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Water Resources in the Salado River Drainage Basin, Buenos Aires, Argentina: Chemical and Microbiological Characteristics

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Abstract: *Buenos Aires Province is located in the region of greatest agrarian importance in Argentina. Studies that have been carried out up to now are mainly hydrogeological, geological, and limnological and focused on localized specific problems. The aim of this article is to determine the chemical composition, including trace elements and the microbiological characteristics, of surface and shallow ground waters at a regional scale as a basis that may allow the relation of the dynamics of the natural systems with that of the economically productive systems.*

Groundwater and surface water were sampled in stations located with a global positioning system (GPS). Chemical and microbiological analyses were carried out using reference analytical methods. A representative group of samples was also analyzed with ICP-MS techniques for the determination of trace elements.

Shallow groundwater is alkaline to strongly alkaline. The high sodium content is due to a cationic exchange process taking place in the clays of pampean loess. Surface waters, strongly alkaline and of sodium-chloride or sodium-sulfate type, come in part from the discharge of groundwater. The concentration of trace elements in shallow groundwater, does not respond strictly to the conditions of regional flow. Rather, their distribution is related to the morphology and distribution of several types of soils in the region.

The microbiological analysis showed that in surface waters the number of total heterotrophic bacteria is within the usual ranges, fluctuating between 1 x 10^3 and 1 x 10^5 CFU/ml. The values of total coliforms and thermotolerant coliforms are in accordance with international established parameters for recreational waters.

Keywords: *Salado River basin, surface water, shallow groundwater, chemical characteristics, microbiological characteristics*

Introduction

Buenos Aires Province is located in the region of the greatest agrarian importance in Argentina, the Pampeana region. The main water course is the Salado River, whose tributaries are the Vallimanca and Las Flores streams. The lower basin of the Salado River (Pampa Deprimida), located between 34° 20' to 38° 59' S and 56° 41' to 63° 23' W, is one of the main animal husbandry areas of the Pampeana plain in proximity to commercial centers (Figure 1). During intense rain periods, these rivers become extensive, slow-moving water sheets due to the width of their main channels and the slight slope. Regional hydrogeology is complex and is conditioned by the existence of local and regional flows (Usunoff, 1994).

These particular morphological conditions facilitate pond and swamp formation during the frequent flooding periods, followed by salt accumulation in soils. Vertical flows are more important than horizontal ones, and prolonged water contact with soils promotes high salt contents. These processes occur more intensely in shallow aquifers, the most economically exploitable resources in this region (Fuschini, 1994).

In the last ten years, intensive agricultural practices have increased considerably affecting water quality. Soil quality corresponds to cattle-raising and agricultural uses. Studies that have been carried out up to now are mainly hydrogeological, geological, and limnological and focus on localized specific problems. There are no integrated and regional studies focused on the influence of different activities upon the resource, the effects of intensification practices within each activity, and the relationship between surface and groundwater.

The aim of this article is to determine the chemical composition, including trace elements and the microbiological characteristics, of surface and shallow groundwater at a regional scale as a basis that may allow the relation

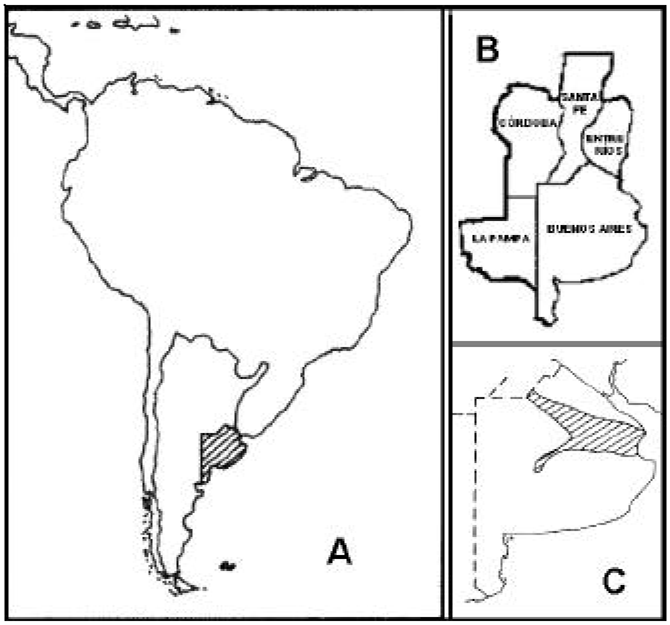

Figure 1. Map of Argentine and Buenos Aires province location in South America (A), The Pampeana Region (B) and location of the Salado River Basin in the Buenos Aires province (C).

of the dynamics of the natural systems with that of the economically productive systems.

Regional characteristics

Due to its natural characteristics, the Pampeana region is the most productive rain-fed area in Argentina. It occupies an extensive plain (522,997 km^2), providing almost 90 percent of the grain, pasture raised meat, and milk production of the country. The primary intensive activities carried out in the region are poultry (for meat and eggs), honey, rabbits, and horticulture.

However, inadequate agricultural management gives rise to problems, such as water and eolian erosion, and physical deterioration due to progressive salinization and nutrient losses in soil. Some 37 percent of the soils are affected by water erosion processes. In all cases, the most degraded areas are those that have recently witnessed intensification of agricultural activities (Solbrig and Vainesman, 1997).

The dominant morphology of the Lower Salado River Basin is a smooth prairie with mild slopes. The Salado River runs along a wide and flat deflation plain which is structurally controlled by deep block movement between recently reactivated fractures. This rambling river presents a great number of meanders and is originated 700 km from its mouth. It travels across the Pampa Deprimida, and it flows into the Samborombón Bay. Its regime is irregular, strongly dependant on rains, with tributaries reaching it from several sectors. During the intense raining periods, these rivers, as a consequence of the full traverse extension of its great beds and the slight slope, can be seen as extensive, slow-draining water sheets. In low-water stages, drainage is limited to the minor riverbeds of brackish waters.

Floods, to which the lower basin is particularly vulnerable, have been a major degradation factor, aggravated in part by infrastructure development. Intense rainfall events produce rapid river, stream, and pond expansion that turn into long-lasting floods and shallow aquifer recharge. When this occurs, shallow aquifers increase their recharge.

Permanent intensification of the agricultural systems located in the upper basin due to the lack of erosion control organic matter restitution and regeneration of the soil structure results in more visible signs of degradation. These consist of superficial crust formation and the formation of a subsurface dense layer due to plowing with both processes being totally related to soil-water economy.

Based on climatological data, the Lower Salado River Basin is classified as of template-humid climate, characterized by alternative dry and wet periods along the year, with annual rainfall of between 900 and 1,000 mm. The annual mean temperature is 16°C, with a maximum in January of 25°C and a minimum of 9°C in June, and the predominant winds come from the north, northwest, and southeast.

Summer rains are usually concentrated in a few days, showing great intensity. Although rain is more abundant during the summer, evapotranspiration is even greater resulting in a negative water balance in these months. Regional hydrological balance shows that average annual rainfall accounts for between 66 to 132 percent of the crops' water needs (Defina and Ravelo, 1975).

According to the Soil Charts (INTA, 1987), two distinctive areas can be established in the Salado River basin (Figure 2). One extends from the Salado River outlet towards the interior up to Monte County, where the 40 upper centimeters of soil profiles contain higher sodium concentration (natracualves and typical natracuols). This area is characterized by sheet-like surface run off which produces very frequent flooding, with salt accumulation.

The second area can be found from Monte County to Lobos County. This area has predominant typical Argiudols soils of scarce depth, occurring commonly on small slopes that emerge from the general flat landscape. Typical Natracuols of scarce depth are less common.

Due to the high sodium contents (Dangavs, 1973), soils in the low lands have developed features of alkalinization and halomorphism. Sodium saturation is higher in the lower levels due to soluble salt leaching from the upper levels. The final result is the formation of an impermeable horizon, which is detrimental to crop root systems (Peinemann, 1997).

Information obtained from soil map analysis showed variable characteristics. Even though the 1:500,000 scale showed well-differentiated areas, at a fieldwork scale of 1:50,000 the situation is different. Chascomús County was typified as mainly cropland and grassland, with mosaic type of soils, and predominantly alkaline lowlands. Lobos County has highly mixed soils, and croplands are widely spread throughout the area. On the other hand in Chascomús and Monte counties, the agricultural soils are well differentiated on the sandy slopes (Figure 2).

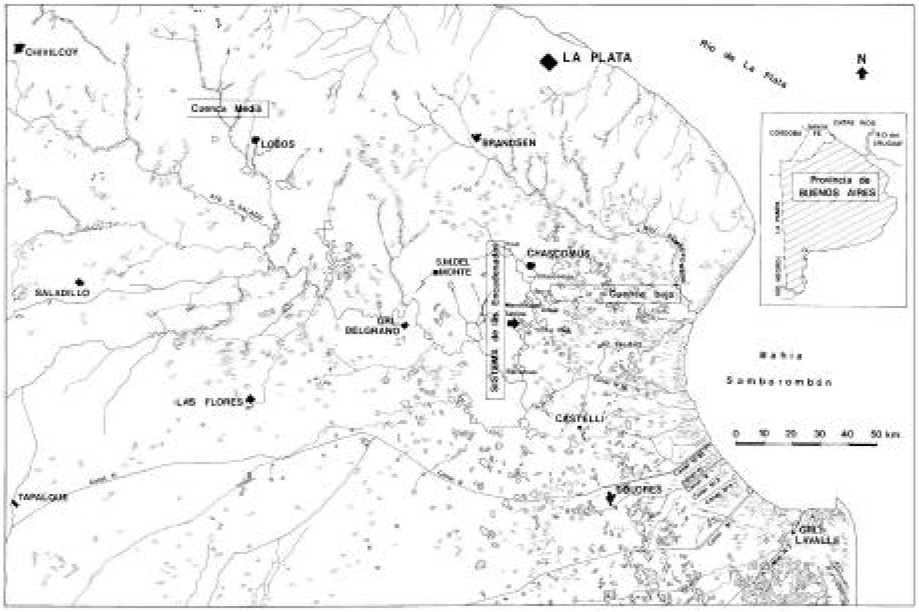

Figure 2. Map showing the Lower Salado River Basin (hydromorphology and three main studied areas – Chascomus, Monte and Lobos)

There are numerous ponds in the Lower basin, which were classified by Frenguelli (1950) and by Ringuelet (1962) based on their hydrologic regime, as exoreic, endoreic, or of a mixed type with effluent, influent, or mixed groundwater, and of permanent, intermittent, and ephemeral nature. These ponds (Las Encadenadas system, Monte, Lobos, among others), originate by embankment of the preexisting river bed by continental loessic sand banks. They may be considered as shallow polimytic lakes, vertically mixed over the year. This region is characterized as a plain with predominantly eolian calcium carbonate accumulation (Pampean loess), with a smooth and very moderate sloping in the south-southeast direction (0.05 percent on the average). However, ponds from the same geomorphological unit, drainage basin, and even from the same system that are only 20 km apart, present different ionic ratios, i.e. Mg/Ca from 0.16 to 1.08 and Ca + Mg/ Na + K from 0.13 to 0.60 (Conzonno and Fernández Cirelli, 1997).

Numerous canalizations and embankments were constructed to modify both permanent and transitory streams, as a way to improve the drainage during flooding periods. As a result, the natural drainage system was altered and, consequently, so has the landscape.

The Lower Salado River Basin's hydrogeology presents the most variable conditions, from water located in sand banks and Quaternary loessic sediments, to that found in Tertiary Formations. The hydrogeological basement is represented by Precambrian metamorphites, Paleozoic granites and sediments, and Permian-Triassic vulcanites, overlain by the Salado River Basin's sedimentary sequence. This sequence is part of the Parana Formation (Green Miocene), and in turn is overlain by the Puelches Sands Formation, (mostly represented by pure, micaceous, fluvial sands with salinity greater than 2 g/L). This "Salty Puelche" is not exploitable for agriculture or for human consumption (Auge and Hernández, 1983).

This sequence is overlain by the Pleistocene Pampean Formation, which fills and levels off Tertiary relief's irregularities, called "Pampean Loess," being eolian in origin, light brown in color, and unconsolidated. It is formed by slime, with subordinate fractions of clay and sand, it is rich in volcanic glass particles, and has variable quantities of calcium carbonate. It has the property to keep excavation walls vertical, which allows the construction of unprotected wells to exploit shallow groundwater, and this fact may contribute to aquifer contamination. From a mineralogical point of view, the material is essentially homogeneous. This region is characterized for having "poor aquifers" or "aquitards." An important element in the sediment mineralogical composition, due to its incidence in water chemistry, is the presence of volcanic glass as well as of calcium carbonate and, less frequently, gypsum.

The sequence is topped with Post-pampean deposits of fluvial, lacustrine, marine, littoral and eolian origin and Holocene age. These accumulations, restricted to the interior depressions (fluvial valleys, the bodies of the ponds) and the coastal boundaries, have scarce development both in a vertical as in an areal sense. The fluvial, lacustrine and marine accumulations are predominantly of fine granulometry (silt-clay) which grants them with an aquiclude to aquitard behavior, with high salinity waters. An exception are the rock shell belt and marine calcareous banks, located parallel to the coast that due to their coarse granulometry and mineralogical composition can act as aquifers, in certain cases, of good quality water. These are used in many riparian localities as potable waters.

Recharge from the phreatic aquifer is autochthonous, indirect, of an areal type and preferably localized in the inter-fluvial sectors. Deeper aquifers discharge into the phreatic groundwater horizon, from which they will, later on, join in and become a part of the Salado River and other important stream basic courses (Sala, 1975).

Water is drawn with wind mills of variable depth, without protective casing, going from 4 to 6 meters in proximity to the river's mouth up to 30 to 35 meters to the West of the Region. Pumps of variable characteristics and depth mostly supply towns and cities. The fact that it is not unusual for water sources in rural areas to be shared both by the local residents and animals must be taken into consideration. This generates a serious problem as different contamination problems related to animal manure are neither quantified nor monitored in the study area (Herrero et al., 1997). Contamination by indicator microorganisms, such as coliforms and thermotolerant coliforms, and their distribution and prevalence in groundwater has not been previously systematically studied in the study area.

Materials and Methods

The Lower Salado River Basin (LSRB) was selected due to the presence of different productive systems, to the piezometric levels of small depth, and the occurrence of shallow lakes (ponds), which represent an applicable model for the rest of the basin. The LSRB is defined by areas with homogenous ecological characteristics (climate, soil, natural vegetation, etc.), which differentiate dairy production areas, as are Lobos and Monte counties, and beef cattle production areas, as in the case of Chascomús county (Figure 2).

These countie s were selected due to their homogenous characteristics, as the result of the analysis of 1:50,000 and 1:500,000 scale topographical charts, and Soil Map, from the INTA, at the same scales. Temperature, evaporation, relative humidity, frost and rainfall incidence from the last 40 years (National Weather Service [SMN]), were taken into consideration. The regional agricultural data was obtained from the Official statistics from Agricultural Surveys and census from the last 40 years (Instituto Nacional de Estadística y Censos [INDEC]), in order to establish the productive systems present.

Sampling was carried out in successive campaigns from October 1997 to March 1999. Based on the results, new sampling stations were added. A total of 137 groundwater samples and 20 surface water-sampling stations, geographically located with a GPS were considered for major ions. Some of these were also considered for trace metal and microbiological analysis. The number of samples is specified in the respective results.

Groundwater samples were taken from hand pumps or wells, 4 to 35 m deep, which represent the main water source for the disperse rural population being used both as drinking water and for agricultural activities. Surface water samples were selected in several points of the river, ponds, and their tributary streams.

Dissolved oxygen, pH, and conductivity determinations were carried out *in situ*. Physical and chemical analysis (Na, K, Ca, Mg, Cl^-, $SO_4^=$, CO_3, HCO_3^-, NO_3^-, and SiO_2) and microbiological analysis of samples (indicator, pathogen and opportunist microbes) were determined using reference analytical methods (APHA, 1998) These samples were simultaneously analyzed with ICP-MS techniques to determine trace elements.

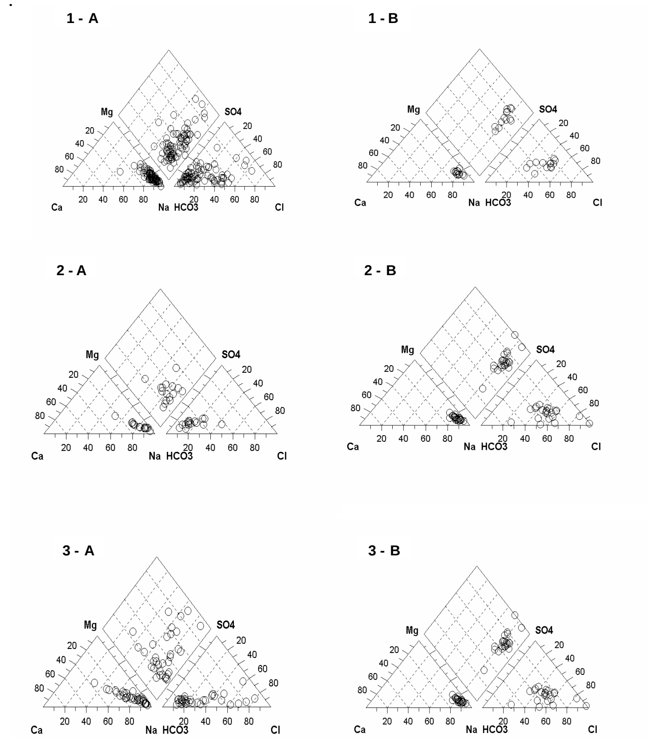

Figure 3. Trilinear Piper diagram showing the chemical characteristics of each of the regions, from ground and surface waters. Region 1: Lobos; Region 2: Monte; Region 3: Chascomus. A=groundwater, B=surface water).

Results and Discussion

Chemical Characteristics

The study area was divided in three regions according to the counties: 1) Lobos, 2) Monte, and 3) Chascomús and coastal zone (Figure 2).

Origin, evolution, and degree of contamination of shallow groundwater, an important source of surface water, were determined considering their hydrodynamic and hydrochemical behavior together with ground lithology. Chemical characteristics were interpreted using the Piper diagram of each of the regions (Figure 3).

In region 1 (Lobos), groundwater may be considered of the sodium bicarbonate type with the exception of one sample, which was of the sodium chloride type. No dominant anion was found in surface waters, which may be considered of sodium chloride/sodium sulfate type. In region 2 (Monte), ground waters and surface waters showed the same characteristics as in Region 1. In Region 3 (Chascomús and the coastal zone), 57 percent of the groundwater samples were of the sodium bicarbonate type. These were located within

Table 1. Chemical characterisitcs of groundwater

		pH	Conductivity ms/cm	TDS mg/L	Na ppm	K ppm	Mg ppm	Ca ppm	Cl- ppm	SO4= ppm	NO3- ppm	HCO3- ppm	SIO2 ppm
Lobos County													
	Minimun	6.70	0.40	200.00	75.70	0.00	0.00	3.80	12.00	19.20	5.00	0.00	nd
n=87	Maximun	8.69	9.00	6,413.00	2,205.60	76.00	300.00	259.40	2,433.6	1,65	250,00	1,878.8	nd
	Median	7.66	1.50	757.00	382.60	29.00	35.70	17.20	89.00	144.00	29.00	851.5	nd
	Average	7.64	1.73	1,086.35	496.55	30.56	47.42	24.13	228.18	235,73	38.67	824.08	nd
	SD	0.34	1.06	1,125.53	372.47	17.64	46.64	30.04	389.48	333.27	35.79	245.63	nd
Monte County													
	Minimun	7.02	1.2	541.5	202.00	8.00	10.00	8.00	37.00	58.00	3.00	542.00	52.00
n= 17	Maximun	7.79	3.00	1,370.00	519.00	40.00	54.00	79.00	502.00	269.00	339.00	913.00	62.00
	Median	7.46	1.6	755.5	325.00	24.00	24.00	23.5	84.00	134.00	31.00	718.00	58.00
	Average	7.47	1.83	825.19	356.47	24.35	27.11	30.68	136.70	140.58	55.94	721.00	57.41
	SD	0.21	0.49	232.83	84.59	9.86	12.65	20.01	122.95	52.63	85.19	91.93	3.04
Chascomus													
County	Minimun	6.63	0.90	428.3	96.00	5.60	6.00	6.00	37.10	19.00	5.00	429.40	19.60
n= 33	Maximun	9.1	21.00	11,292.00	3,741.00	96.70	201.10	305.30	3,652.30	3,143.10	256.00	1,126.90	72.90
	Median	7.85	1.70	785.25	350.00	24.20	31.00	32.00	139.30	58.00	29.00	671.00	63.10
	Average	7.69	2.65	1,415.94	482.22	27.43	45.61	59.25	416.97	198.35	48.12	703.53	61.72
	SD	0.57	3.64	2,059.35	632.70	18.37	48.85	66.12	761.62	538.23	53.58	160.08	9.39

(nd: not determined; SD: standard deviation)

the Encadenadas of Chascomús influence, while the remaining samples were either chlorinated or with no dominant anion. Mixed waters were found in the coastal zone, influenced by marine ingression. Surface waters show sodium as the predominant cation and no dominant anion.

Total Dissolved Solids (TDS) showed variable values in the three regions, having average values of 1,086 mg/L in Lobos, 825 mg/L in Monte and 1,415 mg/L in Chascomús (Table 1). Twenty groundwater samples were selected in the proximity of the Salado River, in the direction of the groundwater flow. TDS, Na and Cl contents are shown in Figure 4. No definitive trend in the west–east direction could be observed.

The higher values shown in Table 1 for Lobos region in comparison with the Monte Region could be explained by the longer periods water takes to go through the Lobos area, which allows a longer contact with aquifer sediments. Other authors have pointed out that in this region there is

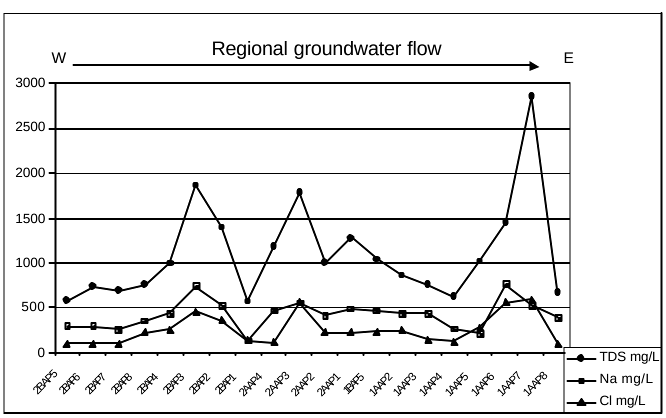

Figure 4. TDS, Na, and Cl contents in the direction of regional groundwater flow

an abnormality in the proximity to the Lobos Pond (Gonzalez and Auge, 1989). Another hypothesis could be a deep discharge from underlying aquifers (Toth, 1999). On the other hand, by considering the samples in the direction of the groundwater flow up to the proximity of the Salado River, salt contents show an increment.

The dominant sediment is the pampean loess, of volcanic pyroclastic origin. Based on the description of Teruggi (1957), the sand fraction is formed by plagioclases, alkaline feldspar, intermediate feldspar (andesine), as well as by vulcanic litoclasts, quartz, and volcanic glass. The composition of the silt fraction is similar to that of the sand fraction, but it contains an increased amount of fresh and altered volcanic glass shards. The clay mineral of this region is montmorillonite. The pampean loess composition also reveals an 8 percent of calcium carbonate as calcite.

Cation exchange capacity of the loessic sediments plays an important role in determining the chemical evolution of groundwater, the main source of surface water (Miretzky et al., 2000). We have also observed this throughout this region.

Base Exchange Index (BEI) and geochemical ratios Na/Ca, Mg/Ca and SO 4 /Cl were analyzed for the twenty samples selected for Figure 4.

The BEI used was (Custodio, 1998):

$$BEI = \frac{Cl - (Na + K)}{Cl} \quad \text{(concentration values in meq/L)}$$

BEI values were between -0.31 and -6, which effectively indicates a Na enrichment due to cation exchange with clays (montmorillonites have a cation exchange capacity of 80 to 120 meq/100g). Infiltrated soils exchange cations, releasing Na ions and taking Ca and Mg from water,

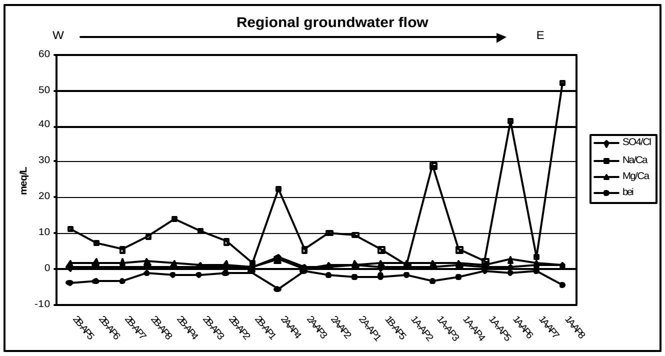

Figure 5. Ionic relations and BEI in the direction of regional groundwater flow (ions in meq/L)

decreasing hardness in water which become of sodium type.

The ionic relationships (Figure 5) do not show any definitive trend, being almost constant throughout the W-E axis. The Na/Ca ratio presents the highest value because of the high sodium content of waters due to the lithology of the basin and cationic exchange. Deviations from the plateau may be better explained by local flows.

Very few studies give detailed information on trace element concentrations in rural zone waters. Most elements are present in concentrations under 100 mg/L, and many are below 0.1 mg/L (Tables 2 and 3). As a consequence, the results shown here are limited to a description of the concentration of those elements with recognized importance, in relation with hydrochemical conditions and development of different types of soils in this region.

Soluble aluminum may interact with magnesium favoring the occurrence of hipomagnesemia (Allen, 1985). Values found were low in groundwater and high in surface waters, and just as iron values are high, near the Salado River mouth. Iron is a highly-distributed element in nature, and just as in the case of manganese, its presence in soils may be the most important source. Manganese presence is high, both in ground waters (average 152.49 ppb) as in surface waters (average 374.72 ppb) (Tables 2 and 3). Data collected from 150 surface water sampling stations in the US, showed an average of 29.4 ppb (NRC, 1996). According to the higher values found in this region, water may provide cattle with around 150 to 200 percent of this element's daily requirements. However, it could also induce a deficient copper absorption in young cattle.

The presence of zinc in water may be explained by the presence of loessic sediment with a melanocratic silicates precursor (amphibole and pyroxenes). This element's presence exceeds the Argentine guidelines proposed by the Hazardous Waste Law (No. 24051), with the higher values found in groundwater (average 159.4 ppb). Concentration in surface waters is very low, probably due to its tendency to precipitate or adsorb in the presence of suspended clay material. Zinc interaction with high values of lead and cadmium may produce deficiency problems in animal health. However, in this zone Zn and Cd are present in innocuous amounts.

Copper values found in surface and well waters are low and did not present any risk of toxicity. Molybdenum presence may be explained by the existence of pyroclastic materials in the sediment.

Arsenic is a natural contaminant in the Pampean region. It is present in 64 percent of the wells and in 75 percent of the surface waters, in concentrations that are over the guideline limits for humans and, in some cases, for animals. These values are similar to those expected in this region, as previous studies had shown (Herrero et al., 1997). These previous studies, which considered 260 sampling stations, showed an average of 0.09 ± 0.12 ppm. Vanadium is found in concentrations below the limits. It is related to bone calcification processes and is a cholesterol synthesis inhibitor. Values found were lower than in other zones of the country (Nicolli et al., 1985), and its presence is associated with clays of an igneous rock precursor.

Selenium values are similar to those found in other regions of the country in 85 percent of the wells. It is presumed to be of volcanic glass origin in this region. Even though its effects are beneficial, excesses may produce similar effects to those of arsenic. On the other hand, the presence of arsenic in water may increase the toxicity of selenium (Catalán Lafuente, 1981).

In a previous work (Galindo et al., 1999; Herrero et al., 2000), the trace element contents were statistically analyzed by Spearman non parametric correlation ($p<0.01$). This correlation analysis helped to understand the geographical distribution in groundwater of the most important elements for animal health and productivity. Results were analyzed in three groups with similar distribution (Figure 6). The first was formed by molybdenum, vanadium, and antimony, which presented an areal distribution from northeast to southwest, reaching the level of the Monte pond, and turning northwest from there. The second was constituted of selenium, chromium, cadmium, and silicon, with a distribution from northwest to southwest, from Monte to General Belgrano. A third group was constituted of copper, iron, zinc, lead, and manganese, which showed a peak values to the north of the region diminishing towards

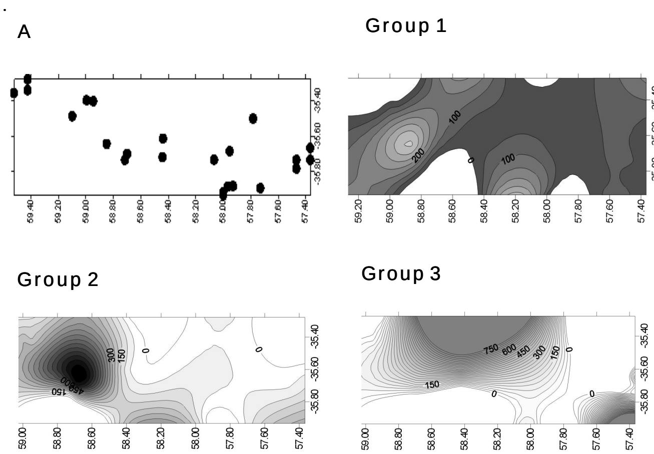

Figure 6. Areal distribution of trace elements grouped in similar categories. A: GPS sampling location. Group 1: Molybdenum ppb distribution; Group 2: Selenium ppb distribution; Group 3: Iron ppb distribution

Table 2. Trace element concentrations in groundwater

[redacted]

Table 3. Chemical characterisitcs and trace elements in surface waters

Parameters	(n= 20)	Minimun	Maximun	Median	Average	SD
pH		6.94	9.50	8.44	8.50	0.74
Conductivity	mS/cm	0.74	29.70	3.00	5.24	6.22
Dis.Oxigen	g/L	2.80	16.50	8.00	8.80	3.96
Na	ppm	195.00	5,285.00	631.00	1,071.5	1,173.45
K	ppm	5.82	135.25	26.16	38.39	33.91
Ca	ppm	15.15	306.43	56.97	68.55	67.80
Mg	ppm	8.51	327.76	35.94	55.88	67.86
HCO3-	ppm	188.00	671.00	429.00	454.80	144.17
Cl-	ppm	108.70	5,537.52	574.58	1,141.68	1,389.75
SO4=	ppm	1.37	4,612.26	573.42	827.75	995.61
Si	ppm	1.32	16.68	8.83	8.06	4.33
B	ppb	182.49	1,580.52	443.88	650.76	438.73
Al	ppb	83.87	8,706.01	742.06	1,477.65	1,974.74
P	ppb	52.95	1,012.78	248.61	326.85	282.10
V	ppb	12.24	278.68	63.07	80.00	65.59
Cr	ppb	0.20	31.22	1.64	4.75	7.91
Fe	ppb	39.47	11,100.19	643.49	1,164.97	2,400.34
Mn	ppb	7.16	3,078.42	173.16	374.72	663.23
Co	ppb	0.49	5.87	1.40	1.74	1.44
Cu	ppb	10.30	35.55	20.62	21.31	6.86
Zn	ppb	11.27	122.09	22.44	29.28	25.19
As	ppb	6.93	220.41	49.38	67.75	52.38
Se	ppb	68.95	363.57	121.39	147.47	77.35
Mo	ppb	1.23	127.04	24.90	37.58	38.63
Br	ppb	245.08	9,417.79	807.12	2,001.06	2,447.87
Cd	ppb	0.14	0.64	0.25	0.27	0.13
Pb	ppb	0.17	10.64	1.41	2.29	2.48

southwest and southeast. Arsenic could not be placed in any of these groups and has maximum values at the Salado River mouth and minimum values towards the west of the region. This trend is opposite to that of selenium.

The presence of trace elements does not strictly respond to regional flow conditions, and water residence time and microflow directions need to be taken into account (Galindo et al., 2000). The distribution of the trace elements is related to the morphology and distribution of the different types of soils in this region.

Microbiological Characteristics

In order to evaluate the microbiological quality of surface and groundwater, results were grouped into the regions mentioned above, that is: Lobos, Monte, and Chascomús. Chascomús is again divided into two sub-regions: the Salado River Mouth sub-region and the Chascomús pond sub-region (Figure 2).

Quality indicators, for example total heterotrophic bacteria, total coliforms, the presence *of Pseudomonas aeruginosa*, as well as specific fecal contamination indicators, such as thermotolerant coliforms, *Escherichia coli*, fecal streptococci, and sulfite–reducing clostridia were determined. Only the specific indicators of fecal contamination show the probability of existence of enteric pathogens. Fecal streptococci average values in surface waters go far beyond the standard set by US Environmental Protection Agency: 33 streptococci/100 ml for recreational waters (US EPA, 1986).

The results show that when surface waters are considered the number of total heterotrophic bacteria is within the usual standards, fluctuating between 1 x 10^3 and 5 x 10^5 CFU/ml. They coincide with other researchers' results, which show that bacterial counting in surface waters in several countries proved to be one of the most variable parameters of water quality, the magnitude fluctuating widely at the same sampling point. (UNEP.Gems/WATER, 1999).

Table 4 shows that surface waters in Monte and Lobos have the greatest number of thermotolerant coliforms, fecal streptococci and sulfite-reducing clostridia.

Table 5 shows that *Escherichia coli* were also found in surface waters in Monte (42.8percent of the samples) and Lobos (82.3 percent of the samples). The results are closely related to fecal contamination due to mainly wastewater in Monte, where the city is located on the pond. In the case of Lobos, the pond is located 5 km south west from the city but the main tributary to the pond carries wastewater from both a meat processing plant and farms.

Table 5 also shows the highest percentage of groundwater and surface water contaminated with *Pseudomonas aeruginosa* (50.0 and 57.1 percent, respectively). The presence of *Pseudomonas aeruginos*a, being an opportunistic pathogenic microorganism, is undesirable in recreational waters, and in drinking water it does not conform to national quality standards.

The presence of *Escherichia coli* in groundwater samples, in these regions is related to the type and number of contamination sources near the well.

Other bacterial species were found in surface waters, for example *Pseudomonas fluorescens,* which was found in surface and groundwater both in the Salado River Mouth region and in Lobos. Among the enterobacteria found, species of the genus *Klebsiella* and *Citrobacter* were determined in surface waters in these regions. In Chascomús and Lobos, *Aeromonas spp*. was determined in surface waters

Table 4. Fecal contamination indicators in surface waters

		Thermotolerant Coliforms /100 ml			*Fecal StreptococcI/100 ml*			*Sulfite-Reducing Clostridia/100 ml*		
Region	*n*	*M*	*m*	*av*	*M*	*m*	*av*	*M*	*m*	*av*
Lobos	17	4,300	<3	36.2	11,000	<3	296.9	1,100,000	3	1,504.8
Monte	14	11,000	<3	1,395.2	1,100	<3	217.1	11,000	3	2,259.7
Chascomús pond	13	460	<3	7.3	240	<3	62.8	390	3	70.0
Salado River Mouth	6	7	4	5	460	23	175.3	91	3	54.6

M: Maximum, m: minimum, av: average

Table 5. Presence of *Escherichia coli* and *Pseudomonas aeruginosa* in 100 ml. Percentage of Positive Samples.

	Groundwater			*Surface Water*		
Region	*n*	Pseudomonas aeruginosa/*100ml*	Eschericchia coli/*100 ml*	n	Pseudomonas aeruginosa/*100ml*	Eschericchia coli/*100 ml*
Lobos	39	15.5%	15.5%	17	29.4%	82.3%
Monte	6	50.0%	25.0%	14	57.1%	42.8%
Chascomús pond	16	37.5%	33.0%	13	50.0%	43.7%
Salado River Mouth	17	0%	11.1%	6	0%	50.0%

Table 6. Fecal contamination indicators in groundwater

		Total Coliforms /100 ml			*Thermotolerant Coliforms/100 ml*			*Fecal Streptococci/100 ml*		
Region	*n*	*M*	*m*	*av*	*M*	*m*	*av*	*M*	*m*	*av*
Lobos	39	11,000	<3	391.7	11,000	3	318.4	1,100	<3	145.1
Monte	6	464	<3	87.3	21	<3	4.2	<3	<3	-
Chascomús pond	16	1,100	<3	154.2	43	<33	2.5	<3	<3	-
Salado River Mouth	17	93	<3	17.6	23	<3	2.5	<3	<3	-

M: Maximum, m: minimum, av: average

used for recreational purposes. The ability to isolate and identify aeromonads from water is very important because of their role in causing human and animal disease, and as alternative indicators of the trophic state of waters (APHA, 1998).

Microbiological analysis results of groundwater samples are shown in Table 6. Minimum and maximum values for total coliforms are indicated as well as those for thermotolerant coliforms and streptococci found in each region. The sulfite-reducing members of the genus *Clostridium* were also found in 31.2 percent of the wells sampled in Lobos. This is an indicator of remote human or animal fecal contamination as sulfite-reducing clostridia can survive for longer periods in water than thermotolerant coliforms and Streptococcus streptococci.

Conclusions

Studies carried out in a large area of the Salado River drainage basin provide a panorama of the chemical and microbiological characteristics of a region highly important for the Argentina economy. Shallow groundwater is used in the studied rural area for agricultural purposes and frequently also for human water consumption. The Pampasic ponds and the Salado River and its tributaries are used for recreation.

The results obtained in the present study, suggest the need of further studies taking into account:

- The quality of the water resources in relation with chemical (major ions) and microbiological characteristics of the actually used water.
- Specific studies of microelement contents both in water and soil as related to animal nutritional needs and toxicity risks.
- Detailed knowledge of spatial water quality at sub-basin level in relation to the productive systems to provide directions for better management practices.
- The relation of microbiological quality of recreational water with human health.

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