Research Paper

Health Risk Assessment of Heavy Metals: Cu, Cd, Pb, Ni and Hg, in Catfish *Ariopsis felis* in Southern Mexico

Carlos Montalvo Romero[1] , Claudia Aguilar Ucán[1*] , Angel Sosa Peralta[1] , Jesus Tagle Reyes[1] , Yunuen Canedo López[1] , Atl Victor Córdova Quiroz[1] , Alejandro Ruíz Marín[1]

1. Department of Chemical Sciences, Faculty of Chemistry, Autonomous University of Carmen, Campeche, Mexico.

ABSTRACT

Background: Metal pollution is a problem in many parts of the world. These metals can be harmful when they exceed the recommended limits. By analyzing metal concentrations in living organisms, it is possible to deduce the bioavailability and the level of environmental contamination for specific metals in an ecosystem. The aim of this study was to determine the heavy metals copper, cadmium, lead, nickel and mercury in edible tissues of fish, to establish the risk analysis for human health. There are currently no studies in this area indicating these factors.

Methods: The edible tissue samples were treated under the techniques of the official mexican standards (NOM-117-SSA1) and analyzed using atomic absorption spectroscopy (flame and graphite). The heavy metal concentrations were used to calculate the estimated daily intakes, target hazard quotients, hazard indices, and target cancer risks for children and adults.

Results: The highest concentrations of copper (138.82 μg/g), cadmium (1.28 μg/g) and lead (3.20 μg/g) in the edible tissue samples exceeded the permissible limits considered in this study while nickel and mercury levels did not. The target hazard quotient indices for copper, cadmium and nickel in specific sites were higher than the United States Environmental Protection Agency (US-EPA) criteria (>1), while the values for mercury and lead were below one. The hazard indices were higher than the US-EPA criteria (>1) in more than 50% of the sites analyzed.

Conclusion: This study is an alert, indicating that inhabitants who consume the fish, particularly children, are at risk of cadmium, lead and nickel toxicity.

Keywords: Carcinogenic risk, Catfish *A. felis,* Health risk assessment, Heavy metals

Introduction

Currently, coastal ecosystems are exposed to a heavy metal pollution due to the current industrial and urban activities. This problem arises from the fact that large amounts of waste materials are dumped without proper advance treatments. Heavy metals are of special interest because they are highly persistent, toxic, and can accumulate in the exposed organisms [1, 2]. During the transport of heavy metals to the sea, they undergo physical and chemical transformations, such as: precipitation, sedimentation and adsorption in the sediments, all of these make them available to the aquatic life [3]. In this context, heavy metals contamination is

a serious threat to aquatic systems due to their toxicity, abundance and persistence in the environment [4].

Cadmium (Cd) is a non-essential element that is generated as a waste material from fertilizer production and other industrial activities. There are no natural sources that generate and release Cd into the environment [5]. In species, such as Galaxias maculatus the effects of Cd on the metabolic processes have been observed, including the deterioration of oxygen consumption, stress parameters, and decreased activity of hepatic catalase enzyme [6]. Copper (Cu) is an essential trace element that can cause harmful effects in fish and tend to accumulate heavy metals in their tissues, causing damages, such as histopathological alterations [7]. Lead (Pb) is a potential threat to aquatic life, leading to decreases in red and white blood cells in both humans and fish. It also decreases blood hemoglobin, and is responsible for a rise in the rate of serum heterophile antigens [8].

Catfish, *Ariopsis felis* (*A. felis*), is produced and marketed in Mexico either captured from the sea or at aquaculture farms. It is popular for its flavor and nutritional benefits, and is a source of high economic profits, its capture and production is carried out by various communities in Mexico [9]. The American Heart Association recommends the consumption of fish for the useful fatty acids contents [10]. There are few studies conducted in Mexico on this subject. One of the studies that was undertaken in the Gulf of Mexico, showed that the abundant toxic metals found in the catfish tissues were chrome (Cr), vanadium (V), and nickel (Ni) [11].

Health risk analyses allow us to predict the possible adverse effects on humans arising from carcinogens and non-carcinogens due to the consumption of species that are exposed to toxic food contaminants. This study was designed to investigate the presence of specific heavy metals and the degree of contamination in edible tissue samples of catfish *A. felis* that grows in Mexico, and to compare the levels with the safe limits set by national and international organizations, such as Food and Agriculture Organization (FAO), World Health Organization (WHO), Ministry of Agriculture Forestry and Fisheries (MAFF), and Official Mexican Standards (NOM).

Materials and Methods

Geographic Area: Pom-Atasta system in Mexico is located in the western part of the Terminos Lagoon, between 18°, 30' and 18°, 35' north latitude and 91°, 50 ' and 92°, 20' west longitude. It is part of the coastal plain of Campeche, supplied by the Grijalva and Usumacinta

rivers. This aquatic system consists of interior lagoons of variable dimensions, with a total area of approximately 300 km² and a depth of 2.7 meters. Atasta and Pom are the largest body of waters, and include banks where clams (*Rangia cuneata*), oysters (*Crassostrea virginica*), crab (*Callinectes sapidus*) and catfish are caught commercially. The water temperature in this area ranges between 25.6 and 32.6°C with the transparency of 20 to 83.3%. The oxygen content in these waters vary widely, from 4.2 to 8.2 ml/L. This aquatic system is dominated by clay silt sediments with a low content of calcium carbonate [12].

Marine Sample Collection: In Atasta Lagoon (Figure 1), fishing make up an important economic activity. To catch the marine organisms, two sampling campaigns were carried out in the rainy and dry seasons (Table 1). The organisms were collected through artisanal fishing techniques, using casting net. A total of 60 catfish samples were caught.

Sample preparation for analyses: The edible tissue was dissected and removed from each fish, using a composite sample type. These tissues were homogenized in a food processor, obtaining a sample of 20 g, which were treated according to the method suggested by the official Mexican standards [13]. The tissue digestion was achieved by the addition of 10 ml of nitric acid (HNO_3; CAS 7697-32-2; Sigma Aldrich) followed by heating the homogenate at controlled temperature and the addition of 2mL hydrogen peroxide H_2O_2 (CAS 7722-84-1; Sigma Aldrich) in 30% solution. The digested samples were concentrated to a volume of 1mL, and filtered through Whatman #32 paper. Finally, the filtrate was made up to 20 ml for the subsequent analyses.

Sample analyses: The edible tissue samples were analyzed in an atomic flame absorption equipment adapted with a Thermo-Scientific brand graphite furnace (iCE 3000). For the quality control of the procedures, the traceable reference materials of the ARSA spectrometric solutions were used. These were produced under the NMX-EC-17025-IMNC-2006 standard (the general requirements for the competence of testing and calibration laboratories). For the quality control and calibration of the equipment, the Limits Of Detection (LD) and Quantification (LQ) were estimated.

Statistical analyses: The variation of the mean concentrations of heavy metal contents in the edible tissue were evaluated according to the climatic season (rainy, dry) and the site, by means of a one way analysis of variance (ANOVA, $\alpha=0.05$), using the statistical package, Statistica software, version 7.1.
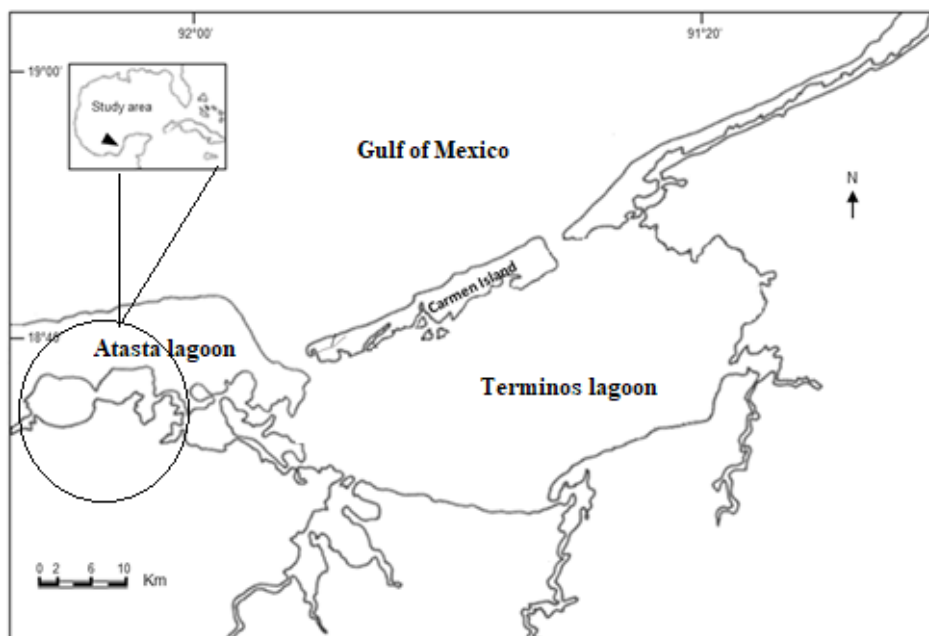
Figure 1. Study area

Risk Analysis: According to the US-EPA [14], the evaluation of health risks is based on such parameters as estimated daily intake (EDI), target hazard quotient (THQ), hazard index (HI) and target cancer risk (TCR), using the following equations (Equation 1):

1. $EDI = \dfrac{(FIR)(MC)}{(Bwc)}$

Where:

FIR = Proportion of fish consumed (100g, children; 240g, adult men/women/week) [9, 15].

MC = Concentration of the metal in μg/g.

Bwa = The average body weight of the population of interest (70kg, men; 60kg, women, and 16 kg, children aged 4-6 years) [15].

Target Hazard Quotient (THQ): To set up these values, the US-EPA risk analysis standards [14] were used. Equation 2 shows the estimate of THQ, in which the correction factors were not used [15-17] .

2. $THQ = \dfrac{(Efr)(EDtot)(FIR)(MC)}{(Rfd)(Bwa)(Atn)}$

Where:

Efr = Frequency of exposure (365 days/year)

EDtot = Frequency of exposure (Mexican population: 70 years).

Rfd = Reference dose of individual metal (μg/g/day); 5×10^{-4} for Hg; 1×10^{-3} for Cd; 4×10^{-3} for Pb; 2×10^{-2} for Ni and 4×10^{-2} for Cu [15-17].

Atn = Average time for non-carcinogens (EfrxEDtot).

Hazard Index (HI): was determined with the individual sum of each of the analyzed factors that represent the target hazard quotient and Equation 3.

3. $HI = \displaystyle\sum_{Toxican\,1}^{Toxican\,n} THQ$

Target Cancer Risk (TCR): was based on Region III values of US-EPA criteria [18], and Equation 4.

4. $TCR = \dfrac{(Efr)(ED)(FIR)(MC)(CPSo)}{(Bwa)(Atn)}$

Where:

Carcinogenic Potency Slope (CPSo): CPSo , oral (μg/g bw/day) 8.5×10^{-3} for Pb, [18] 1.7 for Ni [19] and 2.59×10^{-4} for Cd [19].

Results

Heavy metals in edible tissue samples: In the present study, only the edible tissue (muscles), were selected for analyses. The quality control parameters are shown in Table 2. The results obtained for the edible tissues are shown in Table 3.

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

165

Table 1. Sampling sites and geographic coordinates along Atasta lagoon, Mexico

Sampling Site	Geographical Coordinate
1	8°34'57.69"N 92° 8'39.68"O
2	8°34'57.69"N 92° 8'39.68"O
3	18°34'49.27"N 92° 6'30.09"O
4	18°35'22.17"N 92° 4'50.89"O
5	18°34'47.82"N 92° 4'90.41"O
6	18°35'31.63"N 92° 4'50.22"O
7	18°36'21.76"N 92° 3'55.16"O
8	18°36'45.84"N 92° 4'42.91"O
9	18°37'60.39"N92° 5'17.21"O

Copper: The seasonal averages of Cu were 68.25 µg/g for the dry and 39.74 µg/g for the rainy seasons. The statistical analyses indicated that there were significant differences for the sites and the seasons (P<0.05). The Mexican legislation (NOM) does not consider Cu as a pollutant in fish; however, the international standards set by FAO and WHO allow a maximum of 20 and 30 µg/g respectively, so the detected levels were above these limits (Table 4) [20, 21]. The average values did not exceed any of the required limits.

Cadmium: The concentration of Cd was higher in the dry season with the maximum being 1.2864 µg/g (site 3) which exceeded the permissible limits of 0.5 µg/g by the Mexican legislation NOM [21] and the international limits of FAO and MAFF whose permissible levels are 0.5 and 0.2 µg/g, respectively (Table 4) [20-23]. The average in the dry season were 0.223 and 0.046 µg/g in the rainy season. Statistically, there were significant differences for the climatic season (P<0.05). Total average value did not exceed any of the recommended limits.

Lead: The average value for lead, determined in the dry season, was 0.907 µg/g, which exceeded the values (0.5 µg/g) set by FAO and JECFA (Table 4) [20, 24]. The highest concentration found in the dry season of 3.209 µg/g (site 7) was above the permissible limits of FAO, WHO, NOM, MAFF and JECFA (Table 4) [20-24] whose limits are 0.5, 2.0, 1.0, 2.0 and 0.5 µg/g, respectively. In the rainy season, the average value was 0.0439 µg/g, which did not exceed any of the recommended limits.

In the current study, significant differences existed among the sites and seasons, based on the statistical analysis (P<0.05). However, the average value 0.224 µg/g did not exceed any of the recommended limits.

Nickel: The maximum concentration found for Ni (41.77 µg/g) occurred in the rainy season at site 5. The average values for the dry and the rainy seasons were 5.73 µg/g and 10.22 µg/g, respectivily. Statistically, there were significant differences for Ni per climatic season (P<0.05). The US-FDA [25] has established a maximum limit of 70-80 µg/g of Ni in fish (Table 4), the results obtained by our study were within the international limits.

Mercury: The maximum value of Hg was 0.03 µg/g during the rainy season (site 4) and all of the values determined were lower than the maximum permissible of 0.5 µg/g set by WHO and Mexican legislation (NOM) [21, 22]. The international limits (Table 4) has established a maximum level of 0.05 µg/g for Hg in fish.

Accumulation of Cu, Cd and Pb in specific sites were higher than the recommended limits set by FAO, WHO, NOM, MAFF and JECFA [20-24]. Hence, the human health risk assessments were carried out.

Risk analysis: The evaluation of risks to human health is "The process to estimate the nature and probability of adverse effects on human health when exposed to chemicals in contaminated environments" US-EPA [14]. The Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), Hazard Index (HI) and Target Cancer Risk (TCR) are shown in Tables 5-7.

THQ in children: This value should not exceed 1; if the detected value is lower than one, it is interpreted that there is no evidence of adverse effects or potential carcinogenic risk in the exposed population. In the present study, the THQ value was higher than one for Cu at sites 4 and 7 (dry season) and 1, 3 and 5 (rainy season), for Cd

166

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

Table 2. Quality control parameters.

Metal	Wavelength (nm)	LD (µg/g)	LQ (µg/g)	Standard Calibration (µg/L)	Correlation Coefficient (R²)
Cu	324.8	0.190	0.109	0, 3, 5, 10, 20,50, 100	0.985
Cd	228.8	0.033	1.561	0, 0.1, 0.3, 0.5, 1.5, 3.5	0.989
Pb	217.0	0.095	0.290	0, 0.1, 0.2, 0.5, 5, 10	0.956
Ni	283.3	0.515	0.101	0, 0.1, 2, 10, 20, 30,50	0.956
Hg	253.7	0.036	0.578	0, 0.1, 0.2, 0.5, 1, 1.5, 5	0.995

Table 3. Average values in the edible tissue samples of catfish *A. felis* in µg/g.

Site	Climatic Season	Edible Tissue Samples				
		Cu	Cd	Pb	Ni	Hg
1	1	10.7000	0.6287	0.2567	5.0303	0.0032
2	1	ND	ND	ND	ND	ND
3	1	27.040	1.286*	0.144	14.599	0.002
4	1	96.460	0.022	0.018	14.967	0.029
5	1	ND	ND	ND	ND	ND
6	1	ND	ND	ND	ND	ND
7	1	138.820*	0.069	3.209*	16.963	0.004
8	1	ND	ND	ND	ND	ND
9	1	ND	ND	ND	ND	ND
1	2	46.350	0.002	0.149	20.877	0.001
2	2	ND	ND	ND	ND	ND
3	2	61.300	0.380	0.029	23.131	0.018
4	2	0.850	0.004	0.010	2.199	0.029
5	2	46.000	0.004	0.027	41.774*	0.003
6	2	1.220	0.009	0.027	1.633	0.015
7	2	42.670	0.007	0.046	1.198	0.001
8	2	42.290	0.000	0.110	0.575	0.002
9	2	38.410	0.008	0.003	0.627	0.021
Average* Standard deviation		30.672	0.134	0.224	7.976	0.007
		38.802	0.331	0.748	11.708	0.010

* Determined maximum value. **Average values for 3 replications. Climatic season: 1 (dry); 2 (rainy). ND: Not detected.

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

167

Table 4. Recommended limits of heavy metals in fish (µg/g).

Agency	Year	Cu	Cd	Pb	Ni	Hg	Reference
FAO	1983	30	0.5	0.5	-	0.5	[21]
WHO	1996	20	2	2	-	0.05	[22]
NOM	2009	-	0.5	1	-	1	[23]
MAFF	2000	20	0.2	2	-	-	[24]
JECFA	1989	-	-	0.5	-	0.5	[25]
US-FDA	1993	-	-	-	70-80	-	[26]

Table 5. Estimated daily intake (EDI) (µg/kg/week) values of metals via consumption of edible tissue samples of catfish *A. felis*

Site	Climatic Season	Children: Estimate Based on Mean Body Weight (16 kg)					Adults: Estimate Made Based on the Average Body Weight (70 kg)				
		Cu	Cd	Pb	Ni	Hg	Cu	Cd	Pb	Ni	Hg
1	1	66.875	3.929	3.929	31.439	0.020	36.685	2.155	0.880	17.246	0.010
2	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	1	169.000	8.040	8.040	91.248	0.0183	92.708	4.410	0.4944	50.056	0.010
4	1	602.875	0.137	0.137	93.545	0.183	330.720	0.075	0.0624	51.316	0.100
5	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	1	867.625	0.436	0.436	106.022	0.029	475.954	0.239	11.004	58.160	0.016
8	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1	2	289.680	0.013	0.013	130.481	0.009	158.914	0.0072	0.512	71.578	0.005
2	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	2	383.125	2.378	2.378	144.573	0.116	210.171	1.304	0.101	79.308	0.063
4	2	5. 312	0.030	0.030	13.749	0.186	2.914	0.016	0.034	7.542	0.102
5	2	287.500	0.028	0.028	261.087	0.022	157.714	0.015	0.094	143.225	0.0120
6	2	7. 625	0.061	0.061	10.208	0.098	4.182	0.033	0.095	5.599	0.054
7	2	266.687	0.046	0.046	7.492	0.006	146.297	0.025	0.158	4.110	0.003
8	2	264.312	0.005	0.005	3.593	0.018	144.994	0.002	0.379	1.971	0.010
9	2	240.062	0.055	0.055	3.922	0.135	131.691	0.030	0.011	2.151	0.074

Climatic season: 1 (dry); 2 (rainy). ND: Not detected.

Table 6. Target Hazard Quotient (THQ) and Hazard Index (HI) values of metals via consumption of edible tissue samples of catfish *A. felis*

Site	Climatic Season	Children: Mean Body Weight (16 kg)					HI: Children	Adults: Mean Body Weight (70 kg)					HI: Adults
		Cu	Cd	Pb	Ni	Hg		Cu	Cd	Pb	Ni	Hg	
1	1	0.238	0.561	0.057	0.224	0.005	1.087[**]	0.131	0.307	0.031	0.123	0.003	0.596
2	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	1	0.603	1.148[*]	0.032	0.651	0.005	2.441[**]	0.331	0.630	0.017	0.357	0.002	1.339[**]
4	1	2.153[*]	0.019	0.004	0.668	0.052	2.897[**]	1.181[*]	0.010	0.002	0.366	0.028	1.589[**]
5	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
6	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
7	1	3.098[*]	0.062	0.716	0.757	0.008	4.643[**]	1.699[*]	0.034	0.393	0.415	0.004	2.547[**]
8	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
9	1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
1	2	1.034[*]	0.001	0.033	0.932	0.002	2.004[**]	0.567	0.001	0.018	0.511	0.001	1.099[**]
2	2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
3	2	1.368[*]	0.339	0.006	1.032[*]	0.033	2.780[**]	0.750	0.186	0.003	0.566	0.018	1.525[**]
4	2	0.018	0.004	0.002	0.098	0.053	0.177	0.010	0.002	0.001	0.053	0.029	0.097
5	2	1.026[*]	0.004	0.006	1.864[*]	0.006	2.908[**]	0.563	0.002	0.003	1.023	0.003	1.595[**]
6	2	0.027	0.008	0.006	0.072	0.028	0.143	0.014	0.004	0.003	0.039	0.015	0.078
7	2	0.952	0.006	0.010	0.053	0.001	1.024[**]	0.522	0.003	0.005	0.029	0.001	0.562
8	2	0.943	0.000	0.024	0.025	0.005	1.000[**]	0.517	0.000	0.013	0.014	0.002	0.548
9	2	0.857	0.007	0.000	0.028	0.038	0.932	0.470	0.004	0.000	0.015	0.021	0.511

Climatic season: 1 (dry); 2 (rainy). ND: Not detected. [*]=THQ>1, [**]HI>1.

at site 3 (dry season), and for Ni at sites 3 and 6 (rainy season). THQ values weare less than one for Pb and Hg in all sites and seasons.

HI in Children: In this study, 50% of the sites exceeded the values of the comparison standard, i.e., HI>1.

THQ in Adults: The THQ value in adults were only greater than one for Cu in sites 4 and 7 (dry season).

HI in Adults: The values obtained for 33% of the sites exceeded those of the comparison standards, i.e., HI>1.

For Cu and Hg, the TCR values wwere not determined, and there were no carcinogenic potency slope, oral (CPSo) values [26].

Discussion

The internal organs of fish tend to accumulate heavy metals [27-30]. Analogous results were shown in the fish, Pterois volitans [28]. In an study conducted on Kyphosus vaigiensis, Stegastes rectifraenum and Balistes polylepi [29] the authors concluded that Cd and Cu accumulated differently in the organs. The findings agree with the bioaccumulation studies on muscle, liver and gills in Cyprinus carpio, where no significant differences were found in the metals' levels in the muscle and liver [30], supporting the hypothesis that fish muscle is a good indicator of heavy metals contamination [27-30].

The bioavailability of metals in the muscles of Ictalurus punctatus, Lepomis cyanellus and Lepomis macrochirus is subject to climatic conditions [31], and the findings are

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

169

Table 7. Target Cancer Risk (TCR) values of metals via consumption of edible tissue samples of catfish *A. felis*

Site	Climatic Season	Children: Mean Body Weight (16 kg)			Adults: Mean Body Weight (70 kg)		
		Cd	Pb	Ni	Cd	Pb	Ni
1	1	8.161E-09	4.465E-08	0.003	2.455E-09	1.343E-08	0.001
2	1	ND	ND	ND	ND	ND	ND
3	1	3.416E-08	1.409E-08	0.028	1.021E-08	4.240E-09	0.008
4	1	9.993E-12	2.244E-10	0.030	3.007E-12	6.754E-11	0.0091
5	1	ND	ND	ND	ND	ND	ND
6	1	ND	ND	ND	ND	ND	ND
7	1	1.008E-10	6.980E-06	0.038	3.035E-11	2.100E-06	0.011
8	1	ND	ND	ND	ND	ND	ND
9	1	ND	ND	ND	ND	ND	ND
1	2	9.105E-14	1.512E-08	0.059	2.740E-14	4.551E-09	0.017
2	2	ND	ND	ND	ND	ND	ND
3	2	2.990E-09	5.977E-10	0.0725	9.000E-10	1.798E-10	0.021
4	2	4.757E-13	7.049E-11	0.000	1.431E-13	2.121E-11	0.000
5	2	4.181E-13	5.124E-10	0.236	1.252E-13	1.542E-10	0.071
6	2	2.023E-12	5.274E-10	0.000	6.089E-13	1.587E-10	0.000
7	2	1.161E-12	1.440E-09	0.000	3.495E-13	4.333E-10	5.861E-05
8	2	1.321E-14	8.288E-09	4.480E-05	3.976E-15	2.494E-09	1.348E-05
9	2	1.635E-12	7.379E-12	5.338E-05	4.921E-13	2.220E-12	1.606E-05

Climatic season: 1 (dry); 2 (rainy). ND: Not detected.

consistent with our results. In the current study, the Cu concentrations exceeded those of THQ>1 for five sites in both climatic seasons. Our findings suggest that there might have been a constant source of Cu generation. The Cd level exceeded THQ>1 at one site during the dry season. This finding may be due to the proximity to populated areas. Further, Ni exceeded the comparison values of THQ>1 at two sites during rainy season. Given our findings, the consumption of catfish *A. felis* should be considered a health risk in southern Mexico, mainly for the most vulnerable population, i.e., children. These results are consistent with a previous study, where THQ>1, exceeding the comparison parameters [32] and pointing out to the vulnerability of the population to toxic and persistent bioaccumulative pollutants present in fish.

Cadmium is considered a potent carcinogen according to the International Agency for Research on Cancer (IARC) [33]. Tolerable limits for the increased risk of cancer, according to the New York State Department of Health, (NYSDOH) [34], the TCR categories are defined as: TCR≤10^{-6} low, between 10^{-4} to 10^{-3} moderate, and between 10^{-3} to 10^{-1} high. Also, TCR≥10^{-1} is very high and with a high probability that the exposed population may develop cancer at some point in their lives. Based in our findings, the Cd, and Pb values for children were in the "low risk" category. The Ni values in children were at "moderate risk." For adults, only the Ni concentration was classified at "moderate risk."

The consumption of marine species caught in rivers and lakes is restricted in some countries. It is also advisable that children at ages 1 to 4 years old only should consume an average of 75 g of fish per month. In children aged 5 to 11 years, the recommended amount is 125 g per month, and for pregnant women, the permissible amount is no more than 150 g per month [35].

170

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

Conclusions

Due to lack of effective seashore monitoring and environmental regulations, the lagoons in the Gulf of Mexico are contaminated with heavy metals. This study found large amounts of toxic heavy metals, including copper, lead, nickel and cadmium, at specific sites in the fishing areas along the Gulf of Mexico shoreline. Our health risk assessments of the heavy metals suggest that cadmiun and nickel may contribute to the carcinogenic conditions in humans who consume the catfish caught in these areas. The carcinogenic risk from the heavy metal contaminations to the health of children and adults was found to be from low to moderate. Based on our findings, the consumption of catfish *A. felis* caught in the above-mentioned areas is not recommended. This study contributes significant data to the various agencies in Mexico, other countries, and agencies, such as the US-EPA. Our data are useful to the development of toxicological standards in order to determine the risks to the human health arising from the consumption of foods contaminated with heavy metals. The data in support of the findings of this study are available from the corresponding author.

Limitations of the Study: This study showed contamination of heavy metals in catfish. However, the levels of contamination can be similar in other species in the same area.

Recommendations for Future Studies: Analyze other species such as clams *(R. cuneata)* and oysters *(C. virginica)* in heavy metal contamination studies.

Ethical Considerations

Compliance with ethical guidelines

The study did not involve human participants, therefore, the ethical guidelines did not apply. The study was approved by Autonomous University of Carmen (Code: FQ/1ERP2019/03).

Funding

Authors' contributions

All authors assisted fairly equally with conducting the research, analysis, and writing the manuscript, and provided critical comments on their reviews of the drafts. All authors have read and approved the final version of the manuscript prior to submission.

Conflict of interest

The authors declare no conflicts of interests with any entities in conducting this study.

Acknowledgements

References

[1] Rajeshkumar S, Li X. Bioaccumulation of heavy metals in fish species from the Meiliang bay, Taihu lake China. Toxicol Rep. 2018; 5:288-95. [DOI:10.1016/j.toxrep.2018.01.007] [PMID] [PMCID]

[2] Rajeshkumar S, Liu Y, Zhang X, Ravikumar B, Bai G, Li X. Studies on seasonal pollution of heavy metals in water, sediment, fish and oyster from the Meiliang Bay of Taihu Lake in China. Chemosphere. 2018; 191:626-38. [DOI:10.1016/j.chemosphere.2017.10.078] [PMID]

[3] Aguilar CA, Montalvo C, Rodríguez L, Cerón JG, Cerón RM. American oyster (Crassostrea virginica) and sediments as a coastal zone pollution monitor by heavy metals. Int J Environ Sci Technol. 2012; 9:579-86. [DOI:10.1007/s13762-012-0078-y]

[4] Ekoa Bessa AZ, Ngueutchoua G, Ndjigui PD. Mineralogy and geochemistry of sediments from Simbock lake, Yaoundé area (southern Cameroon): Provenance and environmental implications. Arab J Geosci. 2018; 11(710):1-18. [DOI:10.1007/s12517-018-4061-x]

[5] Aguilar CA, Canedo Y, Montalvo C, Ruíz A, Barreto R. Heavy metal contamination in a protected natural area from southeastern Mexico: Analysis of risks to human health. In: Nazal MK, Zhao H, editors. Heavy metals: Their environmental impacts and mitigation. London: IntechOpen; 2021. [DOI: 10.5772/intechopen.95591]

[6] McRae NK, Gaw S, Glover CN. Effects of waterborne cadmium on metabolic rate, oxidative stress, and ion regulation in the freshwater fish, inanga (Galaxias maculatus). Aquat Toxicol. 2018; 194:1-9. [PMID]

[7] Padrilah SN, Sabullah MK, Shukor MY, Yasid NA, Shamaan NA, Ahmad SA. Toxicity effects of fish histopathology on copper accumulation. Pertanika J Trop Agric Sci. 2018; 41(2): 519-40. http://psasir.upm.edu.my/id/eprint/64489/1/02%20JTAS%20Vol%2041%20%282%29%20May%202018_JTAS-0965-2016_pg519-540.pdf

[8] Tulaby Dezfuly Z, Aramoon A, Alishahi M, Halimi M, Rahnama R. The effects of lead toxicity on the hematological parameters common carp (Cyprinus carpio) at varying salinity levels. Iran J Toxicol. 2020; 14(1):1-8. [DOI:10.32598/ijt.14.1.1]

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

171

Iranian Journal of Toxicology
ARAK UNIVERSITY OF MEDICAL SCIENCES

[9] Gobierno De Mexico. Foro economico de pesca y acuacura [Internet]. 2018 [last updated: 2018]. Available from: https://foroeconomico.conapesca.gob.mx/

[10] Kris-Etherton PM, Harris WS, Appel LJ; American Heart Association. Nutrition Committee. Fish consumption, fish oil, omega-3 fatty acids, and cardiovascular disease. Circulation. 2002; 106(21):2747-57. [PMID]

[11] Vázquez F, Florville-Alejandre TR, Herrera M, Díaz de León LM. Heavy metals in muscular tissue of the catfish, Ariopsis felis, in the southern gulf of Mexico (2001-2004). Lat Am J Aquat Res. 2008; 36(2):223-33. [DOI:10.3856/vol36-issue2-fulltext-5]

[12] Ayala LM, Ramos J, Flores D, Sosa A, Martínez GE. Study area: In: Ayala LM, Ramos J, Flores D, Sosa A, Martínez GE, editors. Marine and coastal ichthyofauna of Campeche. Mexico: Epomex publishing. 2015; 1-60. https://epomex.uacam.mx/view/download?file=14/Ictiofauna%20Marino-Costera%20de%20Campeche%20.pdf&tipo=paginas

[13] No Author. [Test method for the determination of cadmium, arsenic, lead, copper, iron, zinc and mercury in food, drinking water and water purified by atomic absorption spectrometry (Spanish)] [Internet].1994 [Updated 1994 August 16]. Available from: http://www.ordenjuridico.gob.mx/Documentos/Federal/wo69541.pdf

[14] United States Environmental Protection Agency. Regional Screening Levels (RSLs) - generic tables [Internet]. 2022 [Last updated: 2022]. Available from: https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

[15] Soto-Jiménez MF, Amezcua F, González-Ledesma R. Non-essential metals in striped marlin and indo-pacific sailfish in the southeast gulf of California, Mexico: Concentration and assessment of human health risk. Arch Environ Contam Toxicol. 2010; 58(3):810-8. [DOI:10.1007/s00244-009-9452-2] [PMID]

[16] Yi Y, Tang C, Yi T, Yang Z, Zhang S. Health risk assessment of heavy metals in fish and accumulation patterns in food web in the upper Yangtze River, China. Ecotoxicol Environ Saf. 2017; 145:295-302. [PMID]

[17] Adebiyi FM, Ore OT, Ogunjimi IO. Evaluation of human health risk assessment of potential toxic metals in commonly consumed crayfish (Palaemon hastatus) in Nigeria. Heliyon. 2019; 6(1):e03092. [DOI:10.1016/j.heliyon.2019.e03092] [PMID] [PMCID]

[18] United States Environmental Protection Agency. Recommended use of body weight 3/4 as the default method in derivation of the oral reference dose [Internet]. 2022 [Last updated: 22 June 2022]. Available from: https://www.epa.gov/risk/recommended-use-body-weight-34-default-method-derivation-oral-reference-dose

[19] Javed M, Usmani N. Accumulation of heavy metals and human health risk assessment via the consumption of freshwater fish Mastacembelus armatus inhabiting, thermal power plant effluent loaded canal. Springerplus. 2016; 5(1):776. [PMID] [PMCID]

[20] Nauen CE. Compilation of legal limits for hazardous substances in fish and fishery products. Rome: Food and Agriculture Organization of The United Nations; 1983. https://www.fao.org/docrep/014/q5114e/q5114e.pdf

[21] World Health Organization and International Programme on Chemical Safety. Guidelines for drinking-water quality. Vol. 2, Health criteria and other supporting information, 2nd ed. Geneva: World Health Organization; 1996. https://apps.who.int/iris/handle/10665/38551

[22] NORMA Oficial Mexicana. Productos y servicios. Productos de la pesca frescos, refrigerados, congelados y procesados [Internet]. 2009 [Last updated: 2009]. Available from: https://www.dof.gob.mx/normasOficiales/4295/salud2a/salud2a.htm

[23] Executive Agency of the Ministry of Agriculture, Fishers and Food. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal of wastes at sea 1995 and 1996. Suffolk: Executive Agency of the Ministry of Agriculture, Fishers and Food; 1998. https://www.cefas.co.uk/publications/aquatic/aemr51.pdf

[24] Joint FAO/WHO Expert Committee on Food Additives, Food and Agriculture Organization of the United Nations & World Health Organization. Evaluation of certain food additives and contaminants : Thirty-third report of the Joint FAO/WHO Expert Committee on Food Additives [meeting held in Geneva from 21 to 30 March 1988]. Geneva: World Health Organization; 1989. https://apps.who.int/iris/handle/10665/39252

[25] USFDA. Food and drug administration, guidance document for nickel in shell fish DHHS / PHS / FDA / CFSAN / Office of seafood. Washington DC: USFDA; 1993. https://scirp.org/reference/referencespapers.aspx?referenceid=621255

[26] Smith RL. United states environmental protection agency: Region III risk-based concentration table development of risk based concentrations. 1995. https://hwbdocuments.env.nm.gov/Los%20Alamos%20National%20Labs/References/9642.PDF

[27] Ploetz DM, Fitts BE, Rice TM. Differential accumulation of heavy metals in muscle and liver of a marine fish, (king mackerel, Scomberomorus cavalla cuvier) from the Northern Gulf of Mexico, USA. Bull Environ Contam Toxicol. 2007; 78(2):134-7. [DOI:10.1007/s00128-007-9028-7] [PMID]

[28] Montoya-Mendoza J, Alarcón-Reyes E, Castañeda-Chávez MDR, Lango-Reynoso F, Zamudio-Alemán RE. Heavy metals in muscle tissue of Pterois volitans from the Veracruz reef system national park, Mexico. Int J Environ Res Public Health. 2019; 16(23):4611. [DOI:10.3390/ijerph16234611] [PMID] [PMCID]

[29] Serviere-Zaragoza E, Lluch-Cota SE, Mazariegos-Villarreal A, Balart EF, Valencia-Valdez H, Méndez-Rodríguez LC. Cadmium, lead, copper, zinc, and iron concentration patterns in three marine fish species from two different mining sites inside the Gulf of California, Mexico. Int J Environ Res Public Health. 2021; 18(2):844. [DOI:10.3390/ijerph18020844] [PMID] [PMCID]

[30] Alvarado C, Ramírez JM, Herrera-López EJ, Cortez-Valladolid D, Ramírez G. Bioaccumulation of metals in cultured carp (Cyprinus carpio) from lake Chapala, Mexico. Biol Trace Elem Res. 2020; 195(1):226-38. [DOI:10.1007/s12011-019-01845-w] [PMID]

[31] Nevárez M, Leal LO, Moreno M. Estimation of seasonal risk caused by the intake of lead, mercury and cadmium through freshwater fish consumption from urban water reservoirs in arid areas of northern Mexico. Int J Environ Res Public Health. 2015; 12(2):1803-16. [DOI:10.3390/ijerph120201803] [PMID] [PMCID]

[32] Ramírez-Ayala E, Arguello-Pérez MA, Tintos-Gómez A, Mendoza Pérez JA, Díaz-Gómez JA, Pérez RY, et al. Heavy metals in sediment and fish from two coastal lagoons of the Mexican Central Pacific. Lat Am J Aquat Res. 2021; 49(5):818-27. http://lajar.ucv.cl/index.php/rlajar/article/view/vol49-issue5-fulltext-2628

[33] Boffetta P. Carcinogenicity of trace rlements with reference to evaluations made by the: International agency for research on cancer. Scand J Work Environ Health. 1993; 19 (Suppl 1):67-70. [PMID]

[34] New York state department of health NYSDOH. Hopewell precision area contamination: Appendix C-NYS DOH. Procedure for evaluating potential health risks for contaminants of concern. 2007. https://www.health.ny.gov/environmental/investigations/hopewell/appendc.htm

[35] Bellanger M, Pichery C, Aerts D, Berglund M, Castaño A, Cejchanová M, et al. Economic benefits of methylmercury health exposure control in Europe: Monetary value of neurotoxicity prevention. Environ Health. 2013; 12:3. [DOI:10.1186/1476-069X-12-3] [PMID] [PMCID]

Romero CM, et al. Analysis of Health Risk from Heavy Metals. Iran J Toxicol. 2022; 16(3):163-174

173

This Page Intentionally Left Blank