ABSTRACT: In various Latin American countries such as Argentina, Chile, Mexico, El Salvador; Nicaragua, Peru and Bolivia, at least four million people drink water containing arsenic at levels which pose a risk to their health to such an extent that in certain areas this has become a public health problem.

This is a compilation of work carried out on the problem of arsenic in drinking water and its effects on the health of those exposed to it. This situation must be addressed in order to minimize its effects and reduce arsenicism in the affected areas.

The presence of arsenic in the environment and in water sources for human consumption is due to natural geological factors (Mexico, Argentina, Chile, Peru, Nicaragua), anthropogenic activities, including mining and metal smelting (Chile, Bolivia and Peru), electrolytic processes for the production of high quality metals such as cadmium and zinc (Brazil) and, to a lesser extent, the use of organic arsenic-based pesticides in agriculture (Mexico).

It is well known that in most cases the presence of arsenic in surface water and groundwater in Latin America is associated with Tertiary and Quaternary volcanism in the Andes Mountains. It derives from dissolved minerals, erosion and disintegration of rocks and from atmospheric deposition (aerosols). In water it can be found in its trivalent and pentavalent forms.

Arsenic in drinking water is generally found in the form of arsenate and 40% to 100% can be absorbed easily in the gastrointestinal tract (Frederick et al. 1994). Ingested inorganic arsenic is absorbed by the tissues and gradually eliminated by methylation in the kidneys, into the urine. When ingestion is greater than excretion it tends to accumulate in the hair and nails.

The principal means of exposure to arsenic are ingestion and inhalation. It can accumulate in the body after chronic exposure and at certain concentrations causes changes to the skin with secondary effects on the nervous system, respiratory and gastrointestinal tracts, as well as hematopoiesis; it can also build up in the bones, muscles and skin and, to a lesser extent, in the liver and kidneys.

Toxicological and epidemiological studies confirm this information and indicate that chronic ingestion of arsenic in drinking water results in skin lesions, hyperpigmentation and hyperkeratosis of the palms of the hands and soles of the feet; it also causes nervous system disorders, diabetes mellitus, anemia, liver disorders, vascular illnesses and skin, lung and bladder cancer.

Consumption of water containing arsenic over the long term leads to chronic effects and arsenicism. The treatment involves providing patients with drinking water that is free from arsenic. The next step is to monitor the patient and ensure that he is no longer exposed to the element. Other proposed treatments are chelation and improved nutrition.
Its toxicity depends on oxidation, chemical structure and solubility in the biological medium. The scale of arsenic toxicity declines in the following order: arsine > As\(^{3+}\) inorganic > As\(^{3+}\) organic > As\(^{5+}\) inorganic > As\(^{7+}\) organic > arsenic compounds and elemental arsenic. The toxicity of As\(^{3+}\) is 10 times higher than that of As\(^{5+}\) and the lethal dose for adults is 1-4 mg As/kg. For the more common forms such as AsH\(_3\), As\(_2\)O\(_3\), As\(_2\)O\(_5\) this dosage varies between 1.5 mg/kg and 500 mg/kg of body mass (The National Academy of Sciences 1999).

It has been shown that children are more sensitive than adults to arsenic poisoning and are the most affected by arsenicism, because of malnutrition and lack of sanitation in scattered (poor) rural areas. Those most at risk are people living in scattered rural areas, who drink untreated water and are unaware of the risk to which they are exposed. Health, environmental and sanitation authorities must plan water supplies and promote and implement risk prevention and control programs where drinking water contains higher than the recommended levels of arsenic. The programs should involve the authorities, community and local health systems.

1 INTRODUCTION

In various Latin American countries such as Argentina, Chile, Mexico, El Salvador, Nicaragua, Peru and Bolivia at least four million people drink water containing arsenic at levels which pose a risk to their health. The arsenic content of water, especially groundwater, in some cases reaches 1 mg/l. In other regions of the world, such as India, Bangladesh, China and Taiwan the problem is even greater. According to our information, around 6 million people in India are exposed to arsenic; two million of them are children. In the United States, more than 350,000 people drink water that contains more than 0.5 mg/l of arsenic, and more than 2.5 million are supplied with water having an arsenic content in excess of 0.025 mg/l.

The purpose of this work is to provide information from Latin America on this environmental and public health problem, which must be addressed in order to minimize its effects and to reduce arsenicism in the affected areas. It is a bibliographic record of the presence of arsenic in drinking water and its effects on the health of people exposed to it.

2 THE ORIGIN OF ARSENIC IN DRINKING WATER

In general in Latin America, the presence of arsenic in the environment and specifically in water sources used for human consumption is due to natural geological factors (Mexico, Argentina, Chile, Peru) (Sanchez et al. 1998), human activities involving mining and refining of metals (Chile, Bolivia Peru), electrolytic processes producing metals of high quality such as cadmium and zinc (Brazil) and, to a lesser extent the use of organic arsenic-based pesticides (Mexico) (Cebrián et al. 1994).

Natural arsenic in surface water and groundwater in Latin America is associated with Tertiary and Quaternary volcanism in the Andes Mountains, a process which is still continuing and is shown in lava flows, fumaroles, thermal springs and geothermal phenomena related to volcanism in the so-called "Pacific Ring of Fire". This volcanism also influences certain water properties such as high pH, variable alkalinity, low hardness, moderate salinity and the presence of boron, fluorine, silica and vanadium.

This same geological situation produced the important deposits of copper, principally in Chile, Peru and Bolivia, the exploitation and smelting of which has helped to increase already high levels of environmental arsenic.

The geographical conditions of the zone, characterized by high altitude, a scarcity of water and adverse weather conditions have largely limited the development of large cities. Therefore, with the exception of Chile, Argentina and Mexico, exposure by the population of the other countries affected (Peru, Bolivia and El Salvador), is lower.
Arsenic in surface and groundwater derives from dissolved minerals, erosion and disintegration of rocks and from atmospheric deposition. It is also present in aerosols and it may be found in water in the trivalent and pentavalent forms, depending on the environmental conditions. Oxidized forms are found more often in surface water, while the reduced forms are more common in groundwater, particularly at greater depths.

In Argentina the higher arsenic content in water is natural. The arsenic concentration in groundwater in the affected areas is variable, from lower values of 0.10 mg/l up to values in excess of 1 mg/l. The source of arsenic in groundwater in central and northern Argentina is volcanic and, though farming may be responsible to a lesser extent (Benitez et al. 2000).

In Mexico, arsenic is present within the volcanic belt where arsenic-rich soils contaminate the groundwater. Another possible source of contamination is organic arsenic-based pesticides, which have been used since before 1945.

In Chile, arsenic is present in all ecosystems in the north of the country because of the predominance of Quaternary volcanism in the zone. Between 1955 and 1970 in Antofagasta, the average arsenic level in the water was 0.598 mg/l. Current values indicate an average of 0.04 mg/l (Sancha et al. 1998).

In Bolivia, the largest water source for La Paz receives runoff water from the mining area of Milluni before it reaches the treatment plant. In the smelting town where three small companies operate (Calbol, Hormet and Bustos), 0.7% of the arsenic is released into the environment. The soil and drinking water have been found to contain this element, with maximum concentrations in a recreation area near to the Bustos smelter (ECO/PAHO-WHO 1997).

In Peru, the city of Ilo draws water from the Lake Aricota for domestic and industrial use. This lake is fed by two rivers: The River Callazas and the River Salado that pass close to the Yucamane volcano, which appears to be the source of contamination of this water. There is also high exposure to inorganic arsenic at the La Oroya smelter.

Brazil uses some 1,500 tons of arsenic/year for the electrolytic production of zinc and cadmium. Industrial waste and atmospheric emissions of arsine are the main sources of environmental contamination by arsenic. Arsenic concentrations in sediment were 0.1 and 80 mg/k, but higher concentrations were found close to the wastewater outfall near Enseno Cove (Barcellos 1992, ECO/PAHO-WHO 1993).

3 TOXICOLOGY OF ARSENIC

The main forms of human exposure to arsenic are ingestion and inhalation. This element can accumulate in the body as a result of chronic exposure and at certain concentrations causes problems such as changes to the skin (relaxing and dilatation of the pores) with secondary effects on the nervous system; irritation of the respiratory organs and gastrointestinal tract and altered hematopoiesis; it can also accumulate in the bones, muscles and skin and, to a lesser degree, in the liver and kidneys. Epidemiological evidence from people who have suffered prolonged exposure to inorganic arsenic in drinking water is hyperkeratosis of the hands and feet, the principal manifestation of which is skin pigmentation and calluses on the palms and soles of the feet. The presence of arsenic in water, its degree of contamination and the incidence of skin diseases in Argentina and Mexico are described in other studies.

Experiments with laboratory animals indicate that inorganic trivalent arsenic is more toxic than the pentavalent form because pentavalent compounds have less effect on enzyme action, but in vivo these can be reduced to trivalent compounds. The toxicity of arsenic depends on oxidation, chemical structure and solubility in the biological medium. The scale of arsenic toxicity declines in the following order: arsine > As\(^{3+}\) inorganic > As\(^{3+}\) organic > As\(^{5+}\) inorganic > As\(^{5+}\) organic > arsenic compounds and elemental arsenic. The toxicity of As\(^{3+}\) is 10 times higher than that of As\(^{5+}\) and the lethal dose for adults is 1-4 mg As/kg. For the more common forms such as AsH\(_3\), As\(_2\)O\(_3\), As\(_2\)O\(_5\),
this dosage varies between 1.5 mg/kg and 500 mg/kg of body mass (The National Academy of Sciences 1999).

In drinking water, arsenic is generally found in the form of arsenate and 40 to 100% can easily be absorbed (Frederick et al. 1994) in the gastrointestinal tract. Ingested inorganic arsenic passes into the blood stream where it links with hemoglobin and in 24 hours can be found in the liver, kidneys, lungs, spleen and skin. It is found in greater concentrations in the skin, bones and muscles. Accumulation in the skin is because it reacts easily with proteins (with sulphhydryl groups) (Health Canada, Ottawa 1992).

Metabolic changes in arsenic occur essentially in the liver, where endogenous thiols play a critical role in the conversion of As$^{3-}$ and As$^{5-}$. It appears that glutathione (GSH) acts as a reducing agent. The As$^{3-}$ forms can be methylized (oxidation and formation of methylarsenic - As$^{5-}$) if the functional group S-adenosylmethionine (SAM) is accepted. The probable end-product of continuous methylation is dimethylarsenate (DMA). The methylarsenic (As$^{5-}$) and intermediate As$^{3-}$ forms may be toxic and inhibit glutathione reductase (GR), a key enzyme in the metabolism of GSH and whose action (GR) is critical in maintaining the redox reactions of cells (The National Academy of Sciences 1999).

In the human body As$^{3-}$ and As$^{5-}$ act through different mechanisms. The behavior of As$^{5-}$ is similar to that of phosphate, but differs in the stability of its esters. The esters of phosphoric acid are stable, which enables the existence of deoxyribonucleic acid (DNA) and adenosine 5-triphosphate (ATP), however the acidic esters of As$^{5-}$ can be hydrolyzed. The enzymes can accept arsenate and incorporate it into compounds such as ATP, but the analogous compounds thus formed are hydrolyzed immediately. Therefore, the arsenate can deactivate the oxidizing metabolism of ATP synthesis. In contrast, As$^{3-}$ has a high affinity with thiol groups in proteins and can deactivate a variety of enzymes, such as pyruvate dehydrogenase and 2-oxoglutarate dehydrogenase (Frederick et al. 1994, The National Academy of Sciences 1999). However, monomethylarsenate (MMA) and dimethylarsenate (DMA) do not form strong bonds with human biological molecules. This explains why it is less toxic than inorganic arsenic.

The kinetics relating to the toxicity of inorganic arsenic, including cancer has not yet been established. The most acceptable explanation is that a chromosome abnormality is induced without acting directly on DNA.

Ingested inorganic arsenic is absorbed by the tissues and then progressively eliminated by mutilation. It is excreted in urine through the kidneys. When ingestion is greater than excretion it tends to accumulate in the hair and nails. The normal level of arsenic in urine, hair and nails is 5-40 µg/day, 80-250 µg/kg and 430-1080 µg/kg, respectively (The National Academy of Sciences 1999). Human sensitivity to the toxic effects of arsenic vary, depending on genetics, metabolism, diet, state of health and sex, among other factors. These factors should be taken into account in any risk assessment of arsenic exposure. Those at greater risk have a poor ability to methylize arsenic and, therefore, retain more, the most vulnerable being children and people who are undernourished.

In some species of mammals it has been shown that inorganic and organic arsenic are teratogenic and oral ingestion affects fetal growth and prenatal viability. A supplement with a high arsenic content in the diet (e.g. 350-4,500 ng per gram) affects growth and reproduction in animals (The National Academy of Sciences 1999). Studies have shown that urine is the best biomarker for measuring absorbed inorganic arsenic, as blood, hair and nails are less sensitive to exposure (The National Academy of Sciences 1999).

### 3.1 Arsenicism

Consumption of water containing arsenic does not lead to acute cases; rather the effects of drinking small quantities of water over the long term are chronic.

In Bangladesh four stages of arsenicism are recognized:
- **Preclinical**: the patient shows no symptoms but arsenic can be found in tissue and urine samples.
- **Clinical**: at this stage it affects the skin. Darkening of the skin (melanosis), frequently of the palms of the hands, with dark patches appearing on the chest, back, limbs and gums. A more serious symptom is keratosis or hardening of the skin to form nodules on the palms of the hands and soles of the feet. WHO calculates that this stage requires 5 to 10 years of exposure to arsenic.
- **Complications**: more pronounced clinical symptoms and effects on the internal organs. Studies have reported enlargement of the liver, kidneys and spleen. There is also information linking this stage with conjunctivitis, bronchitis and diabetes.
- **Malignty**: development of tumors or cancer of the skin or other organs. In this stage, the person affected may develop gangrene or cancer of the skin, lungs or bladder.

In the first two stages, if the patient drinks water that is free from arsenic, recovery will be almost complete. The third stage can be reversed but the fourth is not (BCAS 1997).

### 3.2 Treatment

Treatment generally involves providing the patient with arsenic-free drinking water. The next step is to monitor the patient and ensure that he is no longer exposed to the element.

Other treatments proposed are chelation and improved nutrition. Chelation has been used in Bengal and Bangladesh, but it is not known whether it can remove arsenic from the skin and it is not effective if the patient continues to drink contaminated water. Evidence from Taiwan shows that nutritional factors can modify the risk of cancer associated with arsenic. Taking vitamins (A and multi-vitamin supplements) and improved nutrition can improve patients' condition, particularly when the skin is affected.

The United States Environmental Protection Agency (USEPA) classifies arsenic as a group A carcinogen because of evidence of its adverse effects on health. Exposure to 0.05 mg/l can cause 31.33 cases of skin cancer per 1,000 inhabitants and a proposal has been made to reduce the acceptance limit of 0.050 mg/l to 0.0010-0.0020 mg/l. The International Agency for Research on Cancer has classified it in group 1 because of evidence on carcinogenicity for human beings. Natural elimination from the human body is through urine, feces, perspiration and skin epithelium (peeling). There is evidence linking arsenic with cancer. However, the carcinogenic dose is not known.

Some studies on the toxicity of arsenic indicate that many current standards based on WHO guidelines are too high and suggest that limit values should be re-evaluated on the basis of epidemiological studies; for example, in Taiwan it is calculated that the limit should be reduced from 0.02 to 0.0005 mg/l. In other cases it would appear that these values should be increased, in accordance with regional conditions. In Latin America, it has been shown that similar levels of arsenic under different conditions (climate, nutrition and others) result in different effects.

### Table 1. Guideline values for arsenic in drinking water established by various regulatory agencies

<table>
<thead>
<tr>
<th>Country / Organization</th>
<th>Maximum level of contamination (MLC), mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canada</td>
<td>0.025</td>
</tr>
<tr>
<td>USA</td>
<td>0.010</td>
</tr>
<tr>
<td>Argentina</td>
<td>0.050</td>
</tr>
<tr>
<td>México</td>
<td>0.050</td>
</tr>
<tr>
<td>Chile</td>
<td>0.050</td>
</tr>
<tr>
<td>World Health Organization (WHO)</td>
<td>0.010</td>
</tr>
<tr>
<td>European Economic Community (EEC)</td>
<td>0.010</td>
</tr>
<tr>
<td>India</td>
<td>0.050</td>
</tr>
<tr>
<td>China</td>
<td>0.050</td>
</tr>
<tr>
<td>Taiwan</td>
<td>0.050</td>
</tr>
</tbody>
</table>
4 EXPOSED POPULATION AND EPIDEMIOLOGICAL STUDIES

The following is a summary of epidemiological studies carried out in American countries, where part of the population is exposed to arsenic in drinking water.

4.1 Argentina

The problem has been known about for more than 50 years when epidemiologists from Cordoba and other provinces found and associated skin damage to arsenic in the drinking water. The first pathological manifestations were known as Bell Ville Disease and then as endemic regional chronic hydroarcenicism (ERCH).

It is estimated that 2,000,000 inhabitants are exposed to arsenic levels in the range 0.002-2.9 mg/l (Sancha & Castro de Esparza 2000). The most seriously affected provinces are Salta, La Pampa, Cordoba, San Luis, Santa Fe, Buenos Aires, Santiago del Estero, Chaco, Tucumán (Pinedo & Zigarán 1998).

The province of Chaco is one of the most seriously affected zones. The most evident effects have been darkening of the skin, lesions, hyperkeratosis, warts, melanosis, leukoderma, basal cell carcinoma and senile keratoma with a high incidence of cancer of the urethra, urinary tract and bladder. It has been shown that with arsenic poisoning keratosis predominates over hyperpigmentation. The types of cancer found were skin cancer and internal cancers (66% of which were in the lungs). Levels of arsenic in the water in this zone, particularly in the neighborhood of San Martin, are in excess of 0.7 mg/l (Benitez et al. 2000, ECO/PAHO-WHO 1993).

In the province of Santiago del Estero, deaths associated with arsenicism have been reported since 1983 and according to data provided by the Secretary for Epidemiology, serious cases in children and women have been found (lesions on the soles of the feet, arms and trunk, melanoderma on the arms and trunk, lesions on the palms of the hands, leucoderma on the back and chest).

In 1997 in Mili, 71 groundwater samples were analyzed, 52% of which had high values of arsenic, up to the maximum of 2.4 mg/l (Herrera et al. 2002). At Gran Porvenir in the department of Banda, Santiago del Estero (474 inhabitants), where samples were taken from 36 households out of a total of 103, the water was found to contain arsenic levels between 0.002 and 0.143 mg/l (19 samples were collected at random), of which 57.89% contained critical concentrations. If we consider that all the samples contained higher than permitted levels of arsenic and that more than 50% of inhabitants drink this water, it is clear that there is a public health problem (De Paredes 1997).

A study of the metabolism of inorganic arsenic in children in three villages in northern Argentina: San Antonio de los Cobres and Taco Pozzo, with arsenic concentrations in the drinking water of 0.2 mg/l, and Rosario de Lerma with 0.65 µg/l, showed that arsenic concentrations in the blood and urine of children in the first two villages were 10 to 30 times higher (0.009 and 0.38 mg/l) than in the blood and urine of children in Rosario de Lerma. The fact that higher percentages of inorganic arsenic were found in children's urine than in that of adults shows that children are more sensitive than adults (Concha et al. 1998).

In the province of Cordoba, in the centre of the country, water contains levels or arsenic in excess of 0.1 mg/l, increasing the risk of cancer and skin changes. Between 1986 and 1991 studies of deaths caused by cancer of the bladder, lungs and kidneys were carried out in 26 districts, previously classified in accordance with the arsenic content in water; the arsenic level in the area where exposure was greatest (San Justo and Union) was 0.178 mg/l. The studies showed a clear dosage-response relation between arsenic in the water and the risk of cancer. Mortality rates for bladder cancer were 2.14 for men and 1.82 for women (95% confidence) in the two districts where exposure was highest. The mortality rates for lung cancer, expressed as low, medium and high rates, were 0.92, 1.54 and 1.77, respectively for men and 1.24, 1.34 and 2.16 for women. Something similar was found for kidney cancer: 0.87, 1.33 and 1.57 for men and 1.00, 1.36 and 1.81 for
women (p < 0.001). These studies did no find a clear relation between the arsenic and mortality due to skin and liver cancer (Hopenhayn-Rich et al. 1996, Hopenhayn-Rich et al. 1998).

In order to update the map of the risk of arsenicism and identify critical areas, the province of Cordoba was divided up according to the geographical criteria of the region: western or mountains and eastern or plains. During the study 100 samples of water (groundwater) were taken from forty locations. The departments identified as critical were San Justo, M. Juarez, Union, Río Cuarto and Río Primero where lung cancer mortality rate was higher versus other cancers: in the western or mountain region, 20.1%; in the eastern or plains region, 37.4%; and to a lesser extent skin cancer, 1.9-2.1%. Other types of cancer affected the prostate, colon, bladder, kidney and larynx. It was found that 57% of the areas studied had concentrations in excess of the values permitted by WHO guidelines (Pinedo & Zigarán 1998).

At present, the water supply regulator of the city of Santa Fe is carrying out three studies with support from PAHO: (1) a risk map of 213 water supplies; (2) an epidemiological study of endemic regional chronic hydroarcenicism; and (3) a correlation between arsenic in drinking water and deaths from 5 associated cancers (Corey 2000).

4.2 Chile

The most serious contamination occurs between latitudes 17°30’ and 26°05’ south and between longitude 67°00’ and the Pacific Ocean. The cities having the highest exposure to arsenic are Antofagasta, Calama, Santiago, Rancagua, Talal, Tocopilla and San Pedro de Atacama. Approximately 500,000 inhabitants are exposed to arsenic contamination. In Antofagasta, between 1955 and 1977 the average arsenic level was found to be 0.598 mg/l while the present values give an average of 0.040 mg/l (Sancha et al. 1998).

Between 1950 and 1993 in Region II studies showed the risk of death caused by different cancers associated with arsenic, principally bronchopulmonary, bladder and renal cancers (Rivera & Corey 1995). In 1970 the annual rate of dermatosis associated with chronic arsenicism was 20 per 100,000. The levels of arsenic in the hair and urine of those exposed were above normal values and a study that included 100 children with dermatosis associated with arsenicism detected 19 cases of Raynaud's Phenomenon (Finkelman et al. 1993).

Between 1994 and 1996 a study was carried out in the northern region of Chile (Arica, Iquique, Copiapó and Antofagasta) aimed at relating arsenic exposure to the risk of contracting lung cancer. Cases of lung cancer and two hospital controls were evaluated (one control was a patient with cancer and the other was a patient without cancer; neither diagnosis related to arsenic). Over 20 months, 151 cases of lung cancer were admitted together with 419 controls (167 with cancer and 242 without cancer). There was a clear dosage-response relation between the average level of arsenic and the risk of cancer (adjusted against a linear regression model that included sex, age and whether the patients smoked tobacco) at 95% confidence, of 1, 1.7 (0.5-5.1), 3.9 (1.2-13.4), 5.5 (2.2-13.5) and 9.0 (3.6-22) for arsenic levels from 0 to 0.40 mg/l (Ferreccio et al. 1998).

In 1998 a risk analysis study into arsenic was carried out as required by the environmental toxins regulations. The project consisted in developing a water, food and air baseline. Samples of water and food were taken all over the country while air was sampled in the north and central zones; these figures were compared with information from the national ingestion and inhalation baseline. The health impact assessment of exposure to arsenic made use of an ecological study and case and control studies, through the ratio with death rates for arsenic-associated cancers (lung, bladder, liver, skin and kidney). The results indicate that the greatest contribution of arsenic to total exposure in the northern zone comes from drinking water (41.7% to 85.3%), this also applied to Santiago and Rancagua (72.7% to 69.3%). In the south diet acquired greater importance and in general, the contribution made by the air was around 1%, with the exception of Copiapó where it was 12.2%. In the north, death rates from lung, skin and bladder cancers were higher. The study shows that the higher death rate in the north is largely attributable to exposure to arsenic. The relative risks for
different cancers (bladder, urinary tract, lung, liver, kidney and larynx) were reported together with heart diseases, ischemia, chronic respiratory illnesses and chronic arsenic-related dermatosis.

Smith et al. carried out a study on skin lesions suffered by the inhabitants of Atacama (Smith et al. 2000). This was a study of eleven families in the Chiu Chiu area, whose drinking water contained 750 to 800 µg/l of arsenic, and eight families in the village of Caspana who were used as a control group. The results showed that four of the six men who drank water contaminated with arsenic for more than 20 years had skin lesions; no cases were recorded in adult women, but two additional cases were found among adolescents. The prevalence of skin lesions in these small groups is comparable to Taiwan and India where the population is more susceptible, probably because of their nutritional level. The inhabitants of the Atacama region showed no alarming cases despite prolonged exposure; perhaps their resistance was due to food rich in vitamin A.

Studies have been carried out on trends in infant mortality associated with exposure to arsenic in two Chilean cities: Antofagasta and Valparaiso. The study was retrospective and aimed to evaluate time and location patterns for infant mortality between 1950 and 1996, using univariant statistical graphing techniques and Poison's linear regression analysis. The results showed high rates of fetal, neonatal and postneonatal mortality in Antofagasta, though not in Valparaiso. The linear regression analysis indicated an association between exposure to arsenic and fetal, neonatal and postneonatal mortality. These findings indicate, though not definitely, an association between arsenic and the increase in infant mortality in Antofagasta (Hopenhayn-Rich et al. 2000).

4.3 Mexico

The first information on arsenic contamination dates from 1962, when 40 serious cases and one death were reported in the urban area of Torreon, Coahuila.

The presence of arsenic in drinking water is a problem found in the Durango, Coahuila, Zacatecas, Morelos, Aguas Calientes, Chihuahua, Puebla, Nuevo Leon, Guanajuato, San Luis Potosi and Sonora aquifers and the Lagunera region, where concentrations have been found that exceed the values given in NOM-127SSA1 (0.05 mg As/l) (Finkelman et al. 1993; Avilés & Pardón 2000). It is estimated that around 450,000 people are exposed.

Studies of arsenic began in the Lagunera region in the states of Durango and Coahuila. Chronic endemic arsenic poisoning was found in this area with extreme outbreaks affecting both animals and humans. A study on arsenic contamination of 128 water wells in 11 districts found a range of 0.008 to 0.624 mg/l; while more than 50% of the samples contained more than 0.05 mg/l. It is thought that around 400,000 people were exposed to arsenic in drinking water with concentrations greater than 0.05 mg/l. This evidence suggests the existence of a medium-term public health problem. Of these groups, a total of 489,634 people face an individual maximum cancer risk of around 4.5 x 10⁻² and 5.7 x 10⁻²; a total of 609,253 people face a risk of between 5.2 x 10⁻³ and 4.1 x 10⁻² (Vega Gleeson 2001).

In the Lagunera region other signs and symptoms of arsenicism have been found, including a 0.7% prevalence of black-foot disease. In order to establish an epidemiological surveillance system in this region, a project entitled “Identification of Early Health Risk for Exposure to Arsenic” was carried out and involved an evaluation of the genotoxic risks and excretion of porphyrins and methylated arsenic derivatives in urine. The aim was to inform decisions of measures to control arsenicism.

At present, Mexico and Argentina, with the support of PAHO, are carrying out a socio-economic study on the impact of arsenic on public health and the viability of alternatives for removing arsenic from the drinking water supply.

4.4 Peru
The south of Peru contains semi-desert areas in which the population drinks water from rivers rising in the Andes and which flow towards the Pacific Ocean. Traces of arsenic have been found in some of these rivers; for example, the River Locumba (0.5 mg As/l), which flows through Puno and Moquegua (the Ilo valley), where approximately 250,000 inhabitants are exposed to this element (Esparza 1989).

In 1994 a study of the arsenic content of drinking water in the Rimac River analyzed 53 samples of drinking water, river, well and spring water; it was found that 84.9% exceeded the limit recommended by the WHO (Infante & Palomino 1994). Nevertheless, no cases of arsenic poisoning have been recorded. In 1999 another study of drinking water in the province of Huaytara, Huancavelica, was carried out. The 31 samples analyzed produced an average of 0.0246 mg/l of arsenic; the highest concentration was found in Pachac, probably because of the presence of a warehouse used to store fertilizers and arsenic-based pesticides (Flores 1999).

In 2002 an evaluation of the River Locumba was carried out and found arsenic levels between 0.4 and 0.2 mg/l. The inhabitants of the valley have been drinking this water for many years and no cases of arsenicism have been reported.

In Puno arsenic levels of up to 0.18 mg/l have been found in recently drilled wells. A study will be made to evaluate alternative means of removing arsenic.

In Lima and Callao, an air monitoring study near a mineral concentrates storage facility (Pb, Cu, Zinc) in Callao was conducted throughout 2000 and consisted in measuring lead and arsenic particulate material at PM$_{10}$ at eight sampling points. The values for arsenic were below the maximum permissible level established by the Ministry of Energy and Mines (6 mg/m$^3$) (Iglesias & González 2001).

4.5 Nicaragua

In 2001, UNICEF invited different national and international institutions to a workshop to discuss the problem of contamination by arsenic in drinking water faced by the inhabitants of El Zapote and surrounding districts, in the Sebaco valley. A form was provided at this meeting for local health personnel to record "Care for patients with arsenicism". 111 people who had drunk water contaminated with arsenic were attended and it was found that those who had ingested higher levels of arsenic were suffering from paresthesia, edema of the lower limbs, burning sensation in the eyes, skin lesions and respiratory problems. Keratosis and hyperpigmentation typical of chronic arsenicism were found; two patients had splenomegalia and hypertension and there were a few cases of hepatomegalia and anemia.

It was recommended that a program of arsenicism prevention, treatment and control be implemented to guarantee continued care and attention for these patients, as well as an education campaign in the affected communities and surrounding areas (Gómez 2002).

Another study carried out by UNICEF identified eight areas where arsenic levels were higher than normal (Santa Rosa del Peñon, La Cruz de la India, Cerro Mina de Agua, Kinuma, El Mojon and Las Pilas). More detailed and systematic studies were recommended, together with the use of less costly analytical methodologies (PIDMA/UNICEF 2002).

4.6 Bolivia

The communities at risk are located in Alto Lima II to the north of the city of El Alto, in the province of Murillo in the department of La Paz and the community of Vinto in the city of Oruro. The total population is approximately 20,000 people (ECO/PAHO-WHO 1997).

A study in El Alto indicated that 70% of children between 5 and 7 years of age, had excessive levels of arsenic in their urine and the effects of oral ingestion on children are skin lesions and neurological symptoms. Another evaluation in the mining area of Vinto, 7 km from the city of Oruro, which used the same methodology as the previous case, found that the most important means
of contamination are from the soil, water and dust, and as children are at greater risk of exposure to arsenic the effects on their health are neurological (ECO/PAHO-WHO 1997).

4.7 Brazil

No areas are known to be affected by natural arsenic; exposure is the result of mining and smelting activities. In 1982 and 1986 two studies were carried out to evaluate the accumulation of arsenic in hair (As/C) in 84 women from the village of Lamarão do Passe. In 1986 an eleven-fold increase in As/C concentrations was found (0.06-0.45 ppm) compared to the 1982 results. The level of arsenic in the air was 5.1 ng/m³.

A study was also carried out in Brazil of 367 workers in a smelter where arsenic in the urine was used as an indicator of exposure. In the group having the greatest exposure (those processing mineral in the smelter), the average concentration was 0.0598 mg/l and 25% of this group revealed concentrations higher than 0.1 mg/l (ECO/PAHO-WHO 1993).

Cases of exposure to arsenic have been found in the village of Lamarão do Passe, located 4 km from a copper smelter (downwind) and in the bay of Sepetiba on the west coast of Rio de Janeiro, contaminated with Cd, Cr, Pb and Zn, where arsenic has been found in the environment, particularly in a local smelter (ECO/PAHO-WHO 1993).

5 CONCLUSIONS AND RECOMMENDATIONS

In Latin America approximately 4,800,000 inhabitants are exposed to arsenic in their drinking water. Therefore, their health is being affected to such a degree that in countries such as Mexico and Argentina it is considered a public health problem. More locally, at risk groups include workers in the mining and metallurgical industries.

The most affected are scattered rural dwellers that drink untreated water and are unaware of the risks to which they are exposed. These people require the health, hygiene and environmental authorities to plan the provision of water and other activities as part of a program of prevention and control of the risks of drinking water containing higher than recommended levels of arsenic. The programs should involve the authorities, community and local health systems.

Toxicological and epidemiological studies confirm earlier scientific data which indicates that chronic ingestion of arsenic in drinking water causes skin lesions such as hyperpigmentation and hyperkeratosis of the hands and feet; nervous system disorders; diabetes mellitus; anemia; liver disorders; vascular diseases (peripheral vascular illnesses such as myocardial infarctions and thickening of the arteries); skin, lung and bladder cancer (the latter particularly in children).

The effects of arsenicism on human reproductive health have not been demonstrated. Nevertheless, it is known that arsenic can pass into the placenta, but more research is required to reveal its genotoxic effects.

Children are more susceptible than adults to arsenic poisoning and those most affected by this illness are the poor (because of malnutrition and inadequate hygiene in poor and rural areas).

Research is required into the effects of arsenic on the health of people exposed to low concentrations in water and other forms of exposure.

In order to address the problem of arsenic in at-risk areas, cases of arsenicism must be identified, sources of arsenic-free water found, or suitable technology used to treat it, alternative sources should be studied for long term use, progress should be monitored and care provided for patients (including vitamin supplements, lotions for those with keratosis, etc.), while water sources and the effectiveness of treatment, if applicable, should be monitored periodically.

Epidemiological and arsenic removal studies as well as national policies, strategies and standards should be developed within an integral conceptual framework, with participation by the different social stakeholders.
It is recommended that a reliable and consistent analytical capability be developed so that the results of laboratory and field studies can be compared; standard validated analytical methods and procedures should be available, together with control samples to ensure the quality of the results obtained.

International bodies and health authorities should publish the fact that the number of people suffering from arsenicism will increase if methods to mitigate the problem are not introduced in time. It is important to demonstrate the social and economic effects of arsenicism on families and how mitigation methods can reduce these effects.

One alternative method of analysis and prediction would be to apply a simulation methodology that would allow experiments to be made with real models in an affected area. The study must contain an epidemiology component and another to evaluate the socio-economic effects on families and the community. The opportunity cost of doing no intervention must also be evaluated.

6 REFERENCES


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