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Research article

Total mercury determination in bivalves *Anadara tuberculosa* sold in open markets from Quito, Ecuador

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ABSTRACT

This study aimed to quantify the amount of total mercury in bivalves *Anadara tuberculosa* supplied from Esmeraldas Province and sold in markets in the Metropolitan District of Quito, Ecuador. The determined total mercury concentration was compared to the permissible limits established by the European Commission and World Health Organization-Food and Agriculture Organization and health risk subsequently assessed. Sampling was conducted in five open markets and involved collecting fifteen specimens from each market. Total mercury was measured through cold vapor atomic fluorescence spectrophotometry. Results showed that samples did not exceed the total mercury threshold value (0.5 mg kg^{-1}). However, samples of *Anadara tuberculosa* from the Ofelia market, which receives fresh products from Eloy Alfaro canton, contained the highest mean levels of mercury contamination, 0.055 mg kg^{-1}. This result could be associated to the influence of illegal mining activity in this area. In addition, methylmercury potential non-carcinogenic risk for consumers exceeded the threshold limit (>1) established by the US Environmental Protection Agency. The daily consumption rate (Rc_{lim}) was determined to be 26.61–38.50 g for a child weight of 14.5 kg, and 128.44–185.84 g for an adult weight of 70 kg. Thus, consuming a higher amount of *Anadara tuberculosa* could negatively affect human health.

1. Introduction

Mercury is a trace metal of concern. It can be naturally present in the environment due to volcanic activity, rock weathering and forest fires, however, anthropogenic activities are the greatest source, principally small-scale gold mining, large-scale industrial processes such as vinyl chloride monomer and chlor-alkali production and in products such as batteries, dental amalgams, measuring and control devices, among others [1]. It is an ubiquitous contaminant that can be transported throughout ecosystems, and deposited in watersheds that play the role as sinks of atmospheric mercury [2]. In Ecuador, estuarine ecosystems are impacted by industrial and agriculture wastes and domestic sewage leading into metal contamination, which affects the habitat of important marine species which are consumed by coastal communities and Andean population [2, 3]. Four main estuarine areas in Ecuador are located in Esmeraldas Province [4], meanwhile, Salado Estuary in the Gulf of Guayaquil, constitutes 80% of the total mangrove area of Ecuador [2].

In the Andean region, the Metropolitan District of Quito (DMQ, for its name in Spanish), Ecuador's capital, has many markets that supply staple food products to both residents and tourists [5]. The wide variety of fresh products found in these markets comes from different regions of the country, particularly Esmeraldas Province [6], which is an area rich in seafood because of its coastal location [7]. Mestanza-Ramón [8], reported that Esmeraldas Province has shown an exponential increase in illegal gold mining activities, affecting water resources, and aquatic and terrestrial ecosystems. In current illegal mining activities, mercury (Hg) is mainly used to extract gold from minerals [9]. Tailings material from the mining operations containing Hg are deposited in sediments and mechanically transported along the river bed or deposited from material transported in suspension [10] which has led to contamination of rivers and estuaries [11, 12]. Mercury deposited in sediments is converted into methylmercury (MeHg) by sulfate-reducing bacterias [13, 14]. The C–Hg bond of MeHg allows this metal to be bioaccumulated in aquatic fauna; under this chemical

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form it joins the food chain and eventually reaches aquatic species consumed by humans [15, 16].

Bivalve mollusks, especially black shell *Anadara tuberculosa*, commonly known in Ecuador as "*concha negra*", "*concha prieta*" or "*concha hembra*", can accumulate large amounts of trace metals in their bodies as they have the ability to filter water and marine sediment particles to feed [17]. In addition, their outer layers are made of chitin, which contains cysteine residues, showing a great affinity for trace metals (especially Hg), facilitating absorption of sulfhydryl groups through the mollusk's biological membranes [18].

The European Commission's Regulation (EU) 2022/617 establishes maximum permissible levels for mercury (fresh weight) in general fishery products and shellfish is 0.5 mg kg^{-1} [19]. Likewise, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) also use this value as the maximum permissible limit [20] of MeHg for fish.

Several researches have determined the contamination from trace metals such as cadmium (Cd), lead (Pb), and chromium (Cr) in bivalve mollusks from Esmeraldas Province; results have showed concentrations that represent a human health risk [17, 21]. Cedeño & Zambrano [22], determined Cd, Hg, and Pb in *Anadara tuberculosa* from El Salto Mangrove, in Esmeraldas Province, while in other areas of Ecuador, as El Oro and Guayas Provinces, few studies have been performed to determine trace metals in bivalve mollusks of commercial importance for consumption [3, 13, 23, 24, 25, 26].Therefore, this study aims to quantify the amount of total mercury (THg) content in *Anadara tuberculosa* samples collected from the main open markets in the DMQ and evaluate the health risk related to Hg exposure. It is important to assess the public health risk related to the consumption of this species, as it is frequently eaten throughout Ecuador and sold in many markets, mainly in Guayaquil, Quito, Cuenca, Tulcán, Riobamba, and the southern part of the country [27].

2. Materials and methods

2.1. Reagents

The following reagents were used in this study: nitric acid (HNO_3, 70%, Fisher Chemical), hydrogen peroxide (H_2O_2, 30%, Loba Chemie), hydrochloric acid (HCl, 37%, Merck); perchloric acid ($HClO_4$, 73%, BDH Chemicals), tin (II) chloride dihydrate ($SnCl_2$, Sigma-Aldrich), and 10 ppm Hg standard (Inorganic Ventures). All reagents were analytical grade. Additionally, mussel tissue (ERM-CE278k, European Commission) was used as the certified reference material, and 18 ΩM deionized water obtained from a Milli-Q water system was used to prepare all solutions; 99.99% pure argon (Linde) and 125 mm quantitative filter paper (Macherey-Nagel) were also used.

The cleaning procedure for all the glassware was performed according to Yánez-Jácome et al. [28], soaking the material in nitric acid 5% (v/v) nitric acid overnight, and then rinsing twice with high-quality reagent water.

2.2. Equipment

Total mercury levels were measured using Mercur Plus, a cold vapor atomic fluorescence spectrophotometry analyzer (Analytik Jena, Jena, Germany) equipped with a low-pressure mercury lamp as the radiation source ($\lambda = 253.7$ nm). The instrumental conditions were the same as reported by Yánez-Jácome et al., [28].

2.3. Study area

There are 52 markets within the DMQ that sells fish and other seafood to consumers [29]. Five sites—La Ofelia, Chiriyacu, América, Yaruquí, and Conocoto—were selected for the present study, as they represent the markets with the largest number of vendors and geographically cover the entire DMQ. Figure 1 shows the map of the DMQ and the selected markets.

2.4. Sample collection

Samples were purchased from vendors in the selected markets. Bivalves come from the Esmeraldas Province, specifically from the areas of Borbón (B) and Tambillo (T), as well as the cantons of Limones (L), Muisne (M), and San Lorenzo (S.L). Samples were collected on days when the bivalves were delivered to each market: Ofelia (Ofe), Chiriyacu (Chiry), América (Ame), Yaruquí (Yaru) and Conocoto (Cono). A composite sample of fifteen bivalves per market was obtained. Bivalves sold in Ofelia, Chiriyacu, América, Conocoto, and Yaruquí markets came from different locations (Tambillo and Borbón; Muise and Tambillo; San Lorenzo and Muisne; San Lorenzo; and Limones, respectively). Purchase of samples was carried out for three times in different weeks, therefore a total of 24 samples were obtained. The samples were collected during the last two weeks on February 2022 to the first week on March 2022.

The bivalve samples had the following characteristics (weight is of meat content for all samples):

- Ofe_T and Ofe_B: 9.23–12.34 g; average 29 mm long
- Chiry_M and Chiry_T: 15.22–20.12 g; average 71 mm long
- Ame_S.L and Ame_M: 8.56–11.49 g; average 29 mm long
- Cono_S.L: 17.57–32.93 g; average 80 mm long
- Yaru_L: 12.65–18.34 g; average 59 mm long

2.5. Sample treatment

The samples were stored in plastic bags, labeled, and transferred to the laboratories of the Pontifical Catholic University of Ecuador (under cool conditions), where they were classified into 24 groups (n = 24), according to the market and its location origin. Each bivalve was washed with a 1% HNO_3 solution to remove mud residue and avoid cross contamination [23]. The soft tissues were subsequently removed and washed with deionized water and kept in plastic bags.

Samples were stored in an ultra-freezer at -25 °C until chemical analysis. The moisture content of each sample was determined by the difference of weight after freeze drying process, for 48 h at -50 °C and 0.150 hPa. Subsequently, samples were pulverized using a fine mill and then were stored in a desiccator to avoid humidity. 0.3 g of each sample were placed into Teflon vessels, and 2 mL of HNO_3, 2 mL of H_2O_2, and 2 mL of $HClO_4$ were added. For acid digestion, the analytical method described by Yánez-Jácome et al. [28], was modified and validated for its use in a bivalve matrix. The digested samples were filtered, 2 mL of HCl were added, and the collected supernatants were brought to a volume of 50 mL each. All pooled samples (n = 24) were digested by duplicate.

2.6. Quality control

The laboratory quality control protocol included external standard daily calibration method with five standards. For the calibration plot, standard solutions of Hg(II) with 1, 2, 3, 4, and 5 μg L^{-1} concentrations were injected using the spectrophotometer's automatic sampler. The solution was prepared from a 50 μg L^{-1} Hg(II) stock solution. For the calibration plot, a correlation coefficient of ($R^2 \geq 0.995$) was obtained.

Mercur-Plus equipment was programmed to measure each sample by triplicate, reporting the average concentration. All the results presented in this study are reported in mg kg^{-1} of fresh bivalve weight (FW).

As a quality control to determine the precision and accuracy of the methodology, for each batch of 10 samples, the ERM-CE278k was used. Recovery percentage and the coefficient of variation (CV%) values were evaluated according to the acceptable limits described in the AOAC Guidelines for Single Laboratory Validation of Chemical Methods for Dietary Supplements and Botanicals [30]. Acceptance for CV% (repeatability and reproducibility) was defined as $<$ 15% and $<$32%, respe

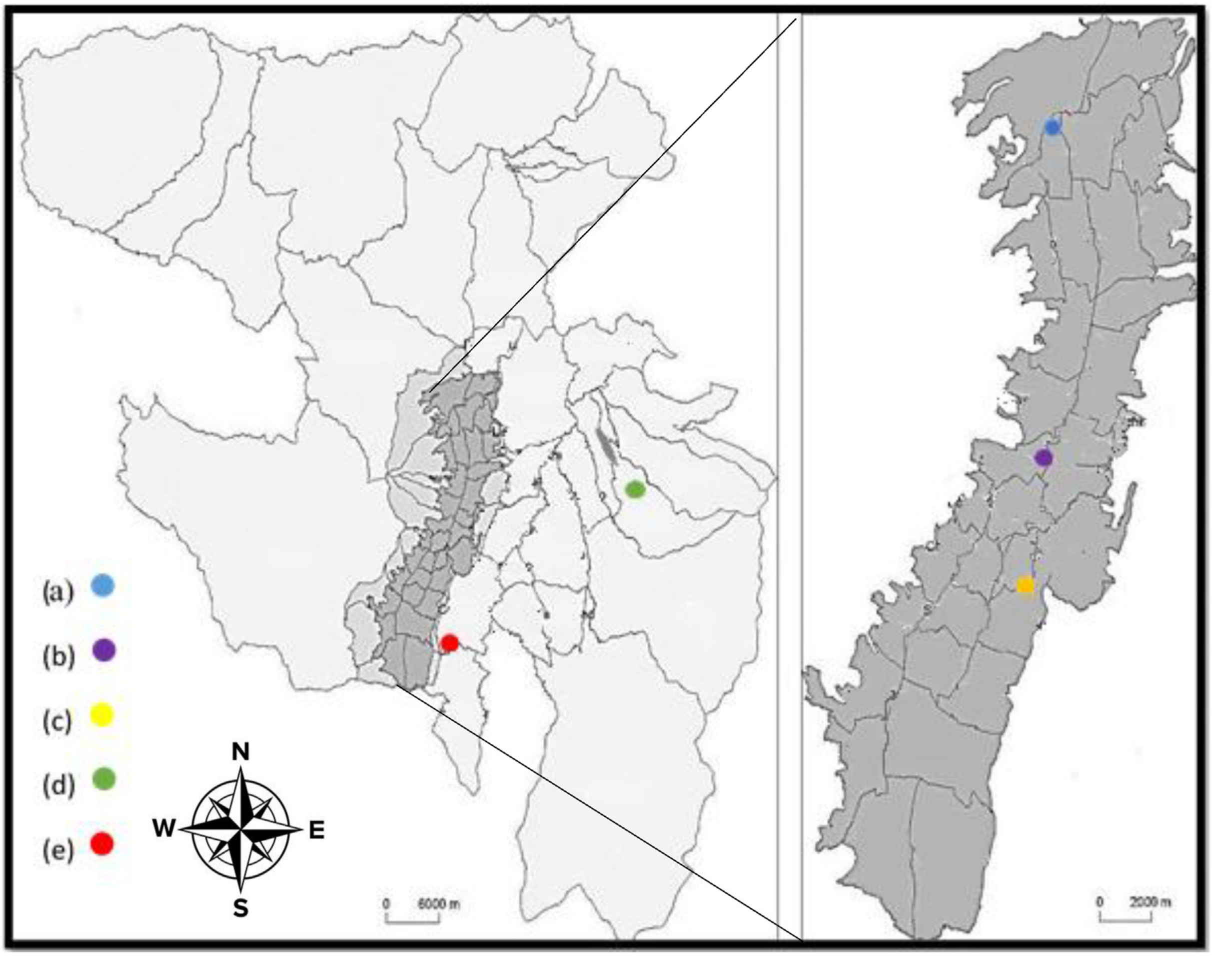

Figure 1. Map of the area containing the sampled markets: (a) Ofelia, (b) América, (c) Chiriyacu, (d) Yaruquí, and (e) Conocoto. Source: SUIM-DMPT.

ctively, and acceptance for percentage recovery values (R%; accuracy) was defined as 70–125%.

For the certified reference material ERM-CE278k, recovery percentage was within the range 91.74% ± 0.0397–109% ± 5.99 ($n = 5$), and repeatability CV% was 3.94% ($n = 5$). Meanwhile, CV% results for reproducibility between duplicates of digested samples were lower than 7.81%. All results were in good agreement with the values established by AOAC.

Based on the analysis of the respective digested reactive blanks, the minimum concentration of THg that could be detected (limit of detection) and quantified (limit of quantification) were calculated and analytically established as 0.11 ± 0.0190 μg L^{-1} and 0.24 ± 0.0190 μg L^{-1} ($n = 5$), respectively.

2.7. Statistical analysis

The arithmetic mean, standard deviation, coefficient of variation (CV %), and recovery of fortifications were calculated using the Microsoft Office Excel (Microsoft office, 2007).

One-way ANOVA was used for the comparison of THg content in black shell from the five different open markets.

2.8. Calculations

For the evaluation of the risk to human health, the level of exposure to MeHg (Ex) was calculated. Taking as a reference an average child weighing 14.5 kg who consumes approximately 200 g of the bivalve and an average adult weighing 70 kg who consumes 400 g [21], the following US EPA (2000) [31] equation was used:

$$Ex = \frac{\mathrm{Cx} \times \mathrm{CR}}{\mathrm{BW}}, \qquad 1$$

where Cx is the metal concentration in the edible portion of the samples (mg kg^{-1}), CR is the mean number of bivalves (kg) consumed daily, and BW is body weight (kg).

The non-carcinogenic health risk assessment (Rx) by food intake was determined using the following US EPA (1986, 2001) equation [32]:

$$Rx = \frac{Ex}{\mathrm{RfD}}, \qquad 2$$

where Ex is the exposure to the contaminant (mg kg^{-1} d^{-1}), and RfD is the reference dose of the chemical substance (mg kg^{-1} d^{-1}). For MeHg, a RfD of $1\text{x}10^{-04}$ was established, according to the Regional Screening Levels [33]. A health risk is considered to exist if the calculated non-carcinogenic risk value exceeds 1; for values less than 1, there are no health risks [32].

To determine the approximate amount of bivalves that can be consumed per day with an acceptable risk, the permissible daily consumption rate for health was calculated using the following equation [31]:

$$CR_{lim} = \frac{\mathrm{RfD} \times \mathrm{BW}}{\mathrm{Cx}} \times 1000, \qquad (3)$$

where CR_{lim} is the permitted daily consumption rate (g d^{-1}), RfD is the chemical reference dose (mg kg^{-1} d^{-1}), BW is body weight (kg), and Cx is the concentration of metal in the edible portion of the samples (mg kg^{-1}).

Table 1. Mean total Hg concentration (mg kg^{-1} FW) and ranges of coefficient of variation in analyzed samples of *Anadara tuberculosa* collected in DMQ markets (n = 24).

Sample	Mean THg content in samples [mg kg^{-1}] (fresh weight)**	CV (%)
América market		
Ame_S.L	0.035	1.00 – 4.59
Ame_M	0.052	0.72 – 4.22
Conocoto market		
Cono_S.L	0.048	0.60 – 4.30
La Ofelia market		
Ofe_T	0.037	0.74 – 2.10
Ofe_B	0.072	0.13 – 1.87
Chiriyacu market		
Chiri_M	0.030	3.57 – 6.47
Chiri_T	0.057	0.92 – 7.81
Yaruquí market		
Yaru_L	0.038	0.68 – 4.26

*The colored numbers in Table 1 indicate the sampling site according to the map in Figure 1.
** Percentage of water content in samples was between 82 to 89%.

The health risk assessment was calculated for different MeHg concentrations (minimum, mean, and maximum).

3. Results

3.1. Total mercury quantification in Anadara tuberculosa samples

The results of the quantification of THg in *Anadara tuberculosa* samples are shown in Table 1. The highest mean THg concentration was found in the samples from the Ofelia market (0.055 mg kg^{-1} FW), with values between 0.029 – 0.115 mg kg^{-1} FW; while the lowest mean THg concentration was found in the Yaruquí market (0.038 mg kg^{-1} FW), with values between 0.024 – 0.064 mg kg^{-1} FW (Figure 2).

The relationships between total Hg concentrations in shellfish and the five selected markets were evaluated using one-way ANOVA and were found to not be statistically significant ($p > 0.05$).

For the Ofelia market, bivalves are supplied from the region of Borbón. In this area, chemical substances were found up to 20 km downstream from mining locations, and, in fact, Borbón and Maldonado, another nearby town, contain sumps for mining pollution [34]. In a study performed by Rebolledo [35], it was shown that rivers and sediments from Esmeraldas Province, principally San Lorenzo and Eloy Alfaro cantons, are contaminated with mercury due to the illegal mining activities practiced in this region. Additionally, it was studied the effect of mining activities in the diversity of fish, and macro invertebrates, showing the necessity of a national legal framework to assess its impact [35]. Moreover, the increase of illegal mining activities have polluted 80% of rivers of San Lorenzo and Eloy Alfaro, which is used as drinking water for the population of certain communities in Esmeraldas [8].

Studies carried out in artisanal small-scale gold mining (ASGM) areas have found elevated concentrations of THg and MeHg in soils, and in downstream water and sediments [36, 37]. Moreover, in a highly contaminated gold mining site in Thailand, elevated Hg concentrations found in collected bivalves, suggested that the sediment bound Hg was bioavailable [38].

In the gold mining districts of Portovelo and Zaruma, in El Oro Province, Southern Ecuador, results showed that water quality and aquatic ecosystems are severely impacted in the Puyango River. Mining and mineral processing activities, tailings discharges rich in cyanide, mercury and other metals, affect rivers and reach at least 160 km downstream of the mining district [39]. Additionally, the sediments of the Puyango River are severely contaminated with mercury. This could be attributed to an increase in mining activities, and to the deforestation in the Andean areas of Ecuador, which leaches natural Hg that is contained in the soils of the region, increasing the flow of Hg towards the lower areas of the hydrographic basins [40].

In a study performed in the estuaries and coastal area of Western Lombok Island in Indonesia, THg concentrations in tissues of bivalves

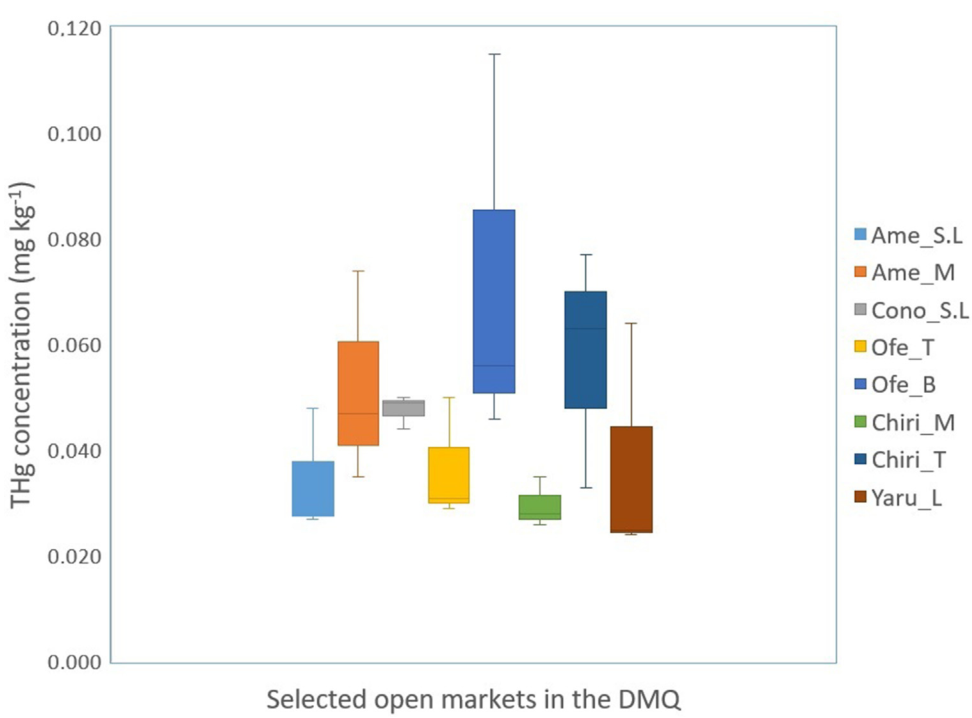

Figure 2. Box plots of total mercury (THg) concentrations in *Anadara tuberculosa* in relation to the selected open markets of the DMQ.

Table 2. Exposure levels, potential non-carcinogenic risk, permissible daily consumption rate for Hg, considering the minimum, mean, and maximum Hg concentrations for adults and children who consume 400 g (adults) and 200 g (children) of *Anadara tuberculosa* per day.

Body weight (kg)	Ex (mg kg^{-1} d^{-1})	Rx (dimensionless)	Rc_{lim} (g d^{-1})
América market			
Minimum MeHg concentration			
14.50	3.72×10^{-04}	3.72	53.70
70.00	1.54×10^{-04}	1.54	259.26
Mean MeHg concentration			
14.50	5.95×10^{-04}	5.95	33.59
70.00	2.47×10^{-04}	2.47	162.16
Maximum MeHg concentration			
14.50	1.02×10^{-03}	1.02	19.59
70.00	4.23×10^{-04}	4.23	94.59
Conocoto market			
Minimum MeHg concentration			
14.50	6.07×10^{-04}	6.07	32.95
70.00	2.51×10^{-04}	2.51	159.09
Mean MeHg concentration			
14.50	6.57×10^{-04}	6.57	30.42
70.00	2.72×10^{-04}	2.72	146.85
Maximum MeHg concentration			
14.50	6.90×10^{-04}	6.90	29.00
70.00	2.86×10^{-04}	2.86	140.00
La Ofelia market			
Minimum MeHg concentration			
14.50	4.00×10^{-04}	4.00	50.00
70.00	1.66×10^{-04}	1.66	241.38
Mean MeHg concentration			
14.50	7.52×10^{-04}	7.52	26.61
70.00	3.11×10^{-04}	3.11	128.44
Maximum MeHg concentration			
14.50	1.59×10^{-03}	1.59	12.61
70.00	6.57×10^{-04}	6.57	60.87
Chiriyacu market			
Minimum MeHg concentration			
14.50	3.59×10^{-04}	3.59	55.77
70.00	1.49×10^{-04}	1.49	269.23
Mean MeHg concentration			
14.50	6.02×10^{-04}	6.02	33.21
70.00	2.50×10^{-04}	2.50	160.31
Maximum MeHg concentration			
14.50	1.06×10^{-03}	1,06	18.83
70.00	4.40×10^{-04}	4,40	90.91
Yaruquí market			
Minimum MeHg concentration			
14.50	3.31×10^{-04}	3.31	60.42
70.00	1.37×10^{-04}	1.37	291.67
Mean MeHg concentration			
14.50	5.20×10^{-04}	5.20	38.50
70.00	2.15×10^{-04}	2.15	185.84
Maximum MeHg concentration			
14.50	8.83×10^{-04}	8.83	22.66
70.00	3.66×10^{-04}	3.66	109.38

Note: Ex: exposure levels; Rx: potential non-carcinogenic risk; RC_{lim}: permissible daily consumption rate.

Anadara granosa and *Anadara antiqua*, ranged between 0.020 – 0.070 mg kg^{-1} and 0.032–0.077 mg kg^{-1}, respectively [41]. This area is potentially affected by tailings and water-containing Hg which is discharged from artisanal gold mining districts. Pataranawat [38], has also reported THg levels in bivalves with values from 0.088 to 0.658 mg kg^{-1}, showing that the greater the distance from the mining site, the less the THg concentration in bivalves.

Regarding to the América, Chiriyacu, Conocoto, and Yaruquí markets, THg levels ranged between 0.024 to 0.077 mg kg^{-1} FW (Figure 2). The results of our study are higher than those reported by M. Cedeño & D. Zambrano [22], with a mean THg concentration of 0.0125 mg kg^{-1}. This study was performed in bivalves from El Salto Mangrove located in Esmeraldas Province, far away from the coastal zone where there is no incidence of mining activities and industrial wastes.

Other studies performed by Riofrio [24] and Ordoñez [25] in *Anadara tuberculosa* bivalves in Huaylá Estuary, Ecuador, showed a mean THg content of 3.36 mg kg^{-1} and 0.685 mg kg^{-1}, respectively. Huaylá Estuary is highly contaminated due to the wastewater discharges from different activities in Puerto Bolivar, El Oro Province, deteriorating the mangrove ecosystem and affecting the marine biota [42].

It has been reported that THg concentration in bivalves varies in the same place between different species and individuals, and the accumulation of this metal depends on the age of the organisms [3]. Bivalve mollusks have been used as biomonitor or sentinel organisms to monitor pollution and ecosystem health disturbance assessment in mangrove areas due to its capacity to integrate biological exposure to toxic trace elements and physicochemical characteristics of the aquatic ecosystem [43, 44, 45].

3.2. Health risk assessment for consumers of Anadara tuberculosa

The mean THg levels of *Anadara tuberculosa* analyzed in the present study were below the permissible limit of 0.5 mg kg^{-1} as per Regulation (EU) 2022/617 [46] and the FAO/WHO [20] guidelines.

In a study performed in *Anadara tuberculosa* from Huaylá Estuary, the mean THg concentration found was 364.38 mg kg^{-1}, significantly exceeding the permissible threshold established by the European Union [23]. On the other hand, in a mangrove area of La Puntilla Estuary, in El Oro Province, black shell samples showed THg concentrations below the detection limit and only one sample showed 0.034 mg kg^{-1} [3]. Alvarado Rivas [39] studied the concentration of arsenic, mercury, lead, and cadmium in water, sediments and shells from Huaylá Estuary, showing that these pollutants levels exceed the maximum permissible level established by the European Union (0.5 mg kg^{-1}). On the other hand [45], analyzed Hg in the bivalves *Anomalocardia brasiliana* from the Sepetiba Bay in Rio de Janeiro. This area is one of the biggest port and industrial complexes that receives high discharges of untreated domestic waste and toxic metals from industrial activities. The results of this study showed that Hg and MeHg concentrations in *A. brasiliana* were five times lower than the safety level for human consumption (0.5 mg kg^{-1}).

Even though black shell sold in open markets in the Metropolitan District of Quito contain low THg levels, seafood is commonly consumed, exposing to populations to this contaminant and posing a potential health risk. According to the EFSA, 2012 [47], MeHg comprises 80% in seafood, however, for the present study, recommendations from the EPA, 2000 [31] were adopted, suggesting that THg should be assumed as MeHg, in order to protect human health. Under this scenario, health risk assessment for *Anadara tuberculosa* was performed.

According to data from the US Centers for Disease Control and Prevention, it is likely that almost every person who has consumed fish or shellfish has small amounts of Hg in their blood owing to its increased incidence in the environment [48]. In Table 2, the results for the potential non-carcinogenic risk (Rx) were higher than one ($Rx > 1$), suggesting that populations who consume black shell may be at risk. This is associated with the minimum value of the oral RfD for Hg, demonstrating that the lower the oral RfD, the greater the non-carcinogenic risk from exposure to Hg [49].

For the Ofelia market, the potential non-cancer risk (Rx) was the highest for children and adults 1.59×10^1 and 6.57, respectively. These results are in good agreement with the available information regarding to the areas where *Anadara tuberculosa* is collected (Borbón).

Exposure to high levels of MeHg has serious consequences for children and adults, as MeHg is a potent neurotoxin. Studies have shown that Hg accumulation in fetuses is usually greater during pregnancy, and infants born with poor birth outcomes, such as prematurity, low birth weight, and may have poor neurodevelopmental outcomes in early childhood [50]. Moreover, MeHg appears to be capable of causing chromosome damage and nuclear perturbations in a variety of system [33] as well as causing damage to both lysosomal and the mitochondrial membranes which might lead to apoptotic cell death [51]. Among countries in the Amazon region, between 1994 and 2018, Ecuador imported 403 tons of mercury, mostly used for illegal mining activities, which release large amounts of Hg into water and soil [52].

Considering the mean concentrations of MeHg, for all the markets sampled, the results for daily consumption rate (Rc_{lim}) were between 26.61–38.50 g and 128.44–185.84 g for children and adults, respectively. These results suggest that consuming *Anadara tuberculosa* in amounts greater than these values could have significantly negative consequences for human health.

Velásquez et al. [3], assessed the mercury Hazard Quotient (HQ) for human health in bivalves from mangrove areas of the estuary adjacent to the Chaguana and Siete Rivers, nevertheless, the HQ presented values less than one. To the best of our knowledge, risk assessment for mercury in shellfish from Ecuador is scarce, however, Romero-Estévez et al. [21] found a potential risk for cadmium in all body weights, and a high health risk for lead in children, through the consumption of *Anadara tuberculosa* by the community members of Santa Rosa Island located in the Cayapas-Mataje Mangrove Reserve, Esmeraldas Province.

4. Conclusions

Concentrations of THg in *Anadara tuberculosa* sold in open markets of DMQ, Ecuador, varied according to the origin source in Esmeraldas Province. Even though THg levels did not exceed the permissible limit established by the European Commission and the FAO/WHO, the evaluation of health risk for children and adults showed a potential non-carcinogenic risk. Results indicated that consumption of *Anadara tuberculosa* might pose a significant health risk. Therefore, it is necessary to continue with further studies to evaluate THg content in samples of *Anadara tuberculosa* sold in order to ensure food consumption safety of Ecuador's population.

Declarations

Author contribution statement

Melissa Nasevilla: Conceived and designed the experiments; Performed the experiments.

Lenys Fernández: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gabriela S. Yánez-Jácome: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Pablo Pozo; Domínguez Granda Luis; Hugo Romero: Contributed reagents, materials, analysis tools or data.

Patricio Espinoza- Montero: Analyzed and interpreted the data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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