Landscape, surface runoff, and groundwater quality in the district of Puán, province of Buenos Aires, Argentina

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ABSTRACT: The Puán district in the southwest of the province of Buenos Aires covers an area of 6,385 km^2 (2,465 mi^2) and has a population of about 18,000 residing in small urban centers and rural areas where farming is the main economic activity. Owing to the absence of freshwater streams and the low level of rainfall, groundwater provides the principal source of water and is used for human and animal consumption, as well as for the growing network of supplementary irrigation. This paper gives an overview of the district's water resources by reporting on the landscape, surface runoff, and groundwater quality within the framework of six geomorphological environments. Groundwater depth, anion-cation content and principal pollutants are measured in representative samples from each geomorphological unit. Pollutants are divided into those of natural origin (arsenic-boron-fluoride) and those induced by anthropic activity. The results obtained provide a basis for the adequate planning of water management, taking into account the consequences of groundwater exploitation and the implementation of preventive measures where necessary.

Keywords: Geomorphology; groundwater quality; Puán, Argentina

The importance attached in recent years to the adequate management of natural resources, particularly water, has given rise to plans for a comprehensive study at the regional level aimed at characterizing this resource. The need to harmonize general and specific features calls for the step-by-step analysis of data corresponding to political-administrative areas called *partidos* (districts).

The southwest of Buenos Aires province is an important nucleus of economic development within the country, as reflected in the extent of dry farming, crop cultivation under irrigation, and growing urban industrial activity. This paper reports on the first of a series of systematic studies designed to elucidate the relationship between landscape, surface runoff, and groundwater quality, this latter being the main source of water for rural and suburban areas.

The district of Puán covers a total area of 6,385 km^2 (2,465 mi^2) between latitude 37°22' and 38°49'S and longitude 62°30' and 63°23' W. The population of about 18,000 is dispersed among the urban centers of Puán, Darregueira, Bordanave, Villa iris, 17 de Agosto, Felipe Solá, and San Germán, as well as a number of rural settlements made up predominantly of small holdings. The main economic activity of the region is livestock production. The scarcity of fluvial water, combined with limited rainfall, means that groundwater aquifers are the prime source of water both for human and animal consumption and for the increasing supplementary irrigation used in farming (Fiorentino et al., 1999). There are to date no systematic studies on water quality, nor has the presence of contaminating ions such as arsenic, fluoride, and boron been investigated.

Thus, three hypotheses are proposed: 1. Groundwater aquifers, mainly phreatic water are the only current and potential source of easily accessible water for the rural population. 2. Within Puán district, groundwater quality is reduced by the presence natural contaminants. 3. The different contaminant concentrations are directly related to landscape position.

In the interests of reducing the public health risk associated with water consumption in the Puán district, this paper determines geomorphological units exhibiting homogeneous conditions and characterizes the groundwater quality in these areas.

Methods and Materials

The methodology is based on a field survey of water conditions using a detailed topographic map (IGM 1957/72) and small-scale multispectral satellite images (Eros Data Center, 1994, 1999) analyzed both visually and digitally. Laboratory analysis was carried out on representative groundwater samples from sites identified as homogeneous. The characterization of the samples with respect to tolerance limits for human and animal consumption and for use in irrigation takes into account the Código Alimentario Argentino (Argentine Food Code) of 1994 and the Guidelines of Food and Agriculture Organization (Ayers and Westcot, 1987). Soil descriptions follow the norms of soil taxonomy (Soil Survey Staff, 1993).

Results and Discussion

The regional environment comprises two large morphostructural units—the Positivo de Ventania in the north, conforming to the typical pampas landscape and covering most of the district, and the Cuenca del Colorado (Colorado Basin) in the south (Gonzalez Uriarte, 1984), constituting the transition to the patagonian landscape. Six geoenvironments (Figure 1) are distinguished on the basis of topographical relief and surface runoff.

The climate corresponds to the Bsk type after the classification of Köppen-Geiger (Strahler, 1989) and is characterized as a dry step with an average annual temperature of less than 18°C. The soil climate is classified as

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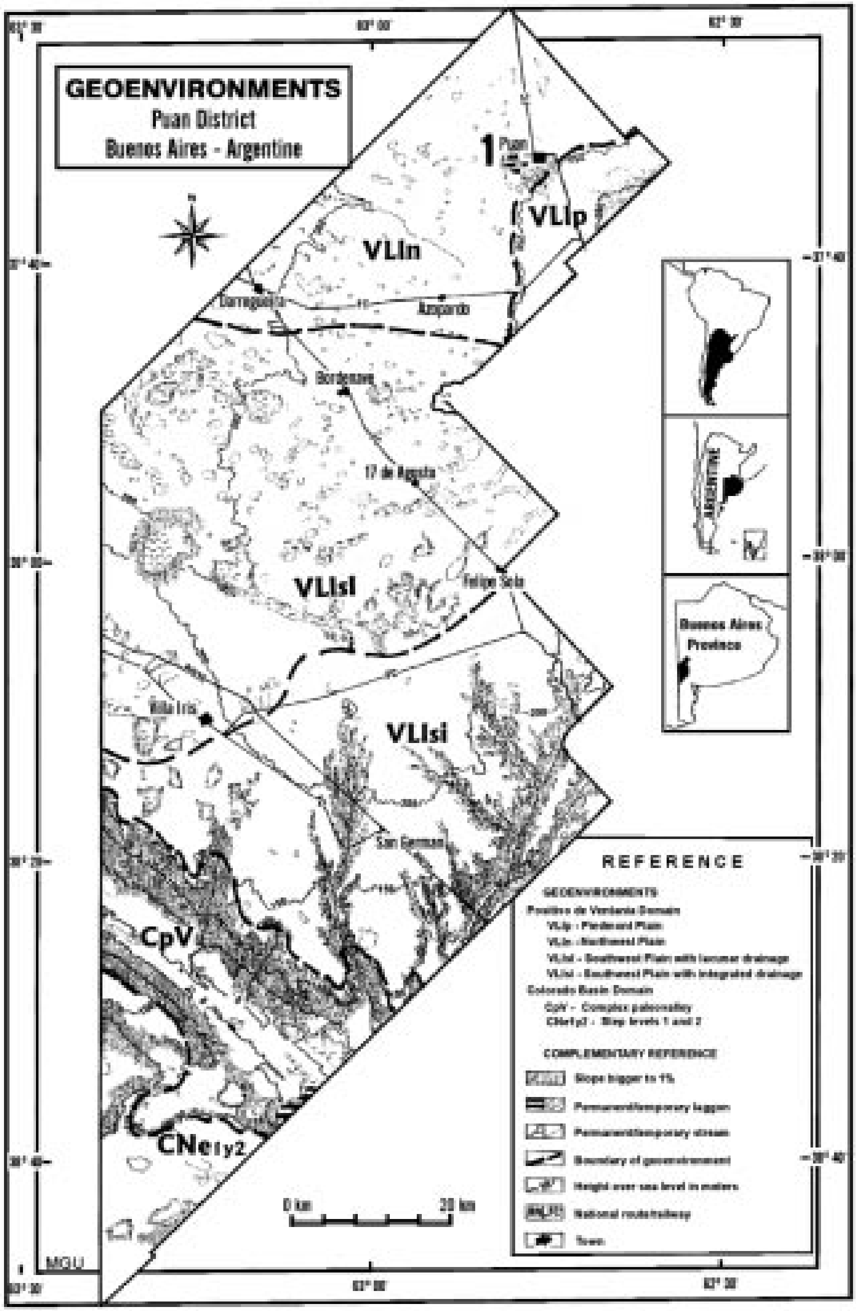
Figure 1
Geoenvironments.



mesic passing from Udoll to Ustoll (Van Wanbecke and Scoppa, 1980). There is a marked gradation in the water regime from values of 700 mm/year (27.5 in/year) in the northeast to 500 mm/year (19.7 in/year) in the extreme south, placing the area in the 0 to -20 range of Thornwaite's water index (Forte Lay et al., 1989).

The overall increase in rainfall over the last 30 years has given rise to a shift in agricultural boundaries. However, lower precipitation levels during the last five years have put increased pressure on farmers to resort to supplementary irrigation and to contemplate the possibility of exploiting groundwater resources.

General relief morphology and surface runoff. The morphology of the district—a transition from pampa to patagonian landscape—comprises mainly plains identified with the two above-mentioned morphostructures.

The pampa landscape, comprising 80.3% of the total district, exhibits high plains ranging from 300 to 100 m (984 to 328 ft) above sea level. The plains extend out from the foothills of the Puán mountain range and its nearest piedmont in the extreme northeast of the district, descending smoothly towards the northwest, west, and southwest with gradients of less than 1%.

The watercourses emerging from the hills disappear from the surface on the fringe of the piedmont and infiltrate to feed the subsurface and groundwater resources. On the plain, however, particularly in the west and southwest sectors, accounting for 50% of the total area of the district, lacunar drainage gives rise to diffuse runoff in a quasi-radial pattern. The at-times very deep depressions containing pools form a line to the south exhibiting gentle topographical elevations conditioned by the deep substructure.

The southernmost section of the plain, accounting for 27.2% of the area, shows a clear incision formed by the runoff, which gradually joins the Chasicó stream. The border of this unit marks the limit of the pampa environment, after which there is a pronounced change in the relief to a sloped landscape, indicating the transition to the Colorado Basin.

The Colorado Basin comprises 19.5% of the total study area and exhibits a much more uneven topography with marked changes in the geomorphological profile and surface formations. The differences in level are in the order of hundreds of meters. Overall gradients are above 1% and in the case of steep slopes, 10%, descending from the pampa plain to a low-lying paleoplain. It is in this very low-lying section that the lowest depression of all occurs—20 m (65.6 ft) below sea level—occupied by the Chasicó Lagoon, lying partly within the Puán district.

Two levels of regionally significant plains are apparent in this topographical section, identified as first- and second-level steps within the morphology of the patagonian landscape. However, owing to their limited presence in the study area and low agricultural potential, the two have been grouped together in one descriptive unit.

Cover. The geomorphological profile exhibits two sections (González Uriarte, 1984). The base structure is made up of a deep layer of compacted siltstone, identified

Table 1. Geomorphologic positions, depth and chemical compositions of phreatic waters in the study area.

Sample	GU	Position	Elevation	Depth	Ph	EC	Ca+Mg	Na	K	As	CO_3	HCO_3	SO_4	Cl	NO_3	Boron	Fluoride
N°		Lat.S-Long.0	(m)	(m)		DS/m	me/l	me/l	Me/l	mg/l	Me/l	me/l	Me/l	me/l	mg/l	mg/l	mg/l
58	VLlp	37°43'-62°35'	307	9.0	7.7	1.114	3.14	5.98	0.15	0.00	—	4.34	0.70	2.68	4.00	0.34	0.73
59		37°31'-62°46'	230	10.0	7.9	1.147	1.57	7.28	0.11	Vest.	—	4.28	1.04	1.82	5.00	0.38	1.56
60	VLln	37°24'-62°47'	185	6.0	7.6	1.481	4.05	8.48	0.11	0.00	—	6.48	3.18	3.30	2.00	0.72	—
39		37°39'-63°11'	190	3.0	7.5	3.800	5.76	31.74	0.46	0.10	—	17.12	14.25	11.08	1.50	1.67	2.56
42		37°39'-63°35'	180	9.0	8.0	1.170	2.13	7.93	0.21	0.08	—	6.64	3.65	3.25	3.50	0.76	2.01
40		37°26'-63°06'	175	10.0	7.4	1.980	6.63	11.30	0.24	0.00	—	8.28	4.52	6.40	2.50	0.80	0.90
41		37°32'-63°21'	171	8.0	7.8	1.022	1.43	7.07	0.22	0.08	—	7.70	1.00	2.38	4.50	0.52	1.78
37	VLlsl	38°01'-62°47'	240	13.0	7.9	2.340	3.53	16.52	0.23	0.00	—	9.50	4.15	5.43	50.00	1.17	2.36
38		37°49'-63°01'	220	8.0	7.5	1.920	12.60	10.43	0.19	0.00	—	4.16	7.50	9.87	6.50	0.37	0.41
46		37°58'-63°34'	170	6.0	8.4	2.650	6.21	16.09	0.30	0.08	—	5.44	17.50	3.76	3.00	0.92	2.18
106		38°09'-63°22'	166	10.0	7.7	1.120	1.33	11.74	0.69	0.30	0.28	4.38	1.60	4.05	50.00	0.91	8.72
36	VLlsi	38°11'-62°42'	190	—	8.2	0.983	1.00	7.07	0.19	0.07	—	6.86	2.30	2.63	5.50	0.51	1.65
100		38°17'-62°58'	185	6.0	7.6	2.120	2.33	18.04	0.26	0.35	1.18	9.00	5.00	6.25	3.00	1.07	10.56
35		38°20'-62°38'	175	35.0	8.5	0.902	1.33	6.74	0.21	0.00	0.24	5.68	1.20	2.60	0.00	0.45	0.18
103		38°29'-62°53'	85	10.0	7.3	11.510	33.99	89.13	0.49	0.00	1.12	6.08	35.00	79.00	175.00	1.78	1.05
97	Cne1	38°44'-63°20'	63	32.0	7.3	4.910	12.29	41.85	0.51	0.00	0.52	4.64	22.50	21.75	70.00	1.06	1.80
96	Cne2	38°50'-63°23'	59	41.0	7.4	1.740	5.53	12.17	0.21	0.05	0.84	6.42	3.00	4.50	260.00	0.50	1.55
105	Cpv	38°24'-63°21'	20	12.5	7.6	6.290	16.33	48.91	0.83	0.00	—	4.16	22.00	31.75	2.50	1.39	2.56
104		38°28'-63°43'	10	3.5	7.4	9.240	32.99	60.87	0.88	0.00	0.80	7.44	37.00	52.25	10.00	1.23	1.14
99		38°39'-63°01'	-10	50.0	7.3	5.000	7.47	35.33	0.49	0.00	0.40	6.80	17.00	24.35	80.00	1.65	2.10

GU: geomorphologic units; H: elevation above sea level; Depth: depth of drillings and wells; EC: electric conductivity.

generically as pampean, covered by a deep layer of hardpan slabs (Finipampean surface), flattened by fluvial erosion in the gulleys left by the considerable runoff. The modern, postpampean deposits overlying the hardpan in erosive discontinuity correspond mainly to sandy loess with an average depth of around 1 m (3.3 ft), which diminishes on the ridges and can reach several meters in the depressions and at the piedmont. These deposits acquire the characteristics of colluvium on the slopes and give rise to a dune relief in the paleoplain.

The distribution of soils (INTA, 1989) is a product of the type of relief, materials and climate; and an association of Tipic, Entic and Lithic Haplustolls and Arguistolls predominates in the eastern section of the district. In the west, the lower precipitation gives rise to the predominance of Entic Haplustolls and Petrocalcic Paleustolls. Entic Haplustolls similarly predominate on the southern slopes, where Ustortent and Ustisamment also appear. Arid soils typical of intrazonal conditions can be observed in the depressions, and in sandy areas Torripsamment is typical.

In terms of the natural vegetation, which is largely decimated, the area corresponds to the Espinal and Pampean provinces (Cabrera, 1976) with characteristic open deciduous woods (caldenal) mixed with perennial shrubs. Low Gramineae and herbaceous pastures predominate toward the east. Psammophilic pastures are common in sandy areas and halophilous vegetation in saline depressions. The predominant crops are grains and forage.

Geoenvironment of the Positivo de Ventanía. The following geoenvironments can be identified in descending order from north to south of the relief:

Piedmont Plain (VLlp): land higher than 250 m (820 ft) above sea level, making up the distal and proximal piedmont of the hill system. Surface drainage is good, groundwater lies at a depth of about 10 m (32.8 ft), and the water in general is of good quality with an electrical conductivity no higher than 1.1 dS.m^{-1}, no arsenic, a low level of boron, and an acceptable level of fluoride.

Northwest Plain (VLln): corresponds to land between 250 and 170 m (820 and 557.6 ft) above sea level, sloping toward the north and the west. Surface drainage is increasingly impeded, and numerous lacunar bodies can be observed as the relief descends. Groundwater lies at a depth of 3 to 10 m (9.8 to 32.8 ft), and electrical conductivity is below 2.0 dS.m^{-1}, though it increases considerably in depressions. Arsenic content varies up to 0.1 mg.l^{-1}, surpassing the tolerance level of 0.05 mg.l^{-1} (Paoloni et al., 2000). Boron traces are, for the most part, above the acceptable level of 0.5 mg.l^{-1}, and fluoride is above the acceptable level (1.3 mg.l^{-1} according to the temperature in the study zone) in most samples.

Southwest plain with lacunar runoff (VLlsl): altitudes of 250 and 150 m (820 and 492 ft) above sea level, decreasing towards the west and south, with no integrated runoff and with frequent pools. Groundwater lies at a depth of 6 to 13 m (19.7 to 42.6 ft), salinity varies between 1.1 and 2.6 dS.m^{-1}, and the arsenic content in one sample is notably high (0.3 mg.l^{-1}). Boron surpasses tolerable limits in most cases. Fluoride content is also above the acceptable level in all but one sample, reaching 8.72 mg.l^{-1}. Two samples in this unit also show high nitrate values (50 mg.l^{-1}).

Southwest plain with integrated runoff (VLlsi): develops below 150 m (492 ft) above sea level and differs from the above units in so far as there is a significant fluvial incision, which flows into the Chasicó endorreic system. Groundwater depth ranges from 35 to 6 m (114.8 to 19.7 ft), following the decrease in altitude. The level of total soluble salts fluctuates considerably between 0.9 and 11.5 dS.m^{-1}, and quite large amounts of arsenic were found, reaching 1.78 mg.l^{-1} in one sample. Boron is present in acceptable or just slightly higher than acceptable quantities, reaching 1.78 $mg.l^{-1}$; and extremely high levels of fluoride are present in the vicinity of the Sanquilcó Grande Stream. Nitrates were only found at one site in the Chasicó valley but show high levels (175 $mg.l^{-1}$).

Geoenvironment of the Colorado Basin. The following units can be identified in the extreme south:

Complex Paleovalley (Cpv): This area exhibits the lowest levels within the Puán district, forming a separation between the Colorado Basin and the plain of the Positivo de Ventania by a difference in level of around 100 m (328 ft). The bed of the plain ranges between 20 m (65.6 ft) above and 20 m (-65.6 ft) below sea level, where the Chasicó Lagoon lies. Owing to partial eolic packing with sand and to the concentration of surface water, the depth of the groundwater varies between 50 and 3 m (164 and 9.8 ft). Conductivity is generally high (5.9 to 9.2 $dS.m^{-1}$), there is no arsenic within the limits of the district, boron is almost triple the acceptable level, and fluoride content reaches 2.6 $mg.l^{-1}$.

Step levels 1 and 2 (Ct): average height between 40 and 120 m (131.2 and 393.6 ft) above sea level, separated one from another by a ridge of some 20 m (65.6 ft). Runoff is not integrated and groundwater is found 31 to 42 m (101.7 to 137.8 ft) down. Salinity fluctuates between 1.7 and 4.9 $dS.m^{-1}$.

Summary and Conclusion

The best quality water is on the piedmont plain.

As surface runoff is prevented, the quality of the water deteriorates in the northwest plain (VnP) and southwest plain with anarchic runoff (VsPa), particularly in the latter.

There continue to be natural contaminants in the groundwater farther from the center of dispersion in the hills, even though surface drainage improves at greater distances.

The worst quality water is found in the geoenvironments of the Colorado Basin.

Thirty-five percent of the studied samples exceed the maximum arsenic level recommended by the Argentine Food Code, 75% exceed the maximum tolerance limits for boron, and 70% exceed the recommended fluoride content.

The highest values of arsenic are found along the southern boundary of the Dominio de Ventania, almost bordering on the Colorado Basin.

In most cases where high nitrate values were found, these could be attributed to local conditions brought about by natural phenomena or anthropic contamination.

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