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The new map of Argentine population exposed to arsenic in drinking water

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ABSTRACT

This study aims to evaluate the population exposed to arsenic in Argentina, proposing a key risk indicator. By employing specific criteria selection, a systematic search of the published evidence on arsenic content in drinking water samples at the provincial level was carried out. Considering the limit recommended by the WHO – 10 μg/L – representativeness of evidence was calculated, as well as the percentage of exposed population (PEP) to high levels of arsenic. For this research, 61 useful publications were found and included in the analysis. They provide relevant data for 50% of the provinces, which represent 70% of the national population. The use of the PEP index, to denote the '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.

Key words: Argentina, arsenic, map, water

HIGHLIGHTS

- Half of the provinces provide representative information on populations exposed to high levels of arsenic.
- The percentage of exposed populations is highly variable, from 0 to almost 100%.
- The use of the PEP index, which refers to the "percentage of exposed population" to elevated arsenic levels, is proposed as a summary variable.
- A map showing different regional situations is drawn showing half of the Argentine provinces and two-thirds of the total population.

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 10 chemicals considered by the World Health Organization to be of major public health concern (WHO 2016). The largest amounts of As in the environment come from natural sources (weathering, biological activity, and volcanic emissions). However, anthropogenic activities, including industrial processes such as mining, metal smelting, pesticide usage, and wood preservatives, also play their part (Litter 2018). Surface and underground water natural resources are affected by the geochemical cycle of arsenic due to many reasons, including the following: 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, such as by consuming contaminated food or water; using it in meal preparation, crop irrigation, or industrial processing; or by inhaling it. Prolonged exposure to inorganic arsenic – through any of these means – can cause acute and chronic poisoning, from skin lesions to neoplasm (Kapaj *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 at 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 by skin lesions and systemic cancerous and non-cancerous alterations resulting from exposure to low levels for prolonged periods, has been known in Argentina since 1913, making the country rank second after the USA among the world's most affected countries (Ministerio de Salud de la Nación 2006). The situation has worsened considering the long-term and chronic impact on human health. A recent piece of research carried out in the Central Region of Argentina has compared arsenic genotoxicity in two groups of the population, one exposed to high levels and one not exposed at all, showing oxidative and genotoxic damage at high levels (Quiroga 2021). Exposure has an impact on chronic diseases, from congenital malformations to neurodegenerative diseases and cancer. Arsenic was classified by the WHO's International Agency for Research on Cancer (IARC) as carcinogenic to humans (Rousseau *et al.* 2005).

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

In its Guidelines for Drinking Water Quality, the WHO established a limit value for arsenic in water. It aims to serve as a world basis for regulatory and standardization tasks in this regard. The recommended limit in drinking water is 10 μg/L (WHO 2022). The Argentine Food Code (CAA by its Spanish acronym) establishes a higher safety limit of 50 μg/L (MSA-ANMAT 2005). However, levels well above this limit have already been reached in the country, even exceeding 200 μg/L (Nicolli *et al.* 1989). Much of the scientific evidence has shown that between the limits of the WHO and the CAA, there is a significant risk to human health.

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

METHODOLOGY

Bibliographic review

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, as well as the Spanish ones, '*arsénico Y agua de consumo Y provincia Y argentina*'.

The selection criteria to include the articles were the following: (1) if the number of drinking water samples 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, considering the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page *et al.* 2020).

Variables construction

After selecting a 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, expressed by the quotient between the total population evaluated (sum of the total bibliography) over the total provincial population. This allowed us 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.

(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 us to obtain the ***Percentage of Exposed Population*** (PEP) per province.

Through these calculations, two variables were obtained for each province, as follows: (a) the '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	× Population exposure index =	% Exposed population
(>30%)	(% of samples >10 μg/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 ones by title or summary filter, 315 publications remained suitable to be analyzed according to the selection

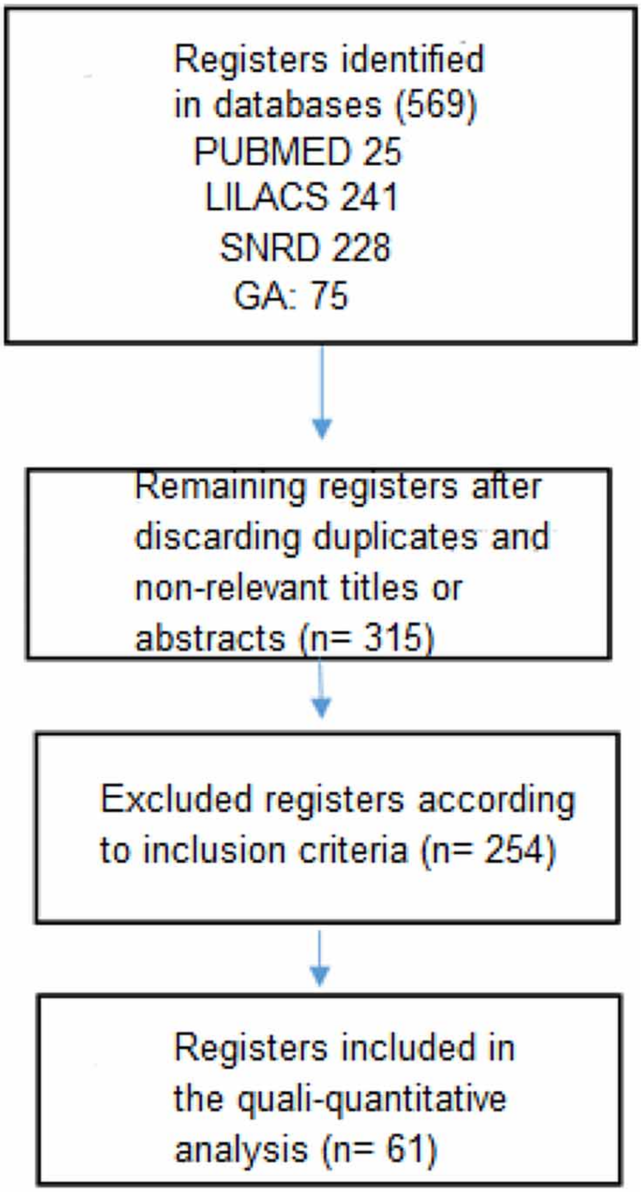

Figure 1 | Systematic review flowchart.

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 includes 12 provinces and represents approximately 32 million inhabitants.

Representativeness and percentages of the exposed population

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

In relation to the PEP, the highest exposure (Table 1) was found in La Pampa (87.98%), followed by Catamarca (78.90%) and Buenos Aires provinces (68.55%). In relation to the provinces with low representativeness (Table 2), the PEP is significantly low between 0 and 10%. However, due to the fact that the sampling is small, the data identified are not precise.

The distribution of the provinces according to the PEP is presented in a graphic (Figure 2). Of a total population of approximately 32 million inhabitants, 55% (around 17 million) are exposed to arsenic levels greater than 10 μg/L in drinking water.

Table 1 | High representativeness and exposure levels to arsenic by province

Provinces	Evaluated population	Total provincial population	Percentage of population under study (%) Representativeness	Percentage of exposed population (PEP) to high levels of As (%) Exposure	Supplementary references
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 & Zigaran (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), Ruggieri *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.* (2009), Sifuentes & Nordberg (2003), Bundschuh *et al.* (2004), Calatayud *et al.* (2019), Navoni *et al.* (2014), CIMA (2020), Litter *et al.* (2015)

Table 2 | Low representativeness and exposure levels to arsenic by province

Provinces	Evaluated population	Total provincial population	Percentage of population under study (%) Representativeness	Percentage of exposed population exposed (PEP) to high levels of As (%) Exposition	Supplementary references
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.* (2009), Guber *et al.* (2009), Nicolli *et al.* (2012), CIMA (2020), Gerstenfeld *et al.* (2012), Soria *et al.* (2009)
Mendoza	245.429	2,043.540	12.01	9.13	Dazat & Ariel (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	Grizmado. (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	-

DISCUSSION

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 those in 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, populations in the west of the United States (BEST 2001) and Mexico (Rodriguez *et al.* 2004) are exposed; while in South America, people in Argentina, Chile, Bolivia, and Peru are exposed (Bundschuh *et al.* 2012).

Argentina has empirically known for more than a century that its drinking water contains high levels of As because there are endemic diseases associated with 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 Argentina 2006) or else showed a general distribution of the population in graphics but did not specify As consumption (Litter *et al.* 2019). Both preliminary reports, using a limit value of 50 μg/L, mention a total exposed population of 1–4 million inhabitants. This piece of research, however, employing the WHO limit (10 μg/L) finds approximately 17 million, more than four times the previous one (2019), are exposed to As.

The accumulation of evidence on the chronic toxicological effects of arsenic ingestion through drinking water has led to a progressive reduction in the threshold limit of arsenic concentrations in water intended for human consumption (Smedley & Kinniburgh 2002). In Argentina and Chile, this threshold is 50 μg/L (Government Of The Republic Of Chile 1984; MSA-ANMAT 2005). This level is intended to be reduced to 10 μg/L, as set by the European Union (European Union 1998), recommended by the World Health Organization (WHO 2022), and proposed since January 2006 by the United States Environmental Agency as a 'Maximum Contaminant Level Goal' (USEPA 2015). According to these standards, the economic implications of ensuring that water has an acceptable arsenic concentration have opened an important debate on the level to be set, both in large areas of developed and developing countries (Smith & Smith 2004). The existing literature

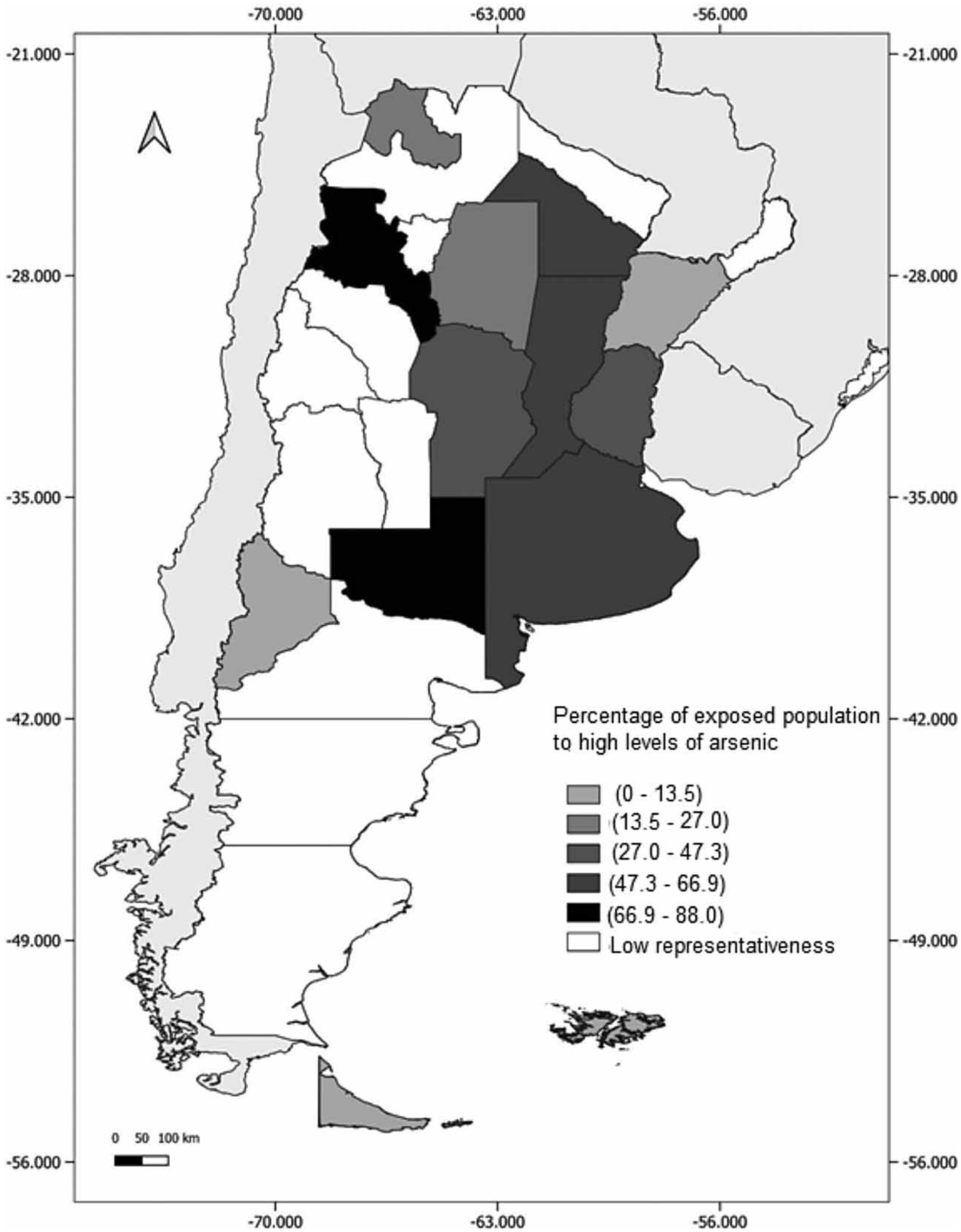

Figure 2 | Map of the population exposed to high arsenic levels in provinces with high representativeness. Argentina. *Source*: elaborated with own data.

confirms that the levels of arsenic in drinking water recommended by the WHO in relation to chronic non-communicable diseases are those that have been shown to be associated with this lower threshold (Rehman *et al.* 2018; Ferragut Cardoso *et al.* 2020; Jaafarzadeh *et al.* 2022).

Although arsenic contamination has been studied exhaustively and for long as acute poisoning (Campbell & Alvarez 1989), pathologies related to deferred impacts over time, such as cancer, were little addressed in the country as specific associated issues. However, recent analyses have demonstrated their link in Argentina (Duarte *et al.* 2022). It is, therefore, necessary to update the information on arsenic in drinking water in the country. In other countries, such as the USA, approximation models on As levels in drinking water have been built at the national level, which has made it possible to define high- and low-risk areas (Ayotte *et al.* 2017). Likewise, Bangladesh has carried out a review of related publications that made it possible to determine an approximate total exposed population (Karim 2000). Other countries, including higher-risk countries, only have partial information available.

This work contributes to highlighting both the existing and missing information. It raises awareness of the situation of a large proportion of Argentina's population in the face of arsenical water consumption. 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, therefore, be deduced that, on provinces with fewer perceived risks of exposure to arsenic publications are fewer than on those that have historically been associated with this environmental toxicant.

Although 'exposed population' is a key – and original – concept in this analysis, 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 assessing 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 is 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.

The methodology employed in this analysis presents some bias, as follows: (1) possible duplications of the exposed populations in each province, given that some studies overlap in these 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, except that interventions have been carried out to remove this element, a scarce, partial, or non-existent issue in Argentina throughout the years.

CONCLUSIONS

This review adds value to the already published evidence, systematizing information and identifying variables that may be useful for eco-epidemiological studies to analyze both humans and fauna. An index is proposed, the '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 the population's consumption of arsenical water, require orderly, organized, and coordinated information to guide actions to provide tools and introduce public policies that benefit inhabitants' lives.

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

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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