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# Microbiological characterization of drinking water and socio-environmental study in the peri-urban area of La Plata, Buenos Aires, Argentina

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## ABSTRACT

The aim was to analyze the groundwater quality and evaluate the socio-environmental factors associated with the indicators of environmental contamination in the peri-urban area of La Plata. A descriptive cross-sectional study was conducted between 2013 and 2023, and six neighborhoods were selected. Water samples were taken according to the Argentine Food Code and a parasitological analysis of the water was performed using ultrafiltration. Socio-environmental analyses were carried out with semi-structured questionnaires and a generalized linear model was used considering a binomial distribution. Of the total water samples, 70% (75/106) indicated that the water is not suitable for consumption. The highest contamination by total coliforms was observed in Abasto, and the risk of contamination by this indicator was higher (odds ratio $> 5$) compared to other neighborhoods. A moderate percentage of fecal coliforms and *Escherichia coli* was found in Melchor Romero and El Peligro, although it was higher than that detected in the other neighborhoods. *Pseudomonas* spp. was observed in all the samples in Arana and in moderate amounts in Abasto and Lisandro Olmos. *Entamoeba* spp. and *Blastocystis* spp. were found in a quarter of the water samples. It is essential to manage environmental sanitation and family health access policies.

**Key words:** fecal coliforms, parasites, peri-urban area, socio-environmental characteristics, water

## HIGHLIGHTS

- The importance of the study is based on 10 years of research on water quality in La Plata.
- Bacteriological analyses made it possible to select neighborhoods where it was necessary to reinforce parasitological studies in water and to understand the socio-environmental impact in a complex area.
- This study provides a significant contribution to regional food security for strengthening action plans and sanitary management.

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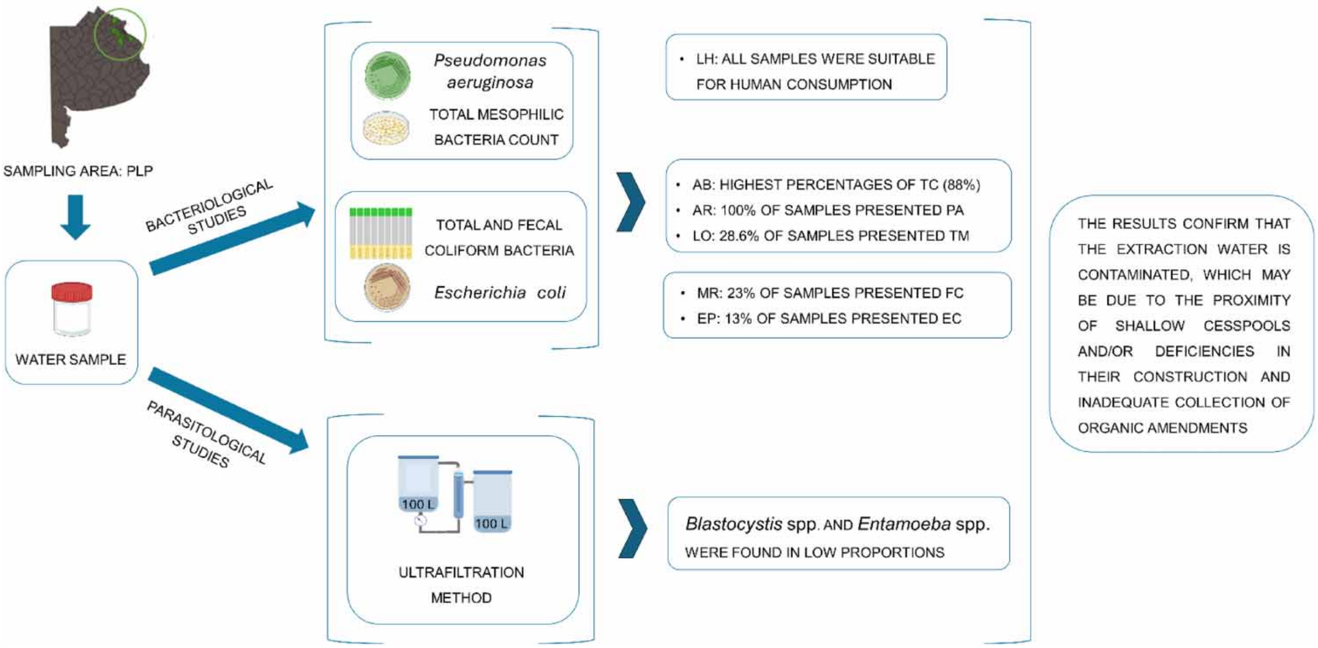
## GRAPHICAL ABSTRACT




## INTRODUCTION

The water cycle is an essential part of environmental systems, contributing to the climate and biological stability of the Earth (Richiardi *et al.* 2023). In rural ecosystems, urbanization processes have led to the creation of peri-urban areas, which are highly vulnerable from a socio-environmental point of view due to the absence of appropriate territorial planning, resulting in serious limitations in terms of access to adequate sanitation infrastructure (Adeyeye *et al.* 2020). According to UNICEF-WHO (2019), nearly one-third of the world population lack access to water services and more than half do not have access to safely managed sanitation facilities. Along these lines, the COVID-19 pandemic has highlighted the vital importance of sanitation, hygiene, and adequate access to safe water to prevent and contain disease. The availability of drinking water supply and sewerage systems is currently far from optimal, which restricts the enforcement of the human right of access to safe water. The quality of water available for human consumption is a determining factor in the health conditions of populations, since it favors both the prevention and transmission of agents that cause diseases (Briñez *et al.* 2012; Żywiec *et al.* 2021).

In Latin America, thousands of families are at risk of contracting preventable diseases due to the waterborne transmission of pathogenic species, such as parasites, bacteria, and viruses, which are responsible for a high prevalence of gastrointestinal diseases in humans and animals (Ravenscroft & Lytton 2022). The main risks to human health associated with the consumption of contaminated water are of microbiological origin, since 80% of all infectious diseases and more than a third of deaths in developing countries are caused by microbes (Guerra & Da Silva 2018; Vildozo *et al.* 2020). Consumption of water with a high number of microorganisms may mainly affect immunosuppressed people, young children, and infants (WHO 2015). The absence of coliform bacteria, *Escherichia coli* (EC) and *Pseudomonas aeruginosa* (PA), is key to achieving good drinking water quality, although controlling the growth of EC and other fecal coliforms (FC) is challenging due to their faster growth rate. In addition, the presence of FC is an indicator of parasites in the water. Outbreaks of *Giardia* spp., *Cryptosporidium* spp., and *Entamoeba coli* have been reported worldwide and are linked to water consumption (Alerte *et al.* 2012; Fletcher *et al.* 2014). Most parasites have a cystic structure that shields them from the immune response of the host and hostile environmental conditions, such as desiccation, nutrient deprivation, high temperatures, oxygen deprivation, and disinfection in wastewater treatment plants (Juaréz *et al.* 2015; Rivero *et al.* 2020).

In Argentina, around 2.6 million people live in areas with limited access to basic services, a situation that is more serious in densely populated areas (INDEC 2010). The province of Buenos Aires exhibits the largest population growth in the country,

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primarily in peri-urban areas with a high rate of unsatisfied basic needs (UBN) (Falcone *et al.* 2020; INDEC 2022). Our hypothesis is that the socio-environmental conditions in which families settle in the peri-urban area of La Plata (PLP) influence the aquifer ecosystem, thereby affecting water quality. The aim of this research was to analyze the quality of groundwater and evaluate the socio-environmental factors associated with indicators of environmental contamination in the PLP.

## METHODOLOGY

### Sampling area and population

The PLP constitutes the southern region of the Buenos Aires horticultural area and represents 9% of the total productive area of the province. PLP has a temperate climate with an average temperature of 16 °C, annual rainfall of 1,040 mm, and relative humidity of 77% (Imbellone & Mormeneo 2011). The predominant soil type is silt loam-textured Argiudol with abundant organic matter (Hurtado *et al.* 2006). The selected area included the neighborhoods of Abasto (AB), Arana (AR), El Peligro (EP), Melchor Romero (MR), Los Hornos (LH), and Lisandro Olmos (LO) (Figure 1). In this region, the wetland area includes 10 watersheds that drain into the Pampean and Puelche semi-confined aquifers (10–30 and 40–60 m in depth, respectively), and the boreholes for water extraction do not always exceed the depth necessary to reach the aquifer (Córdoba 2019) (Figure 2). The population composition and work activities in the peri-urban area are diverse. Most residents are migrant families from neighboring countries, who arrived in Argentina between the 1980s and 1990s. According to estimates from censuses conducted between 2010 and 2022, these families are part of the population with UBN (INDEC 2010; Oyhenart *et al.* 2013; Gamboa *et al.* 2014). In this context, groundwater is used for consumption, hygienic practices, and as a source of supply for crop irrigation.

### Study design

A descriptive cross-sectional study on water quality in the PLP was conducted over a 10-year period, between 2013 and 2023. Sample selection was non-probabilistic and was largely determined by the voluntary participation of families who gave their written consent for the analysis. The percentages of fecal bacteria (total coliforms (TC), FC, EC) and environmental bacteria (PA and mesophilic microorganisms (ME)) were evaluated in groundwater samples from six neighborhoods (AB, AR, EP, MR, LH, and LO), taking into account the environmental contamination indicators established by the Argentine Food Code (Código Alimentario Argentino, CAA). The neighborhoods that had previously shown statistical significance were

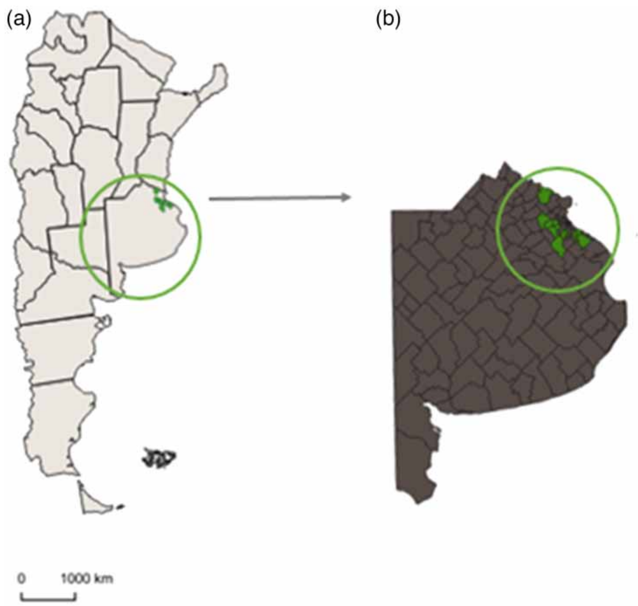


**Figure 1** | Buenos Aires province in Argentina (a), district of La Plata, and sampling area: PLP with the AB, AR, EP, MR, LH, and LO neighborhoods (b).

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**Figure 2** | Map of the watersheds of the basin that drain to Pampas and Puelche aquifers in PLP. *Source*: prepared by the Licensed Gabriel Atilio Rivas based on data from the Ministry of Infrastructure of the Province of Buenos Aires (Falcone *et al.* 2024b).

selected to evaluate socio-environmental data, together with microbiological risk factors. Subsequently, the neighborhoods that reported TC, FC, and EC were selected for parasitological studies in groundwater.

## Collection of water samples

The collection of groundwater samples was carried out at the level of the perforation. A total of 106 water samples were collected in the selected neighborhoods (AB: 27; MR: 35; LO: 7; AR: 11; EP: 15; and LH: 11). For bacteriological analysis, samples of 250 mL water were collected in sterile bottles. The microbiological examinations were carried out according to the methodology described in *Standard methods for the examination of water and wastewater* (American Public Health Association, 2005) and adopted by the CAA. According to the bacteriological results, parasitological studies of the groundwater were carried out in the AB, EP, and MR neighborhoods. Totally, 75 L of water were taken directly from the extraction well. Samples were analyzed by ultrafiltration with modifications, and the Sheather technique was used (Poma *et al.* 2012; Juaréz *et al.* 2015; Falcone 2021; Falcone *et al.* 2024a). The Ziehl–Neelsen technique was applied for the observation of resistant acid-alcohol oocysts, and non-permanent stains such as Lugol were used. Observation was performed using a Leica optical microscope at 100 ×, 400 ×, and 1000× magnifications. Identification of parasitic elements (cysts/oocysts) was based on their morphological characteristics and measurements (OMS 2019; Unzaga & Zonta 2023).

## Survey of socio-environmental data

The socio-sanitary and environmental analyses were carried out with semi-structured and non-invasive questionnaires, which were answered by the families (INDEC 2010; Falcone *et al.* 2020). The living conditions of the population were analyzed by

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means of the following factors: the construction materials of houses (walls and flooring), overcrowding (more than three people per room), access to public services (wastewater disposal, drinking water, and solid waste collection), hygiene habits (handwashing, water treatment, and vegetable hygiene), and pet ownership (dogs and cats).

### Data analysis

The proportions of bacteria indicating fecal contamination (TC, FC, and EC) and environmental contamination (PA and ME) present in groundwater were evaluated in the neighborhoods under study (AB, AR, EP, LO, LH, and MR) using a generalized linear model (GLM) of binomial distribution (Faraway 2006). The neighborhood was included as a fixed-effect predictor variable and the response variables, namely, TC, FC, and EC, were expressed as percentages. The proportions of microbiological data were evaluated according to the following variables: neighborhood (AB, MR, and EP), type of road (paved or dirt), overcrowding, wastewater disposal (sewage system, septic tank, or latrine), solid waste disposal (public waste collection, incineration, or non-sanitary burial), presence of dogs or other animals (cats, pigs, or rabbits), and health coverage. A GLM with a Bernoulli distribution was used for the analysis (Faraway 2006). For each proposed model, the interaction between variables was excluded and the following were tested: the effects of errors, the goodness of fit into the proposed models, and compliance with assumptions. In all cases, the odds ratio (OR) which could be less than, equal to, or greater than 1, and confidence Interval (CI) was calculated. Specifically for those variables that showed a large OR, an OR $>5$ was used as the cutoff point (Faraway 2006). The level of significance was set at $p<0.05$. Statistical analysis was performed using R software (R Core Team 2020). Since the AB, EP, and MR neighborhoods had the highest percentages of TC, FC, and EC, parasitological analyses of groundwater samples were performed.

### Ethics approval and consent to participate

The study was carried out without affecting the physical, psychic, or moral integrity of the participants and protecting their identity. Informed consent was obtained from the participants and the study complied with all the current regulations. It was conducted according to the principles in the Universal Declaration of Human Rights (1948), the ethical standards established by the Nüremberg Code (1947), the Declaration of Helsinki (1964), and its successive amendments. All families signed the informed consent form before participating in the study, and the participants gave written consent for the publication of the analyzed data in this research.

## RESULTS

### Drinking water analysis

Of the total samples studied, 70.7% (75/106) indicated that the water was not suitable for human consumption, and only in the LH neighborhood, no presence of microorganisms was observed. In AB, 88.9% (24/27) of the samples were contaminated with TC, followed by MR with 71.4% (25/35), LO with 57.1% (4/7), AR with 54.5% (6/11), and EP with 20% (3/15). When comparing the percentages of TC between neighborhoods, it was observed that the AB neighborhood had a higher risk of TC contamination (OR $>$ 5; CI: 2.8–362.4) compared to EP, while the risk of TC contamination was equal between the MR and EP neighborhoods. Conversely, the percentage of FC in MR was 22.9% (8/35), and in EP was 13.3% (2/15), whereas it only reached 7.4% (2/27) in AB. No FC were found in the LO neighborhood nor were any statistically significant differences observed in analyses performed between the neighborhoods. The presence of EC was moderate in EP and MR (13.3% (2/15) and 11.4% (4/35), respectively), while lower values were detected in AB (7% (2/27)), and no statistically significant differences were observed between them. EC was not found in the LO neighborhood (Tables 1 and 2).

In the parasitological analysis, a quarter of the water samples were positive for parasites, *Entamoeba* spp. and *Blastocystis* spp. were identified with 8.3% (1/12). *Entamoeba* spp. was identified in the samples from the AB neighborhood and *Blastocystis* spp. was detected in MR and EP neighborhoods

The AR neighborhood presented a PA percentage of 100% (11/11). The AB neighborhood showed a percentage of 37% (10/27), followed by LO with 28.6% (2/7), and lower percentages were found in EP and MR with 13.3% (2/15) and 5.7% (2/35), respectively. The analysis showed that AB had a higher risk of PA with respect to MR (OR $>$ 5; CI: 1.15–81.9) and it was statistically significantly higher than MR. The results indicated that LO had a moderate percentage of ME contamination of 28.6% (2/7), followed by EP of 20% (3/15). The MR and AB neighborhoods had lower percentages of contamination of 5.7% (2/35) and 7.4%, respectively. The presence of ME was not detected in AR, and no statistically significant differences were observed between all the neighborhoods studied (Tables 1 and 2).

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**Table 1** | Bacteriological analysis in water

| | TC | FC | EC | PA | ME |
|---|---|---|---|---|---|
| AB | 88.9% (24/27) | 7.4% (2/27) | 7.4% (2/27) | 37% (10/27) | 7.4% (2/27) |
| AR | 54.5% (6/11) | 9.1% (1/11) | 0% (0/11) | 100% (11/11) | 0% (0/11) |
| EP | 20% (3/15) | 13.3% (2/15) | 13.3% (2/15) | 13.3% (2/15) | 20% (3/15) |
| LH | 0% (0/11) | 0% (0/11) | 0% (0/11) | 0% (0/11) | 0% (0/11) |
| LO | 57.1% (4/7) | 0% (0/7) | 0% (0/7) | 28.6% (2/7) | 28.6% (2/7) |
| MR | 71.4% (25/35) | 22.9% (8/35) | 11.4% (4/35) | 5.7% (2/35) | 5.7% (2/35) |

The table summarizes the tests that were positive for at least one microorganism. These include TC, FC, EC, PA, and total ME.

**Table 2** | Risk factors associated with bacteriological analysis in water

| NEIGHBORHOOD | TC | FC | EC | PA | ME |
|---|---|---|---|---|---|
| AB–AR | NS | NS | NR | NR | NR |
| AB–EP | OR $>$ 5; $p$: 0.009 | NS | NS | NS | NS |
| AB–LO | NS | NR | NR | NS | NS |
| AB–MR | NS | NS | NS | OR $>$ 5; $p$: 0.03 | NS |
| AR–EP | NS | NS | NR | NR | NR |
| AR–LO | NS | NR | NR | NR | NR |
| AR–MR | NS | NS | NR | NR | NR |
| EP–LO | NS | NR | NR | NS | NS |
| EP–MR | OR = 0.1; $p$: 0.017 | NS | NS | NS | NS |
| LO–MR | NS | NR | NR | NS | NS |

NS, not significant; NR, this pair comparison was not selected for analysis; OR, odds ratio.

## Analysis of socio-environmental data

An analysis of the surveys ($N = 239$) revealed that the percentage of people analyzed was proportionally distributed among the following neighborhoods, i.e., 33.9% (81/239) in AB, 34.7% (83/239) in EP, and 31.4% (75/239) in MR. Of the total number of inhabitants, 78.6% (188/239) were children and young people, and 21.3% (51/239) were adults. Most of the families rented the houses they lived in (80.3% (192/239)), which were critically overcrowded (63.2% (151/239)). The survey reported that they had no health coverage (1.7% (4/239)); almost all the subjects surveyed receive health care from public hospitals. Furthermore, half of the families were found to have tested positive for parasites before being tested in the present study (positive for parasites: 49.4% (118/239); previous parasitological analysis: 50.2% (120/239)), and most of them had received information on intestinal parasites (60.3% (144/239)). Regarding personal hygiene, 64.4% (154/239) of the children washed their hands after playing with their pets, after going to the toilet, and before eating, whereas the adults (14.2% (34/239)) reported washing fruits and vegetables with treated water (boiled or chlorinated). Likewise, 59.8% (143/239) of the surveyed population presented at least one health condition, such as lack of appetite, abdominal pain, diarrhea, vomiting, or white spots on the skin.

Almost all the houses received the water supply from private wells (97.9% (234/239)), and the drinking water installation was outdoors in a high percentage of the houses (70.5% (190/239)). Moreover, excrement was disposed of by flush toilet and cesspool (98.7% (236/239)), and the toilets were most frequently installed outside the houses (79.8% (189/239)). Regarding waste disposal, burning or burial prevailed over municipal waste collection by a high percentage (83.7% (200/239) and 1.7% (4/239), respectively), probably due to lack of access. In addition, half of the houses were critically waterlogged (46.9% (112/239)) and were surrounded by dirt roads (48.1% (115/239)). All households had dogs and 22.6% (54/239) had other animals (i.e., cats, rabbits, pigs).

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## DISCUSSION

The importance of this study lies in the information obtained on water quality analyses in the PLP area over more than 10 years. Bacteriological analyses made it possible to select neighborhoods where it was necessary to reinforce parasitological studies in the water. In addition, it was fundamental to understand the socio-environmental impact in a complex area to strengthen sanitary action plans and health management. Therefore, the present research is a significant contribution to be made to achieve regional food security.

The primary source of water in the peri-urban areas of large cities is typically groundwater. A common issue associated with them is the extraction of groundwater from the aquifer layer at a faster rate than it can recharge (Torres *et al.* 2017). The low renewal rate and long residence time affect the aquifer ecosystem and pose a risk to water quality (Ceraso *et al.* 2018). In this respect, the water source can be contaminated by the entrainment of physical, chemical, and microbiological components depending on the existing sanitary infrastructure in the region of extraction (Álvarez *et al.* 2014; Falcone 2021). In this study, a high percentage (70%) of water samples studied in the PLP indicated that the water was not suitable for human consumption due to microbiological contamination. Among the neighborhoods selected for the study, LH was the only one in which all the samples analyzed indicated that the water was suitable for consumption. It is also important to highlight that LH is the founding neighborhood of the La Plata city, and, therefore, it has the highest degree of urbanization. The remaining neighborhoods analyzed have a higher proportion of rural areas, which translates as a higher proportion of water from wells and the presence of septic tanks. In addition, in these neighborhoods, most families produce some crop (tomato, strawberry, sweet bell pepper, lettuce, spinach, others), and in these cases, water from private wells is also used to irrigate and cool the vegetables (Gamboa *et al.* 2014; Falcone *et al.* 2023). In this sense, the results are similar to those observed in a study on the quality of water used for horticulture in Chaco, northern Argentina (Arzú 2020).

The AB neighborhood presented the highest percentages of contamination by TC (88.9%), followed by MR (71.4%). However, the presence of fecal indicators, such as FC and EC, were observed in higher percentages in MR (22.9%) and EP (13.3%), and low values were found mainly in AB (7.4%). During sampling, it was observed that the pipes were installed superficially, and the connections were either precarious or submerged in ditches in direct contact with surface water, making the water circulating through pipes susceptible to contamination by TC, as in the AB neighborhood. However, in both EP and MR, the wells from which drinking water is extracted may be contaminated with fecal matter from cesspools or septic tanks. Water from the Pampas aquifer is the most vulnerable to contamination, and this process may be accelerated by the soil characteristics of the region and the precipitation dynamics (Carbó *et al.* 2009; Córdoba 2019; Morra 2021). It is likely that deficiencies in the construction of the wells (shallow depth, short casing length, lack of cementing of the annular space, etc.) may render the water susceptible to microbiological contamination due to the presence of cesspools, garbage dumps, cats, dogs, and the use of organic fertilizers in their vicinity (Falcone *et al.* 2023). In addition, the percentage of contamination found was lower than that observed in a previous study in the region where it was shown that 96% of the samples analyzed during 2016 and 2017 presented microbiological contamination by FC (García *et al.* 2020). Given these adverse environmental situations, the agricultural peri-urban–rural regions are the most affected due to the presence of other potential risk factors, such as wild animals, flies, poultry houses, and stockyards, among others. In this regard, a parasitic prevalence of 79% was diagnosed in agricultural families (Falcone *et al.* 2020). Likewise, crop soil samples were analyzed and 30% were contaminated with Blastocystis spp. and protozoa (e.g., Giardia spp., Entamoeba spp.). This amount was doubled in vegetables (60%), where the same species of parasites were detected (Falcone *et al.* 2023). These results were associated with the living and production conditions of the families and environmental vulnerability that facilitate the dispersion of parasitic species.

In the parasitological analysis of the drinking water consumed by the families, *Blastocystis* spp. and *Entamoeba* spp. were found in low percentages. These results confirm that the extracted water is contaminated, which may be due to the proximity of shallow cesspools and/or deficiencies in their construction (such as casing and cementing) and inadequate collection of organic amendments (such as guano and chicken litter). Studies conducted in different rural agro-pastoral areas in Argentina indicate that both commensal (e.g. *Entamoeba coli* and *Endolimax nana*) and pathogenic (*Giardia* sp. and *Cryptosporidium* spp.) species are frequent due to water contaminated with human or animal feces (Unzaga *et al.* 2011; Juárez & Rajal 2013; Rivero *et al.* 2020).

In addition, all samples analyzed in the AR neighborhood were found to be contaminated with the environmental indicator PA. This opportunistic pathogen can grow in drinking water without any difficulty due to the formation of biofilms, even in

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previously chlorinated water (Hardalo & Edberg 1997). The LO and EP neighborhoods showed low percentages of PA (28.6% (2/7) and 13.3% (2/15), respectively) and ME (28.6% (2/7) and 20% (3/15), respectively). This could explain the high bacterial load due to contact with the environment. One of the main factors that may be affecting water quality is the defective construction of the wells from which water is extracted and its conduction and conditioning (Mitidieri & Corbino 2012). The results found in this study are similar to those of analyses of drinking water obtained from ground sources reported in other regions of Latin America (Rodríguez *et al.* 2018; Vargas *et al.* 2021; Aguirre 2022).

The quality of the water surveyed in the region seems to indicate that, although families generally treat water with chlorine and/or boiling before consumption, these hygienic practices are not sufficient to eliminate parasitic species (cysts/oocysts), which consequently explains the occurrence of the health conditions reported by the families (i.e., diarrhea, vomiting).

## CONCLUSIONS

It is immediately necessary to deepen the One Health perspective and strengthen environmental health, considering the association with risks to human and animal health. According to the World Health Organization, hand washing is one of the most effective actions that can be taken to reduce the spread of pathogens and to prevent infections and reinfections. However, the sanitary infrastructure on which water quality depends is fundamental to prevent the presence of these microorganisms in animals, people, and the environment, as well as to avoid their dispersion and recirculation.

It is expected that these results, obtained over 10 years of research in the region, will provide valuable information to mitigate the risk of water contamination by the presence of bacteria or parasites, which consequently affects the health of families and their pets or production animals. The articulation between the different disciplines working on water quality analysis, through governmental and non-governmental agents, as well as scientific–academic institutions, is fundamental to build, strengthen, and recirculate knowledge that will allow authorities to develop collective strategies that can be implemented in the community involved. Therefore, it is essential to manage environmental sanitation policies and access to health for families in the PLP region.

## STUDY LIMITATIONS

The increase in rent caused families to frequently change production units and prevented a broader scope of analysis, such as increasing the sample size or performing other more specific detection techniques (PCR). Despite those limitations, the parasitological and bacteriological results of this study revealed important information on environmental health in groundwater in the southwest of the PLP region.

## ACKNOWLEDGEMENTS

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## 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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