Science of the Total Environment 499 (2014) 166–174

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Human health risk assessment with spatial analysis: Study of a population chronically exposed to arsenic through drinking water from Argentina

J.A. Navoni [a,*], D. De Pietri [b], V. Olmos [a], C. Gimenez [c,1], G. Bovi Mitre [d,2], E. de Titto [b], E.C. Villaamil Lepori [a]

[a] Cátedra de Toxicología y Química Legal, Facultad de Farmacia y Bioquímica, Universidad de Buenos Aires, Junín 956, C1113AAD Ciudad Autónoma de Buenos Aires, Argentina
[b] Dirección Nacional de Determinantes de la Salud e Investigación, Ministerio de Salud de la Nación, Av. 9 de Julio 1925, C1073ABA Ciudad Autónoma de Buenos Aires, Argentina
[c] Cátedra Química Analítica I, Universidad Nacional del Chaco Austral. Cmte., Fernández 755 (3700), Pres. Roque Sáenz Peña, Chaco, Argentina
[d] Grupo INQA (Investigación Química Aplicada) Facultad de Ciencias Agrarias, Universidad Nacional de Jujuy, Alberdi 47, piso 1, San Salvador de Jujuy, Jujuy CP 4600, Argentina

HIGHLIGHTS

- Risk assessment (RA) to As using deterministic procedures
- Integration of RA through deterministic procedures with GIS tools
- Analysis of the time-space behavior of the risk area
- Analysis of As effect outcomes through HI
- Broaden the scopes of deterministic approaches

ARTICLE INFO

Article history:
Received 29 June 2014
Received in revised form 18 August 2014
Accepted 18 August 2014
Available online 1 September 2014

Editor: Damia Barcelo

Keywords:
Arsenic
Water pollution
Public health
Risk assessment
Geographic information systems

ABSTRACT

Arsenic (As) is a ubiquitous element widely distributed in the environment. This metalloid has proven carcinogenic action in man.
The aim of this work was to assess the health risk related to As exposure through drinking water in an Argentinean population, applying spatial analytical techniques in addition to conventional approaches. The study involved 650 inhabitants from Chaco and Santiago del Estero provinces. Arsenic in drinking water (Asw) and urine (UAs) was measured by hydride generation atomic absorption spectrophotometry. Average daily dose (ADD), hazard quotient (HQ), and carcinogenic risk (CR) were estimated, geo-referenced and integrated with demographical data by a health composite index (HI) applying geographic information system (GIS) analysis. Asw covered a wide range of concentration: from non-detectable (ND) to 2000 μg/L. More than 90% of the population was exposed to As, with UAs levels above the intervention level of 100 μg/g creatinine.
GIS analysis described an expected level of exposure lower than the observed, indicating possible additional source/s of exposure to inorganic arsenic.
In 68% of the locations, the population had a HQ greater than 1, and the CR ranged between $5 \cdot 10^{-5}$ and $2{,}1 \cdot 10^{-2}$. An environmental exposure area through ADD geo-referencing defined a baseline scenario for space-time risk assessment. The time of residence, the demographic density and the potential health considered outcomes helped characterize the health risk in the region. The geospatial analysis contributed to delimitate and analyze the change tendencies of risk in the region, broadening the scopes of the results for a decision-making process.

1. Introduction

Arsenic (As) is a ubiquitous element widely distributed in the environment. It is transferred from geologic storages to water resources. Consequently, population consuming As contaminated water is chronically exposed to this element.

In Argentina, elevated levels of As in drinking water have been reported since the early twentieth century, being recognized as an endemic region for *Hidroarsenicismo Crónico Regional Endémico* (HACRE) (WHO, 2012). Currently, As in drinking water has been reported with maximum levels near 200 μg/L in Santa Fe (Vázquez et al., 2000), Catamarca (Bocanegra et al., 2002), Chaco (Blanes et al., 2004), Salta

* Corresponding author.
E-mail addresses: jnavoni@ffyb.uba.ar, navoni.julio@gmail.com (J.A. Navoni), depietrid@hotmail.com (D. De Pietri).
[1] Tel.: +54 364 4420137.
[2] Tel.: +54 0388 4221555.

http://dx.doi.org/10.1016/j.scitotenv.2014.08.058
0048-9697/

(Concha et al., 2006), Tucuman (Guber et al., 2009), and Buenos Aires province (Navoni et al., 2012).

Other reports from the provinces of Cordoba (Penedo and Zigaran, 1998), La Pampa (Smedley and Kinniburgh, 2002), Chaco and Santiago del Estero (Bundschuh et al., 2004; MSAL, 2007; Navoni et al., 2006; Smedley and Kinniburgh, 2002) have described higher levels, up to 1 mg/L, hundred folds higher than the international guideline level of 10 μg/L (WHO, 2012).

HACRE or arsenicosis is characterized by a sequence of non-carcinogenic effects such as hyperhidrosis, hyperkeratosis and melanodermia (MSAL, 2001), and a carcinogenic stage that includes skin, bladder, lung, kidney and/or liver cancers (Hopenhayn-Rich et al., 1998; IARC, 2004).

Other pathologies also related to As exposure include bronchitis, chronic obstructive pulmonary disease, bronchiectasis (Smith et al., 1998, 2006), gangrene, hypertension, peripheral vascular disease, cardiac disorders (Astolfi et al., 1982; Hopenhayn-Rich et al., 1996, 1998; Yuan et al., 2007), non-cirrhotic portal fibrosis and peripheral polyneuropathy. Moreover, diabetes mellitus, mental disorder and cognitive development alterations have also been reported to be associated with arsenic exposure (Calderon et al., 2001; Coronado-Gonzalez et al., 2007; Rocha-Amador et al., 2007; Smith et al., 2006; Yuan et al., 2007).

Despite the knowledge of HACRE as a potential health concern in Argentina, little is known about the health risk associated to the consumption of As through contaminated drinking water of the population.

The use of standardized approaches to conduct risk assessment may be insufficient to perform a comprehensive analysis of the risk scenario.

The inclusion of geographic information system (GIS) analysis broadens the scopes in risk assessment process using proximity analysis of contaminant source as a surrogate for exposure, and integrating environmental monitoring data into the analysis of the health outcomes (Nuckols et al., 2004).

The aim of the present study was to perform a more comprehensive risk assessment by adding spatial analysis to the standard exposure assessment.

In this framework, the specific objectives were: 1) to map water and urine samples for spatial pattern analysis; 2) to calculate the average daily dose intake to demarcate areas of exposure in the studied region and 3) to characterize different risk scenarios taking into consideration the time of residence and the distribution of the population.

2. Materials and methods

2.1. Area of study

The study was performed in an area from the North-center region of Argentina in Santiago del Estero province (Banda and Copo departments) and Chaco province (Almirante Brown department). The study included 19 different locations. Three in Banda department: Jumi Pozo (JP), Negra Muerta (NM), and Siete Árboles (7A); 8 in Copo department: San José del Boquerón (SJB), Urutaú (U), Monte Quemado (MQ), Santos Lugares (SL), Venado Solo (VS), La Firmeza (LF), Malvinas (M), and Las Termas (LT), and 8 in Almirante Brown department: Taco Pozo (TP), Santa Teresa de Carballo (STC), Pozo Hondo (PH), El Rosillo (ER), San Telmo (ST), Brasil (BR), El Quinto (EQ), and Kilometro 27 (Km27).

Santiago del Estero and Chaco provinces have a total population of 874,006 and 1,055,259 inhabitants, respectively (INDEC, 2010). Fifty four percent of the population is rural and spread and 46% is settled in urbanized centers. Positive intercensal variation has been observed in the last decade indicating a constant increment in demographic density (17,2% A. Brown; 16,4% Copo; 10,8% Banda). The main economic activities are the production of wood, cotton and tobacco, in addition to livestock, farm animal and horticulture production.

The region is an arid and dry zone with a rainy and a dry season. The former has elevated temperatures and a high rate of rainfalls. The dry season is represented by a critical (low) humidity level of the soil (Servicio meteorológico Nacional, 2013).

2.2. Population

The population consisted in 650 individuals, aged between 1 and 96 years old.

A survey, following a standard questionnaire, was conducted aiming to collect information about customs, dietary habits and demographic data such as age, sex, years of residence and drinking water patterns. The study was performed in accordance with the Ethical Committee of the Hospital de Clinicas, Buenos Aires, Argentina.

All the objectives of the research were fully explained and informed consent was obtained from all participants.

2.3. Sample collection

Sample collection was performed during the period 2010–2011. Water samples (500 mL) were collected in cleaned plastic bottles containing concentrated nitric acid (HNO_3) (final HNO_3 concentration 0.015% v/v) and stored at 4 °C until arsenic quantification (Standard Methods, 1998). Different types of water sources were included: tap water (piped water supply), and well water and other storage devices for rainwater.

Urine samples (first void) were collected in polyethylene flasks, previously soaked in 20% v/v HNO_3, rinsed with distilled water and dried. No conservatives were used and the samples were kept frozen at −20 °C until analysis. A total of 464 samples were obtained. Urine samples were tested for altered biochemical parameters by urine dipstick analysis. A urinary creatinine concentration between 0,3 and 3,0 g/L was also required as sample inclusion criteria (ACGIH, 2009). Twelve urine samples (2.6%) did not meet the inclusion criteria.

Water samples were geo-referenced through their respective geographic coordinates. Water sample collection was performed house-to-house. Urine samples were grouped according to the location where they were collected.

Arsenic concentration was determined in 192 drinking water samples and, according to the inclusion criteria, in 452 urine samples.

2.4. Sample analysis

Arsenic content was quantified in water and urine samples using a flow injection hydride generation atomic absorption spectrophotometric method. The equipment used was an atomic absorption spectrophotometer (Varian 475) with a hydride generator (Varian VGA77) and a manual injector (Rheodyne 7125). Briefly, the method is based on the formation of derivatives of arsenic complexes with cysteine. Then, arsines are generated by reaction with sodium borohydride and hydrochloric acid and carried by a nitrogen stream to a heated quartz cell for their atomization and quantitation by atomic absorption spectrophotometry (Navoni et al., 2009, 2010).

The performance of the quantitative procedure was evaluated, for water samples, by the analysis of a reference material: EP-H-2 (EnviroMAT Drinking Water) and for urine quantitative analysis, by the use of quality control Lyphochek® level 2 (Biorad). The limit of detection (LOD) and the limit of quantitation (LOQ) of the method were 0.7 and 1.2 μg/L, respectively.

Creatinine was performed by the Enzymatic Assay Kit Method (Wiener lab®). Urinary As (UAs) was expressed as μg of As per g of urinary creatinine.

2.5. Exposure assessment

Levels of As in water and urine were evaluated to assess human exposure.