established as safety limits.

3.3 Limits and Consumption Rates

Based on Mendes et al. (2021) [24], Viana et al. (2023) [25], and Viana et al. (2024) [26], it was possible to identify some patterns that differ between the middle and lower portions of Volta Grande, among them the predominant age group, in which the lower portion stands out for having an average age of 40 years, food most consumed and fish consumption frequency of 4 to 6 times/week, all above when compared to the average portion. From the tabulation of the results, it was possible to establish that the Duration of Exposure (DE) was 40 years and the Daily Fish Consumption Rate (DFCR) was 36 g/person/day.

The Estimated Daily Intake (EDI) and the Percentage of Tolerable Weekly Intake (% PTWI) are presented in Table 4. It should be noted that the information extracted from Mendes et al. (2021) [24], Viana et al. (2023) [25], and Viana et al. (2024) [26] served as subsidies for the determination of the indices used in this research.

Table 4. The EDI and % PTWI values recorded for the different metals detected in the fish species.

Fish Species (Middle Portion)	**EDI** ($\mu g\ L^{-1}\ bw^{-1}\ day^{-1}$)				**% PTWI**			
	Al	**Hg**	**Mn**	**Zn**	**Al**	**Hg**	**Mn**	**Zn**
Piaractus mesopotamicus	$1.12E^{-6}$	$1.20E^{-8}$	$5.77E^{-8}$	$5.58E^{-7}$	**9.2**	0.1	0.1	1.3
Plagioscion spp.	$8.83E^{-7}$	$2.50E^{-8}$	$3.81E^{-8}$	$5.24E^{-7}$	**7.3**	0.2	0.1	1.2
Serrasalmus spp.	$9.83E^{-7}$	$2.50E^{-8}$	$3.92E^{-8}$	$6.43E^{-7}$	**8.1**	0.4	0.1	1.5
Cichla spp.	$8.85E^{-7}$	$2.29E^{-8}$	$4.03E^{-8}$	$4.99E^{-7}$	**7.3**	0.2	0.1	1.1
Fish Species (Lower Portion)	**EDI** ($\mu g\ L^{-1}\ bw^{-1}\ day^{-1}$)				**% PTWI**			
	Al	**Hg**	**Mn**	**Zn**	**Al**	**Hg**	**Mn**	**Zn**
Piaractus mesopotamicus	$4.20E^{-7}$	$4.49E^{-9}$	$2.16E^{-8}$	$2.09E^{-7}$	**18.5**	0.2	0.2	2.6
Plagioscion spp.	$3.31E^{-7}$	$9.39E^{-9}$	$1.43E^{-8}$	$1.96E^{-7}$	**14.6**	0.5	0.1	2.4
Serrasalmus spp.	$3.69E^{-7}$	$9.39E^{-9}$	$1.47E^{-8}$	$2.41E^{-7}$	**16.2**	0.5	0.1	3.0
Cichla spp.	$3.32E^{-7}$	$8.57E^{-9}$	$1.51E^{-8}$	$1.87E^{-7}$	**14.6**	0.4	0.1	2.3

In bold the highest values; bw: body weight.

Using the discussion pattern carried out by Miri et al. (2017) [18] and Kwaansa-Ansah et al. (2019) [29], it was found that in relation to the Estimated Daily Intake of fish for the middle portion of Volta Grande do Xingu, it presented the following order of absorption of metals: Al > Zn > Mn > Hg. This pre-concentration pattern is repeated when evaluating the estimated weekly intake rate. The pattern was repeated among all studied species.

In the lower portion of Volta Grande do Xingu, the EDI presented the following uptake order: Al > Zn > Mn > Hg and the % PTWI was: Al > Zn > Hg > Mn, indicating the existence of a difference between weekly intake rates in the studied areas. This condition is similar to that described by Miri et al. (2017) [18]. This analysis sought to classify which species are more susceptible to metal absorption and which are the risks to human health based on EDI and % PTWI indices.

In the area defined as the middle portion, the result of this combination provided the following diagnosis: the most prominent metal was Al and the descending classification of the researched species was *Piaractus mesopotamicus* > *Plagioscion* spp. > *Cichla* spp. > *Serrasalmus* spp.

In the area defined as the lower portion, the result of the combination generated the following interpretation: the highlighted metal was Al, and the absorption ranking of the species *Piaractus mesopotamicus* > *Plagioscion* spp. > *Cichla spp.* > *Serrasalmus* spp.

The results reflect that the areas studied have similar conditions and that anthropic factors, such as the discharge of effluents from mining and industrial activities into the Xingu River, favor the accumulation of metals present in fish [27].

It has been reported in their research that the analysis of EDI and % PTWI allows for assessing the safety level of foods commonly consumed by a given population [21, 22]. Regarding the situation of the researched population, the diagnosis indicates that the most consumed fish in the region present a risk to the health of the population, mainly the species *Piaractus mesopotamicus*.

3.4 Health risk assessment

For the exposure time (TA), information on the frequency of consumption of the main foods was used to calculate the number of days within one year that the resident applies this diet, thus reaching values of 156 days (3 times a week) for the middle portion group and 312 days (6 times a week) for the lower portion group. Having established the rules, the main considerations about the THQ (Table 5) point to the Zn element referring to the *Serrasalmus* spp. in the middle portion, and the species *Piaractus mesopotamicus, Plagioscion* spp., *Serrasalmus* spp. and *Cichla* spp. in the lower portion.

Kwaansa-Ansah et al. (2019) [29] report that the Us Epa (2013) [20] establishes THQs greater than one that imply excessive exposure to the contaminant and, therefore, a risk to food safety.

Table 5. Results of the Total Hazard Quotient (THQ) and Total Target Hazard Quotient (TTHQ).

Species (Middle portion)	**THQ**				**TTHQ**
	Al	**Hg**	**Mn**	**Zn**	
Piaractus mesopotamicus	0.56	0.06	0.20	0.92	**1.74**
Plagioscion spp.	0.44	0.12	0.14	0.87	**1.56**
Serrasalmus spp.	0.49	0.12	0.14	**1.06**	**1.81**
Cichla spp.	0.44	0.11	0.14	0.82	**1.52**
Species (Lower portion)					
Piaractus mesopotamicus	0.74	0.08	0.27	**1.23**	**2.32**
Plagioscion spp.	0.58	0.17	0.18	**1.15**	**2.08**
Serrasalmus spp.	0.65	0.17	0.19	**1.42**	**2.42**
Cichla spp.	0.59	0.15	0.19	**1.10**	**2.03**

THQ and TTHQ >1 (bold) implies a risk to food safety [29].

As for the results of the TTHQs for the species studied, the understanding is that the greatest risk associated with the concentration of metals was attributed to the lower portion, although the middle portion presents values greater than one. As for the total associated risk, the order of accumulation in the species in both the middle and lower portions is *Serrasalmus* spp. > *Piaractus mesopotamicus* > *Plagioscion* spp. > *Cichla* spp. thus demonstrating the health risk of consuming these species.

4. CONCLUSIONS

The research provided a study on the risks associated with the ingestion of food from bioaccumulative processes, such as fish. It was identified statistically that the metals Al, Mn, and Zn appear as the most susceptible to absorption by the studied species and that this condition makes the ingestion of these foods dangerous.

In the analysis of the ingestion rate, the results point to Al, Mn, and Zn with the highest concentration in the fish species analyzed, with emphasis on *Piaractus mesopotamicus* both in the middle and lower portions of the Volta Grande of the Xingu River. These results explain the problem of food security consumed in the Amazon region since the frequency of fish consumption is between 3 and 6 times a week.

With the analysis of THQ and TTHQ, it was verified that the species *Piaractus mesopotamicus* and *Serrasalmus spp.* emerged with a higher toxic risk for humans due to the high content of Al and Zn.

Based on the interpretations of the tests proposed in the investigation and corroborated by the reports of the authors cited in this document, it was possible to verify that there is a problem in the Volta Grande do Xingu region regarding the concentration of metals in the fish of the species most consumed by the local population, which deserves greater attention from both the scientific community and government health agencies.

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