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Health Risk From Consumption Of Fish And Seafood Contaminated With Pb, Cd, Hg, And As In Women From Bahia De Kino, Sonora, Mexico

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Abstract
Consumption of marine products contaminated with heavy metals increases the risk to human health, especially in fishing communities. The objective was to evaluate the potential health risk associated with the consumption of fish and shellfish contaminated with Pb, Cd, Hg, and As among women from Bahia de Kino, Sonora, Mexico. Samples of fish and shellfish were collected, as well as blood samples from 40 women living in the community. The concentration of metals was determined by atomic absorption spectroscopy. The risk to participants health from consuming the marine species studied was calculated using the Hazard Quotient (HQ) equation. The highest levels of Pb, Cd, Hg, and As were found in white clam (31.07 mg/kg), pen shell (2.52 mg/kg), Pacific sharpnose shark (0.67 mg/kg) and pink-mouthed murex (0.71 mg/kg), respectively. The relationship in order of concentration in the marine species evaluated followed the trend of Pb > Cd > Hg > As. In blood serum, the average Pb was 2611.40 ± 5.28 µg/dL, Cd 11.38 ± 0.08 µg/dL, Hg 70.2 ± 0.28 µg/dL, and As 23.30 ± 0.91 ug/dL, which are within the range of risk levels. A potential risk to the health of the participants was found due to the consumption of white clam, pen shell, Pacific sharpnose shark, and pink-mouthed murex based on the HQ values of Pb (4.30), Cd (1.22), Hg (1.08), and As (1.15), respectively. More than 50% of the marine species studied showed high concentrations of at least one of the heavy metals analyzed. There is a potential health risk to the women who participated in this study. Additionally, it is necessary to work on the development of mathematical models that incorporate the concentration of heavy metals in blood serum, whole blood, or other tissues to provide greater certainty in assessing the potential risk of consuming contaminated foods.
Keywords: *Health risk, Fish and shellfish, Heavy metals, Bahia de Kino.*

INTRODUCTION

Heavy metal pollution such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) is currently a serious public health and environmental problem worldwide [1,2]. This occurs when heavy metals are released into the environment from anthropogenic sources, as a result of lack of control and treatment of wastes from industrial, agricultural, port, mining, and domestic activities, or from natural sources, such as geological erosion [3,4]. Because of their importance, a large number of biomonitoring studies of these elements have been carried out worldwide in a variety of animal species [5-7].

In coastal areas of the Amazon, studies have identified up to 47 species of fish for human consumption that are contaminated with heavy metals including As, Pb, Hg, and Cd [8]. Of these heavy metals, arsenic was found in 63.8% of the marine species studied, exceeding the limits set by international regulations. For people who consume these species, this represents a potential health risk [8]. On the Egyptian coast, high levels of Pb and Cd, but not Hg, were found in sardines and shrimps for human consumption during 2019-2021; the health risks were estimated to be higher than 1.26 (Hazard Quotient value) [9].

In African countries such as Nigeria or Ghana on the Guinea coast, high concentrations of heavy metals (i.e. Hg, Ni, Cd, Cu and Zn) have been found in fish for human consumption, in addition to As. All metals were found to be within the global acceptable daily intake limits for human consumption through food. However As was identified as a carcinogenic risk factor in the study population [10,11]. Something similar is happening with As in Hangzhou Bay, China, where it has been found at very high levels in two species of crab and in oysters for human consumption. This represents a carcinogenic risk, especially to children [12-14]. Similar situations have been observed in the Mediterranean and other regions [15-17]. The above suggests that the problem of heavy metal contamination is global but is exacerbated in poor countries by subsistence fishing in coastal regions [12,17].

In Mexico, heavy metal contamination represents a significant public health and environmental concern, especially in marine and coastal ecosystems, since these elements end up in the sea and create an undesirable environment that contaminates the marine organisms that inhabit this space, including fish and shellfish, which are a main food source for people living in coastal communities. Therefore, the consumption of these contaminated foods poses a potential health risk to residents of coastal regions such as Bahia de Kino, Sonora, Mexico [18,19].

The bioaccumulation and toxicity capacity of heavy metals in diverse organs of marine species such as skin, liver, gills, etc., not only affects the vital functions of this organisms, but also threatens human health through the food chain when exceeding acceptable concentration levels. The World Health Organization (WHO) classifies Pb, Cd, Hg, and As as chemicals of high public concern because they are the most prevalent pollutants in the environment and are highly toxic to living organisms [20].

Exposure to high doses of Hg and Pb can cause serious complications affecting the functioning of organs and systems, as well as possible effects on fertility. Although exposure to low doses of these metals poses little threat, repeated exposure on a regular basis can lead to complications ranging from weakness, fatigue, and anxiety to adverse effects on intellectual function. In addition, carcinogenic metals such as Cd and As have the potential to interfere with synthesis and repair of DNA [20-22].

Both men and women can experience adverse effects from heavy metal exposure. Mothers and their children suffer adverse effects when exposed to these contaminants during pregnancy and lactation [23].

In Mexico, from January to September 2024, malignant tumors were the third cause of death with 71,337 deaths. During the same period, in Sonora there were 1,895 deaths from malignant tumors, being the second cause of death in the entity both in women and men [24]. In 2022, in Hermosillo (municipality to which the community of Bahia de Kino belongs), malignant tumors were the seventh cause of death with 106 cases [25].

Food is the main source of exposure to Pb, Cd, Hg, and As for the general population (non-smokers and non-occupationally exposed). These metals are found in varying concentrations in most foods, including fish and shellfish, which are an important source of food in coastal regions [21]. Fish is often the main source of methylmercury in the human diet; this chemical form of mercury affects the central nervous system and can cause serious effects from exposure during pregnancy, including microcephaly, seizures, and mental retardation [26,27].

Consuming these contaminated foods represents a potential health risk to residents of coastal communities such as Bahia de Kino, Sonora, where just over half of the population depends directly or indirectly on fishing activities [27]. The ideal recommendation would be to reduce seafood consumption and change the diet of the population. However, reducing fish and shellfish consumption is not a viable alternative for families that rely on marine resources as their primary food source [28].

Although there is limited evidence of health risk associated with heavy metal contamination in Bahia de Kino, environmental problems have been reported due to a lack of control over fishing, agricultural, and tourist activities. These activities have contaminated the coastal area with chemical waste, disturbing the local flora and fauna and posing a health risk to the community's inhabitants [29-31].

Therefore, the objective of this work was to evaluate the potential health risk associated with the consumption of fish and shellfish contaminated with Pb, Cd, Hg, and As among women from Bahia de Kino, Sonora, Mexico, and to determine the levels of these metals in their blood serum.

MATERIALS AND METHODS

Ethical considerations

This research project was approved by the Research Ethics Committee of the University of Sonora, according to CEI-UNISON document 1/2017.

Study area

Bahia de Kino is located on the Sea of Cortez, 107 km from Hermosillo, the capital of Sonora, Mexico. The community is divided into two parts: Kino Viejo, characterized by fishing activity, and Kino Nuevo, where residential tourism predominates [29]. Bahia de Kino has a population of 6,454 inhabitants, most of whom live in Kino Viejo, where there are serious deficiencies in public services and employment, irregular land ownership, poverty, and social backwardness [29]. The main economic activity is fishing, the most developed by the artisanal fishermen of Bahia de Kino are different species of scales, crustaceans and molluscs. The larger boats arrive from nearby ports. They are destined to catch shrimp and sardines [30].

However, fishing activity suffers from various problems related to the indiscriminate exploitation of marine species, the reduction of food sources for birds and marine mammals because of overfishing, the incidental capture of species that have no commercial value, the high price of fuel, and contamination of the marine environment from anthropogenic sources such as the waste generated by the aquaculture and agricultural activities taking place around the community [29-31].

Fishing is not only a way to earn an income. It's also an important source of protein for the families of Bahia de Kino [29]. Therefore, it is important to analyze the concentration of heavy metals in the marine species of Bahia de Kino and their possible impact on the health of its inhabitants.

Study population

From September to December 2016, 116 mothers with school-age children living in the community of Bahia Kino were randomly recruited to participate in a program to improve their families' food and nutrition security [32]. Fasting blood samples were collected from 45.7% (n=53) of the participating mothers to assess hemoglobin, total cholesterol, HDL and LDL, and glucose concentrations. Blood samples were collected using the Vacutainer system in tubes with and without heparin, ranging from 3 to 5 mL. In the present study, frozen blood serum from 40 participants were used to analyze the presence of Pb, Cd, Hg, and As. All participants gave written informed consent, and the data were kept strictly confidential and used for this research under code.

Socioeconomic and demographic survey and anthropometric measures

A socioeconomic and demographic survey and anthropometric measures were obtained from the participants to know their general characteristics, including age, weight, height, educational level, marital status, gender of the main provider at home, family income, and whether the family participated in a social protection program.

Marine species sample collection

Pacific sierra (*Scomberomorus sierra*), Pacific sharpnose shark (*Rhizoprionodon longurio*), goldspotted sand bass (*Paralabrax auroguttatus*), finescale triggerfish (*Balistes polylepis*), Pacific white shrimp (*Litopenaeus vannamei*), bat ray (*Myliobatis californica*), common octopus (*Octopus vulgaris*), chocolate clam (*Megapitaria squalida*), black clam (*Chione fluctifraga*), white clam (*Dosinia ponderosa*), pen shell (*Atrina maura*), and pink-mouthed murex (*Hexaplex erythrostomus*) were collected directly from fishermen or fishmongers in Bahia de Kino. The number of each species ranged from 3 to 7 specimens and was conducted during the month of June. The collected samples were washed with seawater and placed in a cooler on ice. The cooler was then transported to the laboratory for further analysis. Samples of edible soft tissue and muscle from each marine species were dissected. They were stored at -25 °C for 3 days and then lyophilized (LABCONCO model 77.530; -48 °C; 32× 10-3 mbar) for 48 hours and manually homogenized for 10 minutes using a porcelain mortar [33].

Blood collection

Adult women from Bahia de Kino (n = 40), who signed the informed consent, participated in the collection of blood samples, which was performed with the Vacutainer system in tubes with and without heparin, for which between 3 and 5 mL was collected. These samples were frozen at -120°C in an Infitek ULF150-H130 brand horizontal ultra freezer until used for heavy metal determination by atomic absorption spectroscopy.

Quality control

Prior to the determination of Pb, Cd, Hg, and As in biological samples, a quality control was performed to ensure the reliability and certainty of determining these heavy metals in biological samples. For this purpose, linearity was evaluated using three calibration curves with five concentrations of each chemical element. Each concentration was read in triplicate. For Pb, the concentrations were 10, 20, 30, 40 and 50 μg/L; for Cd, the concentrations were 0.5, 1.0, 2.0 and 4.0 μg/L; for Hg and As, the concentrations were 2, 4, 6, 8 and 20 μg/L. The linear regression coefficient (R^2) and Pearson's correlation coefficient (R) were determined for these concentrations, with an acceptance criterion of $R^2/R \geq 0.995$ [33]. The limit of detection (LOD) and limit of quantitation (LOQ) were determined using 30 digestion blanks. The equations used were $LOD = 3s/\sqrt{n}$, $LOQ = 10s/\sqrt{n}$, where s is the standard deviation and n is the number of blank determinations. Precision was evaluated under repeatability conditions by preparing 10 standards of known concentration (Pb 30 μg/L, Cd 2.0 μg/L, Hg and As 6 μg/L) of each chemical element, read in triplicate (n = 30). The equation $\%CV = (s/\bar{y})*100$ was used, where s is the standard deviation and $\bar{y}$ is the mean of the measurements. The acceptance criterion is %CV ≤ 2 [33]. Finally, 0.500 ± 0.003 g of oyster tissue (NIST 1566b) was digested using the wet method and the percentage recovery (%Rec) was determined. The equation used was $\%Rec = (\bar{y}/\mu)*100$, where $\bar{y}$ is the mean of the measurements and μ is the reference value indicated in the oyster tissue certificate, for each of the chemical elements evaluated (Pb 0.308 mg/kg, Cd 2.48 mg/kg, Hg 0.037 mg/kg, As 7.65 mg/kg). The acceptance criterion is %Rec = 100 ± 5 [34].

Wet digestion of biological samples

0.5 ± 0.005 g of the biological samples (dry weight of fish, shellfish and fresh weight of blood serum) were weighed on a VELABTM analytical balance model VE-210, placed in a 100 mL polypropylene beaker and then digested by the wet method with 10 ml of HNO_3 and then with 10 mL of 30% H_2O_2 to finish the digestion with 5 mL of concentrated HNO_3, heated in a DigiProbe monoblock at 110 °C for one hour inside a gas extraction hood. The resulting acid residue was made up to 50 mL with milliQ water [35].

Analysis of heavy metals in biological samples

The acidic residues resulting from the wet digestion were analyzed by graphite furnace-atomic absorption spectroscopy for cadmium and lead in the Perkin Elmer PinAAcle 900T equipment, read at 229 and 283.4 nm, respectively, using hollow-cathode lamps. For mercury and arsenic, cold vapor mode (with $SnCl_2$) and the hydride generation mode (with $NaBH_4$) was used in the GTA 120 Varian instrument, with readings at 253.7 and 197.2 nm, respectively, using hollow cathode lamps. These laboratory equipments were previously calibrated using three calibration curves and five concentration points for each of the four chemical elements of the heavy metal group. All samples were analyzed in triplicate.

Hazard quotient approach for risk assessment

After determining the concentrations of Pb, Cd, Hg, and As in fish and shellfish and participants' blood serum samples, the following hazard quotient (HQ) equation was used to calculate the risk to human health from consuming the marine species analyzed:

$$HQ = \frac{E}{RfD}$$

Where:

E, is the exposure dose (μg metal/kg/day)

RfD, is the oral reference dose (μg/kg/day). This is the dose of metal that can be consumed daily without risk of adverse health consequences. The reference doses used for all metals were those established by the US-EPA. The *RfD* values were 3.5 and 1.0 μg/kg/day for Pb and Cd, respectively, and 0.3 μg/kg/day for Hg and As [36].

The value of *E* was calculated using the following equation:

$$E = \frac{(C \ x \ I)}{W}$$

Where:

C, it is the concentration of metal in the tissues of marine species (μg/g).
I, is the fish intake in grams per day (33.89 g/day). This value was taken from the figures published in the Statistical Yearbook of Aquaculture and Fisheries of the National Commission of Aquaculture and Fisheries (2023) and is based on the per capita consumption in Mexico of a variety of fish and shellfish species, in different presentations, destined exclusively for human consumption [37].
W, it is the average body weight of an adult (for Mexico it is 70 kg).
If the *HQ* is less than one, it is concluded that consumption of the food poses an imperceptible risk. If the value is greater than one, it is assumed that there is a chance of non-carcinogenic effects, with the probability increasing as the value of *HQ* increases [38].

Statistical analysis

The results obtained for the concentration of Pb, Cd, Hg, and As, in marine species and in the blood serum of women from Bahia de Kino were analyzed by one-way ANOVA with a significance level of 5% (α = 0.05) using the statistical package SPSS version 21. Multiple comparisons of means were performed using the post-hoc Tukey test at a 5% significance level (α = 0.05). The potential health risk was assessed using the hazard quotient approach for risk assessment.

RESULTS

General characteristics of the participants

The mean ± standard deviation values for age, weight, height, and body mass index (BMI) were 33.6 ± 7.0 years, 76.0 ± 14.9 kg, 1.57 ± 0.06 m, and 30.81 ± 5.74 kg/m^2, respectively (Table 1). 51.3% of the participants had only basic education, 87.2% are married or living in common-law marriage, 46.2% work and 17.9% are the main provider for their household. 41.5% were beneficiaries of a social program. The average monthly family income was $402 ± 176.5.

Quality control

Prior to determining of lead, cadmium, mercury, and arsenic in fish, shellfish and blood serum samples, an internal quality control was performed to provide support and confidence in the results obtained from the samples analyzed. The evaluation of linearity from the calibration curves for Pb, Cd, Hg, and As using high-purity standards (Accustandard, New Haven, CT, USA) reflects the regression coefficient (R^2) and Pearson correlation coefficient (R) values above the acceptable values for R^2 and R, which must be equal to or greater than 0.995 (Table 2) [34].

Table 1. Socioeconomic and demographic characteristics of the participants (n = 40).

Variables	**Mean ± SD or %***	**Range**
Household size	5.2 ± 1.7	2 - 11
Number of children	3.1 ± 1.3	1 - 8
Monthly family income (US dollars)	402 ± 176.5	133.6 - 870
Monthly food expenditure	73.3	
Educational level of the participant		
Incomplete elementary school	25.6	
Elementary school or junior high	51.3	
High school	20.5	
Superior	2.6	
Educational level of the partner (n = 34)		
Incomplete elementary school	38.2	
Elementary school or junior high	44.1	
High school	11.8	
Superior	5.9	
Marital status		
Married or living in a common-law marr iage	87.2	
Single, separated, widowed, divorced	12.8	

Participants who are working	46.2	
Participants who are the main provider at ho me	17.9	
Medical service	92.5	
Social program beneficiary	41.5	

SD indicates standard deviation.
*Values are mean ± standard deviation or percentages.

Table 2. Quality control for the determination of lead, cadmium, using GF-AAS, mercury and arsenic, using HG-AAS.

Parameter/Metal	**Lead (Pb)***	**Cadmium (Cd)***	**Mercury (Hg)***	**Arsenic (As)***	**Reference [3]**
Calibration curves	R^2 = 0.9978 R = 0.9991	R^2 = 0.9983 R = 0.9991	R^2 = 0.9993 R = 0.9996	R^2 = 0.9991 R = 0.9996	$R^2 \geq 0.995$ $R \geq 0.995$
Limit of detection (LOD µg/kg)	0.0004	0.0001	0.0023	0.0035	3 ≥ Blank
Limit of quantification (LOQ µg/kg)	0.0013	0.0003	0.0076	0.0116	10 ≥ Blank
Precision (%CV)	1.42	0.98	1.01	1.63	≤ 2%
% Recovery (Oyster tissue NIST 1566b)	100.3	101.2	101.7	102.1	% Recovery 100 ± 5 Range 95 a 105 %

*R^2 = Linear regression coefficient; R = Pearson's correlation coefficient. GF-AAS (Graphite Furnace-Atomic Absorption Spectroscopy). HG-AAS
(Hydride Generation-Atomic Absorption Spectroscopy).

The assessment of precision under repeatability conditions is acceptable since all values obtained for %CV are below the acceptance level of 2%. On the other hand, a certified oyster tissue reference material (NIST 1566b) was used to evaluate the veracity (previously called accuracy) through the recovery percentage (%Rec). The results obtained were 100.3, 101.2, 101.7, and 102.1 %Rec for lead, cadmium, mercury, and arsenic, respectively. Since the acceptance criterion is 100 ± 5%, these results are acceptable [34].

Analysis of heavy metals in biological samples

Fish and shellfish

Table 3 shows the concentration of lead, cadmium, mercury, and arsenic in fish and shellfish. Regarding the evaluation of lead, the marine species with the highest amount was the white clam with 31.07 ± 13.22 mg/kg, showing significant differences among the other species evaluated (α=0.05).

For cadmium, the marine species with the highest concentration was pen shell with 2.52 ± 0.14 mg/kg, showing significant differences from the other species evaluated (α=0.05).

Mercury concentration was higher in Pacific sharpnose shark, goldspotted sand bass, and finescale triggerfish with 0.67 ± 0.002, 0.64 ± 0.004 and 0.62 ± 0.001 mg/kg, respectively, with no significant differences among them, but with significant differences among other marine species (α=0.05).

Concerning the assessment of the concentration of arsenic, the highest concentration was found in pink-mouthed murex with 0.71 ± 0.08 mg/kg and in common octopus with 0.63 ± 0.04 mg/kg with no significant differences between the two, but with significant differences against the other marine species (α=0.05). The relationship in order of concentration would be Pb > Cd > Hg > As.

Blood serum

The blood serum lead levels of the participating women were above the acceptable levels (Table 4). The average value obtained for this metal was 2,611 ± 5.28 µg/dL, while the reference value considered to be out of risk is 70 µg/dL [18]. This represents an important risk factor, as the participating women have 37.3 times this concentration of lead.

Serum cadmium levels were also above the allowable levels (Table 4), with an average of 11.38 ± 0.08 µg/dL, whereas the reference values considered safe are ≤ 5 µg/dL [18] which represents an important risk factor, since the participating women have 2.3 times this concentration of cadmium.

Regarding mercury, the blood serum of the participating women had a concentration of 70.2 ± 0.28 µg/dL (Table 4), which is 14.4 times higher than the maximum value allowed by the Secretary of Health (2000) [18] of ≤ 5 µg/dL, indicating a potential risk.

Finally, the concentration of arsenic in the blood serum of the study population was 23.30 ± 0.91 ug/dL, which is 23.3 times higher than the maximum permissible limit of ≤ 1 µg/dL [18].

According to the results obtained for these heavy metals in blood serum, the relationship in order of concentration would be Pb>Hg>As>Cd.

Potential risk assessment

Table 5 shows the results of the estimation of the potential health risk by the HQ approach from the consumption of marine species and their concentration of lead, cadmium, mercury, and arsenic. The species with the lowest value of potential risk for Pb was pen shell (0.32); for Cd were Pacific sierra, Pacific sharpnose shark, goldspotted sand bass and finescale triggerfish (0.03); for Hg was chocolate clam (0.61); and for As was goldspotted sand bass (0.10).

Table 3. Concentration of heavy metals in fish and shellfish consumed by women from Bahia de Kino, Sonora, Mexico*.

Species	Lead (Pb)	Cadmium (Cd)	Mercury (Hg)	Arsenic (As)
Pacific sierra	4.31	0.06	0.52	0.24
Pacific sharpnose shark	10.83	0.07	0.67	0.35
Goldspotted sand bass	4.88	0.07	0.64	0.06
Finescale triggerfish	10.14	0.07	0.62	0.33
Pacific white shrimp	9.84	0.09	0.45	0.17
Bat ray	9.54	0.11	0.49	0.21
Common octopus	13.13	0.19	0.43	0.63
Chocolate clam	2.47	1.72	0.38	0.27
Black clam	15.09	1.85	0.41	0.47
White clam	31.07	0.32	0.39	0.26
Pen shell	2.34	2.52	0.47	0.22
Pink-mouthed murex	8.91	1.6	0.44	0.71

*Concentration in mg/kg.

Table 4. Concentration of lead, cadmium, mercury, and arsenic in blood serum of women from Bahia de Kino, Sonora.

Potential Risk in Women		
	Mean ± SD*	**Reference [39]**
Lead (Pb)	2,611 ± 5.28 µg/dL	≥ 70 µg/dL
Cadmium (Cd)	11.38 ± 0.08 µg/dL	≥ 5 µg/dL
Mercury (Hg	70.20 ± 0.28 µg/dL	≥ 5 µg/dL
Arsenic (As)	23.30 ± 0.91 µg/dL	≥ 1 µg/dL

SD = standard deviation.
*Values are mean ± standard deviation.

Table 5. Potential risk from the consumption of fish and shellfish based on the concentrations of lead, cadmium, mercury, and arsenic.

Potential Risk of Consumption				
Species	**Pb**	**Cd**	**Hg**	**As**
Pacific sierra	0.60	0.03	0.84	0.39
Pacific sharpnose shark	1.50	0.03	1.08	0.56
Goldspotted sand bass	0.68	0.03	1.03	0.10
Finescale triggerfish	1.40	0.03	1.00	0.53
Pacific white shrimp	1.36	0.04	0.73	0.27
Bat ray	1.32	0.05	0.79	0.34
Common octopus	1.82	0.09	0.69	1.02
Chocolate clam	0.34	0.83	0.61	0.44
Black clam	2.09	0.90	0.66	0.76
White clam	4.30	0.15	0.63	0.42
Pen shell	0.32	1.22	0.76	0.36
Pink-mouthed murex	1.23	0.77	0.71	1.15

The highest potential risk due to lead was found in white clam with a HQ value of 4.30. For cadmium, the highest risk was found in pen shell with a value of 1.22. For mercury, Pacific sharpnose shark presented a high potential risk with a value of 1.08, and finally for arsenic, pink-mouthed murex presented a higher potential risk with a value of 1.15. Since these HQ values are greater than 1, it is determined that there is a possibility of adverse health effects from consumption of the marine species, with the probability increasing as the value of the potential risk increases [38].

Furthermore, for lead, mercury and arsenic, HQ values higher than 1 were obtained in several of the species studied. For lead, in addition to the white clam, the black clam, common octopus, Pacific sharpnose shark, finescale triggerfish, Pacific white shrimp, bat ray, and pink-mouthed murex presented values above 1. While for mercury, in addition to Pacific sharpnose shark, the potential risk from eating goldspotted sand bass was also greater than 1. Finally, for arsenic, in addition to the pink-mouthed murex, the common octopus had a value greater than 1. According to the results obtained for these heavy metals, the relationship in order of potential health risk would be Pb>Hg>As>Cd.

DISCUSSION

The objective of this study was to evaluate the potential health risk associated with the consumption of fish and shellfish contaminated with Pb, Cd, Hg, and As among women from Bahia de Kino, Sonora, Mexico, and to determine the levels of these metals in their blood serum. It is important to mention that the fish and shellfish species evaluated represent the most common and abundant species in this region, for local marketing and own consumption [31]. With regard to the data on common consumption, these were taken from the Statistical Yearbook of Aquaculture and Fisheries of the National Commission of Aquaculture and Fisheries (2023), and are based on a mix of species of fish and shellfish commonly consumed by the Mexican population [37].

The concentration of lead in the analyzed marine species caught in Bahia de Kino exceeds the maximum allowable limits established by NOM-242-SSA1-2009 [39] which range from 0.5 to 1.0 mg/kg in fresh products. It is important to note that the EU, FAO, and WHO have maximum permissible limits of 1.44, 2.4 and 9.6 mg/kg respectively for fresh products [40-42].

The pen shell was the only marine species to exceed the cadmium limits, as NOM-242-SSA1-200939 specifies limits between 0.5 and 2.0 mg/kg, although the chocolate clam and white clam are very close to the limits [43].

The highest concentration of mercury was found in Pacific sharpnose shark, goldspotted sand bass, and finescale triggerfish which are below the permissible limits of NOM-242-SSA1-2009 [39], in the form of methylmercury, since the maximum permissible range is up to 1.0 mg/kg for fresh fish, but the maximum permissible limit for other marine species is 0.5 mg/kg, so the other marine species evaluated do not exceed these limits.

The highest concentrations of arsenic were found in pink-mouthed murex and common octopus. These values are lower than NOM-242-SSA1-2009 [39] as maximum allowable limits of up to 80 mg/kg are reported for shellfish, but nothing is reported for fresh fish. In this sense, fish and shellfish with high concentrations of total arsenic (up to 6 mg/kg wet weight) often have very low concentrations (less than 1 mg/kg wet weight) of inorganic arsenic [44].

Recently, Aguilar et al. (2024) [45] evaluated the levels of Cd, Hg, and Pb in oyster (Crassostrea virginica) tissues from a protected area in southeastern Mexico. This study was designed to analyze the human health risks associated with these metals. They found that the levels of these metals are lower compared to previous studies, so they do not pose a significant risk to the local population [45].

On the other hand, freshwater fish and fish for human consumption in northern Mexico are also contaminated with lead, cadmium, and mercury, according to work by Nevárez et al. (2015) [46]. The concentrations of cadmium (0.235 mg/kg), mercury (0.744 mg/kg) and lead (4.298 mg/kg) were higher than the limits set by European regulations and the Codex Alimentarius [43]. Lead levels in fish from three freshwater reservoirs also exceeded the Mexican regulatory limit of 1 mg/kg. In the Pacific Northwest of Mexico, Rodríguez-Mendívil et al. (2019) [47] found that Hg concentrations in fresh fish samples ranged from 0.14 to 2.14 mg/kg, Pb from 0.04 to 0.32 mg/kg, and Cd from 0.001 to 0.003 mg/kg. The highest concentrations of Hg were found in the species of shortfin mako shark (*Isurus oxyrinchus*) and tope shark (*Galeorhinus galeus*), which is considered a risk factor for the population that consumes these types of marine species [47].

As, Cd, Hg and Pb are among the ten chemicals of highest public concern according to the WHO (2019) [42]. In Mexico, as in other parts of the world, there is concern about the increasing pollution of the environment by toxic metals (such as As, Cd, Hg, Pb) and their potential impact on public health. Toxic elements often enter the body via food; for example, potentially toxic chemicals are known to accumulate in fish and shellfish. This is why maximum levels are set for lead, cadmium and mercury in crustaceans, cephalopods and fish, although no limits are set for arsenic [48].

The levels of lead, cadmium, mercury and arsenic in the blood serum of the participating women were above the permissible limits, which are considered a risk factor for health [18]. These results suggest that work should be done to develop mathematical models that incorporate the concentration of heavy metals in blood serum or whole blood to have greater certainty in assessing the potential risk from frequent consumption of foods, including marine species. In this regard, it is important to mention that the presence of heavy metals (Pb, Cd, Hg and As) in the blood serum of these women may not only be due to the consumption of contaminated fish and shellfish, but there is a possibility that these metals come from another source, including drinking water, fruits, vegetables or other food products. For this reason, it is intended to address this situation in a subsequent research paper [49].

A potential risk to the health of the participants was found due to the consumption of white clam, pen shell, Pacific sharpnose shark, and pink-mouthed murex based one the HQ values for Pb (4.30), Cd (1.22), Hg (1.08), and As (1.15), respectively. In addition, for lead, a potential risk from ingestion was found in 8 of the 12 species under investigation, which was above the reference value for the HQ.

In relation to the present study, a work carried out in the same region of Bahia de Kino, Sonora, Mexico was recently published. In this work, the levels of Fe, Zn, Cu, Mn, and Cr in fish and shellfish for human consumption were evaluated. Although these metals were found to be above the levels allowed by national and international regulations, no health risk was found in women due to frequent consumption, but a health risk was found in children and men when evaluated using the hazard quotient (HQ) and hazard index (HI) [33].

On the other hand, García-Hernández et al. (2018) [50] determined the mercury concentration in 238 fish and shellfish samples collected from the Central Gulf of California, including the area surrounding Bahia de Kino. They also estimated the health risk associated to dietary intake of methylmercury in women living in the region. The authors found that only 6% of the samples exceeded the maximum permissible level of methylmercury. However, they also found that women in these coastal communities had a high consumption of seafood, resulting in a high hazard quotient (HQ = 6.2) due to methylmercury

ingestion. Therefore, they suggest that pregnant women limit their seafood consumption in terms of both portion size and frequency.
Similarly, Pinzón-Bedoya et al. (2020) [28] evaluated the potential risks to human health of Hg, As, Pb, Cd, Cu, and Zn in the fish species most consumed by the coastal population living in the Cienaga Grande de Santa Marta. The authors found that the levels of Cu and Hg consumed exceeded their reference doses and resulted in potential risk values greater than 1, which could adversely affect the health of women of childbearing age and those over 49 years of age, as well as men over 15 years of age [28].
For their part, Ramírez-Ayala et al. (2021) [51] found that in other fishing communities in the coastal lagoons of Jalisco and Colima in Mexico, towards the central Pacific Ocean, they are also at health risk due to the consumption of fish contaminated with Pb, Cd, Hg, and As, since the hazard quotient value obtained by per capita consumption is HQ > 2.50.
Likewise, in the lagoons of southern Mexico, along the Gulf of Mexico, where hardhead catfish (*Ariopsis felis*) is fished and consumed, among other fishery products, Montalvo-Romero et al. (2022) [52] have found contamination by Cu, Pb, Ni, Cd in hardhead catfish tissues, which represents a low to moderate risk, although they do not recommend the consumption of catfish, especially due to the potential carcinogenic risk of Pb and Ni to human health [52].
There are some heavy metals (such as copper and zinc) that are recognized as essential because they perform important functions in living organisms; however, their high consumption may be associated with health problems. Other heavy metals such as cadmium, lead, mercury, and arsenic are nonessential and more toxic to ecosystems and humans [28]. They are released into the environment from natural sources and from human activities, and their levels vary depending on geographic location [21].
Pb, Cd, Hg, and As are pollutants that cause serious health problems and their global emission rate is increasing every year. These elements are not only resistant to degradation under natural conditions but are also capable of bioaccumulation and biomagnification [23]. Due to uptake from soil and water and subsequent transfer through the food chain, these metals are present in most foods [21,28]. Although the toxicity of Pb, Cd, Hg, and As varies depending on the chemical species, amount consumed, and route of exposure, as well as the age, sex, and health status of the individual, constant exposure to these heavy metals can lead to a variety of health effects, including damage to vital organs and the digestive system, impairment of hemoglobin synthesis, decreased bone density, defects in the development of the nervous system, DNA damage, and infertility [3,21].
For this reason, it is important to carry out continuous biomonitoring studies of marine species living in the coastal region of Mexico, especially those that are consumed by the inhabitants of these communities due to their high levels of toxic metals such as Pb, Cd, Hg and As [53,54]. Furthermore, the conduct of these studies will contribute to expanding and updating the scientific knowledge on the environmental and human health problems caused by heavy metal pollution in coastal communities, as well as possible intervention strategies to address these problems [55-57].
Finally, due to their toxicity, it is important to minimize exposure to these heavy metals, especially in vulnerable communities such as Bahia de Kino, Sonora, Mexico. Fishing, especially artisanal fishing, is the most important economic activity of the population. Families in this community depend on the product they catch to generate income and purchase a wider variety of food, in addition to meeting other basic needs. However, some of the product they obtain from fishing is used for personal consumption [29,30]. Like other coastal communities, in Bahia de Kino, marine products are not only a marketing tool, but also the main or only source of high-quality protein for the population [28]. Therefore, the risk to their health from consuming marine products contaminated with heavy metals is a problem that needs to be addressed.

CONCLUSIONS

The present study showed the presence of high average levels of Pb, Cd, Hg and As in the majority of marine species (60%) analyzed in this study. In addition, the concentrations of the metals analyzed were found to be within the range of critical risk levels in the blood serum of the participating women. In this sense exist a potential risk to the health of the participants. These results suggest that work is needed to develop mathematical models that incorporate the concentration of heavy metals in blood serum, whole blood or other tissues to provide greater certainty in assessing the potential risk of consuming contaminated foods, especially marine species, which are a source of economic sustenance and high-quality protein for vulnerable populations such as women in fishing communities.

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Conflict of interest
The authors declare that there is no conflict of interest.

CRediT author statement
AMGA: Conceptualization, Methodology, Writing- Original draft preparation; TQP: Visualization, Investigation; KDMC: Data curation, Writing- Reviewing and Editing; MJM: Formal analysis; Supervision; KKES; Supervision; GDC: Data analysis; MJBT: Data analysis.

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Data Availability:
The data that support the findings of this study are available from the corresponding author.

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