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Estimate of the current exposure of the urban population of northern Chile to arsenic

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Abstract This study presents an estimate of the actual integrated exposure of the urban populations of northern Chile to arsenic. Exposure was assessed by combining data on the levels of arsenic in water, food and air, with information about food consumption and rates of water ingestion and air inhalation. The principal limitations of this study include uncertainties about the dietary intake of arsenic and the lack of knowledge about arsenic speciation, bioavailability and absorption factors. The results showed that the level of exposure of this population to inorganic arsenic fluctuates between 2363 and 125.63 μg As day^{-1}. Ingestion of water was found to be one of the most important routes of exposure.

INTRODUCTION

Approximately 1.5 million people, representing about 10% of the total population of Chile, live in the northern region of the country. The air, water and soil in this region are contaminated with arsenic due to natural and anthropogenic causes.

Water consumed by the population (>600 000 people) of the northern cities of Iquique, Antofagasta, Calama and Tocopilla, contains levels of arsenic that are much higher than the values currently recommended by the World Health Organization (WHO, 1993), but are within the Chilean standards for drinking water quality (INN, 1984). The air also contains arsenic, in variable amounts, as a consequence of the natural contamination and the intensive mining activity carried out in the area (Sancha, 1994). Due to dry conditions, foods such as meat and poultry, milk and dairy products, vegetables, pastry and cereals are imported from other areas of the country where the serious problem of arsenic contamination does not exist.

Epidemiological studies have shown that the rate of cancer associated with exposure to arsenic in this area is considerably higher than the mean cancer rate for the country (Ferreccio *et al.*, 1998; Rivara & Corey, 1995; Smith *et al.*, 1998). The authorities have taken a number of steps to address this situation. The first efforts were taken in the 1970s with the construction and operation of treatment plants to remove arsenic from water (Sancha & Ruiz, 1984). More recently, measures are being taken to regulate the emissions of arsenic from smelting plants that operate in the zone, to reduce the levels that are released into the atmosphere (Wiertz & Rozas, 1996).

It is important to distinguish between the levels of arsenic exposure in the urban and rural populations of northern Chile. The rural areas have primarily aboriginal

populations of less than 5000 people who do not have access to water that has been treated to remove arsenic. In addition, these people become exposed by consuming many kinds of foods that are grown locally in soils that are highly contaminated by arsenic (Sancha *et al.*, 1995). Occasionally, some of these products reach the public markets in urban centres, but in general there is little consumption of these crops by the urban population.

MATERIALS AND METHODS

Samples of air, water and foods were taken in the principal cities of northern Chile. Air samples were taken with high volume PM10 equipment, recording in each case the wind speed and direction. Sampling was conducted 24 h per day, seven days a month for one year. Tapwater samples were taken from various locations in the distribution system. Food samples were taken from the regular public markets.

Arsenic levels were determined using atomic absorption spectrometry and hydride generation (Perkin Elmer 2100 MHS 20). Water samples were analysed for total arsenic and arsenic (III) in the presence of arsenic (V) (Yamamoto *et al.*, 1981; Hinners, 1980). For analytic quality control, SLRS-2 Riverine Water Reference Material for Trace Metals (Marine Analytical Chemistry Standard Program, National Research Council Canada) was used. Total arsenic analyses in vegetables were made after acid digestion with nitric/sulphuric/perchloric acid. Analyses of PM10 environmental filters were made with methods standardized by the Instituto de Salud Pública de Chile.

To assess the exposure, data on the arsenic content of the air, water and food was combined with information provided by the Ministerio de Salud de Chile (MINSAL-Chile) about water ingestion (2 l day^{-1}), air inhalation (20 m^3 day^{-1}) and food ingestion. The information about food ingestion corresponds to recommendations made by MINSAL-Chile and is common to the entire country, regardless of sex, age or geographical location. Limited information on the actual diet, combined with the lack of knowledge concerning speciation, bioavailability and absorption factors for the arsenic entering the body by each route of exposure, are important uncertainties in this exposure assessment.

RESULTS AND DISCUSSION

Tables 1 and 2 show the levels of arsenic, as the inorganic species, to which people in northern Chile are exposed through water and air. Only 60.9% of this population consumes water that meets the international guideline for arsenic (WHO, 1993). There is no international guideline value for arsenic in air for comparison with atmospheric levels.

Table 3 shows information about inorganic arsenic levels in water and air for cities with more than 20 000 people. The cities of Calama and Copiapó have the highest arsenic levels in air due to their proximity to copper smelting plants. Water from the cities of Antofagasta, Calama and Tocopilla is treated to remove the arsenic, whereas the water from Iquique does not receive such a treatment.

Table 1 Arsenic content of the water consumed by the people of northern Chile (1994–1996).

Concentration range (As μg l^{-1})	Population (%)
2 < As = 5	49.48
5 < As = 10	11.42
10 < As = 30	1.05
30 < As = 50	27.28
50 < As = 80	10.40
80 < As = 800	0.37

Table 2 Arsenic content of the air inhaled by the people of northern Chile (1994–1996).

Concentration range (μg m^{-3})	Population (%)
0.005 < As = 0.025	56.93
0.025 < As = 0.050	12.02
0.050 < As = 0.100	15.30
0.100 < As = 0.150	14.95
0.150 < As = 0.250	0.80

Table 3 Average arsenic concentrations in air and water in some cities of northern Chile (1994–1996).

Region	City*	Water (μg l^{-1})	Air (μg m^{-3})
I	Arica	9	0.025
	Iquique	56	0.025
II	Antofagasta	32	0.057
	Calama†	38	0.129
	Tocopilla	40	0.050
III	Copiapó†	4	0.148
	Diego de Almagro	5	0.050
	Vallenar	5	0.050
IV	Coquimbo	6	0.025
	La Serena	5	0.025
	Vicuña	5	0.025
	Ovalle	5	0.025
	Monte Patria	5	0.025
	Illapel	5	0.025
	Salamanca	5	0.025

*Cities with a population of over 20 000 people.
†Cities nears smelting plants.

The total arsenic content in food (unspeciated) is shown in Table 4. The urban population of northern Chile preferentially consumes foods imported from the southern part of the country and only the rural population (aboriginal) consumes locally produced foods (vegetables).

The total arsenic content in the diet of the urban population of the northern region of Chile (Table 5) is an estimated 136.3 μg day^{-1}, 90.81% of which comes from vegetables, rice and fish. The international literature (Weiler, 1987) indicates that in these types of foods, arsenic appears predominantly as organic species. Table 6 shows the exposure of the urban population to arsenic according to the different routes of exposure. In this estimation, the arsenic in air and water is assumed to be the inorganic species. Arsenic in food is estimated to be a mixture of 90.37% organic and 9.63% inorganic forms.

Table 4 Arsenic content in the food consumed by the people of northern Chile, ng g^{-1} fresh base.

Food group		Average
Orchard products and fruits	Foliage	134.9
	Bulbs, tubers and roots	124.8
	Grains	22.7
	Fruits	11.2
Meats	Lamb	8.2
	Pork	12.1
	Cow liver	117.8
	Beef	14.4
	Sausages	24.8
	Poultry	8.1
Dairy products	Milk and milk by-products	5.4
Flour and cereals	Bread	23.6
	Rice	55.1
Seafood	Fresh fish	291.9
	Fresh shellfish	2850.1
	Canned	1188.9

Table 5 Estimated mean daily dietary intake of arsenic by urban populations of northern Chile.

Food	Recommended ingestion* (g person^{-1} day^{-1})	Arsenic (ng person^{-1} day^{-1}): Total	Inorganic	Organic
Bread[†]	225	5 310	3 452	1 858
Rice, pastry, cereal[‡]	220	12 122	4 243	7 879
Potatoes[a]	150	855	85	770
Vegetables[b]	400	53 960	2 698	51 262
Fruits[c]	270	3 024	151	2 873
Dairy[d]	310	1 684	1 263	421
Fish[e]	40	57 745	0	57 745
Meats[f]	35	1 241	931	310
Chicken[g]	50	405	304	101
Total	–	136 346	13 127	123 219

*MINSAL, Chile.

[†]It is assumed that 65% As is inorganic.

[‡]It is assumed that 65% As is inorganic.

[a]Based on a mean concentration of 5.7 ng g^{-1}. It is assumed that 90% As is organic.

[b]Based on a mean concentration of 134.9 ng g^{-1}. It is assumed that 95% As is organic.

[c]It is assumed that 95% As is organic.

[d]It is assumed that 75% As is inorganic.

[e]Based on a mean concentration of 1443.6 ng g^{-1}. It is assumed that 100% As is organic.

[f]Based on a mean concentration of 35.46 ng g^{-1}. It is assumed that 75% As is inorganic.

[g]It is assumed that 75% As is inorganic.

In the cities of Iquique, Antofagasta, Calama and Tocopilla, people are primarily exposed to the inorganic species due to its high content in the water. Air is responsible, in general, for a very small fraction of the total exposure to inorganic arsenic. In the case of Copiapó, the city that has the highest content of arsenic in the air, the contribution of arsenic exposure from air reaches 12.29%, whereas in the other cities it is below 5%. The contribution of arsenic in water to total exposure can range from 30–50% to as high as 80–90% in cities such as Iquique, Antofagasta, Calama and Tocopilla.

Table 6 Estimated contribution of different sources to daily intake of inorganic arsenic by urban populations of northern Chile.

Region	City	Water* (%)	Air† (%)	Food‡ (%)
I	Arica	56.91	1.58	41.51
	Iquique	89.15	0.40	10.45
II	Antofagasta	81.77	1.46	16.78
	Calama	82.91	2.77	14.32
	Tocopilla	84.99	1.06	13.95
III	Copiapó	33.21	12.29	54.50
	Diego de Almagro	41.44	4.14	54.41
	Vallenar	41.44	4.14	54.41
IV	Coquimbo	46.82	1.95	51.23
	La Serena	42.32	2.12	55.56
	Vicuña	42.32	2.12	55.56
	Ovalle	42.32	2.12	55.56
	Monte Patria	42.32	2.12	55.56
	Illapel	42.32	2.12	55.56
	Salamanca	42.32	2.12	55.56

*Assumed consumption of 2 l day^{-1}.
† Assumed inhalation of 20 m^3 day^{-1}.
‡The MINSAL diet (Table 5) is assumed.

The dietary (food) contribution to total exposure is variable, depending upon the arsenic levels in air and water. In those cities where drinking water and air have high arsenic levels, the contribution of inorganic arsenic from food is in the range 10–20%. In the cities where arsenic levels in air and water are low, food constitutes an important source of this contaminant, representing more than 50% of the total exposure. The international literature points out that food is the principal source of exposure to arsenic when the levels in water are low.

CONCLUSIONS

This analysis showed that urban populations of northern Chile are exposed to arsenic levels of between 23.63 and 125.63 μg As day^{-1}, and that ingestion of water represents one of the most important pathways of exposure. Food does not constitute a very significant source of exposure. The analysis was limited by uncertainties about arsenic speciation, bioavailability and absorption factors.

The results have been a useful guide in the efforts of the government of Chile to reduce the population exposure to arsenic. Exposure by the different routes is not necessarily equivalent in terms of dose and biological effects on target organs. The measures that have begun to be implemented have been geared toward reducing the amount of arsenic in drinking water, through treatment, and in air, by regulating emissions from smelters.

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