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Review

Environmental occurrence of arsenic in Colombia: A review

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ABSTRACT

The international literature on the presence of arsenic (As) in Latin America does not disclose the true magnitude of the presence of As in Colombia. In this paper, we summarize the literature on As occurrence in Colombia. The data reveal that As is present in matrices such as soil, sediments and water and in the food chain. Some of the As concentrations exceed the limits specified by national and international regulations. Arsenic higher concentrations are associated with mining regions (e.g., soils, up to 148 mg/kg; sediments, up to 1400 mg/kg) and agricultural areas (e.g., vegetables, up to 5.40 mg/kg; irrigation water, up to 255 μg/L), and underscore the potential human and environmental risks associated with the presence of As in the country. This review highlights the importance of focusing research on understanding the occurrence, origin and distribution of As in Colombia to better understand its environmental and public health impact.

1. Introduction

Arsenic (As) is an element of natural origin that is widely distributed in the atmosphere, hydrosphere and biosphere. Environmental As is associated mainly with two types of sources: a) natural processes such as weathering, biological activity and volcanic emissions and b) human activities such as mining, industrial processes, smelting of metals, production of pesticides and wood preservatives, and use of fossil fuels. Although natural mineralization and microbial activities increase the mobilization of As in the environment, human activities exacerbate As contamination in soil and in water supplies (Litter et al., 2009; Lage et al., 2006).

Arsenic ingestion and/or inhalation at high concentrations may cause various health problems, including diabetes, skin lesions, gastrointestinal disorders, and genetic effects, especially due to its carcinogenic effects (IARC, 2004). In general, the populations most affected by As ingestion are those who live in countries with low incomes where access to clean drinking water is limited. People living in these countries must rely on groundwater exploitation to meet their water supply needs (Bundschuh et al., 2008). In Latin America, the estimated population at risk of As exposure exceeds 14 million people, with hundreds of recorded cases of exposure in countries such as Mexico, Chile and Argentina and potential risks of contamination to populations in Guatemala, Nicaragua, Peru, Bolivia, Brazil, Honduras, Cuba, El Salvador, Ecuador and Uruguay (Litter et al., 2009; Bundschuh et al., 2012a).

Many articles have been published on the problem of As in Latin America. However, there is little information in the international literature on the presence of this toxic metalloid in Colombia. For example, in a special edition of the journal *Science of the Total Environment* (*vol. 429, July 2012*), several review articles compile the most up-to-date information on As in Latin America. Nevertheless, only Bundschuh et al. (2012a) presents specific values for As in Colombia. The absence of data on the occurrence of As in Colombia is understandable because many of the results of studies carried out in Colombia are only available in a limited number of databases of Colombian public and private institutions. In addition, most of these study results are published in Spanish, which limits their distribution and international exposure. We conducted an extensive and in-depth literature review of books, national and international journals, undergraduate and graduate theses produced at Colombian universities, online databases and libraries of academic institutions and Colombian government agencies such as the Colombian Geological Survey (formerly the Colombian Institute of Geology and Mining, INGEOMINAS) and the Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM).

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2. Overview of arsenic worldwide and in Latin America

It is estimated that tens of millions of people worldwide are at risk of exposure to excessive As levels in contaminated water, which constitutes a major public health problem (Smith and Smith, 2004). Arsenic contamination of groundwater has been reported extensively in many countries, including Bangladesh, India, Vietnam, Nepal, Taiwan, China, United States, Spain, Argentina and Chile (Mandal and Suzuki, 2002; Bundschuh et al., 2009). One of the main diseases caused by the consumption of water and/or food contaminated with As is chronic endemic regional hydroarsenicism (CERHA), which occurs after a variable period of exposure to As contents greater than 10 μg/L in drinking water (WHO, 1996). Latin American countries in which As groundwater pollution studies and risk assessments for CERHA in humans populations have been conducted include Argentina, Chile, Mexico Guatemala, Nicaragua, Peru, Bolivia, Brazil and Uruguay (Lillo, 2003; Nicolli, 2006; Bundschuh et al., 2008).

Recently published reviews of the occurrence of As in Latin America reveal a dramatic environmental problem of As water contamination in 14 of the 20 Latin America countries, where human activities in mining areas are the principal cause of As pollution because they increase the mobilization of As in surface water and groundwater (Bundschuh et al., 2012a). Arsenic in water can potentially enter the human food chain through bioaccumulation in fish and seafood, cattle meat, milk and cheese, and edible plants. Contaminated irrigation water can also contribute to accumulation of As in agricultural soils, representing a health risk to local residents (Bundschuh et al., 2012b). Conventional treatments for As removal, as well as newer and cheaper methods, suitable for use in Latin America, have been recently compiled, and some of these represent viable alternatives for reducing As exposure risk for poor and isolated populations of scattered regions of Latin America (Litter et al., 2010).

3. Overview of arsenic in Colombia

Colombia is a country located in the northwestern part of South America, with a land area of 1,141,748 km^2 and a marine extension of 928,660 km^2. The population of Colombia as of 2011 was 46,581,823 (National Administrative Department of Statistics – Departamento Administrativo Nacional de Estadística – DANE, 2011), making it the fourth most populous country in the American continent. Most of the population is located in the central (Andean) and northern (Caribbean) regions of the country. Colombia is composed of 32 geographic regions (Departments) and a Capital District (*Bogotá D.C.*). In large areas of the country, groundwater resources, which are prone to As contamination, are used for human consumption due to deficiencies in the aqueduct system and/or lack of surface water (Callejas, 2007). Although there have been a number of studies on the geology and hydrogeology of Colombia, mainly carried out by the Colombian Geological Service (INGEOMINAS, 2004), scant research has been carried out on As pollution of water in Colombia. It is known that As contamination of groundwater in Colombian aquifers is of mixed origin (natural and anthropogenic) and mainly affects the departments of *Tolima* and *Caldas*, which are located in the central mountain ranges, and *Nariño* in the western Cordillera, which are areas of Neo-Tertiary volcanism. In these areas, the As comes from deposits containing arsenopyrite or other minerals with traces of As (Nicolli, 2006).

Since 2001 and 2003, the United States Environmental Protection Agency (US-EPA) and the World Health Organization (WHO), respectively, have recommend a maximum allowable As level of 10 μg/L in drinking water (US-EPA, 2001; WHO, 2003), a threshold level that Colombia adopted in 2007 as the maximum permissible concentration of As in drinking water (Ministry of Social Welfare and Ministry of Environment, Housing and Territorial Development – Ministerio de la Protección Social y Ministerio de Ambiente, Vivienda y Desarrollo Territorial, 2007). Other limits have been established in Colombian legislation for the maximum allowable As level in irrigation water (0.1 mg/L) and livestock drinking water (0.2 mg/L). Table 1 lists several maximum values currently established in Colombian legislation with respect to the presence, levels and toxicity of As in various matrices.

Ravenscroft (2007) reported a model based on a geographic information system (GIS) database developed by the Environmental Systems Research Institute (ESRI) to predict areas in the world with As risk in groundwater. For Colombia, the model predicts As risk primarily for the northern intermountain basins, where As may be mobilized by reductive dissolution, affecting a population of 1,480,000, with lesser components of risk deriving from and by alkali desorption (180,000 people) in drier areas and from sulfide oxidation (250,000 people) in the intensely mineralized volcanic terrain of the central mountains. The model predicts that the population that is at risk from As pollution in alluvial groundwater is approximately 1,664,092, which is equivalent to 5% of the total population of Colombia.

3.1. Arsenic in minerals, soils and sediments

Most of the mineralogical, geochemical and hydrogeological studies of soils and sediments in Colombia date to the second half of the twentieth century. The existing information has been the result of investigations by INGEOMINAS, which has also produced localization maps for those areas where studies have been conducted. That information is available online in the SICAT database of the Colombian Geological Survey (http://www.sgc.gov.co) and in the "*Catalog of mineral deposits, prospects and manifestations in Colombia*" (Mutis, 1983). In addition, a report by INGEOMINAS (1987) showed that As is usually present in the form of arsenopyrite associated with veins of ore minerals in several Departments, mostly along the central and western Cordillera of Colombia (sites:

Table 1
Maximum arsenic levels in different matrices established by the Colombian legislation.

Matrix type	Limit value	Reference
Water used in Agriculture	0.1 mg/L	Decree 1594 from 1984 (Ministerio de Agricultura, 1984)
Flora and fauna preservation in cold or warm freshwaters, and in estuarine or marine waters	0.1 mg/L	
Water used for livestock	0.2 mg/L	
Drinking water, for human and domestic use	0.01 mg/L	Resolution 2115 from 2007 (Ministerio de la Protección Social y Ministerio de Ambiente, Vivienda y Desarrollo Territorial, 2007)
Waste water disposal	0.01 mg/L	Resolution 3956 from 2009 (Secretaría Distrital de Ambiente, 2009)