

Journal of Water and Health

NEW MAP OF ARGENTINE POPULATION EXPOSED TO ARSENIC IN DRINKING WATER

--Manuscript Draft--

Manuscript Number:	JWH-D-24-00225R3
Full Title:	NEW MAP OF ARGENTINE POPULATION EXPOSED TO ARSENIC IN DRINKING WATER
Article Type:	Research Paper OA
Corresponding Author:	ALEJANDRO OLIVA, MD Universidad Nacional de Rosario Rosario, Santa Fe ARGENTINA
Corresponding Author's Institution:	Universidad Nacional de Rosario
First Author:	Leandro Duarte
Order of Authors:	Leandro Duarte Laura De Gracia Sergio Montico ALEJANDRO OLIVA, MD
Abstract:	<p>This study aims to evaluate the population exposed to arsenic in Argentina, proposing a key risk indicator. By employing specific criteria selection, systematic search of the published evidence on arsenic content in drinking water samples at provincial level was carried out. Considering the limit recommended by the WHO -10µg/L - representativeness of evidence was calculated, as well as the percentage of exposed population to high levels of arsenic.</p> <p>For this research, sixty-one useful publications were found and included in the analysis. They provide relevant data for 50% of the provinces, which represents 70% of the national population.</p> <p>The use of an index, "percentage of population exposed" to high arsenic, is proposed as a summary variable, to homogenize the information in the country. and in this way give it comparative value. Information has been systematized and variables identified that may be useful for analysis in eco-epidemiological studies, detailing the current situation of publications of arsenic in drinking water in Argentina.</p>
Additional Information:	
Question	Response
Has your manuscript been submitted to a conference?	No
<p>HIGHLIGHTS: Please provide up to 5 numbered points which describe the novelty and/or the impact of your research.</p> <p>Note that the highlights should help increase the discoverability of your article. Ensure the highlights are concise, easy to read, and include key search terms (you should not simply rewrite the abstract).</p>	<p>Half of the provinces provide information on populations exposed to high levels of arsenic.</p> <p>The percentage of exposed populations is highly variable, from 0 to almost 100%.</p> <p>The use of the PEP index, "percentage of exposed population" to elevated arsenic levels, is proposed as a summary variable.</p> <p>A map showing different regional situations is drawn –half of the Argentine provinces–two thirds of the total population.</p>
IWA Publishing is committed to ensuring complete transparency regarding conflicts	The authors declare there is not conflict.

<p>of interest. Please complete the Conflict of Interest Statement to certify that the authors are not affiliated with or involved with any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this paper. Please address queries about Conflicts of Interest to the journal office: editorial@iwap.co.uk</p>		
<p>Corresponding Author E-Mail:</p>	<p>aoliva.promas@gmail.com</p>	
<p>Funding Information:</p>	<p>Universidad Nacional de Rosario</p>	<p>Dr. Leandro Duarte</p>
<p>Section/Category:</p>	<p>Risk assessment</p>	
<p>Manuscript Region of Origin:</p>	<p>ARGENTINA</p>	

NEW MAP OF ARGENTINE POPULATION EXPOSED TO ARSENIC IN DRINKING WATER

ARSENIC POPULATION MAP AND ARGENTNE

Leandro Duarte ¹, Laura De Gracia¹, Sergio Montico¹, Alejandro Oliva ^{1*}

^{1*} Centro de Estudios Interdisciplinarios (CEI), Universidad Nacional de Rosario (UNR). Maipú 1065, Of. 309, (2000) Rosario, Argentina aoliva.promas@gmail.com

ABSTRACT

This study aims to evaluate the population exposed to arsenic in Argentina, proposing a key risk indicator. By employing specific criteria selection, systematic search of the published evidence on arsenic content in drinking water samples at provincial level was carried out. Considering the limit recommended by the WHO -10µg/L - representativeness of evidence was calculated, as well as the percentage of exposed population to high levels of arsenic.

For this research, sixty-one useful publications were found and included in the analysis. They provide relevant data for 50% of the provinces, which represents 70% of the national population.

The use of an index, “percentage of population exposed” to high arsenic, is proposed as a summary variable, to homogenize the information in the country. and in this way give it comparative value. Information has been systematized and variables identified that may be useful for analysis in eco-epidemiological studies, detailing the current situation of publications of arsenic in drinking water in Argentina.

Keywords: Argentina - Arsenic - Map - Water -

HIGHLIGHTS

- Half of the provinces provide representative information on populations exposed to high levels of arsenic.

29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

- The percentage of exposed populations is highly variable, from 0 to almost 100%.
- The use of the PEP index, “percentage of exposed population” to elevated arsenic levels, is proposed as a summary variable.
- A map showing different regional situations is drawn –half of the Argentine provinces–two thirds of the total population.

GRAPHICAL ABSTRACT



INTRODUCTION

Arsenic (As) is a ubiquitous element, widely distributed throughout the environment. It can be found in the air, water and land, and is one of the ten chemicals considered by the World Health Organization as major public health concern (WHO, 2022). The largest amounts of As in the environment come from natural sources (weathering, biological activity, volcanic emissions). However, anthropogenic activities – industrial processes like mining, metal smelting, pesticides usage, wood preservatives, etc. – also play their part (Litter, 2018). Surface and underground water natural resources are affected by the geochemical cycle of arsenic due to many reasons: interactions of the aquatic environment with rocks, sediments and soils; emissions from volcanic and geothermal sources; erosion and leaching of geological formations; and mining waste that produce high concentrations of this element in the environment (RSA, 2018).

Humans can be exposed to arsenic in different ways: by consuming contaminated food or water; using them in meal preparation, crops irrigation or industrial processing, and it can also be inhaled. Prolonged exposure to inorganic arsenic – through any of these ways – can cause acute and chronic poisoning, from skin lesions to neoplasm.

Arsenicism is an endemic disease. This is especially true in Argentina, where the population exposed to high levels of arsenic ($> 50 \mu\text{g/L}$) has been calculated in about 4 million; moreover, its accepted level places the country among the most affected ones within Latin America (Litter et al., 2019). Chronic Endemic Regional Hydroarsenicism (HACRE, acronym in spanish) characterized due to skin lesions and systemic cancerous and non-cancerous alterations resulting from exposure to low levels for prolonged periods., which has been known in Argentina since 1913, ranks second after the USA in the world's most affected countries (Ministerio de Salud, Argentina, 2006). The situation has worsened considering the long-term and

75 chronic impact on human health. A recent piece of research carried out in the Central
76 Region of Argentina has compared arsenic genotoxicity in two groups of population,
77 one exposed to high levels and one not exposed at all (Quiroga, 2023). Exposure
78 has an impact on chronic diseases, from congenital malformations to
79 neurodegenerative diseases, and cancer. Arsenic was classified by the WHO's
80 International Agency for Research on Cancer (IARC) as carcinogenic to humans
81 (Rousseau et al, 2005).

82 Perinatal exposure deserves special attention, both intrauterine and during the first
83 years of life. As regards certain cancers, a study carried out in Chile exploring early
84 life exposure and adulthood risks showed a clear association of these two variables.
85 It was thus possible to differentiate the risks of intrauterine and early childhood
86 exposures in periods of high and low exposure (Smith et al., 2006). The literature
87 review confirms this situation as the longest risk period (Young et al., 2018; Martinez
88 et al., 2021).

89 In its Guidelines for Drinking-water Quality, the WHO established a limit value for
90 arsenic in water. It aims to serve as a world basis for regulatory and standardization
91 tasks in this regard. The recommended limit in drinking water is 10 µg/L (WHO,
92 2017). The Argentine Food Code [CAA by its Spanish acronym] establishes a higher
93 safety limit, 50 µg/L (MSA-ANMAT, 2005). However, levels well above this limit have
94 already been reached in the country, even exceeding 200 µg/L (Nicolli et al., 1989).
95 Much of the scientific evidence has shown that between the limits of the WHO and
96 the CAA, there is a significant risk to human health.

97 Despite what has been stated so far, the real proportion of the population exposed
98 to high arsenic level in the country is still unknown. The information available on
99 arsenic content in drinking water is scattered and not updated. Therefore, the
100 objective of this analysis is to carry out a systematic review to collect the published
101 information and evaluate its connection with the exposed population.

102

METHODOLOGY

103¹
2

Bibliographic Review

3
4

104⁵
6

The following open-access databases were analyzed to carry out a systematic search of the available evidence: PUBMED, Google Scholar, Latin American and Caribbean Health Sciences Literature (LILACS) and the National System of Digital Repositories [SNRD by its Spanish acronym] (Argentina). The terms "*arsenic AND water consumption AND Argentina*"; "*arsenic AND water AND Argentina*" were used, and the Spanish ones, "*arsénico Y agua de consumo Y provincia Y argentina*".

105⁷
8

106⁹
10

107¹¹
12

108¹³
14

109¹⁵
16

110¹⁷
18

111¹⁹
20

112²¹
22

113²³
24

114²⁵
26

115²⁷
28

116²⁹
30

117³¹
32

118³³
34

119³⁵
36

120³⁷
38

121³⁹
40

122⁴¹
42

123⁴³
44

124⁴⁵
46

125⁴⁷
48

126⁴⁹
50

127⁵¹
52

128⁵³
54

129⁵⁵
56

130⁵⁷
58

131⁵⁹
60

132⁶¹
62

133⁶³
64

134⁶⁵

The selection criteria to include the articles were the following: 1) if the number of evaluated population was available; 2) if it expressed the number of water samples assessed; 3) if it expressed the As value in absolute terms; and 4) if the analyzed water was for human consumption. All these conditions were considered for each province.

Variables Construction

After selecting valid bibliography, the following items were classified and calculated by provinces:

(1) percentage of total population per province. It was calculated following the National Institute of Statistics and Census (INDEC, 2010) taking into account the total population assessed. This allowed to know the "**representativeness**" of the samples for each province, which means the percentage of the total population of the province represented in the referenced specific studies. A limit of 30% was established to define this variable as high or low, decided on the basis that -approximately- one in three inhabitants were considered within the population under study.

125 (2) considering the number of samples above the WHO value (10 µg/L), the
126 percentage of samples with high levels of arsenic was calculated and this was
127 applied to the total population evaluated., obtaining thus its **exposure index**.

128 (3) the exposure index was applied to the total provincial population, which allowed
129 to obtain the so-called **Percentage of Exposed Population** (PEP) per province.

130 Through these calculations, two variables were obtained for each province: a)
131 "representativeness" of the samples obtained over the total population; and, b) the
132 population "exposure" variable, or PEP. If the sample captured is representative, the
133 exposure percentage can be projected to the rest of the population and interpreted
134 as a provincial index.

REPRESENTATIVENESS	x	POPULATION EXPOSURE INDEX	=	% EXPOSED POPULATION
(>30%)		(% of samples >10 ug/L)		PEP

135 **RESULTS**

136 **Bibliographic Review**

137 As can be seen in the systematic literature review (Figure 1), 569 publications were
138 found. After applying the duplicates or non-relevant by title or summary filter, 315
139 publications remained suitable to be analyzed according to the selection criteria
140 detailed in the Methodology. Then, another 254 articles were excluded in this
141 process, resulting in 61 final publications useful for this research. Relevant
142 information was found for 50% of the Argentine provinces, which represents 70% of
143 the total population nationwide; this is twelve provinces and represents approximately
144 thirty-two million inhabitants.

145 **Representativeness and percentages of exposed population**

146 When analyzing provincial representativeness, the population under study presented
147 a considerable heterogeneity: ranging from 0.35% (the lowest, in Chubut province)

149 to 99% (the highest, in Santa Fe province). An arbitrary limit of 30% was established,
150 which made it possible to obtain two groups: high and low representativeness.

151
152
153 In relation to the Percentage of Exposed Population (PEP), the highest exposure
154 (Table 1) was found in La Pampa (87.98%), followed by Catamarca (78.90%) and
155 Buenos Aires provinces (68.55%). In relation to the provinces with low
156 representativeness (Table 2), the PEP is significantly low, between 0 and 10%.
157 However, due to the fact that the sampling is small, the data identified is not precise.
158 The distribution of the provinces according to the PEP is presented in a graphic
159 (Figure 2). Of a total population of approximately 32 million inhabitants, 55% (around
160 17 million) is exposed to arsenic levels greater than 10 µg/L in drinking water.

161 **DISCUSSION**

162 It has been documented worldwide that millions of people are affected by being
163 exposed to drinking water with high levels of arsenic. Among the largest and most
164 populated areas involved, in Asia, for example, the populations most at risk are: the
165 Gulf of Bengal, in Bangladesh (Rahman et al., 2001); Northeast India (Bhattacharyya
166 et al., 2003); Inner Mongolia in China (Guo et al., 2001); and Taiwan and Vietnam
167 (Smedley et al., 2003). In North and Central America, the west of the United States
168 (BEST, 2001) and Mexico (Rodriguez et al., 2004); and in South America, Argentina,
169 Chile, Bolivia and Peru (Bundschuh et al., 2012).

170 Argentina has empirically known for more than a century that its drinking water
171 contains high levels of As because there are endemic diseases associated to this
172 element. However, the country does not possess unified and precise information to
173 identify its true sanitary risk. There have been two attempts to draft a "map" of this
174 situation but they have shown varied limitations, especially because they referred to
175 isolated values that did not specify the population involved (Ministerio de Salud
176 Argentina, 2006) or else showed a general distribution of the population in graphics
177 but did not specify As consumption (Litter et al., 2019). Preliminary information –using

177 a limit value of 50 µg/L – mentions a total exposed population of 4 million inhabitants.

178 This piece of research, however, employing the WHO limit (10 µg/L) finds an
179 approximate total of 17 million, more than four times the previous one.

180
181 The accumulation of evidence on chronic toxicological effects of arsenic ingestion
182 through drinking water has led to a progressive reduction in the threshold limit of
183 arsenic concentrations in water intended for human consumption (Smedley et al.,
184 2002). In Argentina and Chile, this threshold is 50 µg/L (MSA-ANMAT, 2005; Diario
185 Oficial de la República de Chile, 1984). This level is intended to be reduced to 10
186 µg/L, as set by the European Union (European Union, 1998), recommended by the
187 World Health Organization (WHO, 2004), and proposed since January 2006 by the
188 United States Environmental Agency as a "Maximum Contaminant Level Goal"
189 (MCLG) (USEPA, 2005). According to these standards, the economic implications of
190 ensuring that water has an acceptable arsenic concentration has opened an
191 important debate on the level to be set, both in large areas of developed and
192 developing countries (Smith & Smith, 2004). The existing literature confirms that the
193 levels of arsenic in drinking water recommended by the WHO in relation to chronic
194 non-communicable diseases are those that have been shown to be associated with
195 this lower threshold (Rehman et al., 2018; Ferragut Cardoso & Udoh, 2020;
196 Jaafarzadeh et al., 2022).

197 Although arsenic contamination has been exhaustively and long studied as acute
198 poisoning (Campbell & Alvarez, 1989), pathologies related to deferred impacts over
199 time, such as cancer, were little addressed in the country as specific associated
200 issues. However, recent analyses have demonstrated their link in Argentina (Duarte
201 et al., 2022). It is, therefore, necessary to update the information on arsenic in
202 drinking water in the country. In other countries such as the USA, approximation
203 models on As levels in drinking water have been built at national level, which have
204 made possible to define high and low risk areas (Ayotte et al., 2017). Likewise,

205 Bangladesh has carried out a review of related publications that made possible to
206 determine an (approximate) total exposed population (Karim, 2000). Other
207 countries, including higher-risk countries, only have partial information available.
208 This work contributes in highlighting both the existing and missing information. It
209 raises awareness to the situation of a large proportion of Argentina's population in
210 the face of arsenical water consumption. The wide variability of information observed
211 in this work is mainly due to the particular or regional epidemiological alert, which
212 leads local researchers to delve into the subject. It can be therefore deduced that, in
213 provinces with fewer perceived risks of exposure to arsenic, publications are fewer
214 than in those that have historically been associated with this environmental toxicant.
215 Although "exposed population" is a key -and original- concept in this analysis, an
216 extensive use of this term was not found. Most of the analyzed articles that had to be
217 discarded detail the analytical determinations of water samples and collection sites.
218 However, they do not describe the population under analysis, which is fundamental
219 to assess the true sanitary impact of arsenic contamination in drinking water.
220 Conversely, the number of samples is not a correct parameter to determine the scope
221 of the analysis, nor the level reached by the assessment above the cutoff applied.
222 Undoubtedly, when a region presents epidemiological alarms related to chronic non-
223 communicable diseases related to arsenical contamination in drinking water, it is
224 necessary to evaluate the precise levels of this element in representative samples of
225 the population.
226 The methodology employed in this analysis presents some bias: 1) possible
227 duplications of the exposed populations in each province, given that some studies
228 overlap in these territories without mentioning the specific places of collection; 2)
229 there is a bias inherent to the publications, which is related to sampling, especially in
230 well water, with the distribution of populations in relation to sources of consumption
231 unknown; 3) the concept of exposed population is not included in publications related
232 to arsenic, with the PEP variable, proposed in this work, being an indirect calculation.;

233 4) the temporality of the water evaluations is dissimilar; in any case, arsenic has been
234 described as a stable toxicant in the environment -with little variability- given the
235 fundamentally natural contamination, except that interventions have been carried out
236 to remove this element, a scarce, partial or non-existent issue in Argentina
237 throughout of the years.

238 **CONCLUSIONS**

239 This review adds value to the already published evidence, systematizing information
240 and identifying variables that may be useful for ecoepidemiological studies to analyze
241 both humans and fauna. An index is proposed, the "percentage of exposed
242 population" (PEP) to high arsenic levels as a summary variable, to homogenize the
243 information in the country, giving it thus a comparative value. It has also been
244 validated in a previous work, related to cancer mortality at provinces' departmental
245 level in the central region of Argentina (Duarte et al, 2022).

246 Territorial interventions in health management, especially in sensitive issues such as
247 population's consumption of arsenical water, require orderly, organized and
248 coordinated information to guide actions to provide tools and introduce public policies
249 that benefit inhabitants' life.

250 Finally, the present work allows to identify -indirectly- the areas of high exposure, as
251 a guide to deepen future research that allows to give certainty to these findings.

252 **REFERENCES**

253 **Ayotte** JD, Medalie L, Qi SL, Backer LC, Nolan BT (2017). Estimating the High-
254 Arsenic Domestic Well Population in the Conterminous United States. *Environ Sci*
255 *Technol.* Nov 7;51(21):12443-12454. doi: 10.1021/acs.est.7b02881.

256 **BEST** (Board on Environmental Studies and Toxicology) (2001) Arsenic in drinking
257 water: 2001 update. National Academy Press, Washington D.C., 225 pp. Retrieved
258 from: <https://nap.nationalacademies.org/read/10194/chapter/1>

261 **Bhattacharyya** R, Chatterjee D, Nath B, Jana J, Jacks G, Vahter M (2003). High
262 arsenic groundwater mobilization, metabolism and mitigation -an overview in the
263 Bengal Delta Plain. *Mol Cell Biochem.* Nov;253(1-2):347-55. doi:
264 10.1023/a:1026001024578. PMID: 14619986.

265 **Bundschuh**, J., Litter, M. I., Parvez, F., Román-Ross, G., Nicolli, H. B., Jean, J. S.,
266 ... et al. (2012). One century of arsenic exposure in Latin America: A review of history
267 and occurrence from 14 countries. *Science of the total Environment*, 429, 2-35.

268 **Buti**, C. I., Cancino, F., Ferullo, S., & Gamundi, C. (2015). Diversidad y evaluación
269 toxicológica de peces como indicadores de contaminación por mercurio, plomo,
270 cadmio, cobre y arsénico, provincia de Tucumán, República Argentina. [Diversity and
271 toxicological assessment of fishes as contaminant indicators by mercury, lead,
272 cadmium, cooper and arsenic, Tucumán province, Argentina]. Retrieved from:
273 <https://ri.conicet.gov.ar/handle/11336/13035>

274 **Campbell** JP, Alvarez JA (1989). Acute arsenic intoxication. *Am Fam Physician.*
275 Dec; 40(6):93-7. PMID: 2686377.

276 **Diario Oficial de la República de Chile** (1984). Norma Chilena Oficial N°409/1 Of.
277 N°84. Agua potable. Parte I: Requisitos. Aprobada por el Ministerio de Salud
278 mediante Decreto Supremo N°11 del 16/01/1984 [Official Chilean Norm No. 409/1
279 Of. No.84. Drinking water. Part I: Requisites. Approved by the Ministry of Health by
280 Supreme Decree No. 11 on 01/16/1984]. Published on 03/03/1984. Retrieved from:
281 [https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-
282 del-agua-potable-eeo-1.pdf](https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-del-agua-potable-eeo-1.pdf)

283 **Duarte** LE, Delgado F, Di Leo NC, Bertone CL, Franci Alvarez M, Montico S, et al.
284 (2022). Mortalidad por cáncer, arsénico y nitratos en aguas de consumo y superficies
285 sembradas en Argentina [Mortality from cancer, arsenic, and nitrates in drinking
286 water and cropland in Argentina. Mortalidade por câncer, arsênio e nitratos na água
287 para consumo humano e em áreas semeadas na Argentina]. *Rev Panam Salud
288 Publica.* Aug 30; 46:e129. Spanish. doi: 10.26633/RPSP.2022.129.

289 **European Union** (1998). Directive 98/83/EC relating to human drinking water quality,
290 Official Journal of European Communities L330. Retrieved from: <https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-20151027&from=EN>

293 **Ferragut Cardoso AP, Udoh KT, States JC** (2020). Arsenic-induced changes in
294 miRNA expression in cancer and other diseases. *Toxicol Appl Pharmacol.* Dec 15;
295 409:115306. doi: 10.1016/j.taap.2020.115306.

296 **Guo X, Fujino Y, Kaneko S, Wu K, Xia Y, Yoshimura T** (2001). Arsenic contamination
297 of groundwater and prevalence of arsenical dermatosis in the Hetao plain area, Inner
298 Mongolia, China. *Mol Cell Biochem.* Jun;222(1-2):137-40. PMID: 11678595.

299 **INDEC** (National Institute of Statistics and Census Argentina). 2010 Census.
300 Retrieved from: <https://www.indec.gob.ar/indec/web/Nivel4-Tema-2-41-135>

301 **Jaafarzadeh N, Poormohammadi A, Almasi H, Ghaedrahmat Z, Rahim F, Zahedi A**
302 (2022). Arsenic in drinking water and kidney cancer: a systematic review. *Rev*
303 *Environ Health.* Mar 15; 38(2):255-263. doi: 10.1515/reveh-2021-0168.

304 **Litter M.** (2018). Arsénico en agua. Programa FUTUROS Escuela de Posgrado:
305 Agua + Humedales [Arsenic in water. FUTUROS Program. Postgraduate School].
306 UNSAM Edita, p .210-224. Retrieved from:
307 <https://ri.unsam.edu.ar/bitstream/123456789/911/1/PFAH%202018%20CLM.pdf>

308 **Litter MI, Ingallinella AM, Olmos V, Savio M, Difeo G, Botto L, et al.** (2019). Arsenic
309 in Argentina: Occurrence, human health, legislation and determination. *Sci Total*
310 *Environ.* Aug 1; 676:756-766. doi: 10.1016/j.scitotenv.2019.04.262.

311 **Karim, M. M.** (2000). Arsenic in groundwater and health problems in Bangladesh.
312 Water Research, 34(1), 304-310. Retrieved from:
313 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

314
60
61
62
63
64
65

315 **Martinez** VD, Lam WL (2021). Health Effects Associated With Pre- and Perinatal
316 Exposure to Arsenic. *Front Genet.* Sep 29; 12:664717. doi:
317 10.3389/fgene.2021.664717.
318

319 **Ministerio de Salud Argentina** [Ministry of Health of Argentina] (2006).
320 Epidemiología del HACRE en la República Argentina, Estudio Colaborativo
321 Multicéntrico [Epidemiology of HACRE in Argentina. Collaborative Multicenter Study].
322 Retrieved from:
323 https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en_argentina.pdf
324

325 **MSA-ANMAT** [Ministry of Health – National Administration of Drugs, Food and
326 Medical Technology], (2005). Código Alimentario Argentino-Capítulo XII – Bebidas
327 Hidricas, Agua y Agua Gasificada - Agua Potable - Artículo 982 [Argentine Food
328 Code. Chapt. XII: Hydration beverages, water and gas water. Article 982]- (MSyAs
329 Res. N° 494 on 07/07/94). Retrieved from:
330 <https://www.argentina.gob.ar/anmat/codigoalimentario>
331

332 **Nicolli** H, Suriano J, Gomez Peral M, Ferpozzi L & Baleani O (1989). Groundwater
333 Contamination with Arsenic and other Trace Elements in an Area of the Pampa,
334 Province of Cordoba, Argentina. *Environmental Geology and Water Science* 14 3–
335 16. Retrieved from: <https://link.springer.com/article/10.1007/BF01740581>
336

337 **Organización Mundial de la Salud** (2017). Guías para la calidad del agua de
338 consumo humano [Guidelines for drinking-water quality]. Retrieved from:
339 <https://www.who.int/es/publications/i/item/9789241549950>
340

341 **Quiroga**, AM. (2021). Evaluación de daño oxidativo y genotóxico y su relación con
342 variables nutricionales en poblaciones expuestas a Arsénico en agua de bebida de
343 la zona centro-norte de la provincia de Santa Fe, Argentina. [Assessment of the
344 oxidative and genotoxic damage and its relationship with nutritional variables in
345 populations exposed to arsenic in drinking water from the central-north area of Santa
346

347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365

342 Fe province, Argentina] Revised: January 3, 2023. Retrieved from:

343 <https://bibliotecavirtual.unl.edu.ar:8443/handle/11185/6250>

344 **Rahman** MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D, et al.
345 (2001). Chronic arsenic toxicity in Bangladesh and West Bengal, India – a review
346 and commentary. *J Toxicol Clin Toxicol.*;39(7):683-700. doi: 10.1081/clt-100108509.

347 **Rehman** K, Fatima F, Waheed I, Akash MSH. (2018). Prevalence of exposure of
348 heavy metals and their impact on health consequences. *J Cell Biochem.*
349 Jan;119(1):157-184. doi: 10.1002/jcb.26234.

350 **Rodriguez** R., Ramos J.A., Armienta A. (2004). Groundwater arsenic variations: the
351 role of local geology and rainfall. *Appl. Geochem.*, 19(2), 245-250. Retrieved from:
352 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

353 **Rousseau**, M. C., Straif, K., & Siemiatycki, J. (2005). IARC carcinogen
354 update. *Environmental Health Perspectives*, 113(9), A580-A581.

355 **RSA** Conicet. Grupo AD HOC. Arsénico en agua [Arsenic in water]. - FINAL
356 REPORT - Jul 31, 2018. Retrieved from: [https://rsa.conicet.gov.ar/wp-](https://rsa.conicet.gov.ar/wp-content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf)
357 [content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf](https://rsa.conicet.gov.ar/wp-content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf)

358 **Smedley**, P. L., & Kinniburgh, D. G. (2002). A review of the source, behaviour and
359 distribution of arsenic in natural waters. *Applied geochemistry*, 17(5), 517-568.
360 Retrieved from:
361 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

362 **Smedley** P.L., Zhang M., Zhang G., Luo Z. (2003). Mobilisation of arsenic and other
363 trace elements in fluviolacustrine aquifers of the Huhhot Basin, Inner Mongolia. *Appl.*
364 *Geochem.*, 18(9), 1453-1477. Retrieved from:
365 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

366 **Smith** AH, Smith MM. (2004). Arsenic drinking water regulations in developing
367 countries with extensive exposure. *Toxicology*. May 20;198(1-3):39-44. doi:
368 10.1016/j.tox.2004.02.024. PMID: 15138028.

369 **Smith** AH, Marshall G, Yuan Y, Ferreccio C, Liaw J, von Ehrenstein O, Steinmaus
370 C, Bates MN, Selvin S. (2006). Increased mortality from lung cancer and
371 bronchiectasis in young adults after exposure to arsenic in utero and in early
372 childhood. *Environ Health Perspect.* Aug;114(8):1293-6. doi: 10.1289/ehp.8832.

373 **USEPA** (2005). List of Drinking Water Contaminants & MCLs, February 23rd, 2005.
374 Retrieved from: [https://www.epa.gov/sites/default/files/2015-](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf)
375 [10/documents/ace3_drinking_water.pdf](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf) on 01/06/23.

376 **WORLD HEALTH ORGANIZATION, INTERNATIONAL AGENCY FOR**
377 **RESEARCH ON CANCER (IARC)** (2004). Some Drinking-Water Disinfectants and
378 Contaminants, including Arsenic. Monographs on the Evaluation of Carcinogenic
379 Risks to Humans. Volume 84. Retrieved from: <https://publications.iarc.fr/102>

380 **WHO (2004)**. Guidelines for drinking-water quality Fourth edition incorporating the
381 first and second addenda. ISBN 978-92-4-004506-4 (electronic version). Retrieved
382 from: <https://www.who.int/publications/i/item/9789240045064>

383 **Young** JL, Cai L, States JC. (2018). Impact of prenatal arsenic exposure on chronic
384 adult diseases. *Syst Biol Reprod Med.* Dec;64(6):469-483. doi:
385 10.1080/19396368.2018.1480076.

386

387

388

389

390

391

392

393

394

395

396

397

398

397 **Figure 1. Systematic Review Flowchart**

398
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
399
35
400
37
38
401
39
40
402
42
43
403
44
45
404
47
48
405
49
50
406
52
407
54
55
408
56
57
409
59
60
410
61
62
411
64
65
412

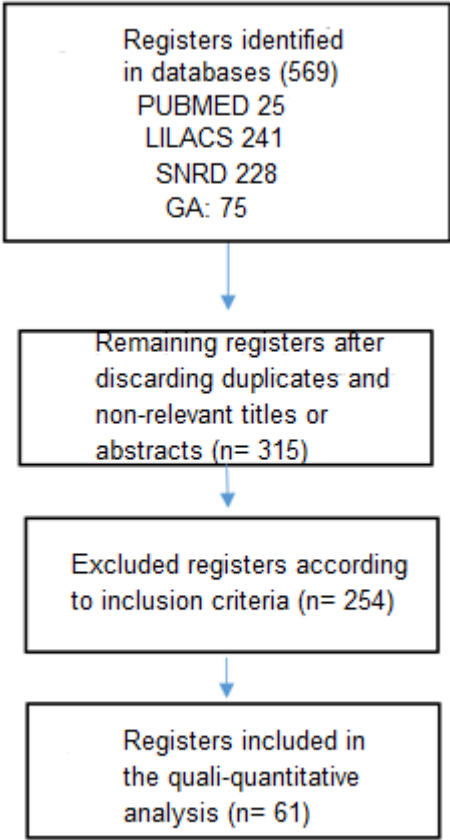


Table 1. High representativeness and exposition levels to arsenic by province

PROVINCES	Percentage of population under study (%)	Percentage of Population exposed (PEP) to high levels of As	Bibliography
	REPRESENTATIVENESS	EXPOSITION	
SANTA FE	99	60.08	ENRES (2019)
LA PAMPA	95.75	87.98 %	Pariani et al., (2014); Vercellino. (2020); O'Reilly et al. (2020)
NEUQUÉN	88.98	0	Center for Environmental Engineering (CIMA), ITBA (2020); Velazquez (2019)
CATAMARCA	86.64	78.9	Rugierri et al. (2009); Saracho et al. (2016); Saracho et al. (2019); Graziano et al. (2013); CIMA (2020); Vilches et al. (2005).
BUENOS AIRES	77.6	68.55	Navoni et al. (2012); RSA CONICET (2018); Galindo et al. (2005).
CORRIENTES	57.17	11.4	CIMA (2020)
CHACO	75.43	53.51	Roshdestwensky et al. (2016); Martínez et al. (2014); Trinelli et al. (2018); Concha et al. (1998); Osicka et al. (2002); CIMA (2020); Buchhamer et al. (2012); Blanes et al. (2011)
CÓRDOBA	70.6	29.09	Villalba et al. (2000); Blarasin et al. (2015); Penedo and Zigarán (1998)
ENTRE RÍOS	61.64	28.02	UNER (2019); CIMA (2020)
TIERRA DEL FUEGO	44	0	CIMA (2020)
JUJUY	34.2	22.27	López Steinmetz et al (2018); CIMA (2020); Murray et al. (2019); Ruggeri et al. (2009)

SANTIAGO DEL ESTERO	32.84	26,36	Bhattacharya et al. (2006); Revelli et al. (2016); Vidoni et al. (2010); Bejarano Sifuentes and Nordberg. (2003); Bundschuh et al. (2004); Calatayud et al. (2019); Navoni et al. (2014); CIMA (2020); Litter et al. (2015)
--------------------------------	-------	-------	--

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

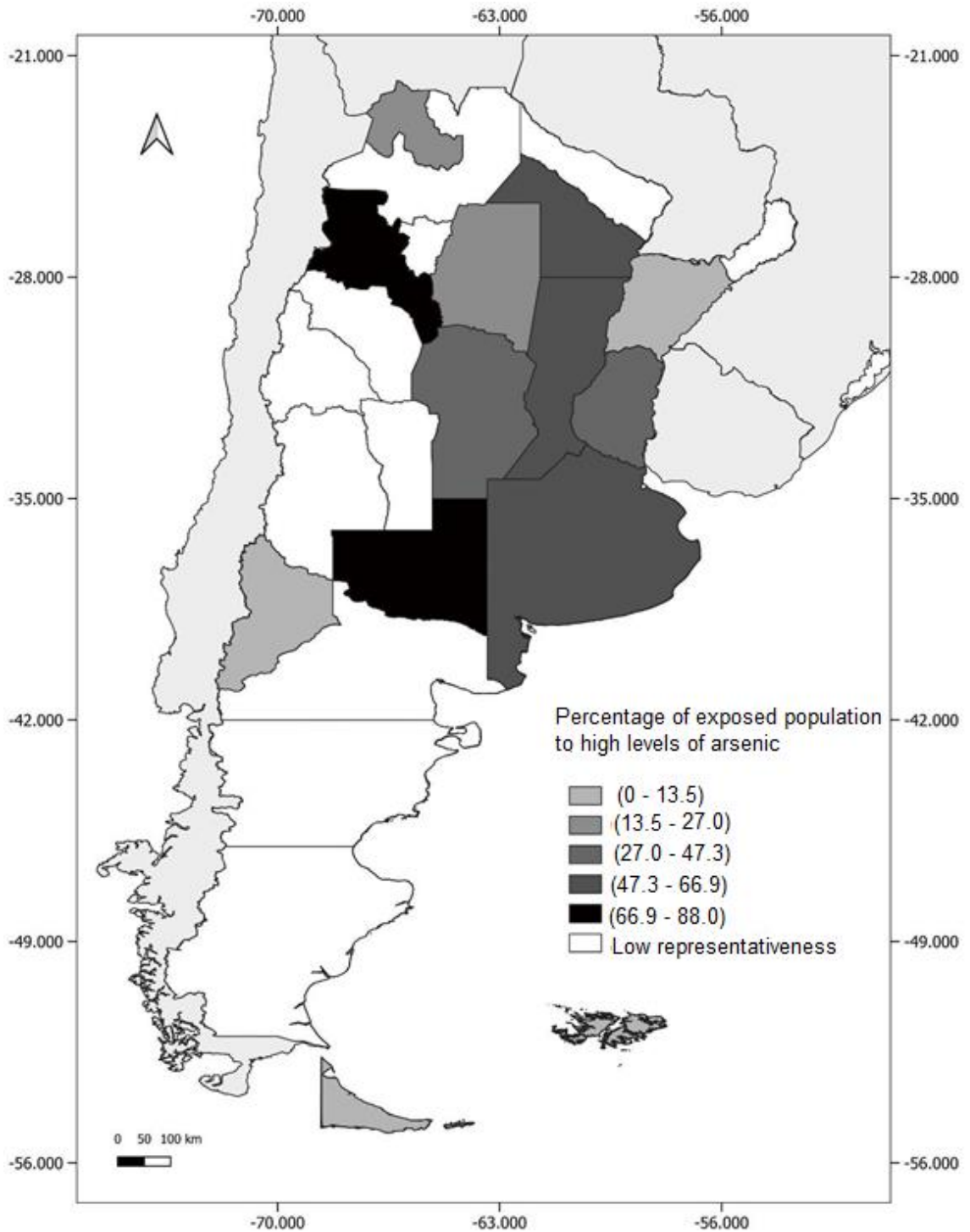
Table 2. Low representativeness and exposition levels to arsenic by province

PROVINCE	Percentage of Population under study (%)	Percentage of exposed population (PEP) (%)	Bibliography
	REPRESENTATIVENESS	EXPOSITION	
SANTA CRUZ	26.79	0	CIMA (2020)
SAN LUIS	20	0	CIMA (2020)
TUCUMÁN	14.11	10.51	Soria de González et al. (2008-2011); Guber et al. (2009); Nicolli et al. (2012); CIMA (2020); Gerstenfeld et al. (2012); Soria et al.
MENDOZA	12.01	9.13	Elia Dazat (2017); CIMA (2020)
SALTA	9.26	5.01	Concha et al. (1998, 2010); Hudson-Edwards et al. (2012); Boujon (2021); CIMA 2020
FORMOSA	8.97	3.99	CIMA (2020)
RÍO NEGRO	8.46	2.77	Grismado. (2012); Garrido (2017); CIMA (2020)
SAN JUAN	4.95	4.95	CIMA (2020) O'Reilly et al. (2010)
MISIONES	2.51	0.84	CIMA (2020)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

LA RIOJA	1.66	0.21	Miguel et al. (2017); Nieves et al. (2013); CIMA
CHUBUT	0.35	0.27	Nieves et al. (2013)
CABA	0	0	CIMA (2020)

Fig. 2. Map of the population exposed to high arsenic levels in provinces with high representativeness. Argentina.



Source: elaborated with own data

NEW MAP OF ARGENTINE POPULATION EXPOSED TO ARSENIC IN DRINKING WATER

ARSENIC POPULATION MAP AND ARGENTNE

Leandro Duarte ¹, Laura De Gracia¹, Sergio Montico¹, Alejandro Oliva ^{1*}

^{1*} Centro de Estudios Interdisciplinarios (CEI), Universidad Nacional de Rosario (UNR). Maipú 1065, Of. 309, (2000) Rosario, Argentina aoliva.promas@gmail.com

ABSTRACT

This study aims to evaluate the population exposed to arsenic in Argentina, proposing a key risk indicator. By employing specific criteria selection, systematic search of the published evidence on arsenic content in drinking water samples at provincial level was carried out. Considering the limit recommended by the WHO -10µg/L - representativeness of evidence was calculated, as well as the percentage of exposed population to high levels of arsenic.

For this research, sixty-one useful publications were found and included in the analysis. They provide relevant data for 50% of the provinces, which represents 70% of the national population.

The use of an index, “percentage of population exposed” to high arsenic, is proposed as a summary variable, to homogenize the information in the country. and in this way give it comparative value. Information has been systematized and variables identified that may be useful for analysis in eco-epidemiological studies, detailing the current situation of publications of arsenic in drinking water in Argentina.

Keywords: Argentina - Arsenic - Map - Water -

HIGHLIGHTS

- Half of the provinces provide representative information on populations exposed to high levels of arsenic.

- 29
- The percentage of exposed populations is highly variable, from 0 to almost 100%.
- 30
- 31
- The use of the PEP index, “percentage of exposed population” to elevated arsenic levels, is proposed as a summary variable.
- 32
- A map showing different regional situations is drawn, half of the Argentine provinces, two thirds of the total population.
- 33
- 34

35 **GRAPHICAL ABSTRACT**



INTRODUCTION

Arsenic (As) is a ubiquitous element, widely distributed throughout the environment. It can be found in the air, water and land, and is one of the ten chemicals considered by the World Health Organization as major public health concern (WHO, 2022). The largest amounts of As in the environment come from natural sources (weathering, biological activity, volcanic emissions). However, anthropogenic activities – industrial processes like mining, metal smelting, pesticides usage, wood preservatives, etc. – also play their part (Litter, 2018). Surface and underground water natural resources are affected by the geochemical cycle of arsenic due to many reasons: interactions of the aquatic environment with rocks, sediments and soils; emissions from volcanic and geothermal sources; erosion and leaching of geological formations; and mining waste that produce high concentrations of this element in the environment (RSA, 2018).

Humans can be exposed to arsenic in different ways: by consuming contaminated food or water; using them in meal preparation, crops irrigation or industrial processing, and it can also be inhaled. Prolonged exposure to inorganic arsenic – through any of these ways – can cause acute and chronic poisoning, from skin lesions to neoplasm.

It has been documented worldwide that millions of people are affected by being exposed to drinking water with high levels of arsenic. Among the largest and most populated areas involved, in Asia, for example, the populations most at risk are: the Gulf of Bengal, in Bangladesh (Rahman et al., 2001); Northeast India (Bhattacharyya et al., 2003); Inner Mongolia in China (Guo et al., 2001); and Taiwan and Vietnam (Smedley et al., 2003). In North and Central America, the west of the United States (BEST, 2001) and Mexico (Rodriguez et al., 2004); and in South America, Argentina, Chile, Bolivia and Peru (Bundschuh et al., 2012).

74 Arsenicism is an endemic disease. This is especially true in Argentina, where the
75 population exposed to high levels of arsenic (> 50 µg/L) has been calculated in about
76 1 million; moreover, its accepted level places the country among the most affected
77 ones within Latin America (Litter et al., 2019). Chronic Endemic Regional
78 Hydroarsenicism (HACRE, acronym in spanish) characterized due to skin lesions
79 and systemic cancerous and non-cancerous alterations resulting from exposure to
80 low levels for prolonged periods., which has been known in Argentina since 1913,
81 (Ministerio de Salud, Argentina, 2006). The situation has worsened considering the
82 long-term and chronic impact on human health, also due to population growth and
83 the length of exposure times without intervention.

84 A recent piece of research carried out in the Central Region of Argentina has
85 compared arsenic genotoxicity in two groups of population -using studies in
86 groundwater- one exposed to high levels, which showed 60 ug/L as an average of
87 the total samples, and one not exposed at all (Quiroga, 2023). Exposure has an
88 impact on chronic diseases, from congenital malformations to neurodegenerative
89 diseases, and cancer. Arsenic was classified by the WHO's International Agency for
90 Research on Cancer (IARC) as carcinogenic to humans (Rousseau et al, 2005).

91 Early childhood exposures (including intrauterine) are a period deserves special
92 attention. As regards certain cancers, a study carried out in Chile exploring early life
93 exposure and adulthood risks showed a clear association of these two variables. It
94 was thus possible to differentiate the risks of intrauterine and early childhood
95 exposures in periods of high and low exposure (Smith et al., 2006). The literature
96 review confirms this situation as the longest risk period (Young et al., 2018; Martinez
97 et al., 2021).

98 In its Guidelines for Drinking-water Quality, the WHO established a limit value for
99 arsenic in water. It aims to serve as a world basis for regulatory and standardization
100 tasks in this regard. The recommended limit in drinking water is 10 µg/L (WHO,
101

101 2017). The Argentine Food Code [CAA by its Spanish acronym] establishes a higher
102 safety limit, 50 µg/L (MSA-ANMAT, 2005). However, levels well above this limit have
103 already been reached in the country, even exceeding 200 µg/L (Nicolli et al., 1989).
104 Much of the scientific evidence has shown that between the limits of the WHO and
105 the CAA, there is a significant risk to human health.

106 Despite what has been stated so far, the real proportion of the population exposed
107 to high arsenic level in the country is still unknown. The information available on
108 arsenic content in drinking water is scattered and not updated. Therefore, the
109 objective of this analysis is to carry out a systematic review to collect the published
110 information and evaluate its connection with the exposed population.

112 **METHODOLOGY**

113 *Bibliographic Review*

114 The following open-access databases were analyzed to carry out a systematic
115 search of the available evidence: PUBMED, Google Scholar, Latin American and
116 Caribbean Health Sciences Literature (LILACS) and the National System of Digital
117 Repositories [SNRD by its Spanish acronym] (Argentina). The terms "*arsenic AND*
118 *water consumption AND Argentina*"; "*arsenic AND water AND Argentina*" were used,
119 and the Spanish ones, "*arsénico Y agua de consumo Y provincia Y argentina*".

120 The selection criteria to include the articles were the following: 1) if the number of
121 evaluated population was available; 2) if it expressed the number of water samples
122 assessed; 3) if it expressed the As value in absolute terms; and 4) if the analyzed
123 water was for human consumption. All these conditions were considered for each
124 province.

126

Variables Construction

127₁
127₂

After selecting valid bibliography, the following items were classified and calculated

128₁
128₂

by provinces:

129₁
129₂

(1) percentage of total population per province. It was calculated following the

130₁
130₂

National Institute of Statistics and Census (INDEC, 2010) taking into account the total

131₁
131₂

population assessed. This allowed to know the "**representativeness**" of the samples

132₁
132₂

for each province, which means the percentage of the total population of the province

133₁
133₂

represented in the referenced specific studies. A limit of 30% was established, since

134₁
134₂

it is representative of a population exposure analysis, considering that the captured

135₁
135₂

samples are covering above a third of the provincial inhabitants.

136₁
136₂

(2) considering the number of samples above the WHO value (10 µg/L), the

137₁
137₂

percentage of samples with high levels of arsenic was calculated and this was

138₁
138₂

applied to the total population evaluated., obtaining thus its **exposure index**.

139₁
139₂

(3) the exposure index was applied to the total provincial population, which allowed

140₁
140₂

to obtain the so-called **Percentage of Exposed Population** (PEP) per province.

141₁
141₂

Through these calculations, two variables were obtained for each province: a)

142₁
142₂

"representativeness" of the samples obtained over the total population; and, b) the

143₁
143₂

population "exposure" variable, or PEP. If the sample captured is representative, the

144₁
144₂

exposure percentage can be projected to the rest of the population and interpreted

145₁
145₂

as a provincial index.

146₁
146₂

REPRESENTATIVENESS	x	POPULATION EXPOSURE INDEX	=	% EXPOSED POPULATION
(>30%)		(% of samples >10 ug/L)		PEP

147₁
147₂

148₁
148₂

149₁
149₂

150₁
150₂

150

151 RESULTS

152 Bibliographic Review

153 As can be seen in the systematic literature review (Figure 1), 569 publications were
154 found. After applying the duplicates or non-relevant by title or summary filter, 315
155 publications remained suitable to be analyzed according to the selection criteria
156 detailed in the Methodology. Then, another 254 articles were excluded -following
157 exclusion criteria- in this process, resulting in 61 final publications useful for this
158 research. Relevant information was found for 50% of the Argentine provinces, which
159 represents 70% of the total population nationwide; this is twelve provinces and
160 represents approximately thirty-two million inhabitants.

161 Representativeness and percentages of exposed population

162 When analyzing provincial representativeness, the population under study presented
163 a considerable heterogeneity: ranging from 0.35% (the lowest, in Chubut province)
164 to 99% (the highest, in Santa Fe province). An arbitrary limit of 30% was established,
165 which made it possible to obtain two groups: high and low representativeness.

166 In relation to the Percentage of Exposed Population (PEP), the highest exposure
167 (Table 1) was found in La Pampa (87.98%), followed by Catamarca (78.90%) and
168 Buenos Aires provinces (68.55%). In relation to the provinces with low
169 representativeness (Table 2), the PEP is significantly low, between 0 and 10%.
170 However, due to the fact that the sampling is small, the data identified is not precise.
171 The distribution of the provinces according to the PEP is presented in a graphic
172 (Figure 2). Of a total population of approximately 32 million inhabitants, 55% (around
173 17 million) is exposed to arsenic levels greater than 10 µg/L in drinking water.

174
175
176
177

177

DISCUSSION

178

This work contributes in highlighting both the existing and missing information about the situation of a large proportion of Argentina's population in the face of arsenical water consumption. The map presented here allows to identify, in the first instance, the provinces that have useful data and those that do not. And, secondly, the differences in their levels of exposure.

179

180

181

182

183

184

185

186

187

188

189

190

191

192

193

194

195

196

197

198

199

200

201

202

203

204

205

206

207

208

209

210

211

212

213

214

215

216

217

218

219

220

221

222

The wide variability of information observed in this work is mainly due to the particular or regional epidemiological alert, which leads local researchers to delve into the subject. It can be therefore deduced that, in provinces with fewer perceived risks of exposure to arsenic, publications are fewer than in those that have historically been associated with this environmental toxicant.

Although "exposed population" is a key -and original- concept in this analysis, an extensive use of this term was not found. Most of the analyzed articles that had to be discarded detail the analytical determinations of water samples and collection sites. However, they do not describe the population under analysis, which is fundamental to assess the true sanitary impact of arsenic contamination in drinking water. Conversely, the number of samples is not a correct parameter to determine the scope of the analysis, nor the level reached by the assessment above the cutoff applied. Undoubtedly, when a region presents epidemiological alarms related to chronic non-communicable diseases related to arsenical contamination in drinking water, it is necessary to evaluate the precise levels of this element in representative samples of the population.

Argentina has empirically known for more than a century that its drinking water contains high levels of As because there are endemic diseases associated to this element. However, the country does not possess unified and precise information to identify its true sanitary risk. There have been two attempts to draft a "map" of this situation but they have shown varied limitations, especially because they referred to isolated values that did not specify the population involved (Ministerio de Salud

205 Argentina, 2006) or else showed a general distribution of the population in graphics
206 but did not specify As consumption (Litter et al., 2019). Preliminary information –using
207 a limit value of 50 µg/L – mentions a total exposed population of 1 million inhabitants
208 (Ministerio de Salud Argentina, 2006). The present analysis, however, employing the
209 WHO limit (10 µg/L) finds an approximate total of 17 million, much more than the
210 previous one.

211 The accumulation of evidence on chronic toxicological effects of arsenic ingestion
212 through drinking water has led to a progressive reduction in the threshold limit of
213 arsenic concentrations in water intended for human consumption (Smedley et al.,
214 2002). In Argentina and Chile, this threshold is 50 ug/L (MSA-ANMAT, 2005; Diario
215 Oficial de la República de Chile, 1984). This level is intended to be reduced to 10
216 µg/L, as set by the European Union (European Union, 1998), recommended by the
217 World Health Organization (WHO, 2004), and proposed since January 2006 by the
218 United States Environmental Agency as a "Maximum Contaminant Level Goal"
219 (MCLG) (USEPA, 2005). According to these standards, the economic implications of
220 ensuring that water has an acceptable arsenic concentration has opened an
221 important debate on the level to be set, both in large areas of developed and
222 developing countries (Smith & Smith, 2004). The existing literature confirms that the
223 levels of arsenic in drinking water recommended by the WHO in relation to chronic
224 non-communicable diseases are those that have been shown to be associated with
225 this lower threshold (Rehman et al., 2018; Ferragut Cardoso & Udoh, 2020;
226 Jaafarzadeh et al., 2022).

227 Although arsenic contamination has been exhaustively and long studied as acute
228 poisoning (Campbell & Alvarez, 1989), pathologies related to deferred impacts over
229 time, such as cancer, were little addressed in the country as specific associated
230 issues. However, recent analyses have demonstrated their link in Argentina (Duarte
231 et al., 2022). It is, therefore, necessary to update the information on arsenic in
232 drinking water in this country. In other countries such as the USA, approximation

models on As levels in drinking water have been built at national level, which have made possible to define high and low risk areas (Ayotte et al., 2017). Likewise, Bangladesh has carried out a review of related publications that made possible to determine an (approximate) total exposed population (Karim, 2000). Other countries, including higher-risk countries, only have partial information available.

The methodology employed in this analysis presents some bias: 1) possible duplications of the exposed populations in few provinces, given that some studies overlap in their territories without mentioning the specific places of collection; 2) there is a bias inherent to the publications, which is related to sampling, especially in well water, with the distribution of populations in relation to sources of consumption unknown; 3) the concept of exposed population is not included in publications related to arsenic with the PEP variable, proposed in this work, being an indirect calculation.; 4) the temporality of the water evaluations is dissimilar; in any case, arsenic has been described as a stable toxicant in the environment -with little variability- given the fundamentally natural contamination, unless interventions have been carried out to eliminate this element; a scarce, partial or non-existent issue in Argentina.

CONCLUSIONS

This review adds value to the already published evidence, systematizing information and identifying variables that may be useful for ecoepidemiological studies to analyze both humans and fauna. An index is proposed, the "percentage of exposed population" (PEP) to high arsenic levels as a summary variable, to homogenize the information in the country, giving it thus a comparative value. It has also been validated in a previous work, related to cancer mortality at provinces' departmental level in the central region of Argentina (Duarte et al, 2022).

Territorial interventions in health management, especially in sensitive issues such as population's consumption of arsenical water, require orderly, organized and

260 coordinated information to guide actions to provide tools and introduce public policies
261 that benefit inhabitants' life.

262 Finally, this work allows to identify -indirectly- the areas of high exposure, as a guide
263 to deepen future field investigations that permit to give certainty -or not- to these
264 findings.

265 REFERENCES

266 **Ayotte** JD, Medalie L, Qi SL, Backer LC, Nolan BT (2017). Estimating the High-
267 Arsenic Domestic Well Population in the Conterminous United States. *Environ Sci*
268 *Technol.* Nov 7;51(21):12443-12454. doi: 10.1021/acs.est.7b02881.

269 **BEST** (Board on Environmental Studies and Toxicology) (2001) Arsenic in drinking
270 water: 2001 update. National Academy Press, Washington D.C., 225 pp. Retrieved
271 from: <https://nap.nationalacademies.org/read/10194/chapter/1>

272 **Bhattacharyya** R, Chatterjee D, Nath B, Jana J, Jacks G, Vahter M (2003). High
273 arsenic groundwater mobilization, metabolism and mitigation -an overview in the
274 Bengal Delta Plain. *Mol Cell Biochem.* Nov;253(1-2):347-55. doi:
275 10.1023/a:1026001024578. PMID: 14619986.

276 **Bundschuh**, J., Litter, M. I., Parvez, F., Román-Ross, G., Nicolli, H. B., Jean, J. S.,
277 ... et al. (2012). One century of arsenic exposure in Latin America: A review of history
278 and occurrence from 14 countries. *Science of the total Environment*, 429, 2-35.

279 **Buti**, C. I., Cancino, F., Ferullo, S., & Gamundi, C. (2015). Diversidad y evaluación
280 toxicológica de peces como indicadores de contaminación por mercurio, plomo,
281 cadmio, cobre y arsénico, provincia de Tucumán, República Argentina. [Diversity and
282 toxicological assessment of fishes as contaminant indicators by mercury, lead,
283 cadmium, cooper and arsenic, Tucumán province, Argentina]. Retrieved from:
284 <https://ri.conicet.gov.ar/handle/11336/13035>

285 **Campbell** JP, Alvarez JA (1989). Acute arsenic intoxication. *Am Fam Physician.*
286 Dec; 40(6):93-7. PMID: 2686377.

288 **Diario Oficial de la República de Chile** (1984). Norma Chilena Oficial N°409/1 Of.
289 N°84. Agua potable. Parte I: Requisitos. Aprobada por el Ministerio de Salud
290 mediante Decreto Supremo N°11 del 16/01/1984 [Official Chilean Norm No. 409/1
291 Of. No.84. Drinking water. Part I: Requisites. Approved by the Ministry of Health by
292 Supreme Decree No. 11 on 01/16/1984]. Published on 03/03/1984. Retrieved from:
293 [https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-](https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-del-agua-potable-eeo-1.pdf)
294 [del-agua-potable-eeo-1.pdf](https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-del-agua-potable-eeo-1.pdf)
295 **Duarte** LE, Delgado F, Di Leo NC, Bertone CL, Franci Alvarez M, Montico S, et al.
296 (2022). Mortalidad por cáncer, arsénico y nitratos en aguas de consumo y superficies
297 sembradas en Argentina [Mortality from cancer, arsenic, and nitrates in drinking
298 water and cropland in Argentina. Mortalidade por câncer, arsênio e nitratos na água
299 para consumo humano e em áreas semeadas na Argentina]. *Rev Panam Salud*
300 *Publica*. Aug 30; 46:e129. Spanish. doi: 10.26633/RPSP.2022.129.
301 **European Union** (1998). Directive 98/83/EC relating to human drinking water quality,
302 Official Journal of European Communities L330. Retrieved from: [https://eur-](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-20151027&from=EN)
303 [lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-20151027&from=EN)
304 [20151027&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-20151027&from=EN)
305 **Ferragut Cardoso** AP, Udoh KT, States JC (2020). Arsenic-induced changes in
306 miRNA expression in cancer and other diseases. *Toxicol Appl Pharmacol*. Dec 15;
307 409:115306. doi: 10.1016/j.taap.2020.115306.
308 **Guo** X, Fujino Y, Kaneko S, Wu K, Xia Y, Yoshimura T (2001). Arsenic contamination
309 of groundwater and prevalence of arsenical dermatosis in the Hetao plain area, Inner
310 Mongolia, China. *Mol Cell Biochem*. Jun;222(1-2):137-40. PMID: 11678595.
311 **INDEC** (National Institute of Statistics and Census Argentina). 2010 Census.
312 Retrieved from: <https://www.indec.gob.ar/indec/web/Nivel4-Tema-2-41-135>
313 **Jaafarzadeh** N, Poormohammadi A, Almasi H, Ghaedrahmat Z, Rahim F, Zahedi A
314 (2022). Arsenic in drinking water and kidney cancer: a systematic review. *Rev*
315 *Environ Health*. Mar 15; 38(2):255-263. doi: 10.1515/reveh-2021-0168.

316 **Litter M.** (2018). Arsénico en agua. Programa FUTUROS Escuela de Posgrado:
317 Agua + Humedales [Arsenic in water. FUTUROS Program. Postgraduate School].
318 UNSAM Edita, p .210-224. Retrieved from:
319 <https://ri.unsam.edu.ar/bitstream/123456789/911/1/PFAH%202018%20CLM.pdf>
320 **Litter MI, Ingallinella AM, Olmos V, Savio M, Difeo G, Botto L, et al.** (2019). Arsenic
321 in Argentina: Occurrence, human health, legislation and determination. *Sci Total*
322 *Environ.* Aug 1; 676:756-766. doi: 10.1016/j.scitotenv.2019.04.262.
323
324 **Karim, M. M.** (2000). Arsenic in groundwater and health problems in Bangladesh.
325 *Water Research*, 34(1), 304-310. Retrieved from:
326 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>
327
328 **Martinez VD, Lam WL** (2021). Health Effects Associated With Pre- and Perinatal
329 Exposure to Arsenic. *Front Genet.* Sep 29; 12:664717. doi:
330 10.3389/fgene.2021.664717.
331
332 **Ministerio de Salud Argentina** [Ministry of Health of Argentina] (2006).
333 Epidemiología del HACRE en la República Argentina, Estudio Colaborativo
334 Multicéntrico [Epidemiology of HACRE in Argentina. Collaborative Multicenter Study].
335 Retrieved from:
336 [https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en](https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en_argentina.pdf)
337 [argentina.pdf](https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en_argentina.pdf)
338
339 **MSA-ANMAT** [Ministry of Health – National Administration of Drugs, Food and
340 Medical Technology], (2005). Código Alimentario Argentino-Capítulo XII – Bebidas
341 Hidricas, Agua y Agua Gasificada - Agua Potable - Artículo 982 [Argentine Food
342 Code. Chapt. XII: Hydration beverages, water and gas water. Article 982]- (MSyAs
343 Res. N° 494 on 07/07/94). Retrieved from:
344 <https://www.argentina.gob.ar/anmat/codigoalimentario>
345
346 **Nicolli H, Suriano J, Gomez Peral M, Ferpozzi L & Baleani O** (1989). Groundwater
347 Contamination with Arsenic and other Trace Elements in an Area of the Pampa,
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365

343 Province of Cordoba, Argentina. *Environmental Geology and Water Science* 14 3–

344 16. Retrieved from: <https://link.springer.com/article/10.1007/BF01740581>

345 **Organización Mundial de la Salud** (2017). Guías para la calidad del agua de
346 consumo humano [Guidelines for drinking-water quality]. Retrieved from:

347 <https://www.who.int/es/publications/i/item/9789241549950>

348 **Quiroga, AM.** (2021). Evaluación de daño oxidativo y genotóxico y su relación con
349 variables nutricionales en poblaciones expuestas a Arsénico en agua de bebida de
350 la zona centro-norte de la provincia de Santa Fe, Argentina. [Assessment of the

351 oxidative and genotoxic damage and its relationship with nutritional variables in
352 populations exposed to arsenic in drinking water from the central-north area of Santa
353 Fe province, Argentina] Revised: January 3, 2023. Retrieved from:

354 <https://bibliotecavirtual.unl.edu.ar:8443/handle/11185/6250>

355 **Rahman MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D, et al.**
356 (2001). Chronic arsenic toxicity in Bangladesh and West Bengal, India – a review
357 and commentary. *J Toxicol Clin Toxicol.*;39(7):683-700. doi: 10.1081/clt-100108509.

358 **Rehman K, Fatima F, Waheed I, Akash MSH.** (2018). Prevalence of exposure of
359 heavy metals and their impact on health consequences. *J Cell Biochem.*
360 Jan;119(1):157-184. doi: 10.1002/jcb.26234.

361 **Rodriguez R., Ramos J.A., Armienta A.** (2004). Groundwater arsenic variations: the
362 role of local geology and rainfall. *Appl. Geochem.*, 19(2), 245-250. Retrieved from:
363 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

364 **Rousseau, M. C., Straif, K., & Siemiatycki, J.** (2005). IARC carcinogen
365 update. *Environmental Health Perspectives*, 113(9), A580-A581.

366 **RSA Conicet. Grupo AD HOC. Arsénico en agua [Arsenic in water]. - FINAL**
367 **REPORT - Jul 31, 2018.** Retrieved from: [https://rsa.conicet.gov.ar/wp-](https://rsa.conicet.gov.ar/wp-content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf)
368 [content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf](https://rsa.conicet.gov.ar/wp-content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf)

369 **Smedley, P. L., & Kinniburgh, D. G.** (2002). A review of the source, behaviour and
370 distribution of arsenic in natural waters. *Applied geochemistry*, 17(5), 517-568.

371 Retrieved from:

372 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

373 **Smedley P.L., Zhang M., Zhang G., Luo Z. (2003).** Mobilisation of arsenic and other
374 trace elements in fluviolacustrine aquifers of the Huhhot Basin, Inner Mongolia. *Appl.*
375 *Geochem.*, 18(9), 1453-1477. Retrieved from:

376 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

377 **Smith AH, Smith MM. (2004).** Arsenic drinking water regulations in developing
378 countries with extensive exposure. *Toxicology*. May 20;198(1-3):39-44. doi:
379 10.1016/j.tox.2004.02.024. PMID: 15138028.

380 **Smith AH, Marshall G, Yuan Y, Ferreccio C, Liaw J, von Ehrenstein O, Steinmaus**
381 **C, Bates MN, Selvin S. (2006).** Increased mortality from lung cancer and
382 bronchiectasis in young adults after exposure to arsenic in utero and in early
383 childhood. *Environ Health Perspect*. Aug;114(8):1293-6. doi: 10.1289/ehp.8832.

384 **USEPA (2005).** List of Drinking Water Contaminants & MCLs, February 23rd, 2005.
385 Retrieved from: [https://www.epa.gov/sites/default/files/2015-](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf)
386 [10/documents/ace3_drinking_water.pdf](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf) on 01/06/23.

387 **WORLD HEALTH ORGANIZATION, INTERNATIONAL AGENCY FOR**

388 **RESEARCH ON CANCER (IARC) (2004).** Some Drinking-Water Disinfectants and
389 Contaminants, including Arsenic. Monographs on the Evaluation of Carcinogenic
390 Risks to Humans. Volume 84. Retrieved from: <https://publications.iarc.fr/102>

391 **WHO (2004).** Guidelines for drinking-water quality Fourth edition incorporating the
392 first and second addenda. ISBN 978-92-4-004506-4 (electronic version). Retrieved
393 from: <https://www.who.int/publications/i/item/9789240045064>

394 **Young JL, Cai L, States JC. (2018).** Impact of prenatal arsenic exposure on chronic
395 adult diseases. *Syst Biol Reprod Med*. Dec;64(6):469-483. doi:
396 10.1080/19396368.2018.1480076.

397

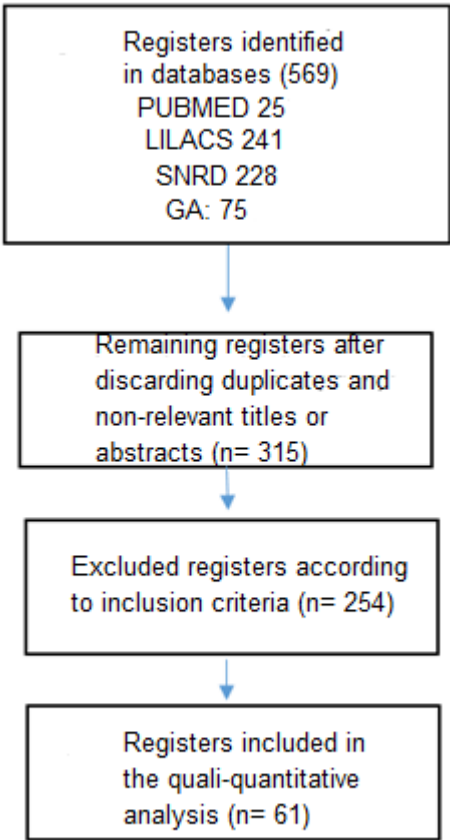
398

399

400

399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414

Figure 1. Systematic Review Flowchart



417 **Table 1. High representativeness and exposure levels to arsenic by province**

PROVINCES	Percentage of population under study (%)	Percentage of Population exposed (PEP) to high levels of As	Bibliography
	REPRESENTATIVENESS	EXPOSITION	
SANTA FE	99	60.08	ENRES (2019)
LA PAMPA	95.75	87.98 %	Pariani et al., (2014); Vercellino. (2020); O'Reilly et al. (2020)
NEUQUÉN	88.98	0	Center for Environmental Engineering (CIMA), ITBA (2020); Velazquez (2019)
CATAMARCA	86.64	78.9	Rugierri et al. (2009); Saracho et al. (2016); Saracho et al. (2019); Graziano et al. (2013); CIMA (2020); Vilches et al. (2005).
BUENOS AIRES	77.6	68.55	Navoni et al. (2012); RSA CONICET (2018); Galindo et al. (2005).
CORRIENTES	57.17	11.4	CIMA (2020)
CHACO	75.43	53.51	Roshdestwensky et al. (2016); Martínez et al. (2014); Trinelli et al. (2018); Concha et al. (1998); Osicka et al. (2002); CIMA (2020); Buchamer et al. (2012); Blanes et al. (2011)
CÓRDOBA	70.6	29.09	Villalba et al. (2000); Blarasin et al. (2015); Penedo and Zigarán (1998)
ENTRE RÍOS	61.64	28.02	UNER (2019); CIMA (2020)
TIERRA DEL FUEGO	44	0	CIMA (2020)
JUJUY	34.2	22.27	López Steinmetz et al (2018); CIMA (2020); Murray et al. (2019); Ruggeri et al. (2009)

SANTIAGO DEL ESTERO	32.84	26,36	Bhattacharya et al. (2006); Revelli et al. (2016); Vidoni et al. (2010); Bejarano Sifuentes and Nordberg. (2003); Bundschuh et al. (2004); Calatayud et al. (2019); Navoni et al. (2014); CIMA (2020); Litter et al. (2015)
--------------------------------	-------	-------	---

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

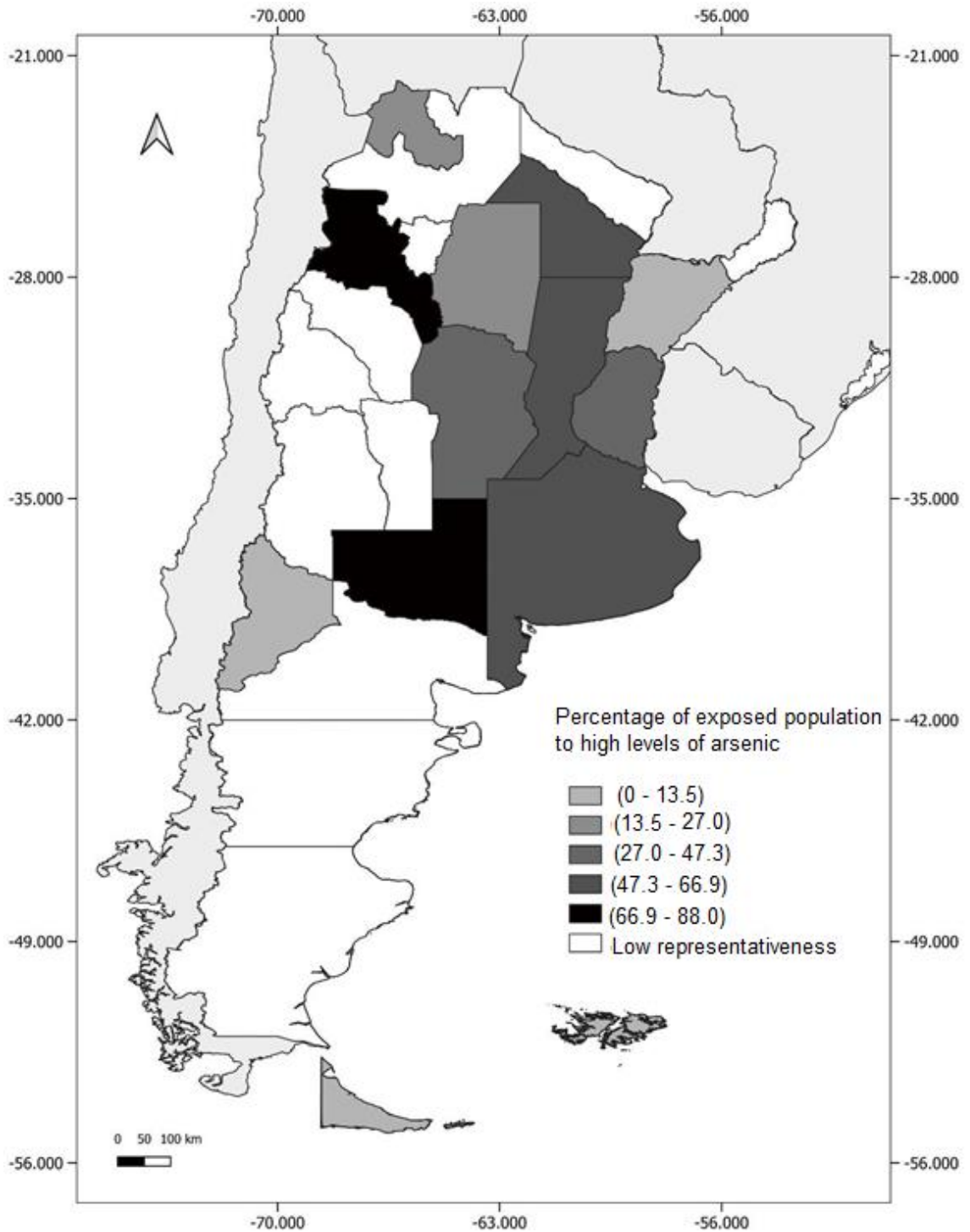
Table 2. Low representativeness and exposition levels to arsenic by province

PROVINCE	Percentage of Population under study (%)	Percentage of exposed population (PEP) (%)	Bibliography
	REPRESENTATIVENESS	EXPOSITION	
SANTA CRUZ	26.79	0	CIMA (2020)
SAN LUIS	20	0	CIMA (2020)
TUCUMÁN	14.11	10.51	Soria de González et al. (2008-2011); Guber et al. (2009); Nicolli et al. (2012); CIMA (2020); Gerstenfeld et al. (2012); Soria et al.
MENDOZA	12.01	9.13	Elia Dazat (2017); CIMA (2020)
SALTA	9.26	5.01	Concha et al. (1998, 2010); Hudson-Edwards et al. (2012); Boujon (2021); CIMA 2020
FORMOSA	8.97	3.99	CIMA (2020)
RÍO NEGRO	8.46	2.77	Grismado. (2012); Garrido (2017); CIMA (2020)
SAN JUAN	4.95	4.95	CIMA (2020) O'Reilly et al. (2010)
MISIONES	2.51	0.84	CIMA (2020)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

LA RIOJA	1.66	0.21	Miguel et al. (2017); Nieves et al. (2013); CIMA
CHUBUT	0.35	0.27	Nieves et al. (2013)
CABA	0	0	CIMA (2020)

Fig. 2. Map of the population exposed to high arsenic levels in provinces with high representativeness. Argentina.



Source: elaborated with own data

NEW MAP OF ARGENTINE POPULATION EXPOSED TO ARSENIC IN DRINKING WATER

ARSENIC POPULATION MAP AND ARGENTNE

Leandro Duarte ¹, Laura De Gracia¹, Sergio Montico¹, Alejandro Oliva ^{1*}

^{1*} Centro de Estudios Interdisciplinarios (CEI), Universidad Nacional de Rosario (UNR). Maipú 1065, Of. 309, (2000) Rosario, Argentina aoliva.promas@gmail.com

ABSTRACT

This study aims to evaluate the population exposed to arsenic in Argentina, proposing a key risk indicator. By employing specific criteria selection, systematic search of the published evidence on arsenic content in drinking water samples at provincial level was carried out. Considering the limit recommended by the WHO -10µg/L - representativeness of evidence was calculated, as well as the percentage of exposed population to high levels of arsenic.

For this research, sixty-one useful publications were found and included in the analysis. They provide relevant data for 50% of the provinces, which represents 70% of the national population.

The use of an index, “percentage of population exposed” to high arsenic, is proposed as a summary variable, to homogenize the information in **the country and, in this way,** give it comparative value. Information has been systematized and variables identified that may be useful for analysis in eco-epidemiological studies, detailing the current situation of publications of arsenic in drinking water in Argentina.

Keywords: Argentina - Arsenic - Map - Water -

HIGHLIGHTS

- Half of the provinces provide representative information on populations exposed to high levels of arsenic.

- 29
- The percentage of exposed populations is highly variable, from 0 to almost 100%.
- 30
1
2
- The use of the PEP index, “percentage of exposed population” to elevated arsenic levels, is proposed as a summary variable.
- 31
3
4
- A map showing different regional situations is drawn –half of the Argentine provinces–two thirds of the total population.
- 32
5
6
7
33
8
9
10
34
11
12

13
35 **GRAPHICAL ABSTRACT**
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28



36
50
37
51
52
53
54
38
55
56
39
57
58
59
40
60
61
41
62
63
64
42
65

INTRODUCTION

Arsenic (As) is a ubiquitous element, widely distributed throughout the environment. It can be found in the air, water and land, and is one of the ten chemicals considered by the World Health Organization as major public health concern (WHO, 2022). The largest amounts of As in the environment come from natural sources (weathering, biological activity, volcanic emissions). However, anthropogenic activities – industrial processes like mining, metal smelting, pesticides usage, wood preservatives, etc. – also play their part (Litter, 2018). Surface and underground water natural resources are affected by the geochemical cycle of arsenic due to many reasons: interactions of the aquatic environment with rocks, sediments and soils; emissions from volcanic and geothermal sources; erosion and leaching of geological formations; and mining waste that produce high concentrations of this element in the environment (RSA, 2018).

Humans can be exposed to arsenic in different ways: by consuming contaminated food or water; using them in meal preparation, crops irrigation or industrial processing, and it can also be inhaled. Prolonged exposure to inorganic arsenic – through any of these ways – can cause acute and chronic poisoning, from skin lesions to neoplasm (Kapaj S et al, 2006).

Arsenicism is an endemic disease. This is especially true in Argentina, where the population exposed to high levels of arsenic (> 50 µg/L) has been calculated in about 4 million; moreover, its accepted level places the country among the most affected ones within Latin America (Litter et al., 2019). Chronic Endemic Regional Hydroarsenicism (HACRE, acronym in spanish) characterized due to skin lesions and systemic cancerous and non-cancerous alterations resulting from exposure to low levels for prolonged periods, which has been known in Argentina since 1913, ranks second after the USA in the world's most affected countries (Ministerio de

70 Salud, Argentina, 2006). The situation has worsened considering the long-term and
71 chronic impact on human health. A recent piece of research carried out in the Central
72 Region of Argentina has compared arsenic genotoxicity in two groups of population,
73 one exposed to high levels and one not exposed at all, **showing damage oxidative
74 and genotoxic at high levels** (Quiroga, 2023). Exposure has an impact on chronic
75 diseases, from congenital malformations to neurodegenerative diseases, and
76 cancer. Arsenic was classified by the WHO's International Agency for Research on
77 Cancer (IARC) as carcinogenic to humans (Rousseau et al, 2005).

78 Perinatal exposure deserves special attention, both intrauterine and during the first
79 years of life. As regards certain cancers, a study carried out in Chile exploring early
80 life exposure and adulthood risks showed a clear association of these two variables,
81 **suggest that exposure to arsenic in drinking water during early childhood or in utero
82 has pronounced pulmonary effects, greatly increasing subsequent mortality in young
83 adults from both malignant and nonmalignant lung disease** (Smith et al., 2006). The
84 literature review confirms this situation as the longest risk period (Young et al., 2018;
85 Martinez et al., 2021).

86 In its Guidelines for Drinking-water Quality, the WHO established a limit value for
87 arsenic in water. It aims to serve as a world basis for regulatory and standardization
88 tasks in this regard. The recommended limit in drinking water is 10 µg/L (WHO,
89 2017). The Argentine Food Code [CAA by its Spanish acronym] establishes a higher
90 safety limit, 50 µg/L (MSA-ANMAT, 2005). However, levels well above this limit have
91 already been reached in the country, even exceeding 200 µg/L (Nicolli et al., 1989).
92 Much of the scientific evidence has shown that between the limits of the WHO and
93 the CAA, there is a significant risk to human health.

94 Despite what has been stated so far, the real proportion of the population exposed
95 to high arsenic level in the country is still unknown. The information available on
96 arsenic content in drinking water is scattered and not updated. Therefore, the

97 objective of this analysis is to carry out a systematic review to collect the published
98 information and evaluate its connection with the exposed population.

99 **METHODOLOGY**

100 *Bibliographic Review*

101 The following open-access databases were analyzed to carry out a systematic
102 search of the available evidence: PUBMED, Google Scholar, Latin American and
103 Caribbean Health Sciences Literature (LILACS) and the National System of Digital
104 Repositories [SNRD by its Spanish acronym] (Argentina). The terms "*arsenic AND*
105 *water consumption AND Argentina*"; "*arsenic AND water AND Argentina*" were used,
106 and the Spanish ones, "*arsénico Y agua de consumo Y provincia Y argentina*".

107 The selection criteria to include the articles were the following: 1) if the number of
108 **drinking water samples** evaluated population was available; 2) if it expressed the
109 number of water samples assessed; 3) if it expressed the As value in absolute terms;
110 and 4) if the analyzed water was for human consumption. All these conditions were
111 considered for each province, **consider the PRISMA guidelines (Page et al, 2021)**.

112 **Variables Construction**

113 After selecting valid bibliography, the following items were classified and calculated
114 by provinces:

115 (1) percentage of total population per province. It was calculated following the
116 National Institute of Statistics and Census (INDEC, 2010) taking into account the total
117 population assessed, **expressed by the quotient between the total population**
118 **evaluated (sum of the total bibliography) over the total provincial population**. This
119 allowed to know the "**representativeness**" of the samples for each province, which
120 means the percentage of the total population of the province represented in the
121 referenced specific studies. A limit of 30% was established to define this variable as

high or low, decided on the basis that -approximately- one in three inhabitants were considered within the population under study.

(2) considering the number of samples above the WHO value (10 µg/L), the percentage of samples with high levels of arsenic was calculated and this was applied to the total population **evaluated, obtaining** thus its **exposure index**.

(3) the exposure index was applied to the total provincial population, which allowed to obtain the so-called **Percentage of Exposed Population** (PEP) per province.

Through these calculations, two variables were obtained for each province: a) "representativeness" of the samples obtained over the total population; and, b) the population "exposure" variable, or PEP. If the sample captured is representative, the exposure percentage can be projected to the rest of the population and interpreted as a provincial index.

REPRESENTATIVENESS	x	POPULATION EXPOSURE INDEX	=	% EXPOSED POPULATION
(>30%)		(% of samples >10 ug/L)		PEP

RESULTS

Bibliographic Review

As can be seen in the systematic literature review (Figure 1), 569 publications were found. After applying the duplicates or non-relevant by title or summary filter, 315 publications remained suitable to be analyzed according to the selection criteria detailed in the Methodology. Then, another 254 articles were excluded in this process, resulting in 61 final publications useful for this research. Relevant information was found for 50% of the Argentine provinces, which represents 70% of the total population nationwide; this is twelve provinces and represents approximately thirty-two million inhabitants.

Representativeness and percentages of exposed population

146 When analyzing provincial representativeness, the population under study presented
147 a considerable heterogeneity: ranging from 0.35% (the lowest, in Chubut province)
148 to 99% (the highest, in Santa Fe province). An arbitrary limit of 30% was established,
149 which made it possible to obtain two groups: high and low representativeness.

150 In relation to the Percentage of Exposed Population (PEP), the highest exposure
151 (Table 1) was found in La Pampa (87.98%), followed by Catamarca (78.90%) and
152 Buenos Aires provinces (68.55%). In relation to the provinces with low
153 representativeness (Table 2), the PEP is significantly low, between 0 and 10%.
154 However, due to the fact that the sampling is small, the data identified is not precise.
155 The distribution of the provinces according to the PEP is presented in a graphic
156 (Figure 2). Of a total population of approximately 32 million inhabitants, 55% (around
157 17 million) is exposed to arsenic levels greater than 10 µg/L in drinking water.

159 **DISCUSSION**

160 It has been documented worldwide that millions of people are affected by being
161 exposed to drinking water with high levels of arsenic. Among the largest and most
162 populated areas involved, in Asia, for example, the populations most at risk are: the
163 Gulf of Bengal, in Bangladesh (Rahman et al., 2001); Northeast India (Bhattacharyya
164 et al., 2003); Inner Mongolia in China (Guo et al., 2001); and Taiwan and Vietnam
165 (Smedley et al., 2003). In North and Central America, the west of the United States
166 (BEST, 2001) and Mexico (Rodriguez et al., 2004); and in South America, Argentina,
167 Chile, Bolivia and Peru (Bundschuh et al., 2012).

168 Argentina has empirically known for more than a century that its drinking water
169 contains high levels of As because there are endemic diseases associated to this
170 element. However, the country does not possess unified and precise information to
171 identify its true sanitary risk. There have been two attempts to draft a "map" of this
172 situation but they have shown varied limitations, especially because they referred to
173 isolated values that did not specify the population involved (Ministerio de Salud

174 Argentina, 2006) or else showed a general distribution of the population in graphics
175 but did not specify As consumption (Litter et al., 2019). Both preliminary reports,
176 using a limit value of 50 µg/L, mention a total exposed population of 1 to 4 million
177 inhabitants. This piece of research, however, employing the WHO limit (10 µg/L) finds
178 an approximate 17 million, more than four times, the last previous one (2006).

179
180 The accumulation of evidence on chronic toxicological effects of arsenic ingestion
181 through drinking water has led to a progressive reduction in the threshold limit of
182 arsenic concentrations in water intended for human consumption (Smedley et al.,
183 2002). In Argentina and Chile, this threshold is 50 µg/L (MSA-ANMAT, 2005; Diario
184 Oficial de la República de Chile, 1984). This level is intended to be reduced to 10
185 µg/L, as set by the European Union (European Union, 1998), recommended by the
186 World Health Organization (WHO, 2004), and proposed since January 2006 by the
187 United States Environmental Agency as a "Maximum Contaminant Level Goal"
188 (MCLG) (USEPA, 2005). According to these standards, the economic implications of
189 ensuring that water has an acceptable arsenic concentration has opened an
190 important debate on the level to be set, both in large areas of developed and
191 developing countries (Smith & Smith, 2004). The existing literature confirms that the
192 levels of arsenic in drinking water recommended by the WHO in relation to chronic
193 non-communicable diseases are those that have been shown to be associated with
194 this lower threshold (Rehman et al., 2018; Ferragut Cardoso & Udoh, 2020;
195 Jaafarzadeh et al., 2022).

196
197 Although arsenic contamination has been exhaustively and long studied as acute
198 poisoning (Campbell & Alvarez, 1989), pathologies related to deferred impacts over
199 time, such as cancer, were little addressed in the country as specific associated
200 issues. However, recent analyses have demonstrated their link in Argentina (Duarte
201 et al., 2022). It is, therefore, necessary to update the information on arsenic in
202 drinking water in the country. In other countries such as the USA, approximation
203 models on As levels in drinking water have been built at national level, which have

203 made possible to define high and low risk areas (Ayotte et al., 2017). Likewise,
204 Bangladesh has carried out a review of related publications that made possible to
205 determine an (approximate) total exposed population (Karim, 2000). Other
206 countries, including higher-risk countries, only have partial information available.
207 This work contributes in highlighting both the existing and missing information. It
208 raises awareness to the situation of a large proportion of Argentina's population in
209 the face of arsenical water consumption. The wide variability of information observed
210 in this work is mainly due to the particular or regional epidemiological alert, which
211 leads local researchers to delve into the subject. It can be therefore deduced that, in
212 provinces with fewer perceived risks of exposure to arsenic, publications are fewer
213 than in those that have historically been associated with this environmental toxicant.
214 Although "exposed population" is a key -and original- concept in this analysis, an
215 extensive use of this term was not found. Most of the analyzed articles that had to be
216 discarded detail the analytical determinations of water samples and collection sites.
217 However, they do not describe the population under analysis, which is fundamental
218 to assess the true sanitary impact of arsenic contamination in drinking water.
219 Conversely, the number of samples is not a correct parameter to determine the scope
220 of the analysis, nor the level reached by the assessment above the cutoff applied.
221 Undoubtedly, when a region presents epidemiological alarms related to chronic non-
222 communicable diseases related to arsenical contamination in drinking water, it is
223 necessary to evaluate the precise levels of this element in representative samples of
224 the population.
225 The methodology employed in this analysis presents some bias: 1) possible
226 duplications of the exposed populations in each province, given that some studies
227 overlap in these territories without mentioning the specific places of collection; 2)
228 there is a bias inherent to the publications, which is related to sampling, especially in
229 well water, with the distribution of populations in relation to sources of consumption
230 unknown; 3) the concept of exposed population is not included in publications related

231 to arsenic, with the PEP variable, proposed in this work, being an indirect calculation.;

232 4) the temporality of the water evaluations is dissimilar; in any case, arsenic has been

233 described as a stable toxicant in the environment -with little variability- given the

234 fundamentally natural contamination, except that interventions have been carried out

235 to remove this element, a scarce, partial or non-existent issue in Argentina

236 throughout of the years.

237 **CONCLUSIONS**

238 This review adds value to the already published evidence, systematizing information

239 and identifying variables that may be useful for ecoepidemiological studies to analyze

240 both humans and fauna. An index is proposed, the "percentage of exposed

241 population" (PEP) to high arsenic levels as a summary variable, to homogenize the

242 information in the country, giving it thus a comparative value. It has also been

243 validated in a previous work, related to cancer mortality at provinces' departmental

244 level in the central region of Argentina (Duarte et al, 2022).

245 Territorial interventions in health management, especially in sensitive issues such as

246 population's consumption of arsenical water, require orderly, organized and

247 coordinated information to guide actions to provide tools and introduce public policies

248 that benefit inhabitants' life.

249 Finally, the present work allows to identify -indirectly- the areas of high exposure, as

250 a guide to deepen future research that allows to give certainty to these findings.

251 **REFERENCES**

252 **Ayotte** JD, Medalie L, Qi SL, Backer LC, Nolan BT (2017). Estimating the High-

253 Arsenic Domestic Well Population in the Conterminous United States. *Environ Sci*

254 *Technol.* Nov 7;51(21):12443-12454. doi: 10.1021/acs.est.7b02881.

257 **BEST** (Board on Environmental Studies and Toxicology) (2001) Arsenic in drinking
258 water: 2001 update. National Academy Press, Washington D.C., 225 pp. Retrieved
259 from: <https://nap.nationalacademies.org/read/10194/chapter/1>

260 **Bhattacharyya** R, Chatterjee D, Nath B, Jana J, Jacks G, Vahter M (2003). High
261 arsenic groundwater mobilization, metabolism and mitigation -an overview in the
262 Bengal Delta Plain. *Mol Cell Biochem.* Nov;253(1-2):347-55. doi:
263 10.1023/a:1026001024578. PMID: 14619986.

264 **Bundschuh**, J., Litter, M. I., Parvez, F., Román-Ross, G., Nicolli, H. B., Jean, J. S.,
265 ... et al. (2012). One century of arsenic exposure in Latin America: A review of history
266 and occurrence from 14 countries. *Science of the total Environment*, 429, 2-35.

267 **Buti**, C. I., Cancino, F., Ferullo, S., & Gamundi, C. (2015). Diversidad y evaluación
268 toxicológica de peces como indicadores de contaminación por mercurio, plomo,
269 cadmio, cobre y arsénico, provincia de Tucumán, República Argentina. [Diversity and
270 toxicological assessment of fishes as contaminant indicators by mercury, lead,
271 cadmium, cooper and arsenic, Tucumán province, Argentina]. Retrieved from:
272 <https://ri.conicet.gov.ar/handle/11336/13035>

273 **Campbell** JP, Alvarez JA (1989). Acute arsenic intoxication. *Am Fam Physician.*
274 Dec; 40(6):93-7. PMID: 2686377.

275 **Diario Oficial de la República de Chile** (1984). Norma Chilena Oficial N°409/1 Of.
276 N°84. Agua potable. Parte I: Requisitos. Aprobada por el Ministerio de Salud
277 mediante Decreto Supremo N°11 del 16/01/1984 [Official Chilean Norm No. 409/1
278 Of. No.84. Drinking water. Part I: Requisites. Approved by the Ministry of Health by
279 Supreme Decree No. 11 on 01/16/1984]. Published on 03/03/1984. Retrieved from:
280 [https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-
281 del-agua-potable-eeo-1.pdf](https://www.aguadelvalle.cl/media/vcah4xoj/normas-nch-409-calidad-y-muestreo-del-agua-potable-eeo-1.pdf)

282 **Duarte** LE, Delgado F, Di Leo NC, Bertone CL, Franci Alvarez M, Montico S, et al.
283 (2022). Mortalidad por cáncer, arsénico y nitratos en aguas de consumo y superficies
284 sembradas en Argentina [Mortality from cancer, arsenic, and nitrates in drinking
285

285 water and cropland in Argentina. Mortalidade por câncer, arsênio e nitratos na água
286 para consumo humano e em áreas semeadas na Argentina]. *Rev Panam Salud*
287 *Publica*. Aug 30; 46:e129. Spanish. doi: 10.26633/RPSP.2022.129.

288 **European Union** (1998). Directive 98/83/EC relating to human drinking water quality,
289 Official Journal of European Communities L330. Retrieved from: [https://eur-
290 lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-
291 20151027&from=EN](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:01998L0083-20151027&from=EN)

292 **Ferragut Cardoso AP, Udoh KT, States JC** (2020). Arsenic-induced changes in
293 miRNA expression in cancer and other diseases. *Toxicol Appl Pharmacol*. Dec 15;
294 409:115306. doi: 10.1016/j.taap.2020.115306.

295 **Guo X, Fujino Y, Kaneko S, Wu K, Xia Y, Yoshimura T** (2001). Arsenic contamination
296 of groundwater and prevalence of arsenical dermatosis in the Hetao plain area, Inner
297 Mongolia, China. *Mol Cell Biochem*. Jun;222(1-2):137-40. PMID: 11678595.

298 **INDEC** (National Institute of Statistics and Census Argentina). 2010 Census.
299 Retrieved from: <https://www.indec.gob.ar/indec/web/Nivel4-Tema-2-41-135>

300 **Jaafarzadeh N, Poormohammadi A, Almasi H, Ghaedrahmat Z, Rahim F, Zahedi A**
301 (2022). Arsenic in drinking water and kidney cancer: a systematic review. *Rev*
302 *Environ Health*. Mar 15; 38(2):255-263. doi: 10.1515/reveh-2021-0168.

303 **Litter M.** (2018). Arsénico en agua. Programa FUTUROS Escuela de Posgrado:
304 Agua + Humedales [Arsenic in water. FUTUROS Program. Postgraduate School].
305 UNSAM Edita, p .210-224. Retrieved from:
306 <https://ri.unsam.edu.ar/bitstream/123456789/911/1/PFAH%202018%20CLM.pdf>

307 **Kapaj S, Peterson H, Liber K, Bhattacharya P.** Human health effects from chronic
308 arsenic poisoning--a review. *J Environ Sci Health A Tox Hazard Subst Environ Eng*.
309 2006;41(10):2399-428. doi: 10.1080/10934520600873571.

310 **Karim, M. M.** (2000). Arsenic in groundwater and health problems in Bangladesh.
311 *Water Research*, 34(1), 304-310. Retrieved from:
312 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

313 **Litter** MI, Ingallinella AM, Olmos V, Savio M, Difeo G, Botto L, et al. (2019). Arsenic
314 in Argentina: Occurrence, human health, legislation and determination. *Sci Total*
315 *Environ.* Aug 1; 676:756-766. doi: 10.1016/j.scitotenv.2019.04.262.

316
317 **Martinez** VD, Lam WL (2021). Health Effects Associated With Pre- and Perinatal
318 Exposure to Arsenic. *Front Genet.* Sep 29; 12:664717. doi:
319 10.3389/fgene.2021.664717.

320 **Ministerio de Salud Argentina** [Ministry of Health of Argentina] (2006).
321 Epidemiología del HACRE en la República Argentina, Estudio Colaborativo
322 Multicéntrico [Epidemiology of HACRE in Argentina. Collaborative Multicenter Study].
323 Retrieved from:
324 [https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en](https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en_argentina.pdf)
325 [argentina.pdf](https://www.argentina.gob.ar/sites/default/files/2006_epidemiologia_del_hacre_en_argentina.pdf)

326 **MSA-ANMAT** [Ministry of Health – National Administration of Drugs, Food and
327 Medical Technology], (2005). Código Alimentario Argentino-Capitulo XII – Bebidas
328 Hidricas, Agua y Agua Gasificada - Agua Potable - Artículo 982 [Argentine Food
329 Code. Chapt. XII: Hydration beverages, water and gas water. Article 982]- (MSyAs
330 Res. N° 494 on 07/07/94). Retrieved from:
331 <https://www.argentina.gob.ar/anmat/codigoalimentario>

332 **Nicolli** H, Suriano J, Gomez Peral M, Ferpozzi L & Baleani O (1989). Groundwater
333 Contamination with Arsenic and other Trace Elements in an Area of the Pampa,
334 Province of Cordoba, Argentina. *Environmental Geology and Water Science* 14 3–
335 16. Retrieved from: <https://link.springer.com/article/10.1007/BF01740581>

336 **Organización Mundial de la Salud** (2017). Guías para la calidad del agua de
337 consumo humano [Guidelines for drinking-water quality]. Retrieved from:
338 <https://www.who.int/es/publications/i/item/9789241549950>

339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365

339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367

Page MJ, Moher D, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. BMJ. 2021 Mar 29;372:n160. doi: 10.1136/bmj.n160.

Quiroga, AM. (2021). Evaluación de daño oxidativo y genotóxico y su relación con variables nutricionales en poblaciones expuestas a Arsénico en agua de bebida de la zona centro-norte de la provincia de Santa Fe, Argentina. [Assessment of the oxidative and genotoxic damage and its relationship with nutritional variables in populations exposed to arsenic in drinking water from the central-north area of Santa Fe province, Argentina] Revised: January 3, 2023. Retrieved from: <https://bibliotecavirtual.unl.edu.ar:8443/handle/11185/6250>

Rahman MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D, et al. (2001). Chronic arsenic toxicity in Bangladesh and West Bengal, India – a review and commentary. *J Toxicol Clin Toxicol.*;39(7):683-700. doi: 10.1081/clt-100108509.

Rehman K, Fatima F, Waheed I, Akash MSH. (2018). Prevalence of exposure of heavy metals and their impact on health consequences. *J Cell Biochem.* Jan;119(1):157-184. doi: 10.1002/jcb.26234.

Rodriguez R., Ramos J.A., Armienta A. (2004). Groundwater arsenic variations: the role of local geology and rainfall. *Appl. Geochem.*, 19(2), 245-250. Retrieved from: <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

Rousseau, M. C., Straif, K., & Siemiatycki, J. (2005). IARC carcinogen update. *Environmental Health Perspectives*, 113(9), A580-A581.

RSA Conicet. Grupo AD HOC. Arsénico en agua [Arsenic in water]. - FINAL REPORT - Jul 31, 2018. Retrieved from: <https://rsa.conicet.gov.ar/wp-content/uploads/2018/08/Informe-Arsenico-en-agua-RSA.pdf>

Smedley, P. L., & Kinniburgh, D. G. (2002). A review of the source, behaviour and distribution of arsenic in natural waters. *Applied geochemistry*, 17(5), 517-568. Retrieved from: <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

367 **Smedley** P.L., Zhang M., Zhang G., Luo Z. (2003). Mobilisation of arsenic and other
368 trace elements in fluviolacustrine aquifers of the Huhhot Basin, Inner Mongolia. *Appl.*
369 *Geochem.*, 18(9), 1453-1477. Retrieved from:
370 <https://www.sciencedirect.com/science/article/abs/pii/S0043135499001281>

371 **Smith** AH, Smith MM. (2004). Arsenic drinking water regulations in developing
372 countries with extensive exposure. *Toxicology*. May 20;198(1-3):39-44. doi:
373 10.1016/j.tox.2004.02.024. PMID: 15138028.

374 **Smith** AH, Marshall G, Yuan Y, Ferreccio C, Liaw J, von Ehrenstein O, Steinmaus
375 C, Bates MN, Selvin S. (2006). Increased mortality from lung cancer and
376 bronchiectasis in young adults after exposure to arsenic in utero and in early
377 childhood. *Environ Health Perspect*. Aug;114(8):1293-6. doi: 10.1289/ehp.8832.

378 **USEPA** (2005). List of Drinking Water Contaminants & MCLs, February 23rd, 2005.
379 Retrieved from: [https://www.epa.gov/sites/default/files/2015-](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf)
380 [10/documents/ace3_drinking_water.pdf](https://www.epa.gov/sites/default/files/2015-10/documents/ace3_drinking_water.pdf) on 01/06/23.

381 **WORLD HEALTH ORGANIZATION, INTERNATIONAL AGENCY FOR**
382 **RESEARCH ON CANCER (IARC)** (2004). Some Drinking-Water Disinfectants and
383 Contaminants, including Arsenic. Monographs on the Evaluation of Carcinogenic
384 Risks to Humans. Volume 84. Retrieved from: <https://publications.iarc.fr/102>

385 **WHO (2004)**. Guidelines for drinking-water quality Fourth edition incorporating the
386 first and second addenda. ISBN 978-92-4-004506-4 (electronic version). Retrieved
387 from: <https://www.who.int/publications/i/item/9789240045064>

388 **Young** JL, Cai L, States JC. (2018). Impact of prenatal arsenic exposure on chronic
389 adult diseases. *Syst Biol Reprod Med*. Dec;64(6):469-483. doi:
390 10.1080/19396368.2018.1480076.

391
392
393
394
395

395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410

Figure 1. Systematic Review Flowchart

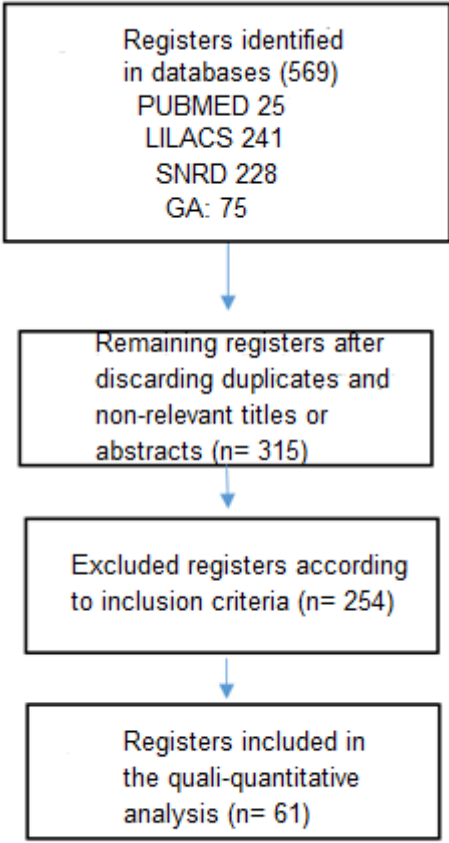


Table 1. High representativeness and exposition levels to arsenic by province

PROVINCES	EVALUATED POPULATION	TOTAL PROVINCIAL POPULATION	Percentage of population under study (%)	Percentage of Population exposed (PPE) to high levels of As (%)	Bibliography
			REPRESENTATIVENESS	EXPOSITION	
SANTA FE	3.509.459	3.544.908	99	60.08	ENRES (2019)
LA PAMPA	350.099	361.859	95.75	87.98	Pariani et al., (2014); Vercellino. (2020); O'Reilly et al. (2020)
NEUQUÉN	632.482	710.814	88.98	0	Centro de Ingenieria en Medio Ambiente (CIMA), ITBA (2020); Velazquez (2019)
CATAMARCA	372.173	429.562	86.64	78.9	Rugierri et al. (2009); Saracho et al. (2016); Saracho et al. (2019); Graziano et al. (2013); CIMA (2020); Vilches et al. (2005).
BUENOS AIRES	13.598.621	17.523.996	77.6	68.55	Navoni et al. (2012); RSA CONICET (2018); Galindo et al. (2005).
CORRIENTES	693.298	1.212.696	57.17	11.4	CIMA (2020)
CHACO	852.062	1.129.606	75.43	53.51	Roshdestwensky et al. (2016); Martínez et al. (2014); Trinelli et al. (2018); Concha et al. (1998); Osicka et al. (2002); CIMA (2020); Buchhamer et al. (2012); Blanes et al. (2011)
CÓRDOBA	2.711.679	3.840.905	70.6	29.09	Villalba et al. (2000); Blarasin et al. (2015); Penedo and Zigarán (1998)
ENTRE RÍOS	878.726	1.425.578	61.64	28.02	UNER (2019); CIMA (2020)
TIERRA DEL FUEGO	81.722	185.732	44	0	CIMA (2020)
JUJUY	277.571	811.611	34.2	22.27	López Steinmetz et al (2018); CIMA (2020); Murray et al. (2019); Ruggeri et al. (2009)
SANTIAGO DEL ESTERO	348.402	1.060.906	32.84	26,36	Bhattacharya et al. (2006); Revelli et al. (2016); Vidoni et al. (2010); Bejarano Sifuentes

					and Nordberg. (2003); Bundschuh et al. (2004); Calatayud et al. (2019); Navoni et al. (2014); CIMA (2020); Litter et al. (2015)
--	--	--	--	--	--

412

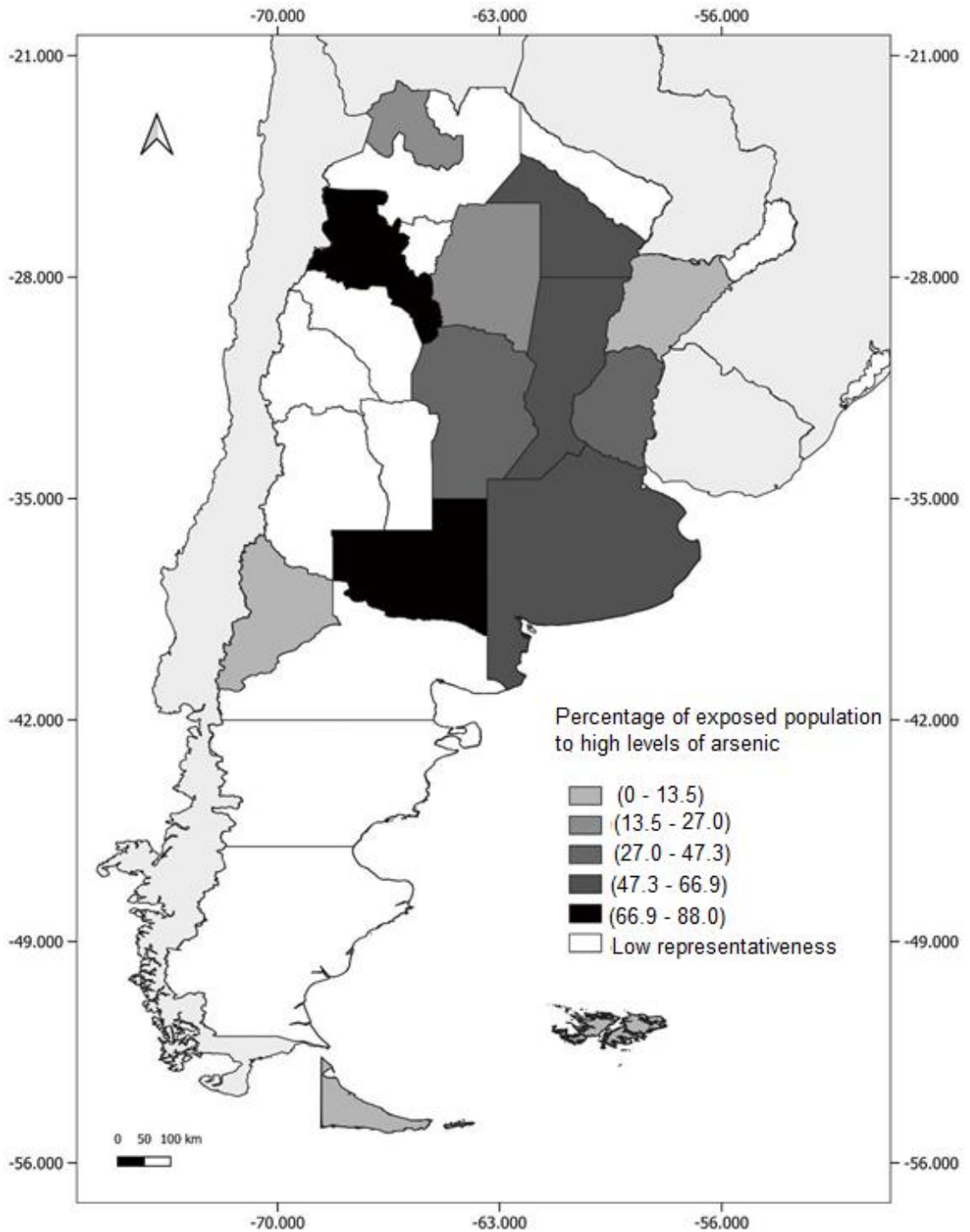
- 1
- 2
- 3
- 4
- 5
- 6
- 8
- 9
- 10
- 11
- 12
- 13
- 14
- 15
- 16
- 17
- 18
- 19
- 20
- 21
- 22
- 23
- 24
- 25
- 26
- 27
- 28
- 29
- 30
- 31
- 32
- 33
- 34
- 35
- 36
- 37
- 38
- 39
- 40
- 41
- 42
- 43
- 44
- 45
- 46
- 47
- 48
- 49
- 50
- 51
- 52
- 53
- 54
- 55
- 56
- 57
- 58
- 59
- 60
- 61
- 62
- 63
- 64
- 65

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65

Table 2. Low representativeness and exposition levels to arsenic by province

PROVINCES	EVALUATED POPIULATION	TOTAL PROVINCIAL POPULATION	Percentage of population understudy (%)	Percentage of Population exposed (PPE) to high levels of As (%)	Bibliograpy
			REPRESENTATIVENESS	EXPOSITION	
SANTA CRUZ	90.343	337.226	26.79	0	CIMA (2020)
SAN LUIS	108.414	542.069	20	0	CIMA (2020)
TUCUMÁN	244.360	1.731.820	14.11	10.51	Soria de González et al. (2008-2011); Guber et al. (2009); Nicolli et al. (2012); CIMA (2020); Gerstenfeld et al. (2012); Soria et al.(2009)
MÉNDOZA	245.429	2.043.540	12.01	9.13	Elia Dazat (2017); CIMA (2020)
SALTA	133.469	1.441.351	9.26	5.01	Concha et al. (1998); Hudson-Edwards et al. (2012); Boujon (2021); CIMA 2020
FORMOSA	54.485	607.419	8.97	3.99	CIMA (2020)
RÍO NEGRO	63.515	750.768	8.46	2.77	Grizmodo. (2012); Garrido (2017); CIMA (2020)
SAN JUAN	40.731	822.853	4.95	4.95	CIMA (2020) O'Reilly et al. (2010)
MISIONES	32.095	1.278.873	2.51	0.84	CIMA (2020)
LA RIOJA	6.372	383.865	1.66	0.21	Miguel et al. (2017); Nievas et al. (2013); CIMA (2020)
CHUBUT	2.074	592.621	0.35	0.27	Nievas et al. (2013)
CABA	0	3.121.707	0	0	-----

Fig. 2. Map of the population exposed to high arsenic levels in provinces with high representativeness. Argentina.



Source: elaborated with own data

SUPPLEMENTARY REFERENCES

Bhattacharya, P., Claesson, M., Bundschuh, J., Sracek, O., Fagerberg, J., Jacks, G et al (2006). Distribution and mobility of arsenic in the Rio Dulce alluvial aquifers in Santiago del Estero Province, Argentina. *Science of the total Environment*, 358(1-3), 97-120.

Blanes, P. S., Buchhamer, E. E., & Giménez, M. C. (2011). Natural contamination with arsenic and other trace elements in groundwater of the Central–West region of Chaco, Argentina. *Journal of Environmental Science and Health, Part A*, 46(11), 1197-1206.

Blarasin M. T. Blarasin Adriana Edith Cabrera Adriana Edith Cabrera Edel Mara Matteoda E del Mara Matteoda. ARSÉNICO Y FLÚOR EN EL AGUA SUBTERRÁNEA EN EL SUR DE CÓRDOBA (ARGENTINA), ASPECTOS GEOQUÍMICOS, CONFLICTOS DE USO Y GESTIÓN DEL RECURSO. Retrieved from: [Arsenic and Fluoride in groundwater in Cordoba \(Argentina\)](#)

Boujon, P. S. (2021). Caracterización Hidrogeológica e Hidroquímica en los alrededores de la Ciudad de Tartagal. Salta, Argentina. Retrieved from: [Caracterización Hidrogeológica e Hidroquímica en los alrededores de la Ciudad de Tartagal. Salta, Argentina](#)

Buchhamer, E. E., Blanes, P. S., Osicka, R. M., & Giménez, M. C. (2012). Environmental risk assessment of arsenic and fluoride in the Chaco Province, Argentina: Research advances. *Journal of Toxicology and Environmental Health, Part A*, 75(22-23), 1437-1450.

Bundschuh, J., Farias, B., Martin, R., Storniolo, A., Bhattacharya, P., Cortes, J et al. (2004). Groundwater arsenic in the Chaco-Pampean plain, Argentina: case study from Robles county, Santiago del Estero province. *Applied Geochemistry*, 19(2), 231-243.

Calatayud, M., Farias, S. S., de Paredes, G. S., Olivera, M., Carreras, N. Á., Giménez, M. C. et al (2019). Arsenic exposure of child populations in Northern Argentina. *Science of the total environment*, 669, 1-6.

Centro de Ingenieria Ambiental (CIMA), ITBA (2020). Retrieved from: <https://www.agenciatss.com.ar/un-mapa-del-arsenico-en-argentina/>

Concha, G., Nermell, B., & Vahter, M. V. (1998). Metabolism of inorganic arsenic in children with chronic high arsenic exposure in northern Argentina. *Environmental health perspectives*, 106(6), 355-359.

Dazat, E., & Ariel, R. (2017). *Evaluación química del efecto de la actividad ganadera en la reducción de arsénico en el agua freática del NE de Mendoza* (Doctoral dissertation, Universidad Nacional de Cuyo. Facultad de Ciencias Exactas y Naturales). Retrieved from: [Evaluación química del efecto de la](#)

1
2
3
4 actividad ganadera en la reducción de arsénico en el agua freática del NE
5 de Mendoza
6

7 **Enress** - Ente Regulador de Servicios Sanitarios. Retrieved from:
8 <http://www.enress.gov.ar/?s=laboratorio&lang=en>
9

10 **Facultad de Ciencias Agrarias, UNER (2019)**; Informe realizado a pedido del
11 Instituto Nacional del Cáncer (disponible, no publicado)
12

13
14 **Galindo, G.**, Giraut, M. A., Fernandez-Turiel, J. L., Medina, V., & Gimeno, D.
15 (2006). Valores de arsénico en aguas de dos cuencas de la Llanura Pampeana,
16 Buenos Aires, Argentina. Retrieved from:
17 <https://digital.csic.es/handle/10261/209514>
18
19

20 **Garrido, M. E.** (2017). *Evaluación hidroquímica de los niveles acuíferos del Grupo*
21 *Neuquén, en área de yacimientos hidrocarburíferos de la Provincia de Río*
22 *Negro* (Doctoral dissertation). Retrieved from: [Evaluación hidroquímica de los](#)
23 [niveles acuíferos del Grupo Neuquén, en área de yacimientos hidrocarburíferos de](#)
24 [la Provincia de Río Negro](#)
25
26

27 **Gerstenfeld, S.**, Jordán, A., Calli, R., Farías, P., Malica, J., Peña, M. L. G y col.
28 (2012). Determinación de zonas de riesgo al agua arsenical y prevalencia de
29 HACRE en Villa Belgrano, Tucumán, Argentina. *Revista Argentina de Salud*
30 *Pública*, 3(10), 24-29.
31
32

33 **Graziano, M.**, Rosin, P., Ramos, C. S., Borón, I., Ruiz, M., Garelli, F. M y col
34 (2013). Minería y Vulnerabilidad de la Calidad del Agua para Riego y Consumo en
35 la Localidad de Tinogasta. In *VIII Congreso Argentino de Hidrogeología y VI*
36 *Seminario Latinoamericano sobre Termas Actuales de la Hidrología Subterránea*
37 *(La Plata, 17 al 20 de septiembre de 2013)*. Retrieved from:
38 <https://sedici.unlp.edu.ar/handle/10915/104210>
39
40

41 **Griznado, C. E.** (2012). Evaluación de la fluctuación de las concentraciones de
42 flúor y arsénico en agua de consumo humano de áreas de la línea sur de la
43 Provincia de Río Negro. Retrieved from: [Evaluación de la fluctuación de las](#)
44 [concentraciones de flúor y arsénico en agua de consumo humano de áreas de la](#)
45 [línea sur de la Provincia de Río Negro](#)
46
47
48

49 **Guber, R. S.**, Tefaha, L., Arias, N., Sandoval, N., Toledo, R., Fernández, M y col.
50 (2009). Contenido de arsénico en el agua de consumo en Leales y Graneros
51 (Provincia de Tucumán-Argentina). *Acta bioquímica clínica latinoamericana*, 43(2),
52 201-207.
53
54

55 **Hudson-Edwards, K. A.**, & Archer, J. (2012). Geochemistry of As-, F-and B-
56 bearing waters in and around San Antonio de los Cobres, Argentina, and
57 implications for drinking and irrigation water quality. *Journal of Geochemical*
58 *Exploration*, 112, 276-284.
59
60
61
62
63
64
65

1
2
3
4 **Litter, M.** (2018). Arsénico en agua. INFORME FINAL. Retrieved from:

5
6 [ARSÉNICO EN AGUA - Red de Seguridad Alimentaria](#)

7
8 **López Steinmetz, L. C., & Diaz, S. L.** (2018). Estimación de riesgo carcinógeno
9 por exposición crónica al arsénico a través del agua de consumo en la Puna,
10 Jujuy. *Revista Argentina de Salud Pública*, 9(37), 15-21.

11
12 **Martínez, G. J., Beccaglia, A. M., & Llinares, A.** (2014). Problemática hídrico-
13 sanitaria, percepción local y calidad de fuentes de agua en una comunidad toba
14 (qom) del Impenetrable (Chaco, Argentina). *Salud colectiva*, 10, 225-242.

15
16 **Miguel, R E;** Gonzalez Ribot, J V; Martínez, M L; Poveda, E; Turne, D.
17 ARSÉNICO, FLÚOR Y NITRATO EN AGUA SUBTERRÁNEA UTILIZADA PARA
18 CONSUMO HUMANO. VALLE ANTINACO–LOS COLORADOS, LA RIOJA,
19 ARGENTINA. Retrieved from: [_ARSÉNICO, FLÚOR Y NITRATO EN AGUA](#)
20 [SUBTERRÁNEA ...](#)

21
22
23 **Murray, J., Nordstrom, D. K., Dold, B., Orué, M. R., & Kirschbaum, A.** (2019).
24 Origin and geochemistry of arsenic in surface and groundwaters of Los Pozuelos
25 basin, Puna region, Central Andes, Argentina. *Science of the Total*
26 *Environment*, 697, 134085.

27
28
29 **Navoni, J. A., De Pietri, D., Garcia, S., & Villaamil Lepori, E. C.** (2012). Riesgo
30 sanitario de la población vulnerable expuesta al arsénico en la provincia de
31 Buenos Aires, Argentina. *Revista Panamericana de Salud Pública*, 31, 1-8.

32
33
34 **Navoni, J. A., De Pietri, D., Olmos, V., Gimenez, C., Mitre, G. B., De Titto, E et al.**
35 (2014). Human health risk assessment with spatial analysis: study of a population
36 chronically exposed to arsenic through drinking water from Argentina. *Science of*
37 *the Total Environment*, 499, 166-174.

38
39
40 **Nicolli, H. B., García, J. W., Falcón, C. M., & Smedley, P. L.** (2012). Mobilization
41 of arsenic and other trace elements of health concern in groundwater from the Salí
42 River Basin, Tucumán Province, Argentina. *Environmental Geochemistry and*
43 *Health*, 34, 251-262.

44
45 **Nievas, H. O., Pizzio, F., Ferri, F. O., Alvarez, J., Karkanis, C., Tomellini, G., y col.**
46 (2013). Línea de base ambiental de agua y sedimento de wscorrentía
47 superficial para la quebrada Alipán, sierra de Velasco, La Rioja. *Revista de la*
48 *Asociación Geológica Argentina*, 70(3), 351-365.(a)

49
50
51 **Nievas, H. O., Caruso, M., Pizzio, F., Ferri, F. O., & Pérez, S.** (2013). Monitoreo
52 ambiental de aguas superficiales y subterráneas, consideración de áreas
53 sensibles, distrito uranífero Pichiñán Este, departamento Paso de Indios, provincia
54 del Chubut. *Revista de la Asociación Geológica Argentina*, 70(3), 327-334.(b)

55
56 **O'Reilly J, Watts MJ, Shaw RA, Marcilla AL, Ward NI.** Arsenic contamination of
57 natural waters in San Juan and La Pampa, Argentina. *Environ Geochem Health*.
58 2010 Dec;32(6):491-515. doi: 10.1007/s10653-010-9317-7.

1
2
3
4 **Osicka, R. M.**, Agulló, N. S., Herrera Ahuad, C. E., & Giménez, M. C. (2002).
5 Evaluación de las concentraciones de fluoruro y arsénico en las aguas
6 subterráneas del Domo Central de la Provincia del Chaco. Retrieved from:
7 [Evaluación de las concentraciones de fluoruro y arsénico en las aguas](#)
8 [subterráneas del Domo Central de la Provincia del Chaco](#)
9

10
11 **Pariani, A.**, Perea Muñoz, J. M., Castaldo, A. O., García Martínez, A., Giorgis, A.,
12 Angón, E., ... y col (2014). Concentración de flúor y arsénico en el agua de red de
13 General Pico (Argentina) durante el periodo 2007-2013. Retrieved from:
14 <https://repo.unlpam.edu.ar/handle/unlpam/4394>
15

16
17 **Penedo M, Zigarán A.** (2018) Hidroarsenicismo en la provincia de Córdoba.
18 Actualización del mapa de riesgo e incidencia. Retrieved from:
19 <http://www.bvsde.paho.org/bvsaidis/impactos/peru/argsam024.pdf>
20

21
22 **Revelli, GR;** Sbodio, OA; Costa, GV. Estudio epidemiológico de arsénico en agua
23 subterránea para consumo humano en el territorio del Cluster Lechero Regional,
24 Argentina. *Acta toxicol. argent* ; 24(2): 105-115, set. 2016.
25

26
27 **Roshdestwensky, S. E.**, Corace, J. J., Pilar, S., & Forte, J. (2016). Evaluación de
28 la calidad del agua e hidroarsenicismo en la Provincia del Chaco-Argentina.
29 Retrieved from: <https://repositorio.unne.edu.ar/handle/123456789/27786>
30

31
32 **Ruggieri, F.**, Fernández-Turiel, J. L., Gimeno, D., Garcia-Valles, M. T., Saavedra,
33 J., & Córdoba, G. D. V. (2009). Contenido y distribución de arsénico y otros
34 elementos trazas en aguas de Antofagasta de la Sierra, Catamarca, Argentina. .
35 Retrieved from: <https://digital.csic.es/handle/10261/209756>
36

37
38 **Saracho, M., Segura, L., Flores, M., Agüero, N., Rodríguez, G., Leguizamón, M.,**
39 **y col** (2016). Caracterización hidrogeoquímica y presencia de contaminantes
40 naturales en el agua de localidades de la Paz. In *XXXIX Reunión de Trabajo de la*
41 *Asociación Argentina de Energías Renovables y Medio Ambiente (ASADES)(La*
42 *Plata, 2016)*. Retrieved from: <https://sedici.unlp.edu.ar/handle/10915/65273>
43

44
45 **Saracho, M., Segura, L., Lobo, P., & Agüero, N.** (2019). Calidad del agua utilizada
46 para consumo humano en el salar De pipanaco. Catamarca. *Avances en Energías*
47 *Renovables y Medio Ambiente*, 23, 79-90.
48

49
50 **Sifuentes, G. B.**, & Nordberg, E. (2003). *Mobilisation of Arsenic in the Rio Dulce*
51 *Alluvial Cone, Santiago del Estero Province, Argentina* (Doctoral dissertation,
52 Master thesis. Department of Land and water resources engineering). Retrieved
53 from: [Mobilisation of Arsenic in the Rio Dulce Alluvial](#)
54 [Cone, Santiago del Estero Province, Argentina](#)
55

56
57 **Soria de González, A.**, Guber, R. S., Martínez, M., Arias, N., Tefaha, L.,
58 Sandoval, N. y col (2009). Alteraciones bioquímicas en individuos expuestos al
59
60
61
62
63
64
65

1
2
3
4 arsénico en el agua de bebida en Tucumán, Argentina. *Acta bioquímica clínica*
5 *latinoamericana*, 43(4), 611-618.
6

7 **Trinelli, M. A.**, Mallou, F., González, M., El Kassis, Y., Rodríguez, A., Casullo, M
8 y col (2018). Calidad de agua para consumo en tres localidades de la provincia de
9 Chaco, Argentina. *4to Encuentro de Investigadores en Formación en Recursos*
10 *Hídricos*. Retrieved from: [Calidad de agua para consumo en tres localidades de la](#)
11 [provincia de Chaco, Argentina](#)
12
13

14 **Velazquez, V. G.** (2019). *Distribución del arsénico en el agua de la provincia de*
15 *Neuquén* (Bachelor's thesis, Universidad Nacional del Comahue. Facultad de
16 Ciencias del Ambiente y la Salud). Retrieved from:
17 <https://rdi.uncoma.edu.ar/handle/uncomaid/13929>
18
19

20 **Vercellino, Carla Antonella** "Presencia de arsénico en aguas subterráneas en la
21 localidad de Abramo (La Pampa) y riesgo de HACRE" (2020). Retrieved from:
22 <https://repositorioslatinoamericanos.uchile.cl/handle/2250/4297343?show=full>
23
24

25 **Vidoni, R.**, Pacini, V., Ingallinella, A. M., & Sanguinetti, G. (2009). Remoción de
26 arsénico, hierro y manganeso en agua subterránea en planta piloto ubicada en
27 una escuela rural. *AUGMDOMUS*, 1. Retrieved from:
28 <https://sedici.unlp.edu.ar/handle/10915/15889>
29
30

31 **Vilches, F. E.**, Palomeque, L. I., Córdoba, G. D. V., Fuentes, S. E., & Navarro
32 García, L. F. (2005). El arsénico en la provincia de Catamarca, Argentina.
33 In *Arsenico en aguas: origen, movilidad y tratamiento, IV Congreso Hidrogeológico*
34 *Argentino. Río Cuarto* (pp. 103-110).
35
36

37 **Villalba, G.**, BLARASIN, M., & CONIGLIO, J. (2000). CARACTERÍSTICAS
38 GEOHIDROLÓGICAS DE LA CUENCA DEL ARROYO EL TALITA, BATOLITO
39 CERRO ÁSPERO, CÓRDOBA, ARGENTINA. *Águas Subterrâneas*. Retrieved
40 from: <https://aguassubterraneas.abas.org/asubterraneas/article/view/24340>
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65