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CASE REPORT

# From uncertainty to environmental impacts: reflection on the threats to water in Chacabuco Province (Chile): a combined approach in social sciences and geochemistry

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**Abstract**
This article discusses the uncertainty about water quality in the Province of Chacabuco (Santiago Metropolitan Region) in Chile, a region marked by very strong pressure on the resource, both natural (drought) and anthropogenic (urban growth, agricultural intensification, industrialisation, and mining activity). Our main objective was, through an interdisciplinary research approach, to understand how the uncertainty concerning the state of hydro systems becomes central in the social representations of the inhabitants, since there is no consensus amongst regional stakeholders about environmental impacts nor is there evidence of pollution. By cross-referencing geochemical data on water quality and the inhabitants' discourse on the resource, we identified those factors that create uncertainty about water resources: institutional lack of knowledge of the state of the resource, scientific difficulties in understanding the functioning of the hydro system, water and ground quality data that are difficult to interpret given the persistent drought, and the inhabitants' distrust of data producers, in a context of planned regulatory zoning of polluting activities in the area. We also show the negative effects that the lack of trustworthy information has on the daily lives of local communities living near industrial infrastructures: anxiety, health concerns, and mistrust of drinking water, even though it is potable.

**Keywords** Chile · Chacabuco Province · Water quality · Uncertainty · Interdisciplinary approaches for sustainable science

## Introduction

Chile has been going through a period of "mega-drought" for the past decade (Centro de Ciencia del Clima y la Resiliencia (CR)2 2015; Garreaud et al. 2019), especially in the Central Zone. The central issue today is access to quality drinking water for human consumption, in a neoliberal model of natural resource governance that promotes self-regulation of the water rights market (Budds 2020) and extractivism (Bustos et al. 2019). The significant decrease in annual rainfall is a key cause of this situation, but scarcity is also a social construct, which exacerbates the physical constraints induced by climate change (Clarimont 1999; Budds 2012; Blot and Besteiro 2017; Oppliger et al. 2019). In other words, in addition to the drought probably induced by climate change, the interaction and increasing pressure exerted by the withdrawals of human activities in time and space create the conditions for scarcity with a demand for water that may exceed the renewal capacities of the hydro systems. The province of Chacabuco, located on the northern outskirts of Santiago (Fig. 1) and administratively composed of three municipalities (Colina, Lampa and Til Til), has undergone major changes over the past 30 years, both in the social composition of its population and in its productive activities. The

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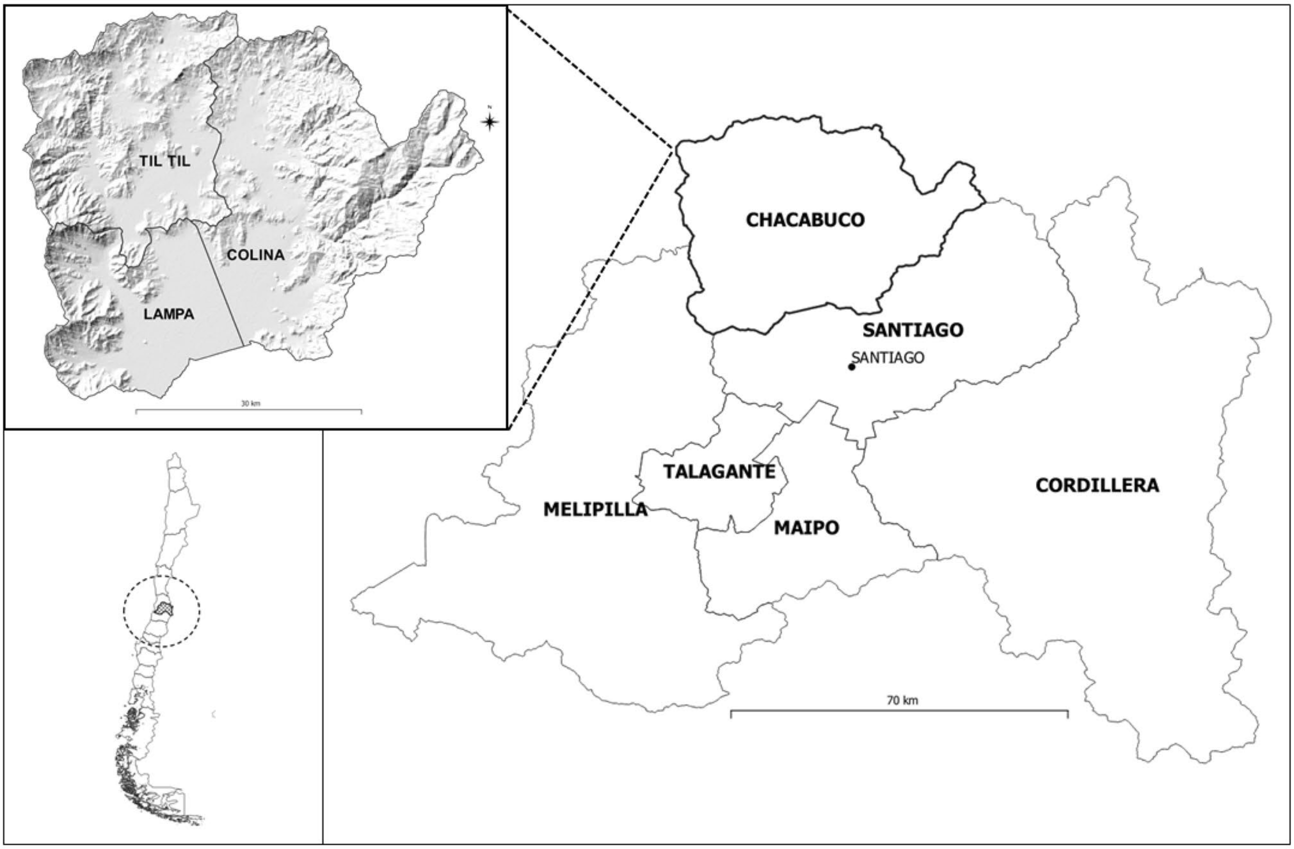



**Fig. 1** Location map of Chacabuco Province, Santiago Metropolitan Region, Chile

transformation of this region is such that Til Til, the northernmost municipality, has been described by the media as an "environmental sacrifice zone". This situation generates mobilisations for the right to live in a healthy environment (Jorge et al. 2020).

During our first field visit in 2018, female residents of the municipality of Til Til spontaneously mentioned their suspicions concerning a possible relationship between the occurrence of diseases and the potential pollution of drinking water with inorganic trace elements such as metals or metalloids, particularly arsenic (**As**), but they lacked reliable information to prove that they were exposed to pollutants in their living environments. Despite the reassuring discourse of the institutions and the industries regarding the water supplied, the inhabitants of the province of Chacabuco are in a situation of *uncertainty* regarding the quality of the water. Now, suspected inorganic **As** in ground and surface water in this area, as elsewhere in Latin America, is considered to be highly carcinogenic (Muñoz et al. 2017) and implicated in various cancers (lung, kidney, and bladder), as well as skin diseases (ATSDR 2007).

This article reports on the first results of the exploratory and interdisciplinary project CARE, which stands for *Characterisation of Arsenic presence in water and atmosphere in Chile*: *Risks for Environment and human health* with respect to its three main objectives: (i) to understand the regional mechanisms that create uncertainty concerning water resources amongst residents; (ii) to help characterise the state of contamination throughout the province; and (iii) to characterise the links between uncertainties relating to the state of hydro systems and the state of social relations, in particular a tendency for regional conflicts to occur (see Fig. 2, as a graphical abstract of our research strategy and objectives).

Regarding the paradigm of our research design, this work is based on the philosophical assumptions of the advocacy and participatory worldviews as defined by Creswell (2009). The purpose of the research is to highlight that there is an environmental concern regarding the issue of the environmental sacrifice zone and water quality. Also, based on social constructivism, our objective is to rely on the participants' view of the situation under study (Fig. 2). From there, we have privileged a mixed method of research including quantitative data to contrast the interpretation of the vision of the inhabitants on their environmental living or working places. More specifically, our approach advocates for

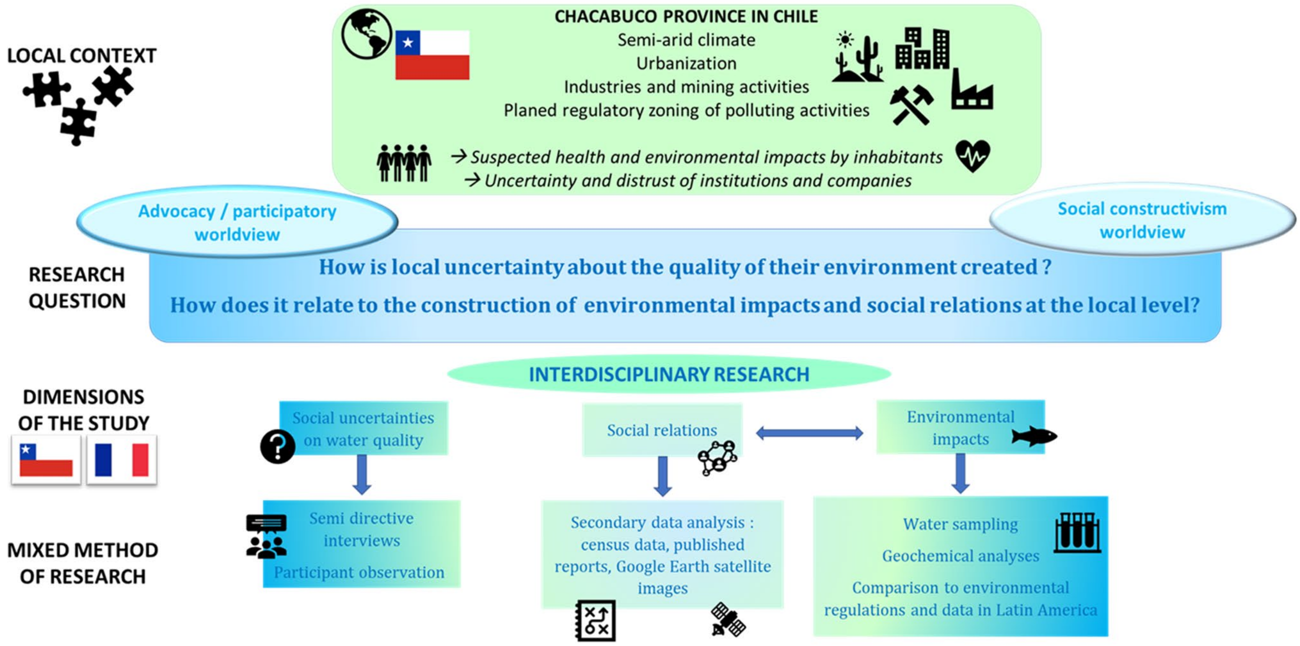



**Fig. 2** Graphical abstract of the interdisciplinary research strategy and experimental design

an action programme to give voice to potentially impacted people and raise their awareness to improve their lives. In this sense, the inhabitants of the concerned region in Chile contributed directly to identify the data collection points and indirectly to design questions through the doubts they expressed. Thus, in carrying out this study, we are convinced that pointing out dysfunctions, uncertainties and injustices can change the lives of the participants and the functioning of the institutions in which individuals work or live.

## Theoretical framework

Through their discourses, the inhabitants of the different parts of the province of Chacabuco that we met regularly expressed their concern about the current state of their region but also about its future, both from the point of view of water availability and pollution and its impacts on health, and from the point of view of the underlying causes that disrupt or could disrupt the hydraulic systems. The fact that uncertainty is posed as a problem by a heterogeneous group of inhabitants underlines its social dimension. Our hypothesis is that, although the complexity of the uncertainty surrounding water quality does not allow problems to be qualified as risks and dealt with as such (Callon et al. 2001), it *does not inhibit collective action against polluting activities*. However, the actions implemented are insufficient to constitute a real opposition force to characterise and regulate the impacts of polluting activities on the environment and health.

Psychological studies on the issue of uncertainty have shown that when people consider uncertainty to be problematic and intolerable, they have "*difficulty taking action, they experience negative emotions (such as frustration or stress)*" (Ouellet 2014, p. 10). However, as sociology has shown since Crozier and Friedberg (1977), the control of areas of uncertainty is also a strategic asset that enables those who appropriate it to increase their freedom of action and hence their power to act.

Following Dousset (2018), we believe that studying situations that sow doubt, even to the point of questioning the relevance of and trust in institutions, makes it possible to trace the social regulation at work and to understand the conditions of "conflict-making" associated with a feeling of social non-recognition (Honneth 2004; 2006).

Finally, one of the means to remove uncertainty linked to water quality in this province is to carry out water sampling and perform geochemical analyses, searching for the metal(loid)s suspected by the populations and potentially emitted by industrial and mining activities in the surroundings. Our interdisciplinary study will combine all these social and geochemical methods to better question this problem about uncertainty.

## Materials and methods

### Study site

Several studies performed in the last decades in Chile have reported environmental contamination by metal(loid)s, especially arsenic (Romero et al. 2003; Rodríguez-Oroz et al. 2018; Tapia et al. 2018, 2019a, 2019b; Bundschuh et al. 2021). Most of these studies concern northern Chile in the Northern Atacama Region (Tapia et al. 2018), and the Antofagasta Region (Valdés et al. 2015), or southern Chile in the Biobio region (Rodríguez-Oroz et al. 2018) or Talcahuano city (Tume et al. 2018).

By contrast, a few studies have already focussed on our research area: the province of Chacabuco. This province is located in the central zone of Chile, between the Cordillera Coast and the Andes. Geographically, it is located in the Santiago Metropolitan Region, very close (about 35 km) to Santiago city, the main socio-economic and urban centre of the country (Fig. 1). However, due to the proximity of the capital, the presence of several potential sources of inorganic pollutants, and the questions raised by the inhabitants about water contamination, this province of Chacabuco needs to be studied further. Indeed, in this region, as often in Chile (Rodríguez-Oroz et al 2018; Tume et al. 2008, 2014), we have already identified different geogenic (volcanism, erosion of volcanic and granitic rocks, weathering and natural leaching processes, and thermal springs) and anthropogenic sources (industrial areas, accelerated mobilisation from metal ore deposits by mining and related activities, pesticides and fertilisers used for agriculture; vehicular traffic emissions; coal deposits and their mining) of metal(loid) emissions to the environment (see Fig. 3 for source locations and the latter for more details) that are of interest for further study.

The Central Zone (32°S to 38°S) has a Mediterranean climate, with precipitations during cold winters, whilst summers are dry (Viers et al. 2019). Nevertheless, since 2010, annual rainfall deficits in this region have fluctuated between 25% and 40% (Garreaud et al. 2019) and even reached 70–80% in 2019.[1] At the scale of Santiago, between 2007 and 2019, only 2 years have (barely) had normal rainfall, with rainfall in 2019 being 82 mm for a usual annual mean of 362 mm (Dirección General de Aeronáutica Civil 2020). Thus, the Mediterranean climate originally present in the province of Chacabuco has evolved into a semi-arid climate.

The province of Chacabuco belongs to the Río Mapocho Bajo sub-catchment area, which is part of the Maipo river catchment area with a mixed snow and rain regime, which is the main source of drinking water and irrigation water for the Metropolitan Region.

The decrease in water supply affects the availability of the surface network, which is currently mostly dried up, but also the recharge of the underground network, which has become the main source of drinking water and irrigation water for the local population.

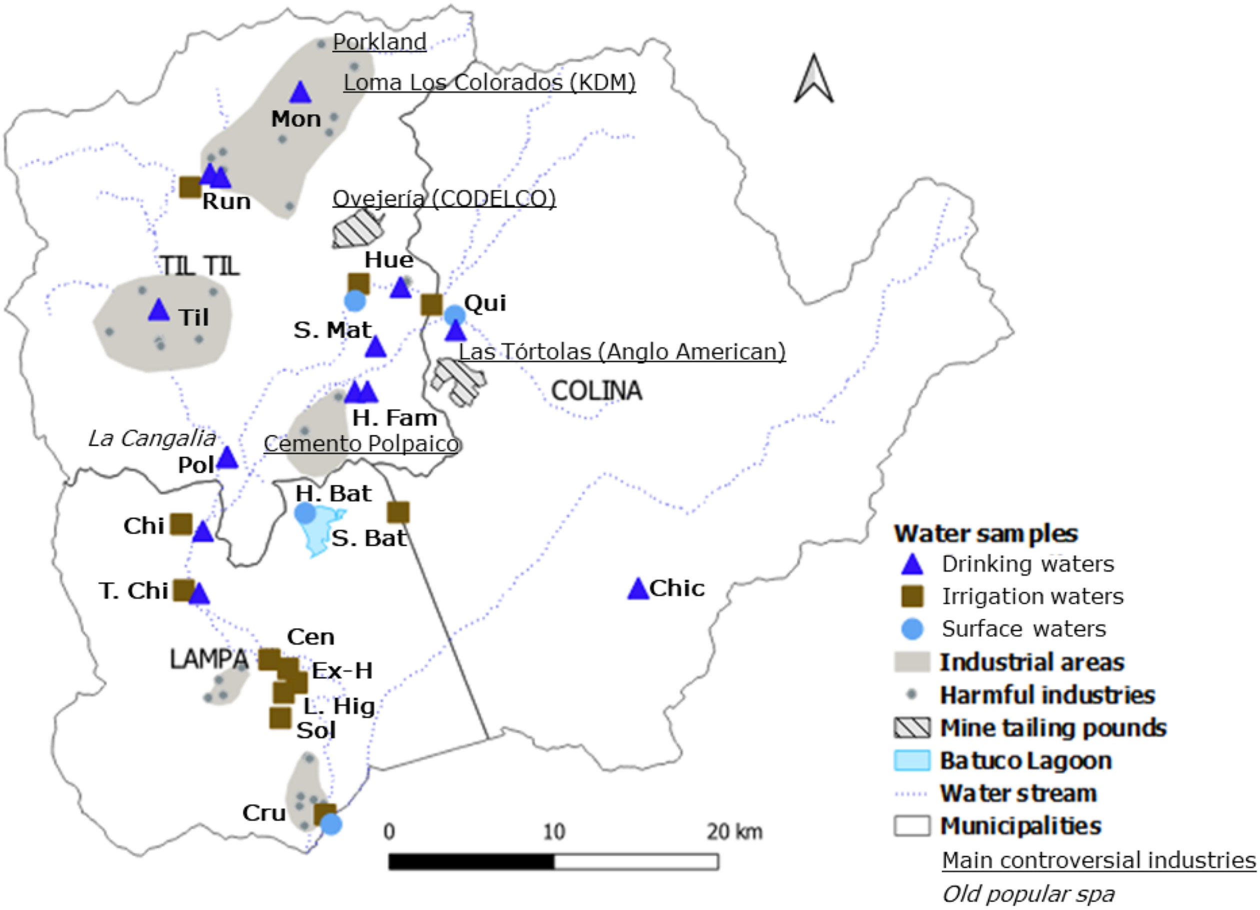
### Field investigation

The research work was carried out on the same site and jointly in several disciplines (geochemistry, geography, and sociology), with, on one hand, a social survey on the relationship between communities and water and, on the other hand, a campaign to measure the quality of drinking water distributed to the inhabitants, but also of surface and groundwater, sometimes used for irrigation. The different localities of the three municipalities of the province of Chacabuco we sampled are listed and shown in Fig. 3. These data were complemented by an analysis of secondary information sources such as Google Earth satellite images and the Chilean population censuses of 2002 and 2017.

### Social representations of environmental resources and impacts

The results obtained are based on the analysis of different data sources and their cross-referencing. Between 2018 and 2020, during five field missions (from 10 days to 4 months), data were collected on the practises and representations of water-related risks (shortage, pollution, and flooding) through a survey of the local populations of the province's three municipalities. The information was gathered using three qualitative research methods: participatory mapping workshops (5), to make a diagnosis of the water-related problems as perceived by the inhabitants of different localities (Poncet 2018) and then to compare them on a provincial scale; individual semi-structured interviews (38); and participant observations from inhabitants, user organisations, mining workers, and provincial public–private dialogue bodies when we took samples and set up the measurement devices. The network or snowball non-probability sampling technique was used to identify the participants in the interview survey (17 residents with social representation in community organisations and 21 without). Whether it was during the semi-structured mapping workshops (interview guide and development of the mapping phases) or during the qualitative interviews, what we wished to collect were above all the territorial diagnoses according to the actors (made by the inhabitants) based on an analysis of the practises and social representations in order to identify the relationships with the territories and the environmental impacts measurement. We used the support of the map during the

[1] https://www.uchile.cl/noticias/168766/sequia-los-desafios-para-chile-de-un-futuro-con-menos-agua.




| *Concerned municipality of Chacabuco province* | *Abbreviations of localities* |
|---|---|
| ***Til Til*** | Montenegro (**Mon**); Rungue (**Run**); Til Til Downtown (**Til**); Polpaico (**Pol**); Santa Matilde (**S. Mat**); Huechún (**Hue**); Huertos Familiaries (**H. Fam**) |
| ***Lampa*** | Chicauma (**Chi**); Taco de Chicauma (**T. Chi**); Central Lo Vargas (**Cen**); Ex- Hacienda Lampa (**Ex-H**); Las Higueras (**L. Hig**); Sol de Septiembre (**Sol**); Crucero-Peralillo (**Cru**); Humedal de Batuco (**H. Bat**); Santa Carolina de Batuco (**S. Bat**) |
| ***Colina*** | Quilapilún Bajo (**Qui**); Chicureo (**Chic**) |

**Fig. 3** Water sampling points (for drinking, irrigation, and surface water) and main polluting industries in the study area, Chacabuco province, Chile

workshops and the interviews to collect spatialized representations. Both the interviews and workshops were recorded, then transcribed in full and analysed through a thematic content analysis (Paillé and Mucchielli 2016) which consists of identifying the recurrent themes evoked during the interviews (transcriptions, listening or note-taking during the observation). Each theme corresponds to recurring social representations in the discourses. At the same time, to ensure their relevance and representativeness, we proceeded to an analytical questioning by querying the collected corpus with questions such as: What vision do the inhabitants have of their living space? What terms do they use to describe their territory? How do the inhabitants represent the quality of their environment? Do they question it and if so, in what way?

## Assessment of the quality of drinking, irrigation, and surface water

The environmental studies were carried out mainly in the municipalities of Til Til and Lampa, and to a lesser extent in Colina. The local contacts were essential for identifying water quality measurement sites. A total of 31 domestic and surface water samples from different sources were collected during the southern hemisphere winter (July 2019) in several locations: 15 samples from the drinking water distribution network supplied by Rural Drinking Water Committees (RDWCs) or Cooperatives (in rural areas), private companies (in urban areas) or supply trucks; 9 samples of deep well water used for irrigation and 7 samples of surface water (agricultural dams, irrigation canals, lagoon, rivers, and wetlands). The samples were taken in non-dry areas and according to the possible sources of contamination (from mining, industrial, and agricultural activities). Finally, a sample of drinking water was taken from the municipality of Olmué, in a neighbouring catchment area, to serve as a control for this study. Actually, the municipality of Olmué corresponds to another watershed and the drinking water distribution network is supplied by the Valparaíso province. All the water sampling points are listed in Fig. 3.

Water sampling was performed in Teflon bottles, using ultra-clean procedures. Surface water samples were also filtered in the field immediately after the sampling, using a 20 mL syringe and 0.2 µm cellulose acetate, pre-cleaned membranes or a 0.4 µm Teflon pre-cleaned membrane for mercury (**Hg**). All samples (surface, sub-surface, and drinking water) were stored in 60 mL polytetrafluoroethylene (PTFE) bottles, with the exception of samples for **Hg** analyses, that were stored in 15 mL polyethylene bottles, after adding 3 drops of bi-distilled solution of hydrogen chloride (HCl), and kept cooled (4 °C) until the metal(loid)s analyses. Solutions for metal(loid)s analyses were acidified to ~ pH 2 with double-distilled $HNO_3$.

Metal(loid)s concentrations (except for **Hg**) were determined by Induced Coupled Plasma-Mass Spectroscopy (ICP-MS, iCAP Q, Thermo Scientific- Kinetic Energy Discrimination mode using He) at the AETE-ISO platform (OSU OREME/Université de Montpellier, France) and at the GET laboratory. The Certified Reference Materials ION 015 (lot 1109, 157 Environment Canada) and SLRS-6 (National Research Council Canada) were analysed to check both the accuracy and the reproducibility of the analyses of metal(loid)s. Metal(loid) concentrations were determined with external calibration using (Be, Sc, Ge, Rh, and Ir) as internal standards to correct potential sensitivity drifts. Typical limits of quantification were: 0.035, 0.001, 0.001, 0.007, 0.008, 0.012, 0.004, 0.021, 0.004, 0.003, and 0.032 µg $L^{-1}$ for As, Cd, Co, Cr, Cu, Mn, Ni, Pb, Sb, V, and Zn, respectively. Uncertainties associated with the measurement were inferior to 3%. The agreement of certified sample analysis with certified concentrations was better than 85% for Cr and Pb, and 95% for As, Cd, Co, Cu, Mn, Ni, Sb, V, and Zn.

For **Hg**, after one night with 100 µL BrCl in each sample, **Hg** was analysed with an atomic fluorescence spectrometer after reduction with $SnCl_2$ and gold-trap preconcentration at the GET laboratory. Limit of quantification was about 2 pg for Hg. The certified reference ORMS-5 was used to check and correct the calibration curve made with CRM NIST 3133. CRM NIST 3133 is analysed seven times along the analysis sequence to correct bias along the day (20% of standard deviation) and samples by bracketing standard (typically one standard—six samples—one standard).

The concentrations in certified samples were in agreement with the recommended concentrations within the corresponding range of uncertainty. The reproducibility of our analyses (10 analyses of the sample material) was found to be between 5 and 10% for the elements presented in this work.

Finally, values obtained for metal(loid) concentrations in water samples were compared to the recommended values from the international Water Quality Guidelines (WQG) established by the World Health Organization (2005) and the Chilean Official recommendation NCh 409/1 (Norma Chilena oficial de 1984 modified in 2005) for drinking water (see Table 1 in Supplementary Information; modified from Maurice et al. 2019). Furthermore, although stagnant surface water from lagoon, agricultural reservoirs, and wetlands is not consumed by the population, it could cause contamination of ecosystems and indirectly generate health impacts through contamination of ground layers, food webs, or through crop irrigation. Consequently, we also compared the surface water data to standards set for irrigation water, not only to drinking water standards.

## Results

Our interdisciplinary study in this Chacabuco province has led to three major results that mainly explain the uncertainty felt by the inhabitants.

Firstly, the population lives here in a region of recent and unlimited industrialisation and urbanisation, and they have lost confidence in the efforts performed to preserve their natural resources such as water. Second, for climatic, geographic, and social reasons, it remains difficult to characterise environmental contamination, resulting in a lack of scientific knowledge in this area of Chile. Finally, local people are looking for answers to reduce areas of uncertainty, but the latent state of conflict is temporized by public and private regulation policies, and so doubts subsist.

### Recent industrialisation of the region has led to uncertainty about the quality of the environment

#### From a rural to an industrial peri-urban space

Thirty years ago, the province of Chacabuco did not lack water. At that time, it was an agricultural region feeding

**Table 1** Summary of concentration values measured in water samples (drinking, surface, and groundwaters; expressed in µg $L^{-1}$) for the three elements exceeding the quality guidelines: As, Mn, and Se, in the three municipalities of Til Til, Colina, and Lampa

| Metal(loid) content in water samples | Til Til | | | Colina | | Lampa | | |
|---|---|---|---|---|---|---|---|---|
| | Drinking waters | Surface waters | Ground waters | Drinking waters | Surface waters | Drinking waters | Surface waters | Ground waters |
| | $n=10$ | $n=3$ | $n=1$ | $n=2$ | $n=1$ | $n=2$ | $n=3$ | $n=8$ |
| **As** in µg $L^{-1}$(min–max) | 1.58–**27.88** | 5.00–**20.46** | 3.49 | 1.19 –3.30 | 5.50 | 0.90 –1.82 | 4.83–**69.46** | 1.15–6.14 |
| **Mn** in µg $L^{-1}$(min–max) | <LOD–1.05 | 0.58–**4623.00** | 3.29 | 0.13–0.93 | 11.09 | 0.06–0.10 | 15.60–**231.20** | <LOD –16.97 |
| **Se** in µg $L^{-1}$(min–max) | <LOD–4.90 | <LOD–2.47 | 0.85 | <LOD–0.22 | 1.22 | <LOD–1.74 | <LOD–1.66 | <LOD–**25.54** |

Values exceeding the Chilean standards appear in bold

the city of Santiago. In 1997, the province became part of the Metropolitan Region when the Plan Regulador Metropolitano de Santiago (PRMS, Metropolitan Regulating Plan of Santiago) was revised, which accelerated the transformation of this rural agricultural region into an urban periphery. In response to the expansion of the metropolis, the PRMS provides for the creation of urbanisation zones intended for Santiago's inhabitants who wish to acquire a large plot of land in gated community residences. Several zones have thus been opened; each intended to accommodate several tens of thousands of inhabitants.

At the same time, industrialisation has been increasing. The KDM Companies landfill (*relleno sanitario*) Loma Los Colorados in 1995, two tailing ponds (*relaves mineros*), Las Tórtolas in 1996 and Ovejería in 1999, and the Porkland pig farm in 2008 (14,450 pigs until 2015) were added to the infrastructures already present (Fig. 3), such as the Polpaico cement factory (Cemento Polpaico) (1955). Reinforcing this trend, the PRMS plans to concentrate the hazardous activities of the whole agglomeration in Lampa and Til (Jorge et al. 2020; Ministerio de Vivienda y Urbanismo 2010).

Finally, there are the legacies of older mining activities. In 1877, Til Til had 51 mines and was the third most important gold mining site in Chile, which was then the third largest gold mining country in the world (Ilustre Municipalidad de Til Til 2008). The tailings from these past activities have mostly remained in place, to the extent that some sites are now prohibited for certain uses (for instance, sector of La Cangalia, Fig. 4). This raises the question of the cumulative effect of tailings from closed and active mines on the health of the population and on the quality of the environment, particularly water.

## Socio-economic changes resulting in increasing pressure on the water resource

The recent evolutionary dynamics of the province of Chacabuco are reflected in a strong demand for the water resource, linked to a combination of factors. These dynamics are described from field observations and the observation of aerial images available on Google Earth at various dates, coupled with literature review.

As evidenced by the 2002 and 2017 censuses, during this recent 15-year period, the province absorbed 12.8% of the metropolitan growth, with very strong population growth in Colina and Lampa. Til Til, which is further out, is growing much more slowly, but still faster than the average for the Metropolitan Region (Fig. 5).


**Fig. 4** Sign indicating a "contaminated area" in the sector La Cangalia (municipality of Til Til) and prohibiting recreation on this site ("Camping, swimming, and parking are not allowed, La Cangalia area, penalty fee of 266 USD // Contaminated area")

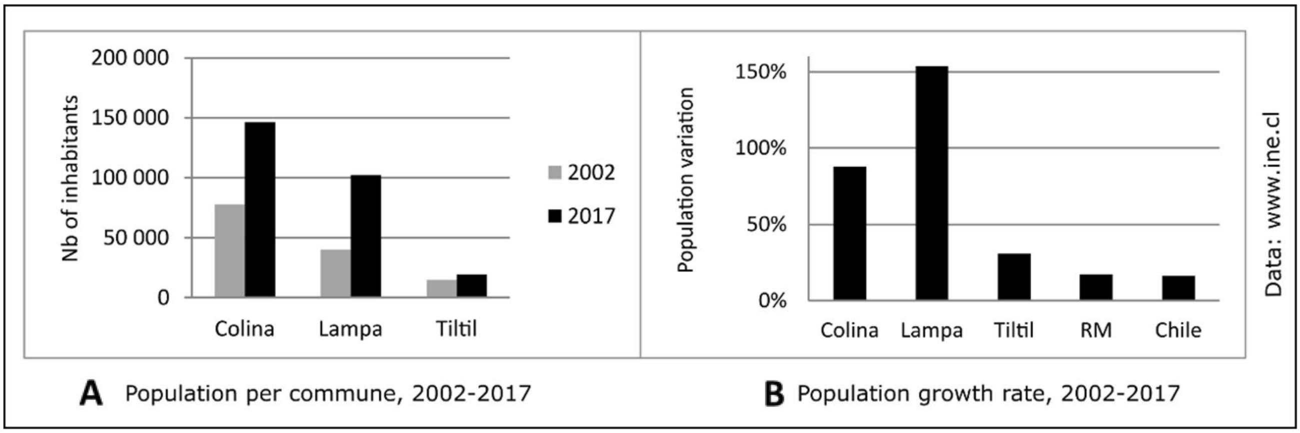



**Fig. 5** Population change, 2002–2007 (from INE, Chile)

The local population has diversified with the massive arrival of peri-urban populations (Nicolas-Artero 2015). The settlement of high-income populations, particularly in Colina, is associated with a lifestyle that is not water-efficient. Field and aerial observations show that the "condominios" (secure residences) include individual swimming pools and sometimes even artificial lagoons for leisure activities (Ayres de Chicureo, Piedra Roja, Hacienda Chacabuco), and are abundantly watered to maintain a green appearance. The increase in the number of residences also raises the issue of wastewater management, particularly in rural areas not connected to sewerage systems (source: interviews with inhabitants).

On the other hand, intensive agriculture has developed, mainly oriented towards the production of fruit for export. This is a technically advanced agriculture based on irrigation, which now has to pump large quantities of water from aquifers (Budds 2012), given the semi-arid nature of the province and the significant decrease in water supplied by the irrigation canals.

The province of Chacabuco is gradually trading its agricultural vocation for an industrial one. Aerial observation shows the increase of industry and housing and the decrease of agriculture due to urban growth (and maybe drought) (Fig. 5). These activities combined with mining activities are major consumers of water. The Polpaico cement plant in Til Til held 2.9% of the municipality's water rights in 2019, whilst mining activity used 7.4% of the water rights in this municipality (excluding the cement plant) (according to the Dirección General de Aguas (DGA) website: http://www.dga.cl).

Public planning policies and the natural and social dynamics specific to the Santiago agglomeration have thus led to the province of Chacabuco becoming a heterogeneous space, where highly polluting industries are found juxtaposed with well-to-do neighbourhoods, spaces of intensive production of agriculture with agricultural land abandoned for lack of water, and green neighbourhoods with localities that only have water for a few hours a day. The deliberate concentration of polluting companies thus creates a region that is unequally affected from an environmental point of view, with, on one hand, in the north and south-west of the province, sectors that accumulate severe environmental pressures and, on the other hand, privileged neighbourhoods that benefit from the amenities of this peri-urban region (Lukas et al. 2020).

One can only wonder what impact this concentration of polluting activities might have on water quality, whether on the water consumed by the inhabitants or on the surface or groundwater systems.

## The difficulty of characterising environmental contamination

### Existing data: partial, scattered, and often opaque information

It is difficult to find data on the functioning of aquifers and their potential recharge capacity (Suárez et al. 2021), with respect to both their natural and their anthropic dimensions. According to Budds (2012), no one is sure how much water there is in the environment or how much water is used. This uncertainty is recognised and denounced as one of the shortcomings of Chile's decades-long water policy (Ministerio de Obras Públicas 2015, p. 278). Added to this is the uncertainty of the extent of the effects of global warming, leading to a worrying outlook for the future availability of water.

Water quality data are similarly uncertain. Publicly available data on water quality and potability are scarce, incomplete, and not up-to-date, focussing mainly on the surface network and limited to a few parameters (Banco Mundial 2011). In Chile, the Dirección General de Aguas (DGA, General Directorate of Waters), under the Ministerio de Obras Públicas (MOP, Ministry of Public Works), is responsible for collecting, generating, and publishing information on surface and groundwater quality. For this purpose, it has a water quality monitoring network in most of the country's basins. The Maipo basin, of which the study area is a part, has a secondary water quality standard (Ministerio del Medio Ambiente 2014). This standard establishes environmental quality levels according to 11 monitoring zones for the basin: in our case, the Estero Lampa zone is defined from the source in the Til Til estuary to the confluence with the Mapocho River. For all the surveillance zones, environmental quality levels are measured for 12 parameters, which are monitored annually by the surveillance programme. Of all the parameters measured in Estero Lampa, only dissolved oxygen does not comply with the limits established by the standard (5 mg $L^{-1}$) between 2015 and 2018.

In parallel, in 2020, the Superintendencia de Medioambiente (SMA, Superintendency of the Environment) dictates the programme of measurement and control of the environmental quality of water for the secondary environmental quality standards for the protection of inland surface waters of the Maipo River basin (MMA & SMA, 2020). The monitored parameters included dissolved oxygen, electrical conductivity, pH, Chloride, Sulphate, Biological Oxygen Demand, Nitrate, Orthophosphate, dissolved lead **Pb**, nickel **Ni** and zinc **Zn** and total chromium **Cr**, and new control stations are integrated. On the other hand, there is the National Environmental Control Information System, SNIFA, which is a public access web platform (https://snifa.sma.gob.cl/), developed by the SMA that provides information to the public on the control and sanctioning processes carried out by the SMA, under a territorial approach, together with rulings, sentences, and resolutions of authorities, related to environmental matters. It also includes access to public records of environmental instruments and sanctions. This platform records four complaints, audits, and compliance programmes in the three communes of the province of Chacabuco related to environmental sanitation between 2016 and 2020.

Despite this background, the government departments disseminate official data that are often incomplete for different reasons including frequency (irregular or infrequent data collection), scale (only the most important basins concerned and a lack of the local level), and monitoring parameters (only elements recognised as being toxic to human health) (see Instituto Nacional de Derechos Humanos 2018). For example, the Dirección General de Aguas (DGA, General Directorate of Waters), which has tried to update and diversify its data collection in recent years, publishes on its website partial results of waters sampled concerning only the total content (not filtered water) of main water constituents and some trace elements. Quantitative and qualitative water databases do not interact with each other and an efficient system that would centralise updated and spatialized water information seems to be lacking. Nevertheless, this public institution is currently developing Strategic Water Management Plans for the 101 basins of Chile. The contribution of these indicative documents would be to take stock of current and projected water supply and demand at the national level to implement a series of actions, and also to reduce the gaps concerning hydrographic information.

Conversely, public institutions have not taken sufficient ownership of the issue and there is now an imbalance in the production and dissemination of public and private information. Some information is available in the form of reports on drinking water quality produced by private companies. The mining company CODELCO (Corporación Nacional del Cobre) has put online daily and monthly the results of its monitoring measurements carried out in RDWC shafts near the Ovejería settling pond,[2] located in eastern Til municipality, close to populated areas (Figs. 3, 7). The Anglo American mining company, whose settling pond is situated in northern Colina municipality, in the same area as Ovejería's, shares air quality and water quality measurements twice a year. The results that have been made public meet the thresholds set by the Chilean standard.

For its part, very little scientific data are produced by academic research laboratories for this province. Results are not always consistent according to the sectors studied. For example, recent studies conducted by the University of Chile (Mellado Tigre 2008; Guerrero et al. 2015) on surface water (Batuco Lagoon and the locality of Huechún) conclude that there is no metal(loid) contamination, including **As**. However, investigations by Tchernitchin et al. (2006) and Tchernitchin (2014) showed that **As** had been detected (17.8 µg $L^{-1}$) at levels that are almost double the Chilean NCh 409 standard for drinking water (10 µg $L^{-1}$), but do not reach the Chilean NCh 1333 standard for irrigation water (100 µg $L^{-1}$) in the Rungue agricultural dam. Tchernitchin (2014) also reports very high manganese (**Mn**) levels for this dam (2,872 mg $L^{-1}$), which greatly exceed the Chilean regulatory thresholds (NCh 409/1) and the international standard (WHO 2005), and which could potentially cause groundwater contamination.

Finally, at the local level, data on drinking water are often produced by Rural Drinking Water Committees. Their values are in accordance with the NCh 409/1 standard. In recent years, occasional episodes of exceeding the standard's thresholds, particularly for iron, As and nitrates, have been reported in the RDWC of Colina. In contrast, the municipality of Til Til, more exposed to nuisances and pollution than its neighbouring municipalities, published a report listing

[2] https://www.codelco.com/prontus_codelco/site/edic/base/port/monitoreo_apr.html.

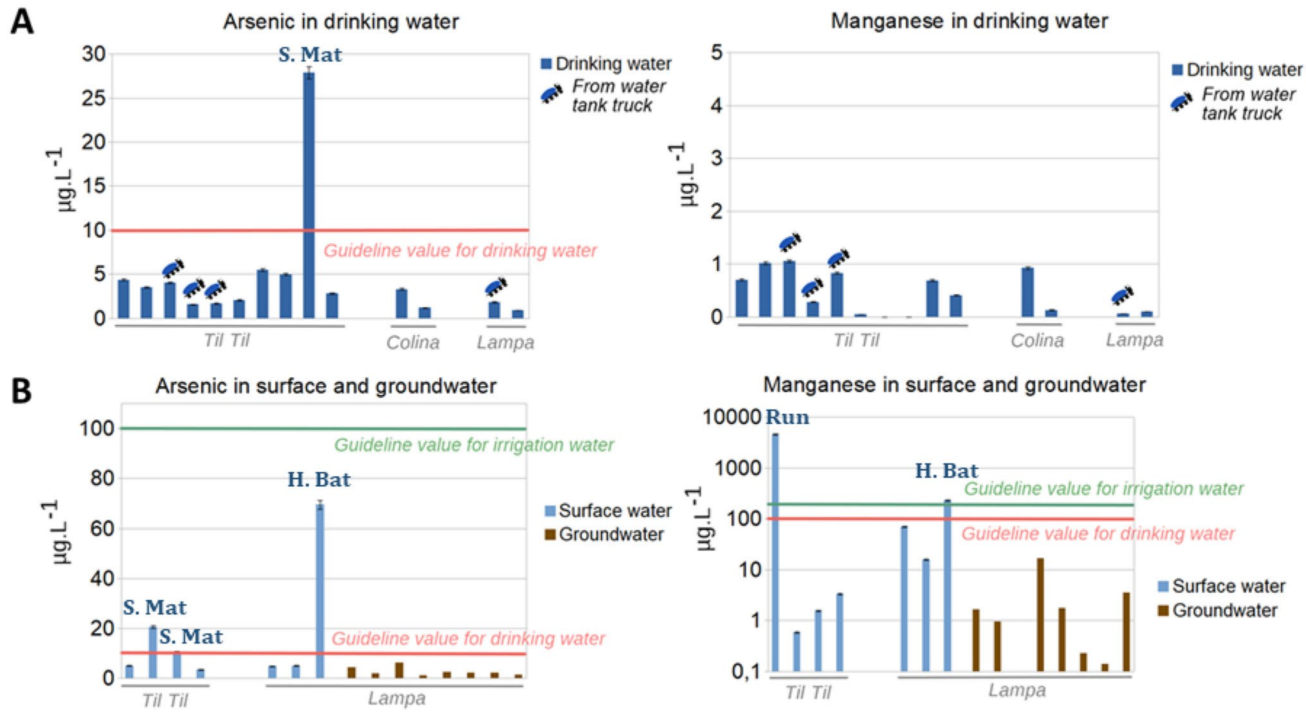



**Fig. 6** Concentrations of As and Mn in drinking water (**A**) and surface and groundwater (**B**). Values are expressed in µg $L^{-1}$ for the different sites studied. Regulations are represented by bold lines in green (for irrigation water) or red (for drinking water)

the sources of pollution identified in its territory (Ilustre Municipalidad de Til Til 2008).

Consequently, the existing data appear to be disparate and contradictory. They all come from very specific studies and conclude that conditions are “normal”, even if they sometimes suggest that there are potential health and environmental impacts.

## Our geochemical characterisation of the province of Chacabuco

To compensate for this lack of data, additional geochemical analyses were carried out as part of our study. The results are presented in Figs. 6 and 7 and in Table SI-2 (in Supplementary Information). Moreover, a summary of our geochemical data with the minimum and the maximum values for the three elements (arsenic, manganese, and selenium) exceeding the quality guidelines (WHO regulation) is proposed in Table 1.

Our geochemical results show that the water consumed at almost all the sites sampled is free of metallic pollution, as the data obtained are well below the limits set by the World Health Organization (WHO). As a reminder, regarding Latin America, in Argentina, the limit set for **As** in drinking water is 50 µg $L^{-1}$ (Blanes et al. 2004), whilst in Chile this value is regulated by the Chilean drinking water standard (NCh409/1. of 2005) at 10 µg $L^{-1}$ (Table 2 in Supplementary Information), which is the same value as for international standards.

Only one of the deep wells surveyed was reported as having **As** levels above the international potability thresholds: 27.88 µg $L^{-1}$ of arsenic at the water surface of the deep well (80 m) in the village of Santa Matilde (Fig. 6 Table 1). The water from this well, built for the inhabitants by CODELCO and handed over to the Santa Matilde RDWC, is intended for human consumption. However, due to mistrust and suspicion of metallic contaminants in this well water, the families concerned do not consume it and instead get their water in cans.

Concerning surface water, **As** concentrations exceeding the potability standards were found in the wetlands of the Batuco Lagoon in Lampa (69.46 µg $L^{-1}$, as shown in Figs. 6 and 7 but also in Table 1) and downstream of the Huechún agricultural dam in Til Til (10.45 µg $L^{-1}$ in the reservoir and 20.46 µg $L^{-1}$ in the wetlands further downstream). In both cases, it corresponds to stagnant surface water, rich in organic matter, which retains metal(loid)s by complexation and adsorption. The values recorded are higher than the national medians reported by Tapia et al. (2019b) with values of 10 and 5 µg $L^{1}$ for the basic statistics for surface water and groundwater respectively, for the whole of Chile, from north to south. However, the values measured are still below the threshold set in Chile for irrigation water (Table 1). Indeed, the Chilean standard regulates water according to

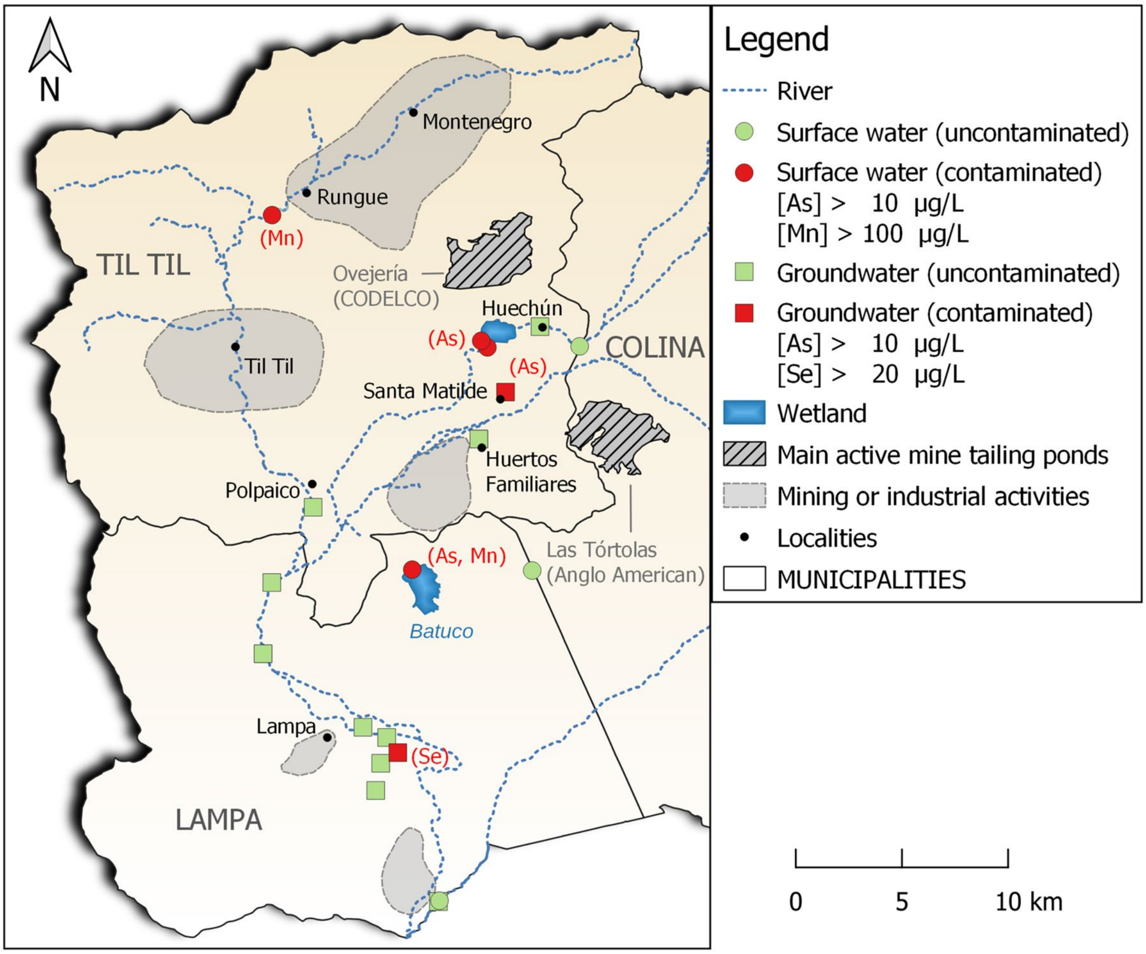



**Fig. 7** Water quality in surface and groundwater in the Chacabuco region with regards to As, Mn, and Se concentrations

its use; thus, for irrigation the threshold value retained for **As** increases to 100 µg $L^{-1}$ (Guerrero et al. 2015).

In addition, elements used in agricultural inputs or industrial activities are also found in the environment, sometimes exceeding regulatory values. In particular, very high levels of **Mn** (Table 1) were measured in the Rungue agricultural dam in July 2019 with a concentration of 4623 µg $L^{-1}$, which greatly exceeds the regulated values of 100 and 400 µg $L^{-1}$ laid down by, respectively, the Chilean standard (NCh 409/1) and the international standard (WHO 2005) governing potability (Fig. 6). For information, less and less used because of the drought, the Rungue dam is currently used very occasionally when water levels allow it (only once in 2021) to feed the irrigation canals that lead to Til Til. Although **Mn** is an essential nutrient, exposure to high levels via inhalation or water ingestion may cause some adverse health effects (Williams et al. 2012). Actually, it has been suggested that neurological effects, along with increased reports of mild symptoms (such as forgetfulness, anxiety, or insomnia), may be caused by low, but physiologically excessive, amounts of **Mn**, and these effects appear to increase in severity as the exposure level or duration of exposure increases (chronic effects). Similarly, the levels found for selenium (**Se**) also exceed Chilean standards for drinking water (set at 10 µg $L^{-1}$) and irrigation (set at 20 µg $L^{-1}$) in a sample taken from groundwater in Ex-Hacienda Lampa (25.54 µg $L^{-1}$, see Table 1 and Fig. 7).

In the end, some of the waters tested (stagnant and from a deep well, Figs. 6 and 7; Table 1) showed high levels of **As**, **Se,** and **Mn**, suggesting the possible existence of contamination of anthropic origin (industrial or agricultural). The comparison between our results in Santa Matilde RDWC's well and those of CODELCO's monitoring done at the same place in July and August 2019 (in line with the standard) also raises questions. It is therefore difficult to conclude whether there is clear evidence of metallic pollution in this area, but the characteristics described suggest that this region could be strongly impacted.

## The difficulty for local people to reduce areas of uncertainty

### Areas of uncertainty that encourage vigilance and the search for information

In the province, the risk of pollution is mainly perceived by the inhabitants of Til Til, Lampa and the northern part of the Colina municipality, who live in the sectors where industries are multiplying, so that the threat, far from being stable, is, on the contrary, growing. Conversely, some inhabitants of Colina and Lampa, living in areas far from industries and with access to good-quality water, are not really aware of this. The distribution of water in tankers, paradoxically, does not solve either the problem of access to water (which is rationed) nor that of water quality (testimonies of abdominal pains following the consumption).

In general, the inhabitants we met denounced a lack of transparency and accessibility to information on the state of groundwater and hydro systems, which creates areas of uncertainty and contributes to a climate of mistrust and vigilance. Locally, we observed doubt as a social construct created from a set of presumptions in the minds of local populations: all kinds of "clues" are collected and used as evidence that there is contamination and potential health impacts. The concerns expressed become the driving force behind a search for "objective" signals to qualify environmental contamination. In terms of health, some female residents spontaneously mentioned the risk of illness and health problems linked to local sources of contamination. The observation of cancer cases in the people around them (participatory workshop in Til Til, 2018) or spontaneous abortions and foetal malformations (interview with residents of Crucero-Peralillo, Lampa, 2019) was interpreted as a consequence of water or air pollution of industrial origin.

As such, the charges refer to a range of companies responsible for landfill and waste treatment sites, agro-industrial and agrochemical activities, and mining activities. The focus is on the mining companies, Anglo American and CODELCO. The towns of Huertos Familiares, Santa Matilde, and Huechún are each less than 4 km from a mine tailing pond. Their proximity to mining infrastructures is in itself considered to be *"unhealthy"* and generates the feeling of "living on borrowed time": *"we know… that they are killing us little by little. Yes, people know"* (Santa Matilde resident, 06/01/2020). For the majority of those interviewed, past accidents suggest future episodes of pollution.

Finally, for a minority of inhabitants who live near large farms (table grapes, olive production), the focus on the mines hides the impacts of agriculture, in terms of water pumping and chemical pollution from the use of agricultural inputs.

In the absence of public monitoring of the environmental quality and its impact on health, residents are constantly seeking information and acting to ensure their own safety. Thus, two communities (Huechún and Huertos Familiares) have each contacted the *Universidad de Chile,* a research organisation which they trust, to carry out chemical analyses: *"to make sure that we live in a healthy environment, we have asked for soil and water tests"* (Huechún resident, 08/01/2020). These analyses did not reveal any existing pollution at the time of the measurements but the population continues to feel permanently exposed to pollution.

## A latent current of conflict throughout the province

The inhabitants we met consider themselves to be neglected or even disregarded by the institutions that give priority to industry in the regional development process: *"If you had to weigh up what is more important to the State at the moment, whether it is the people of Huertos Familiares or Anglo American, for them Anglo American is more important. Because it provides resources and all that"* (Huertos Familiares resident, 07/01/2020). The lack of recognition (Honneth 2004, 2006) is one of the key ingredients behind social mobilisations.

Individually or collectively, the mobilisations can enable the populations to be heard and the legitimacy of their claims to be recognised. Sometimes, people participate in demonstrations organised during socio-environmental conflicts such as against the Porkland pig farm in 2012 or the installation of the CICLO company's toxic waste treatment plant in 2017 (Jorge 2020); sometimes, it is a specific event that triggers concern and amplifies the perception of risks (Kasperson et al. 1988).

In 2012–2013, for example, the inhabitants, and especially the women, of Lampa took action following the discovery by the *Universidad de Santiago de Chile*[3] of arsenic levels three times higher than the norm in their drinking water. They had independent laboratories analyse the water to get the authorities to recognise the pollution, and organised demonstrations, as a result of which they obtained the installation of a drinking water treatment plant to remove the arsenic.

In another example, following the earthquake of 2010, a collective of women from Huertos Familiares alerted the public authorities to the lack of a perimeter around the danger zone (yet stipulated in the *Decreto Ley N°248 of 2007*) in the event of a rupture or collapse of the Las Tórtolas

[3] https://www.mch.cl/reportajes/descontaminando-arsenico-en-cuencas/.

tailing pond. First disregarded by the authorities, their struggle turned into a public–private participation body under the aegis of the United Nations Development Programme in Chile (UNDP-Chile) still in force today. By 2020, their initial request had still not been met. This example illustrates the lack of risk prevention tools on the part of companies, a situation tacitly allowed by a lack of State enforcement of existing legislation. Indeed, *"it is also with full knowledge of the facts that decisions aimed at protecting health and/or the environment may not be taken […]. Many economic activities legally generate risks"* (Boudia and Jas 2016).

Conversely, some people living in communities near dangerous infrastructures choose not to act and, in some cases, even prefer *"not to know"* to continue *"living peacefully"*: *"I know we are in a bad situation, but learning about it makes me angry […] Because you get sick afterwards. […] Personally, I don't want to know too much, because nothing can be done. […] Of course, that doesn't mean that I don't know"* (Santa Matilde resident, 06/01/2020). They believe that it is futile to fight against powerful companies. Sometimes, their inertia is also linked to a relation of dependency, when they work for one of these companies.

The discontinuity of mobilisations over time and their local character do not give rise to an open conflict on a provincial scale neither to a real opposition force to adjust the balance of power. It seems that the latent state of conflict is weakened by the deployment of a series of instruments of social regulation, whether public (via the institutionalisation of conflicts) or private (via the distribution of part of the benefits of the controversial activities), which tend to diminish claims and ensure a sort of *status quo* amongst water users.

## Regulatory policies that limit the consolidation of a citizen opposition force

The injustice felt about the deterioration of water resources is partly compensated by the financing of local projects, particularly with regard to access to or improvement of drinking water service. These measures are mostly welcomed by the populations, who are waiting for concrete solutions to the water crisis.

In villages where drinking water wells have dried up (RDWC of Rungue) or are unsuitable for consumption (RDWC of Montenegro), tankers are additionally financed by the municipalities and the Regional Government and by companies settled in the territory, such as KDM and Aguas Andinas. When the wells of the RDWCs run dry, the transfer of drinking water wells (RDWC of Santa Matilde) or the co-financing of infrastructure (RDWC of Huechún) by the mining companies Anglo American and CODELCO is strategic, and communities frequently resort to such solutions to recover sustainable access to drinking water more quickly, as the waiting time for public funding is several years: *"CODELCO does do some good, but that does not make it any less harmful. […] CODELCO has made a commitment to the community that, in the event of a water crisis, people will always have water"* (Huertos Familiares resident, 07/01/2020).

At the same time, Anglo American's installation of a sophisticated telemetry system for the province's Rural Drinking Water Committees, which allows real-time monitoring of water volumes from a distance, is appreciated but also seen as a means of controlling available water supplies that could be misused: *"I don't like it, it gives me a bad feeling. […] Information is power"* (Batuco resident, 10/06/2019).

Inhabitants of Huertos Familiares testified that the mining companies have encouraged communities to form organisations to receive financial aid: *"They said that CODELCO would only negotiate with organisations"* (07/01/2020). Compensation measures thus create alliances and divisions within local communities. The fact that inhabitants are dependent on companies does not encourage them to question the latters' practises and inhibits the political capacity of beneficiary communities to collectively address social and environmental issues: *"All the organisations that receive money don't want to stand up against the mining companies" (Ibid.)*. This situation is reminiscent of the one described by Juteau-Martineau in Ecuador concerning oil activities (2019). The historical evolution of the structural economic and social vulnerability of populations combined with the evolution of the instruments of public regulation of these activities (the obligation of social compensation) has led to the diversion of environmental norms from their primary objective (the right to a healthy environment): on one hand, populations accept pollution in exchange for economic and social favours granted by companies; on the other hand, companies accept to trickle down a share of oil profits to ensure social peace (Juteau-Martineau 2019).

Nor do these mitigation measures reduce uncertainties and environmental impacts, quite the contrary, and, moreover, this is not the purpose behind them. The uncertainty of local communities regarding the quality of their environment is sustained by private actors and public institutions. It would therefore appear that the *"production of ignorance"* (Boudia and Jas 2016) is an institutionalised strategy for maintaining control of economic interests. As its use in the Salar de Atacama has also been reported by Babidge (2006), this could be a common practise. The pursuit of extractive activities leads successive governments to accept certain hazards and environmental impacts to ensure the growth of its economy at the expense of certain 'sacrificed' regions.

## General discussion

### A need for complete and permanent environmental monitoring of the study area

The water consumed by the population appears free of metallic pollution, as defined by the WHO guidelines. However, our results showed some fairly high levels of metal(loid)s (**As**, **Cu**, **Se,** and **Mn** in particular) in one of the deep wells surveyed and in surface waters (in the wetlands of the Batuco Lagoon and downstream of the Huechún agricultural dam), sometimes exceeding the Chilean and international standards for water potability. Although we are not aware of any scientific data on the geochemical background of the area, it seems clear that this zone is marked by a naturally metallic-enriched background, which explains the current and past mining activities.

Thus, the possible origin of these metal(loid)s is debatable, mainly with regard to the mining and industrial activities that consume a lot of water in the area, but above all it raises questions about the evolution of the situation with regard to the climate change underway. Obviously, it is quite likely that mining activities in the area (extraction but especially storage in tailing ponds) remobilises these elements and accelerates their dispersion in surface waters or contaminates groundwater. This point has already been highlighted by the hydrogeology report of Cereceda Puyol (2013), showing that in the Rungue area intended for the CICLO toxic waste storage project, the groundwater is not suitable for consumption or irrigation due to the proximity of the settling pond of the former REFIMET mine. It suggests possible seepage with high levels of iron (**Fe**), arsenic (**As**), and cadmium (**Cd**) from the retention basin.

However, in attempting to go further in the conclusions regarding the potential contamination of the area, we ran into hydrological and geographical difficulties. It is indeed very difficult to take water samples due to the marked drought in the area, as in other regions of Chile.

While Tchernitchin's (2014) measurements were made during the dry season of a dry year, our measurements correspond to samples taken during the southern winter. Thus, even though it is important to place these studies, in the case of samples taken at moments "t", outside of any seasonality and in limited areas, **As** seems to be present continuously in stagnant waters, confirmed by repetitions of our analyses in January 2020, in the middle of the dry season in this area of Chile. The values recorded for **As** are about 50 $\mu g\ L^{-1}$ for the Batuco Lagoon wetland in Lampa and 5 $\mu g\ L^{-1}$ for water from the Huechún agricultural well, located near the Santa Matilde residential area. This shows the presence of **As**, even when the water table was at its lowest.

These **As** concentrations, even though they remain relatively low at present, could prove even more alarming in the future with the expected worsening of the drought. Climate change could also increase potential contamination by **As** due to a possible enrichment of stagnant surface waters by concentration of this metalloid as a result of evaporation processes, as already demonstrated in Mexico for arsenic and fluorides in arid zone aquifers (Alarcón-Herrera et al. 2020). Conversely, under conditions of intense rainfall leading to exceptional flooding (which remains quite possible in a Mediterranean regime), this situation could also worsen and lead to rare (but not impossible) flooding phenomena, which would lead to rapid leaching, remobilising the polluting elements in the soil and surface water of the area. This phenomenon has for example already been highlighted in the former mining district of Salsigne (France), which was one of the largest **As** mining basins in the world in the twentieth century (Khaska et al. 2015; Delplace et al. 2022).

Thus, the current severe drought could hide the problems of water resource quality and, in addition to the lack of a detailed spatio-temporal characterisation of the area, reinforce the difficulties of obtaining reliable and regular data. The current situation therefore does not allow for a clear scientific vision and amplifies the existing anxiety of local populations about the future. It is thus necessary to set up permanent environmental monitoring in the Chacabuco province hydro system.

### The lack of data in the literature and from experience on the environmental state of the area is glaring in comparison with other areas in Chile and Latin America.

Exposure to **As** via drinking water has been much more widely documented in other areas of Chile, and even in other Latin American countries (including Mexico) or in the USA, where there are concentrated areas of extraction or storage of sub-surface resources as there are here (Bundschuh et al. 2012; Caceres et al. 2005; Tapia et al. 2012). For example, at the South American scale, the study conducted by Tapia et al. (2019a) on the "Altiplano-Puna" high plateau, whose region extends over parts of Argentina, Bolivia, Chile, and Peru, aimed to monitor **As** levels in the environment and its effects on human populations. This study has revealed high concentrations of **As** in Chile and Peru, mainly of natural origin (mineral deposits, brines, hot springs, and volcanic rocks), which could affect 3 million inhabitants. Arsenic is found in all types of water on the Altiplano-Puna plateau over a wide range of concentrations (from 0.01 to 10 mg $L^{-1}$). However, indigenous communities seem to have adapted, and do not show serious deleterious effects, as their bodies have developed the ability to metabolise **As** efficiently.

Moreover, within Chile itself, the Coquimbo, the Northern Atacama, and the Antofagasta regions have been studied much more widely (Dittmar 2004; Pizarro et al. 2016; Tapia et al. 2018; 2019a). In the Coquimbo region, the hydrogeochemical processes controlling **As** and other metal(loid) contaminations have been extensively studied, particularly in the Elqui River (Dittmar 2004). Deposits of chalcopyrite and arsenopyrite, linked to geothermal and mining activities in the area, were found and the presence of arsenate was revealed at levels above drinking water standards, which led to decontamination work being undertaken. In the Northern Atacama region, large-scale mining activities (notably the Potrerillos and El Salvador mines) have been established for a long time and have been reported to have an impact on the environment, due to the proximity of the Chañaral Bay and two protected national parks (the Pan de Azúcar on the Pacific coast and the Nevado de Tres Cruces in the Andes). In addition, a comprehensive 3-year study was carried out in the basins of the Northern Atacama Region (Tapia et al. 2018) to better characterise the metal(loid)s in the waters and their origin to better constrain these sources of pollution and protect the populations and the environment. In particular, this study showed significant increased levels of Li (78,662 times the global average for a dissolved element in river water) > **As** (2,787 times) > molybdenum **Mo** (680 times) > antimony **Sb** (72 times) and to a lesser extent, increased levels of cadmium **Cd** and copper **Cu** (17 and 14 times the global average, respectively). Surface waters in the area showed naturally increased levels of dissolved **As**, lithium (**Li**), **Mo,** and **Cd**, whilst **Cu** and **Sb** levels were assumed to be related to mining activities. During the intense flooding of the El Salado River in March 2015, contaminant trace elements were remobilised in the Andes and the El Salado Alto basin, where high concentrations were recorded, especially due to the sudden creation of a hydrological connection between adjacent basins, which could also happen in our study area.

In the Antofagasta region, similar studies have been carried out and have even focussed on the levels of polluting elements accumulated in the plants consumed (Pizarro et al. 2016) to highlight the risks associated with the bioavailability of elements, including arsenic, after ingesting plants grown in contaminated areas.

Thus, in comparison, in the province of Chacabuco, there is a severe lack of data. Few studies have been carried out, and as a result, the presence of arsenic and/or the possible behaviour of metal(loid)s in this potentially impacted environment is still unknown and reinforces the idea of an "environmental sacrifice zone".

## Environmental standards in question

It is worth noting the normative difference applied in Chile between the threshold for arsenic in drinking water set at 10 μg $L^{-1}$ (NCh409/1. of 2005) and that in irrigation water set at 100 μg $L^{-1}$ (Guerrero et al. 2015). Thus, even if irrigation or surface water with levels of **As** that are above those of potability standards is not consumed, people could be indirectly but chronically exposed to inorganic arsenic when using this water, which is suspected to be contaminated, for food preparation, washing, or irrigation (Schuhmacher-Wolz et al. 2009; WHO 2012).

Moreover, these standards are not necessarily met for packaged water. Thus, the use of water brought from Santiago in tankers or the purchase of water in cans are not reliable solutions, either from an environmental or a health point of view. Actually, a recent study of Daniele et al. (2019) on the chemical composition of Chilean bottled waters (available on the Chilean market and purchased in randomly selected shops in the city of Santiago) revealed that 30% of the analysed samples exceeded the values of arsenic (**As**) permitted by Chilean drinking water regulations, the World Health Organization and the United States Environmental Protection Agency. Moreover, in 40% of the samples, the $NO_3$ content was higher than groundwater values, suggesting that the bottled water came from surface water. Furthermore, this study highlights the fact that there is an inconsistency between the Chilean norms that regulate bottled water and those that regulate drinking water.

## The prism of uncertainty as a preferred tool for analysis

From a theoretical point of view, the concept of uncertainty is therefore relevant insofar as, first, the validity of the scientific diagnoses in the present case study does not enable us to state with certainty that there is no pollution (Trudeau 2002, p. 103) and, second, the asymmetries of power between communities and companies. In the case studied, the institutional diagnoses diverge with, on one hand, studies highlighting the presence of **As** in Chilean surface and groundwater (and at levels above the recommended values in the studied area) and, on the other hand, the results of analyses of drinking water which, on the contrary, comply with the Chilean standard. These contradictory diagnoses are compounded by the lack of public data on a mining area that concentrates various industries and therefore various types of pollution. The lack of knowledge of the hydro system, the lack of monitoring and transparency on the impacts of polluting activities, and the failure to resolve the water management issues raised by residents in consultation forums (Ministerio de Obras Públicas 2015) increase doubts by fuelling residents' feeling of being exposed or even contaminated. Moreover, unequal access to information leads to a latent mistrust between, on one hand, local residents who depend on insufficient public data and, on the other, mining companies that produce their own private data on the state of groundwater to serve their interests in planning copper extraction systems.

### A breeding ground for future conflict

In this context, a feeling of anxiety and a climate of mistrust have increased tensions between the actors, generating a breeding ground for conflict (Honneth 2006). The feelings of injustice felt by some communities are growing as new industrial projects are developed. They are the result of decisions imposed by the authorities and interpreted as contempt by a part of the inhabitants, which appear as democratic failures. This feeling of being the “patio trasero” (backyard) of the metropolitan region (Allain 2020) maintains the inhabitants' distrust of the incomplete data provided by the State or the companies, which do not provide the necessary guarantees to ensure the tranquillity and safety of the inhabitants. Distrust of mining companies is not unique to the province of Chacabuco. The rejection by local communities of the truths promised by the "Corporate Social Responsibility principle of transparency" is also present in other mining regions of Chile, such as in the Atacama desert (Babidge 2015). The type of information circulating and the level of information to which inhabitants have access, as well as the energy used to obtain information, are constitutive and indicative of the power relations at work (Blot 2005; Blot and Besteiro 2017).

In the context of Chile’s breathless ultraliberal system, the current situation implies the emergence of an additional risk in the future around the ungovernability (Chamayou 2018; Fontaine 2003) of the region under study, given the likelihood of greater conflict in the coming years within the system of actors around three risky issues: control and access to water, water quality, and also hydraulic infrastructures (Lukas and Fragkou 2014). Existing tensions could be aggravated by the cumulative effects of climate change on one hand, and the multiplication of industrial and real estate projects that produce socio-spatial inequalities related to water on the other, as some work on the province of Chacabuco has suggested (Nicolas-Artero 2015). Finally, it is also the growing gap between the social demand for drinking water (access and quality) and the commitment of public entities to meet it, to the benefit of financially more profitable demands, which creates harmful impacts leading the region into a lasting conflict situation.

## Conclusion

The combination of quantitative and qualitative approaches to the research problem through the intersection of social and environmental sciences makes this research original. This study conducted in the province of Chacabuco shows that regional planning has led to a densification of uses that put pressure on water resources, which are already weakened by climate change. From the point of view of its quality, according to our analyses, traces of metallic contamination of stagnant surface water and deep wells have been found but remain sporadic, due to the current dry climatic conditions. In this context, the population identifies areas of uncertainty with regard to health and environmental impacts; it takes action in response to threats, but it remains subordinate to the power relations dominated by industrial companies. The social and political regulations at work continue to sow doubt in the minds of the public, maintaining the existing productive system and postponing as long as possible decisions concerning conflictual economic and socio-environmental issues.

Moreover, whilst drought partly excuses the difficulty in characterising water quality, it also serves to conceal multifactorial pollution and the gradual degradation of the inhabitants’ environment. In view of the health and environmental issues that mobilise the inhabitants, the long-term production of independent and transparent information on surface and groundwater on a provincial scale could reduce the asymmetries of power on one hand, and on the other hand remove the subsisting doubts and thus ease the existing tensions.

The few measurements carried out so far have focussed on pollution by metal(loid)s, leaving aside potential pollution linked to agricultural use (Fernández and Gironás 2021) and domestic use. Then, in a context where access to water is threatened, water quality may paradoxically become a secondary concern in the future: we are already seeing a certain resignation amongst inhabitants in the face of possible pollution of wells, particularly with arsenic, as has been shown in other countries affected by drought (Becerra et al. 2015). Moreover, although water has been the main social issue to date, air quality in a populated area is also a major issue in this highly industrialised area.[4]

Finally, there is a much broader process that could change the situation in this region. A new constitution, resulting from the social protest of 2019, is expected to come into

[4] This is why, our teams are currently working on air quality biomonitoring by studying the kinetics of atmospheric deposition using simple indicators and the exposure of endemic epiphytic plants (*Tillandsias aeranthos*) for effective and rigorous biomonitoring in the province.

being in 2022, marking the definitive end of the Pinochet era from which the current body of water law originated. Equitable access to water and the reduction of social and environmental inequalities is one of the major issues at stake in this constituent democratic process. It is therefore possible that the priorities of water management and the balance of power will change in the coming years.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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