Lead and Cadmium Bioaccumulation in Fresh Cow’s Milk in an Intermediate Area of the Central Andes of Peru and Risk to Human Health

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Abstract: The dairy basin of the Mantaro River located in the centre of Peru faces serious anthropogenic disturbances as it receives emissions and discharges from the metallurgical mining activity located in the headwaters of the basin and milk contaminated with lead (Pb) and cadmium (Cd) endangers the environmental and human health, especially children. To measure the concentrations of Pb and Cd in milk and the dangers of their consumption in the Peruvian population, 40 milk samples were collected and quantified by atomic absorption spectrometry. The mean concentration of Pb in milk was 15 ± 2.6 µg/kg, which represented 75% of the Maximum Limit (ML), and that of Cd was 505 ± 123 µg/kg, which exceeded the ML by more than 194 times. The estimated weekly intake of Pb for people aged 2–85 years was below the Provisional Tolerable Weekly Intake (PTWI) references, determining risk coefficients (CRD) < 1. Weekly Cd intake was much higher than the PTWIs and CRDs were between 14 and 34, indicating that consumers would experience carcinogenic health effects, with children being at higher risk than adults, therefore, milk from the area is not safe for consumption. Cd would be transferred mainly through the soil (water)-grass-milk pathway, due to its presence in irrigation water and in fertilizers that contain Cd. The main pathway for Pb entry would be air-soil (water)-milk grass, from the fine particles emitted into the air by the mining-metallurgical activity, developed approximately 90 km from the study area.

Keywords: cadmium; lead; dietary exposure; dietary risk; target hazard quotient; hazard index; contaminated milk

1. Introduction

The presence of bioactive peptides, essential amino acids, fat, lactose, calcium, zinc, magnesium, phosphorus, selenium, riboflavin, pantothenic acid, vitamins A, B1, and B12, and other nutrients [1], their therapeutic effects, flavour, and easy digestion make bovine milk widely consumed by the general population.

In children, it benefits their growth, bone development, and health [2,3], is included in the healthy eating guidelines of many countries, and included in school feeding and food assistance programs, and in adults, protective effects on bone health, prevention of chronic diseases, cardiovascular, metabolic, type 2 diabetes and cancer are reported [4,5]. It is an important protein source for populations with limited access to other foods of animal origin.
The beneficial effects of milk can be negated by the bioaccumulation of heavy metals that industrialization and urbanization release into the environment, especially lead (Pb) and cadmium (Cd), toxic metals that easily enter the food chain [6].

Background information on Pb and Cd contents in whole milk in different parts of the world shows large variations associated with the type and level of anthropogenic contamination, the proximity of emission sources, and the type of production system, with the highest contamination problems reported in farms close to mining and metallurgical activities (Tables 1 and 2).

Table 1. Pb content in whole milk samples from various countries (2016–2022).

| Year | Country  | Samples (n) | Rank (ug/kg) | Means (ug/kg) | Method   | Reference |
|------|----------|-------------|--------------|---------------|----------|-----------|
| 2022 | Bangladeshi | 64          | 0.005–0.02   | 0.013 ± 0.004 | AAS      | [7] Hasan et al., 2022 |
| 2021 | Ecuador  | 58          | 1.6–719      | 208           | AAS      | [8] De la cueva et al., 2021 |
| 2020 | Kazakhstan | 120         | 1–8          | 4.5           | AAS      | [9] Sarsembayeva et al., 2020 |
| 2020 | Peru     | 20          | 540–600      | 580 ± 18      | AAS      | [10] Chirinos & Castro, 2020 |
| 2020 | Russia   | 1500        | 75–110       | 88            | AAS      | [11] Safonov, 2020 |
| 2019 | Turkey   | 20          | 25–124       | -             | ICP-MS   | [12] Koyuncu & Alwazeer, 2019 |
| 2019 | Poland   | 20          | 12–13        | -             | ICP-MS   | [13] Sujka et al., 2019 |
| 2018 | Iran     | 72          | 32.83 ± 20.8 | 2.7           | AAS      | [14] Sobhanardakani, 2018 |
| 2018 | Iran     | 118         | 0–250        | 47 ± 3.9      | GFAAS    | [15] Norouzirad et al., 2018 |
| 2018 | Indonesia | 30          | -            | 558 ± 43      | AAS      | [16] Harlia et al., 2018 |
| 2016 | Iran     | 50          | -            | 14            | Voltammetry | [17] Shabhazi et al., 2016 |
| 2016 | Iran     | 85          | 0.7–23.7     | 3.24 ± 1.32   | AAS      | [18] Noori et al., 2016 |

The average consumption of milk per capita in the world is 100 kg/year, with high variation according to countries/regions. In Peru, by 2020 the per capita milk consumption was 81 kg/year, which is still low in relation to the 130 kg recommended by the FAO [20].

To improve the consumption of milk, its safety and good production practices must be guaranteed throughout the entire production chain, with special care in its contamination by heavy metals such as lead (Pb) and cadmium (Cd), which do not have any biological function and its presence in milk has adverse effects on various organic systems [21,22]. High levels of Pb during pregnancy are associated with lower birth weight and decreased neonatal physiological indicators, which in the long term affect the neuropsychological development of children [9,23–25]. Cd intake damages many systems and organs and causes various types of cancer and death [26]. According to the classification of the International Agency for Research on Cancer, a Cd is a Group 1 carcinogen, while inorganic Pb is a group 2 carcinogen [27] and is considered a priority 2 and 7 pollutant in food [28].

Since Pb and Cd have a long exposure life, difficult biodegradation, inadequate decomposition, and high levels of bioaccumulation, their transfer to the food chain makes them very dangerous, and their presence in milk and the risks of their consumption must be evaluated [21,29–32].
In mining and metallurgical areas located at the headwaters of river basins in the Peruvian Andes, Pb and Cd emissions can exceed the maximum permissible limits (MPL), contaminating atmospheric, water, and soil resources and easily entering the food chain. Fine particles laden with heavy metals can travel many kilometres through the air and settle in water and soil, bioaccumulate in pastures, and are transferred to crops and other livestock products for human consumption, such as milk [10,33,34]. Additionally, the discharge of mine tailings and industrial and domestic runoff into water sources used for irrigation, the proximity of roads from engine combustion, and the use of phosphorus fertilizers and pesticides containing phosphate rock high in Cd, are sources of milk contamination [33,35,36].

Although there is significant research worldwide on the accumulation of Pb and Cd in milk [6,36], in Peru, there is limited knowledge on the concentration of Pb and Cd in milk and milk products. In a previous study, we evaluated the risk of Pb and Cd in milk from an area located 20 km from the La Oroya Metallurgical Complex [37] and there are no studies of risks from these metals in areas of greater livestock activity, such as the Mantaro basin, the main source of dairy products for large cities, where the population and the authorities are unaware of the health consequences of the accumulation of Pb and Cd in milk.

Considering that for whole milk Pb should not exceed 20 µg/kg [38,39], and according to the International Dairy Federation, Cd should not exceed 2.6 µg/kg [14,40], the objectives of the study were to determine the concentration of Pb and Cd in milk produced in a livestock area of the Mantaro Valley basin and to assess the risk of the Peruvian population aged 2 to 85 years from exposure to these two metals through milk consumption, providing evidence for the population and management authorities to adopt the necessary measures.

2. Materials and Methods
2.1. Study Area
In October 2019 and April 2020, 40 milk samples were collected from cows in a livestock area in the central highlands of Peru (Latitude: −11.8219, Longitude: −75.3922; 11°49′19″ S, 75°23′32″ W; 3300 masl), located 92 km from the largest mining-metallurgical industry in the central highlands and one kilometre from the central highway with high interprovincial traffic, an area of intense agricultural activity, whose production is mainly sold in the markets of the Peruvian capital, where more than 30% of the national population is concentrated.

In general, pastures in the area are irrigated with water from the Canal de la Margen Izquierda del Río Mantaro (CIMMIR), which carries water contaminated by different liquid emissions from mining activities and domestic waste. In the study area, the cows are raised in an extensive system with cultivated pastures (Lolium multiflorum and Trifolium repens), with daily grazing of approximately 9 h.

Figure 1 shows a map showing the location of the study area, an agricultural valley located in central Peru.

2.2. Sample Preparation and Analysis
Immediately after milking, milk samples were taken from 20 s and third calving Brown Swiss cows. From each cow, 250 mL of milk were collected following the protocol of the Peruvian Technical Standard 202.112:1998 revised in 2013 [41,42], using sterile polyethylene bottles of first use with prior acid wash and rinsed with deionized water, keeping the samples in the cold chain (−18°C) for shipment to the accredited laboratory Baltic Control, Lima-Peru. Prior to digestion, 50 g of each homogenized sample were placed in porcelain crucibles to be dried at 100 °C to constant weight. They were incinerated in a muffle at 450 °C/15 h, and after cooling they were bleached with 2 mL of 2 N HNO₃ and dried in thermostatic plates and were re-incinerated at 450 °C/1 h. The ashes were recovered with 20 mL of 0.1 N HNO₃ and filtered through Watman 40 paper and stored in polypropylene tubes under refrigeration. High purity reagents (Merck KGaA, Darmstadt, Germany) were used.
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In the quantification of Pb and Cd, the AOAC 973.35 method was followed, using a flame atomic absorption spectrometer (NAMBEI AA320N), with wavelengths of 283.3 nm and 228.8 nm, respectively, according to the sensitive lines specified in hollow cathode lamps, with Pb and Cd detection limits of 0.0045 and 0.002 mg/kg, respectively [43]. Standards of 1000 mg/kg for each element were used as standards for the calibration curve. To verify the precision of the analytical method, Pb and Cd standard solutions of 155 ± 0.04 and 150 ± 0.05 mg/kg milk were used, and the concentrations of their corresponding runs were 147.14 and 152.50 mg/kg.

The precision of the instrumental methods and analytical procedures was verified by performing duplicate samples. The concentrations of Pb and Cd are expressed in µg/kg.

To provide complementary information, the concentration of Pb and Cd in 6 soil samples and 6 grass samples from the same sampling site was determined using atomic absorption spectrometry. For Pb and Cd, in Peru, the Environmental Quality Standard for agricultural soils refers to a maximum of 70 and 1.4 mg/kg, respectively [44]. Samples were digested using the USEPA method 3050B (SW-846). For digestion, 1 g of the dry sample treated with concentrated nitric acid (HNO₃) and hydrogen peroxide (H₂O₂) was used. Hydrochloric acid (HCl) was added to the initial digest and the sample was heated at reflux to increase metal solubility. The digest was diluted to a final volume of 100 mL.

2.3. Risk Assessment

2.3.1. Exposure Assessment (EDI)

Exposure was assessed for the Peruvian population using mean Pb and Cd levels in milk and the mean milk consumption rate published in various studies [45–49]. For the study, the daily milk intake considered for ages 2–5, 6–19, 20–39, 40–59, and 60–85 years of age were 0.500, 0.600, 0.157, 0.154, and 0.195 kg, respectively. The median weights of Peruvian males and females aged 2–85 years correspond to the 2011 Peru Nutritional...
Status report [50], and there are no more current national reports on this parameter, so it remains valid.

Exposure to Pb and Cd from milk consumption was determined as follows: [15,51,52]:

\[
\text{EDI} = \text{CM} \times \frac{\text{DMI}}{\text{BW}},
\]

where EDI is the estimated daily intake of the metal in µg/kg BW/d, BW is the body weight (kg), CM is the metal concentration in milk (µg/kg) and DMI is the daily milk intake (kg).

2.3.2. Dietary Risk Coefficient (DRC)

The daily exposure (µg/day/kg BW) was used to calculate the weekly exposure of each metal (WI: µg/week from milk consumption) for comparison with the provisional tolerable weekly intake (TWI) established for each metal by Joint FAO/WHO Expert Committee on Food Additives (JECFA) [53,54], and the Joint FAO/WHO Expert Committee on Food Additives [55] and World Health, 2012, and to estimate the dietary risk coefficients (DRC) as follows:

\[
\text{DRC} = \frac{\text{WI}}{\text{TWI}},
\]

where:
- DCR is the dietary risk coefficient.
- WI is the amount of metal ingested during one week by milk consumption (µg/week).
- TWI is the tolerable weekly intake of the metal (µg/week).

A DRC of less than 1 indicates an acceptably low risk, while a ratio greater than 1 indicates a high health risk [56,57].

2.3.3. Target Hazard Quotient (THQ)

The potential chronic non-carcinogenic hazard risk from Pb and Cd from milk consumption was expressed as THQ, and calculated as follows: [58]:

\[
\text{THQ} = \left(\frac{\text{EF} \times \text{ED} \times \text{DMI} \times \text{CM}}{\text{RfD} \times \text{ABW} \times \text{ET}}\right),
\]

where
- EF is the frequency of exposure to metal per year (365 d).
- ED is the exposure period equivalent to the thematic longevity (70 years).
- DMI is the daily milk intake (litres)
- CM is the concentration of the metal in milk (mg/kg)
- RfD is the reference dose for the metal (mg/kg/d)
- ABW is the average body weight (60 kg)
- ET is the exposure time in days (70 × 365 = 25,550 d)

The reference doses (RfD) for Cd and Pb are 0.001 and 0.0035 mg/kg/d, respectively [50–61]. If the THQ is >1, high risk is evident and if <1 there is no risk.

2.3.4. Hazard Index (HI)

The HI was used to assess the potential chronic risk to human health when more than one heavy metal is involved. It represents the long-term risk and was determined by the sum of the hazard quotients (THQ) of the different metals [6,35,62]:

\[
\text{HI} = \sum \text{THQ},
\]

There is no risk to human health if HI < 1 [30,35].

To make comparisons of our findings with other studies, estimates have been made for a person aged 25 years and 60 kg body weight and 16 kg for children [15,63].

2.3.5. Data Processing Techniques

Data were analyzed using Excel-2007 and SPSS (IBM, Endicott, NY, USA) version 23. Pb and Cd contents are expressed as mean ± SD, minimum value, and maximum value.
Exposure to these metals was also assessed and weekly intake curves and risk coefficients were generated.

3. Results

3.1. Concentration of Pb and Cd in the Milk Assessed

The lowest and highest levels of Pb in milk were 10 and 20 µg/kg. For Cd, the values were 280 and 690 µg/kg and had a normal distribution (Table 3).

Table 3. The concentration of Pb and Cd in milk and comparison with MPLs for whole milk (n = 40).

| Variable | Mean | SD | VC, % | Minimum | Maximum | MPL, µg/kg |
|----------|------|----|-------|---------|---------|------------|
| Pb, µg/kg | 15b  | 2.6| 17.90 | 10      | 20      | 20 a       |
| Cd, µg/kg | 505 a| 123.2| 24.41 | 280     | 690     | 2.6 b      |

a,b, Average values for each metal with different letters vary statistically with its corresponding MPL (p < 0.01). MPL: Maximum permissible limit, SD: Standard deviation, CV: coefficient of variation.

As complementary information, it is indicated that the average concentrations and standard deviation of Pb and Cd in 6 soil samples from the study area were 49.87 ± 6.27 and 10.13 ± 3.06 mg/kg, and the concentrations of Pb and Cd in the pastures were 5.28 ± 1.89 and 2.74 ± 0.82 mg/kg, respectively.

3.2. Dietary Intake and Risk to Pb and Cd from Milk Consumption

Using the average concentrations of Pb and Cd per kilogram of raw milk in the study area (15 and 505 µg) and the average daily milk intake by age in persons aged 2–85 years, the daily and weekly intake of these metals and the corresponding dietary risk were estimated (Table 4).

Table 4. Daily Pb and Cd exposure from milk consumption in populations aged 2–85 years—Perú.

| Age (Year) | Body Weight/sex (kg) | DMI (kg) | EDI Pb (µg/kg BW/d) | EDI Cd (µg/kg BW/d) | EDI Pb/d (µg) | EDI Cd/d (µg) |
|------------|----------------------|----------|---------------------|---------------------|--------------|--------------|
|            | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female | Male | Female |
| 2          | 12.40 | 11.80 | 0.500 | 0.605 | 0.636 | 20.36 | 21.40 | 7.5 | 7.5 | 252 | 252 |
| 5          | 17.90 | 17.40 | 0.500 | 0.419 | 0.431 | 14.11 | 14.51 | 7.5 | 7.5 | 252 | 252 |
| 10         | 29.60 | 29.80 | 0.600 | 0.304 | 0.302 | 10.24 | 10.17 | 9.0 | 9.0 | 310 | 310 |
| 15         | 51.70 | 49.30 | 0.600 | 0.174 | 0.183 | 5.86 | 6.15 | 9.0 | 9.0 | 310 | 310 |
| 20         | 60.30 | 53.50 | 0.157 | 0.038 | 0.046 | 1.27 | 1.54 | 2.3 | 2.4 | 76 | 82 |
| 30         | 66.30 | 59.60 | 0.157 | 0.034 | 0.041 | 1.15 | 1.38 | 2.3 | 2.4 | 76 | 82 |
| 40         | 69.30 | 61.60 | 0.154 | 0.032 | 0.039 | 1.06 | 1.32 | 2.2 | 2.4 | 74 | 81 |
| 50         | 67.60 | 60.70 | 0.154 | 0.032 | 0.040 | 1.09 | 1.34 | 2.2 | 2.4 | 74 | 81 |
| 60         | 64.80 | 59.20 | 0.195 | 0.043 | 0.052 | 1.44 | 1.74 | 2.8 | 3.1 | 93 | 103 |
| 70         | 59.30 | 54.50 | 0.195 | 0.047 | 0.056 | 1.58 | 1.89 | 2.8 | 3.1 | 93 | 103 |
| 80         | 56.30 | 52.90 | 0.195 | 0.049 | 0.058 | 1.66 | 1.95 | 2.8 | 3.1 | 93 | 103 |
| 85         | 55.60 | 49.50 | 0.195 | 0.050 | 0.062 | 1.68 | 2.08 | 2.8 | 3.1 | 93 | 103 |

DMI: Daily Milk Intake, Kg. EDI: Estimated daily intake.

In children aged 2–5 years, the estimated daily intake of Pb and Cd per kg body weight decreases with age, with younger children being more exposed to the effect of these toxic metals. For the consumption of 500 g of milk per day, the daily intakes of Pb and Cd in children aged 2–5 years were 7.5 and 252 µg, rising until the age of 19 years and then decreasing in adults.

The dietary risk coefficients (DRC) for Pb and Cd in children aged 2 and 5 years were 0.17 and 0.12; while for Cd were 24.6 and 17.0, very high-risk values for this age group (Table 5).

For all ages, the DRCs for Pb are below 1; while for Cd, they are above 1, reaching 24.6 in 2-year-olds, determining that the milk produced in the study area is of very high risk for children and would be unfit for human consumption.
Table 5. Weekly intake and dietary risk to Pb and Cd from milk consumption in populations aged 2–85 years in Peru.

| Age (Year) | WI Pb (µg) | WI Cd (µg) | TWI (µg) | DRC Pb | DRC Cd |
|------------|------------|------------|----------|--------|--------|
|            | Male       | Female     | Male     | Female | Pb     | Cd     | Male | Female | Male | Female |
| 2          | 52.50      | 52.50      | 1767     | 1767   | 310    | 72     | 0.17 | 0.17   | 24.6 | 24.6   |
| 5          | 52.50      | 52.50      | 1767     | 1767   | 448    | 104    | 0.12 | 0.12   | 17.0 | 17.0   |
| 10         | 63.00      | 63.00      | 2121     | 2121   | 740    | 172    | 0.09 | 0.09   | 12.4 | 12.4   |
| 15         | 63.00      | 63.00      | 2121     | 2121   | 1293   | 300    | 0.05 | 0.05   | 7.0  | 7.0    |
| 20         | 15.86      | 17.12      | 534      | 576    | 1508   | 350    | 0.01 | 0.01   | 1.5  | 1.7    |
| 30         | 15.86      | 17.12      | 534      | 576    | 1658   | 385    | 0.01 | 0.01   | 1.4  | 1.5    |
| 40         | 15.86      | 17.12      | 534      | 576    | 1663   | 386    | 0.01 | 0.01   | 1.4  | 1.5    |
| 50         | 15.33      | 16.90      | 516      | 569    | 1695   | 393    | 0.01 | 0.01   | 1.3  | 1.5    |
| 60         | 15.83      | 16.90      | 516      | 569    | 1683   | 354    | 0.01 | 0.01   | 1.9  | 2.1    |
| 70         | 19.43      | 21.42      | 654      | 721    | 1483   | 327    | 0.01 | 0.02   | 2.0  | 2.2    |
| 80         | 19.43      | 21.42      | 654      | 721    | 1390   | 322    | 0.01 | 0.02   | 2.0  | 2.2    |

WI: Weekly intake. TWI: Weekly reference intake. DRC: Dietary Risk Coefficient.

Figures 2 and 3 show the weekly intake curves (WI) of Pb and Cd, and the DRC curves by age and sex in relation to the maximum risk safety limit. These curves were constructed with the 2–85-year data to generate continuous lines.

Figure 2. Weekly intake of Pb and Cd by age and sex in relation to the provisional maximum weekly intake (µg). At the top is the Pb WI, and at the bottom is the Cd WI.
3.3. Target Hazard Quotient (THQ)

To make comparisons of our findings with other studies, we show results determined in 25-year-old adults with a bodyweight of 60 kg [40,53], in this case consuming 150 g of milk per day. The THQs for Pb and Cd were 0.01 and 1.26, respectively.

As the THQ\(_{Cd}\) is >1, high risk is evident for 25-year-olds consuming 150 g of milk containing Cd at a concentration of 0.505 mg/kg daily, whereas the THQ\(_{Pb}\) < 1 indicates no risk from the intake of this milk.

In children weighing 16 kg, around 4 years of age, who consume 0.5 kg of milk daily, the THQ\(_{Pb}\) was 0.134 and the THQ\(_{Cd}\) was 15.78, showing a very high risk of Cd for children of this age.

There is a high risk due to the high presence of Cd in the milk produced in the study area.

Figure 3. Dietary risk coefficient of Pb and Cd intake by age and sex in relation to the upper safe limit of risk. At the top is the Pb DRC, and at the bottom is the Cd DRC.
3.4. Hazard Index

In this study, the hazard index (HI), which is the sum of the THQ of Pb and Cd per consumption of 150 g of milk for an average 25-year-old person weighing 60 kg was 1.27; of this value, only 0.85% corresponds to Pb and 99.15% to Cd.

In the case of 4-year-old children weighing 16 kg and consuming 500 g of milk/day, the HI is 15.91, with 0.84% corresponding to Pb and 99.16% to Cd, a result that indicates that the main component of the hazard index is given by the presence of Cd in the milk.

4. Discussion

4.1. Concentration of Pb and Cd in Raw Milk

In this study, Pb and Cd concentrations in whole milk were between 10–20 and 280–690 µg/kg, respectively, values much higher than those reported in studies conducted in other regions of the world, where even milk did not contain Cd [64], and as reported in studies in recent years (Tables 1 and 2).

In this study the average Pb content has represented 75% of the MPL which is 20 µg/kg [38,39]; however, its prolonged consumption can cause adverse health effects, and behavioural and learning abnormalities in children [65], who absorb 5–10 times more of the ingested Pb than adults [66] and because their developing nervous system is more vulnerable to the heavy metal toxic effects than the adult brain [67].

The average Cd content in the milk samples was 194 times more than the MPL set by International Dairy Federation (2.6 µg/kg) [32,40]. This concentration is well above values reported in Obilić, where the thermal plants “Kosovo A and B” are located, where whole cow’s milk had 40 µg/kg Cd [68].

The high Cd content in milk from the study area could cause serious health problems in the consuming population, damaging different organ systems and giving rise to various types of cancer [26–28].

Our results are like those reported in other developing countries where animals consume feed and water contaminated with Pb and Cd from industrial emissions that exceed the maximum limits; while the contents of these metals in milk produced in developed countries, with more controlled industrial activity and more rigorously applied regulations [69], are below those determined in this study.

Higher concentrations of heavy metals in milk are reported in areas close to mining and metallurgical activities, in industrial and high traffic areas, on farms using phosphorus fertilizers, pesticides and fungicides, and when pastures are irrigated with untreated wastewater, canal water loaded with sewage and mining and industrial effluents [70,71].

Lower Pb and Cd concentrations (47 and 4.7 µg/kg) are reported in milk produced in stables near oil fields [15] and industrial areas in Iran (14 and 3.5 µg/kg) [72].

Comparing our results with other studies conducted in the southern highlands of Peru, in the “Coata” river basin, in an area close to emissions and wastewater disposal from mining activity reports Pb and Cd contents of 210 and 3.7 µg/kg [73]. In Umachiri micro-watershed, Puno highlands, the Pb and Cd milk contents exceeded the MPL by 638 and 45 times [74].

In a livestock area located approximately 20 km from the La Oroya Metallurgical Complex, Pb and Cd concentrations of 580 and 20 µg/kg have been reported [10], with Pb contents higher than in the present study, but much lower in Cd. Said area milk has Pb as the main source of contamination present in the dust and vapours emitted by this industry that is deposited in the soil and water.

In our study, the Pb content in the soil (49.87 mg/kg) represented 71% of the maximum level established in the Environmental Quality Standard for agricultural soils [44], and its route of entry into the soil would be through irrigation water from the CIMIRM and fine dust particles and vapours from the mining-metallurgical industry of La Oroya.

In the Cd case, in this study, the soil contained 10.13 mg/kg, 7.2 times higher than the MRL [44], and its pathway of entry into the soil would be mainly due to its presence in phosphorus fertilizers and agrochemicals [75–77], in CIMIRM irrigation water and from
fine particles that are transported through the air from La Oroya by the action of the winds [78]. This high Cd content in the soil-plant system bioaccumulates in milk, resulting in a high Cd content in this staple food for the Peruvian population.

Phosphorus agrochemicals are based on phosphate rock containing Cd, and triple superphosphate contains 53.2 mg Cd/kg [75,79,80].

4.2. Dietary Intake and Risk to Pb and Cd from Milk Consumption

The estimated daily intake of Pb (7.5 µg) in children aged 2–5 years, for daily consumption of 500 g of milk, was 2.5 times higher than the provisional tolerable daily intake estimated by the US Food and Drug Administration-FDA (3 µg/day) and would affect the neurodevelopment of children [81–83].

Our result is similar to those reported in farms and markets in Edirne, Turkey, where the intake of toxic metals was below the Turkish Food Codex levels [84], but is much lower than that recorded in children aged 1–7 years in La Plata, Buenos Aires-Argentina, with a daily intake of 138 µg/day and the food groups with the highest Pb intake were processed meat (15.4%), pastries (14.8%), milk (12.5%) and meat (11.7%) [85].

Regarding the weekly reference intake (TWI) of Pb, this increases with age; for children aged 2, 3, 4 and 5 years it is estimated at 300, 375, 455 and 520 µg, and in this study, for the consumption of 500g of milk daily, the values were below the corresponding TWI, determining CRDs below 1, so that this milk from the point of view of its Pb content would not be considered a health risk; however, given the scientific data reporting a number of health problems in children with less than 5 µg/dL of Pb in blood, sustained consumption of this milk may be risky over time [81].

Regarding Cd, in children aged 2–5 years in this study, the estimated daily intake of Cd from consumption of 500 g of milk was 253 µg, a value 44 times higher than the estimated provisional tolerable daily intake of 0.36 µg/kg body weight [54,86], which for children weighing 16 kg would be 5.71 µg.

A provisional tolerable weekly intake (PTWI) of Cd 2.5 µg/kg b.w. guarantees a high level of protection for all consumers, including exposed population subgroups and vulnerable groups [15,54,86]. In our study, for male children aged 2, 3, 4 and 5 years, with average body weights of 12.4, 14.4, 14.4, 16.1 and 17.9 kg, the Cd PTWIs would be 31, 36, 40 and 45 µg/week, respectively, and for 500 g of milk daily consumption these children they would have a weekly intake of Cd of 1764 µg, values 57, 49, 44 and 39 times higher than their corresponding PTWI; therefore, the milk produced in the study region would not be suitable for consumption.

The DRCs for Cd were higher than 1 for all ages, being of higher risk for children because the rates of intake, absorption and accumulation of heavy metals are higher than in adults [24,87,88]; in addition, deficiencies of iron, zinc, and calcium, favour the absorption of Pb and Cd, and deficiencies of B-complex vitamins and vitamin C can exacerbate the adverse effects of Pb poisoning [29].

Regarding THQs, our results in adults weighing 60 kg show a value below 1 for Pb and above 1 for Cd. In children, the THQ was above 15. The HIs were also greater than 1 at all ages, a result of great concern if we consider that simultaneous exposure to two or more metals may have cumulative effects [56,57].

Previous studies carried out in Peru have indicated that milk produced in the vicinity of the mining and metallurgical industry is not suitable for human consumption due mainly to high Pb concentration, while in this study the milk has a high content of Cd. It is important to know the level of contamination of milk by heavy metals and to estimate the dietary risk of its consumption to ensure an adequate intake of safe and innocuous milk. It highlights the importance of the results to be considered in the formulation of standards on maximum levels of these metals in milk and dairy products consumed by the Peruvian population, identifying the main sources of contaminants.
4.3. Implications for Peru

In the central area of the Peruvian Andes, there is a traditional dairy farming activity, from family production units to consolidated dairy farms, which for years sold raw milk to large dairy industries; however, in the last decade, the daily collection volume of these companies has been reduced by 73%, generating an available supply of fresh milk for direct consumption or for home industrialization by small informal producers who do not guarantee the safety and quality of the milk and their derivatives.

The bioaccumulation of heavy metals through milk consumption can lead to a variety of toxic effects in a variety of body tissues and organs, especially when Cd is classified by the International Agency for Research on Cancer as carcinogenic to humans (Group 1) [89] and Pb as probably carcinogenic to humans (Group 2 A) [90].

Considering the results of the present study, the 120,000 L per day produced in the Mantaro Valley alone would be unfit for human consumption, due to the potential risk associated with Pb and Cd, especially due to the high content of Cd. [31]. The presence of Pb and Cd in the milk evaluated would have two sources of entry, those coming from emissions to air and water from the mining-metallurgical industry developed in the central highlands of the country, and the metals present in phosphorus fertilizers, mainly Cd, which enter the food chain through the soil-plant-animal system, and which are ultimately transferred to milk and other agricultural products.

Another important aspect of our findings points to the need for review and update of tolerable intake levels of Pb and Cd and strict public measures to minimize contamination of the food chain and reduce the risk to human and animal health from consumption of food contaminated with heavy metals [91].

5. Conclusions

This study presents an assessment of the risk for Pb and Cd from the milk consumption produced in a central area of the Peruvian Andes, investigating whether the average consumption of milk in people aged 2 to 85 years constitutes a potentially important source of exposure to these metals and if it poses a health risk.

The average concentration of Pb in the milk samples represented 75% of the maximum limit suggested by the Codex Alimentarius, and the average concentration of Cd was more than 194 times the maximum limit of international standards.

The estimated weekly intake of Pb from the average consumption of milk in the Peruvian population aged 2–85 years does not exceed the references for weekly intake and the dietary risk coefficients were less than 1. The weekly intake of Cd greatly exceeded the references and the risk coefficients ranged between 1.3 and 24.6, being higher in children, which indicates a high potential risk for the consumption of milk produced in the environmental and productive conditions of this region of the world.

Our findings provide scientific evidence for the Peruvian government to establish a monitoring program for the content of Pb and Cd in fresh milk, prior to the establishment of national maximum limits, identifying the sources of contamination and recommending corrective measures to drastically reduce the presence of these metals. heavy in the air, irrigation water, soil, grasses, and other feedstuffs used in Peruvian dairy farming.

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