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Manganese Intake in a Human Population Located Near a Mine Tailings Dam in Huechún Village, Chile

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Abstract

Introduction: The environmental effects of the mining industry, include potential contaminants that affect soil, water and foodstuffs. Drinking water is the main route of manganese (Mn) to humans and, vegetables are an important human food, with increasing consumption in rural communities.

Objective: The aim of this study was to measure Mn-concentration in soil, drinking water and vegetables (edible part of lettuce, (*Lactuca sativa)),* in the rural village of Huechún, Chile, the inhabitants of which live near a mine tailings dam.

Materials and Methods: Atomic absorption spectrometry (AAS) was used to quantify Mn in soil, drinking water and lettuce. The analyses revealed the presence of Mn in all analyzed samples, with concentrations below the thresholds established by national and international regulations.

Results: Mn-concentrations in drinking water according with sampling period exceeded the safe level recommended by the U.S. EPA and European Union (50 μg L^{-1}) but were insufficient to severely impair in intellectual functions in children mainly.

Conclusion: Based on the results of this report, we believe that the Mn intake of the inhabitants of Huechún may not pose a health risk.

Keywords: *Manganese; Mining Industry; Drinking Water; Vegetables; Human Health Risk*

Abbreviations

AAS: Atomic Absorption Spectrophotometry; EC: Electric Conductivity; NTU: Nephelometric Turbidity Unit; W-Mn: Water-Manganese; S-Mn: Soil-Manganese; H-Mn: Hair-Manganese; T-Mn: Total Manganese; B-Mn: Bioavailable Manganese; b.w.: Body Weight; w.w.: Wet Weight; WHO: World Health Organization; FAO: Food and Agriculture Organization; EFSA: European Food Safety Authority; JECFA: Joint Expert Committee on Food Additives; USEPA: United States Environmental Protection Agency; DTPA: Diethylenetriaminepentaacetic Acid; PTWI: Provisional Tolerable Weekly Intake; TDI: Tolerable Daily Intake

Introduction

Mining is an extractive activity that consists of obtaining selective minerals and other materials from the Earth´s crust, which often involves physical extraction, of large quantities of materials to recover only small volumes of the desired product. The environmental effects of the mining industry include contaminants that affect soil, water, and air [1]. Some metals such as cadmium (Cd), manganese (Mn), copper (Cu) and zinc (Zn) are highly toxic in small concentrations and soluble conditions and can be absorbed by humans [2,3].

Environmental metal exposure normally occurs as co-exposure to multiple metals such as cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), chromium (Cr), and manganese (Mn). Among these metals, Mn is an essential trace element, but it is toxic, especially for brain function, when abnormal deposition occurs in the body [4]. Several human enzymatic reactions, including those involved in the formation of healthy cartilage and bone, the urea cycle of waste, excretion, mitochondrial maintenance, glucose production and wound healing [5]. Enzymes such as Mn-superoxide dismutase and pyruvate carboxylase serve to activate certain kinases, transferases and other enzymes [6].

Industrial activities (i.e. metallurgy and mining) and drinking water are the main sources of Mn exposure. Evidence from cross-sectional studies has indicated that groundwater and industrial emissions from ferromanganese alloy plants and mining are the main sources of environmental Mn-exposure. Manganese quantities in soil may be elevated when the soil is near to a mining source or industrial operation that use this metal, with the polluted soil possibly resulting in children having excessive exposure. Therefore, children are exposed to Mn mainly by inhaling pollutants from industrial emissions and by drinking polluted water [7].

Biomarkers such as hair, blood and teeth are generally used to measure manganese concentrations in environmental samples of drinking water, p articulate matter and soils [8]. Hair is a more sensitive indicator of environmental Mn-exposure than blood. The presence of Mn in soil results in uptake into vegetables and animal food, and the primary source of Mn in the general population is food [9].

Manganese, like other trace elements, is essential in the human diet, but excessive exposure to manganese can have neurotoxic effects. It is a fact that occupational Mn-exposure in adults can cause Parkinsonian-like movement disorders. This consequence of excess Mn appears to be due partly to its interaction with other metals like iron (Fe) [10].

High Mn levels in water (W-Mn), are common in groundwater because this element leaches from Mn-bearing mineral rocks into aquifers [11]. Higher W-Mn is associated with better performance intellectual quotient (IQ) among boys only a large percentage of children were exposed to drinking water manganese under 50 μg L^{-1} [7]. Numerous studies have indicated that a high concentration of Mn in drinking water is associated with impaired cognitive abilities, adaptative behavior, or both, in children aged 6 to 13 years. In children under 6 years of age, studies have revealed that prolonged exposure to Mn has a negative effect on neurological development, mainly cognitive and motor development. Girls were more susceptible to Mn-exposure than boys in terms of cognition and motor [12,13]. Due to the rapid and crucial neurodevelopment that occurs during early life, children are potentially more vulnerable than adults to cognitive changes from exposure to neurodevelopmental toxins [9].

In the Chinese province of Shanxi, 92 children 11 - 13 years of age exposed to 240 - 350 μg Mn L^{-1} in water, had elevated hair Mn-concentrations (H-Mn), impaired manual dexterity and speed short-term memory and visual identification when compared with children from a control area [14]. Nonetheless, the concentrations measured are not unusual in the America. In New England 45% of public wells have Mn - concentrations higher than 30 μg L^{-1} [11]. Bouchard., *et al*. carried out a cross-sectional study that included children´s home tap water. The median W-Mn concentration was 34 μg L^{-1} and H-Mn increased with Mn intake from water consumption, but not with dietary Mn-intake. These studies suggest that Mn exposure from groundwater is associated with intellectual impairment in children [12]. However, Leonhard., *et al*. did not observe a significant association between hyperactivity and a W-Mn concentration of 20 μg L^{-1} [9].

Aim of the Study

The aim of this study was to measure the environmental Mn exposure via drinking water and food (vegetables) of inhabitants living near mine tailings dams.

Materials and Methods

Description of study area

The study area was Huechún village, located in the Til Til District in the Metropolitan Region, 35 km north west of Santiago in Chile.

The Ovejería mine tailings dam of the National Copper Corporation´s (Spanish: Corporación del Cobre, CODELCO) Andina Division is located 5 km from Huechún village. It has been in operation for the last 20 years. Mine tailings are contributed by two mines named Río Blanco and Sur, located in the Andes highlands, and are transported for about 77 km to Huechún. The total planned capacity of the mine tailings deposit was 1300 million tons, which would cover 4400 Ha. At present, the Ovejería mining wastes deposit stores 19% of its total capacity, which accounts for approximately 850 Ha [15].

Community of Huechún

The population of Huechún is 340. Agriculture is the main economic activity, carried out on small holdings. The inhabitants´ diet consists mainly of vegetables and animal meat.

The community of Huechún and CODELCO´s Andina Division, have expressed concern over possible pollution by the Ovejería deposit with exposed inhabitants have required information from the local authorities and asking for biomonitoring of different metallic contaminants which can be harmful to health.

Materials

Soil samples: Soil samples (n = 20) were collected monthly between May and October 2014 and January 2015, from depths of 0 - 10 cm in the housing, school and agricultural areas of Huechún. Samples were transported to the Soil and Water Chemistry Laboratory of the University of Chile where they were dried at 40°C to constant weight, sieved to particle size (2 mm) and stored at ambient temperature.

Drinking water samples: Drinking water samples were collected from the kitchen taps of selected house and the school after allowing the water to run through the pipes for 5s [16]. Samples from nine selected points (n = 1/each point) were obtained monthly between May and October 2014 and January 2015 and were then transported to the Soil and Water Chemistry Laboratory of the University of Chile to measure pH, electric conductivity (EC) and total solids, according with the Chilean Water Standard (NCh 409/1.Of.2005). Finally, samples were stored and refrigerated (4°C) until Mn-analysis [17].

Lettuce (Lactuca sativa) samples. Pot experiments

Thirty-day-old lettuce plants were placed in plastic containers (1- L capacity) filled with soil approximately 2 kg) obtained from sampling points S1, S7 and S8 which were selected because these points present the highest Mn-concentrations. Plants were irrigated three times per week with 250 mL of tap water for each container over eight weeks. This experiment was conducted under ambient conditions in the research greenhouse of the School of Agricultural Science, of the University of Chile [18].

Methods

Mn-concentrations in soil samples

Total (t) and bioavailable (b) Mn-concentrations (i.e. concentration of the element that can be incorporated into an organism) were determined. Bioavailable - Mn concentrations were measured using the atomic absorption spectrophotometry (AAS) method, prior to extraction by DTPA [19,20]. Total-Mn concentrations were measured using the AAS method prior to acid digestion (HNO_3 cc and H_2O_2) [1].

Mn-concentrations in drinking water samples

Mn-concentration in drinking water samples were determined by AAS and direct aspiration [19].

Mn-concentrations in lettuce leaves (Lactuca sativa)

Total-Mn concentration in the edible part of lettuce were measured with the AAS method, using the dry via and acid digestion (HNO_3 cc + H_2O_2) [1,28,29].

Results and Discussion

The chemical parameters in drinking water present pH and EC ranges measured in different sampling points and periods (Table 1). pH and the total solids values were within the maximum limits established by the national regulations, which specify a pH range in drinking water between 6.5 to 8.5 and a total solids concentration below 1500 mg L^{-1} (NCh 409/1.Of. 2005).

Sampling date	Classification of waters	pH	Electric conductivity/ dS m^{-1}	Dissolved solids/mg L^{-1}	Turbidity/NTU
May, 2014	Drinking	7.8 - 7.9	0.69	442 - 448	0.20 - 0.70
	Different uses	7.1 - 8.0	0.60 - 0.90	407 - 585	0.20 - 25.0
June, 2014	Drinking	7.8 - 7.9	0.58 - 0.59	455 - 459	0.45
	Different uses	7.9 - 8.0	0.51 - 0.78	418 - 588	0.40 - 12.0
July, 2014	Drinking	7.8 - 7.9	0.63 - 0.65	461 - 468	0.20
	Different uses	7.5 - 7.9	0.28 - 0.85	278 - 639	0.60 - 13.0
August, 2014	Drinking	7.6 - 7.7	0.69	502 - 513	0.25 - 0.40
	Different uses	7.7 - 8.0	0.27 - 0.91	276 - 742	0.25 - 11.0
September, 2014	Drinking	6.7 - 6.8	0.66 - 0.67	456 - 460	< 0.20
	Different uses	6.4 - 7.7	0.59 - 0.90	424 - 609	0.20 - 1.60
October, 2014	Drinking	7.1	0.68	474	0.30
	Different uses	6.9 - 7.7	0.06 - 0.92	206 - 624	0.20 - 64
January, 2015	Drinking	6.7 - 7.1	0.63 - 0.68	439 - 493	0.50 - 0.60
	Different uses	6.3 - 7.3	0.33 - 0.99	255 - 671	0.20 - 80

Table 1: *Range of pH, electrical conductivity, dissolved solids and turbidity values at the nine water sampling points in Huechún.*

With respect to drinking water turbidity, the results show that the values are within the range established by the national standard: 4 - 20 NTU.

In table 2 is observed that the W-Mn concentration varies in each sampling period. The maximum level fluctuated between 30 - 90 µg L^{-1}, exceeding the 50 µg L^{-1} maximum limit established by the U.S. EPA and lower than both Chilean (100 µg L^{-1}) and WHO standards (400 µg L^{-1}).

Table 3 presents the Mn-concentration ranges (mg kg^{-1}) in soil collected at a depth of 10 cm, by sampling period.

The results regarding Mn-concentration ranges in soil samples collected at a depth of 10 cm, show high levels of total-Mn but not bioavailable-Mn; therefore, exposure to Mn in the soil does not pose a risk to human health.

Sampling period	W-Mn concentration/μg L^{-1}
May 2014	10 - 60
June 2014	10 - 40
July 2014	10 - 30
August 2014	10 - 30
September 2014	≤ 10
October 2014	≤ 10
January 2015	10 - 90

Table 2: *Mn-concentration ranges (μg L^{-1}) in drinking water, by sampling period.*
W-Mn: Water Manganese.

Sampling period	S-Mn concentration/mg kg^{-1}	
	T-Mn	B-Mn
May 2014	710 - 1090	16 - 57
October 2014	830 - 1260	9 - 33
January 2015	670 - 1030	7 - 83

Table 3: *Mn-concentration ranges (mg kg^{-1}) in soil, by sampling period.*
S-Mn: Soil Manganese; T-Mn: Total Manganese; B-Mn: Bioavailable Manganese.

The difference between the T-manganese and B-manganese found in the soil of Huechún could be a result of the acidity of the water. The oxidation states of manganese in the soil can be: Mn (II), Mn (III) and Mn (IV). In acid soils they take it mainly as soluble Mn (II), while in neutral or slightly alkaline soils the precipitated oxides of Mn (II) and Mn (IV) predominate. Therefore, plant roots play an important role in the mobilization or immobilization of bioavailable manganese in soils.

Sampling site	Leaf-Mn concentration/mg kg^{-1} (w.w.)	Mn-intake/1 unit/300 g
S1	10.1	3.0
S7	9.8	2.9
S8	7.6	2.3

Table 4: *Mn-concentrations (mg kg^{-1}, w.w.) in lettuce (Lactuca sativa) and intake calculated for consumption of one unit.*
w.w.: Wet Weight.

Table 4 shows that Mn - concentrations in lettuce (*Lactuca sativa)* ranged from 7.6 mg kg^{-1} to 10.1 mg kg^{-1}, w.w., depending on the sampling site.

Due to of the scarcity of previous reports on Mn - intake in manganese - rich areas, it is not possible to compare our results with other studies; Mn-intake from this food we consider high, which exceed Mn - day consumption in all age group (Table 5).

Table 5 shows nutritional Mn-consumption levels suggested by different international organizations and authors, classified by age group; these recommendations vary according to age and physiological status, with the highest Mn consumption recommended for adults (men and women).

Age group	Mn-consumption/mg day^{-1}
Adult men	2.3
Mature women	1.8
Pregnant women	3.0
Children and teen - agers	1.2 - 2.2
Children (3 - 5y)	0.5 - 2.0
Children (6 - 13y)	1.5 - 1.9

***Table 5:** Nutritional Mn-consumption by age group.*
Reference: Das., et al. 2015 [25]; European Food Safety Authority (EFSA), 2013 [24], Food and Nutrition Board, 2004 [28].

The concentration of Mn in drinking water varies by location, ranging from 1 to 100 μg L^{-1}, but can exceed 200 μg L^{-1} in well water. Exposure from water is usually minor. The United States Environmental Protection Agency (U.S. EPA), European Union, United Kingdom, Canada and Japan have been indicated 50 μg L^{-1} as the safe level for Mn in drinking water [7]. The World Health Organization (WHO) has established a health-based water - Mn (W-Mn) standard of 500 μg L^{-1} [6]. This standard has been questioned, because it is "based partly on debatable assumptions, where information from previous reports has been used without revisiting original scientific articles" [21].

Our results were lower than the levels indicated in WHO (500 μg L^{-1}) and, Chilean regulations (100 μg L^{-1}) and similar the safe level established by the U.S. EPA and European Union (50 μg L^{-1}) between international agencies. However, children exposed to manganese at levels common in drinking water (30 μg L^{-1}) can show intellectual impairment [12]. It is possible that a safe level of Mn in drinking water of 20 μg L^{-1} did not present a significant association with hyperactivity [13].

Toxic amounts of waterborne Mn (≥ 2 times the acceptable level) have been reported in wells in areas in which soil Mn-concentrations were found to be exceptionally high. Populations that rely on well water from groundwater sources with a propensity for Mn-contamination have reported learning impairment in children who consume unfiltered well water [22]. However, exposure to Mn from water consumption has been of little concern because the intake of the element via water ingestion including water used in food preparation (e.g. juice made from concentrate, soup, diluted coffee and tea) is low compared with intake via food, except for infants [13].

These findings suggest that Mn in drinking water is metabolized differently than that in food and can lead to overload and subsequent neurotoxic effects, expressed as intellectual impairments in children. This suggests that there might be differences in the regulation of Mn present in food and water [23].

The primary source of Mn is the diet, which usually provides the required 3.0 mg d^{-1} for pregnant women, 1.8 mg d^{-1} for mature women, 2.3 mg d^{-1} for adult men, 1.2 – 2.2 mg d^{-1} for children and teenagers, 0.5 – 2.0 mg d^{-1} children (3 – 5 y), and 1.5 – 1.9 mg d^{-1} children (6 – 13 y) (Table 5). Toxicity from dietary exposure has not been reported [24-26].

Dietary-Mn intake from the edible part of lettuce in our study was similar to the recommended dietary allowance of 2.3 - 3.0 mg d^{-1} for adults (men and pregnant women) and highest for children and teen-agers (Table 5). However, these values correspond to the intake of 300 g day^{-1} of lettuce only; hence, if other Mn-containing foods are consumed daily by an inhabitant of Huechún, Mn intake should be higher.

The parameter most commonly used for the evaluation of heavy metals and metalloids in foodstuffs and human health risk assessment, is the Provisional Tolerable Weekly Intake (PTWI) established by the Food and Agricultural Organization (FAO) for the United Nations/World Health Organization (WHO), Joint Expert Committee on Food Additives (JECFA). The PTWI value is an estimate of the amount of a contaminant that can be consumed by a human over a life time without appreciable risk [27].

The JECFA has established 2.5 mg Mn kg^{-1} body weight (bw) $week^{-1}$ as the amount of Mn that can be consumed by a human without any risk [28].

We expressed the PTWI as tolerable daily intake (TDI = PTWI/7 days), with a value of 0.36 mg Mn/kg bw/day. Assuming a mean body weight of 70 kg for an adult and 45 kg in the 13 - 15 age group, the reference intakes stated by the FAO/WHO are equivalent to 25.2 mg Mn day^{-1} and 16.2 mg Mn day^{-1} (TDI x kg body weight), respectively [29]. These values are higher than those proposed by different International organizations (Table 5).

Due to the lower bioavailable Mn concentrations measured in soil where lettuce samples were collected relative to the high total Mn concentrations (Table 3) the Mn-concentrations measured in the vegetable were low. This finding demonstrates that approximately 30% of b-Mn is translocated to the leaves. Hence, a large fraction of the b-Mn present in the cultivated soil (70%) is accumulated in the roots or does not enter to the plant. The first possibility is more likely [30].

This study is the first work to estimate Mn - intake from drinking water and vegetables grown near mine tailings dams. The obtained data provides the basis for research that, through calculations of intake and epidemiological studies, could lead to specific legislative control of Mn in vegetables produced or consumed in these areas. Therefore, this study strengthens the growing literature on human Mn exposure.

However, our findings are not likely to be explained by anthropogenic contaminants only, because Mn contamination of water and vegetables in the study area can arise from natural processes associated with the bedrock geology.

Conclusion

Based on the results of this report and USEPA and WHO guidelines, we believe that the Mn intake of the inhabitants of Huechún, especially children, may not pose a health risk. However, national and international guidelines for safe Mn levels in drinking water should be revised.

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Conflict of Interest

The authors declare no conflict of interest.

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