Fluoride variations in groundwater of an area in Buenos Aires Province, Argentina

E. Kruse · J. Ainchil

Abstract Spatial variations of fluoride concentration in groundwater in the town of Saldungaray, Argentina affect water quality for human supply and decrease the aquifer reserves. The study region is a piedmont area, located near a hill area (west) and the fluvial valley of the Sauce Grande River (east). Two hydrogeological units can be identified: bedrock and clastic sediments. These sediments consist of sandy silt with a variable amount of calcium carbonate. Its greatest thickness occurs near the river where it is 60 m. Groundwater flow coincides with topography. Fresh water is exploited from this unit and it has low salt contents (dissolved solids 400 to 800 mg/l). Fluoride concentration varies between 0.2 and 5 mg/l. The groundwater flow and hydrogeological characteristics related to spatial variations of fluoride content are analyzed. The quality of water is a critical parameter in determining the overall quality of human lives, and the occurrence of high fluoride concentrations can have a pronounced impact on groundwater quality.

Keywords Groundwater quality · Fluoride concentration · Groundwater flow · Buenos Aires Province · Argentina

Introduction

Fluoride concentrations in drinking water are important for public health. Fluoride contributes to dental health and to the maintenance of appropriate bone density. The fluoride concentration in most natural water, which has a dissolved solids concentration of less than 1,000 mg/l, is less than 1 mg/l (Hem 1985). The factors which influence the fluoride concentrations in natural water are geological, hydrogeological, geochemical and anthropogenic (Gosselin and others 1999).

Fluoride concentrations of more than 2 mg/l have been reported in low-salinity water of the "pampa" region in the provinces of Buenos Aires, La Pampa, Córdoba and Santa Fe in Argentina (Castro and others 1998). There are sites in this large region where fluoride concentrations can reach 20 mg/l. It limits the use of this water for human consumption. Furthermore, high fluoride concentration often occurs near the towns where groundwater is the sole water source. This is the case of Saldungaray (Fig. 1). In this paper the authors analyze the hydrogeological features of the region, and then the relation between spatial variations of fluoride concentration and the behavior of groundwater.

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Site description

The study area includes a piedmont region and the fluvial valley of the Sauce Grande River. Piedmont slopes are 1% and occur between 210 and 250 m a.s.l.

The climate is humid temperate. The mean annual rainfall is about 850 mm/year and the mean temperature is 16 °C (60 °F). The rainfall monthly distribution is uniform with summers being more rainy, leading to a maximum by March (110 mm). Estimates of actual evapotranspiration by empirical formulas represent about 75% of rainfall. The monthly water budget shows water excess in winter and spring. The possibilities of groundwater recharge are higher during these periods, despite these being times of lower rainfall (Kruse and others 1995).

Materials and methods

The field survey included a well survey, vertical electrical soundings, and geological and geomorphologic reconnaissance. These tasks allowed characterization of groundwater. The survey area was approximately 3,500 hectares, including the urban area and its surroundings.

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Fig. 1
Location of the study area

Aerial photographs on a scale of 1:20,000 were used to recognize the geologic and geomorphologic characteristics which influence the hydrogeological behavior.
The well survey included level measurements and sampling of 40 wells. It represents an average of one well per each approximately 90-ha area. This survey allows us to know the hydrodynamic and hydrochemical conditions of the groundwater.
The vertical electrical soundings consisted of the measurement of 18 stations in the Schlumberger configuration. The objective was to provide specific information about the thickness and depths of the aquifer.
Two exploration wells were executed by taking lithological samples, verifying and interpreting the vertical electrical soundings, test pumping the aquifer, and taking water samples.

Hydrogeological setting

In the study area bedrock and an aquifer system can be identified. Paleozoic bedrock outcrops are in hills near the study region. Quartzitic rocks are dominant in this unit. The systems of fractures, joints and stratification planes give a low secondary permeability.
The aquifer system is a clastic unit of primary permeability of Cenozoic age. Groundwater is exploited from this unit. This unit consists of a basal conglomerate and a sequence (locally known as Pampean sediments) composed predominantly of eolian clay to sandy silt, or loess, with variable amounts of calcium carbonate. In this formation there is a prevalence of very fine sand and silt, and it contains calcic plagioclase, alkali feldspar, volcanic rock fragments, vitroclasts and unstable heavy minerals, such as hornblende and augite. The existence of micas, apatite, zircon and epidote is rare. The Pampean sediments are derived primarily from Mesozoic–Pleistocene Andean volcanoes (Teruggi and others 1957). These sediments are characterized by a relatively high content of vitroclasts. The vitroclast content can be more than 50% of the mineralogical composition (Riggi and others 1986).
The vitroclast distribution allows the distinguishing of three levels which show percentage differences. The superior level extends up to approximately 10-m depth and the vitroclast content varies between 0 and 10%. The middle level is defined as being between 10- and 25-m depths with values between 15 and 55%, and the inferior level presents variable values between 0 and 15%.
The sediment thicknesses were determined to be very significant for this study. The thickness variations can be observed in Fig. 2. The greatest thicknesses occur to the west of the city where they exceed 60 m. There is also an increase of the sediment thicknesses towards the river where they reach 60 m.

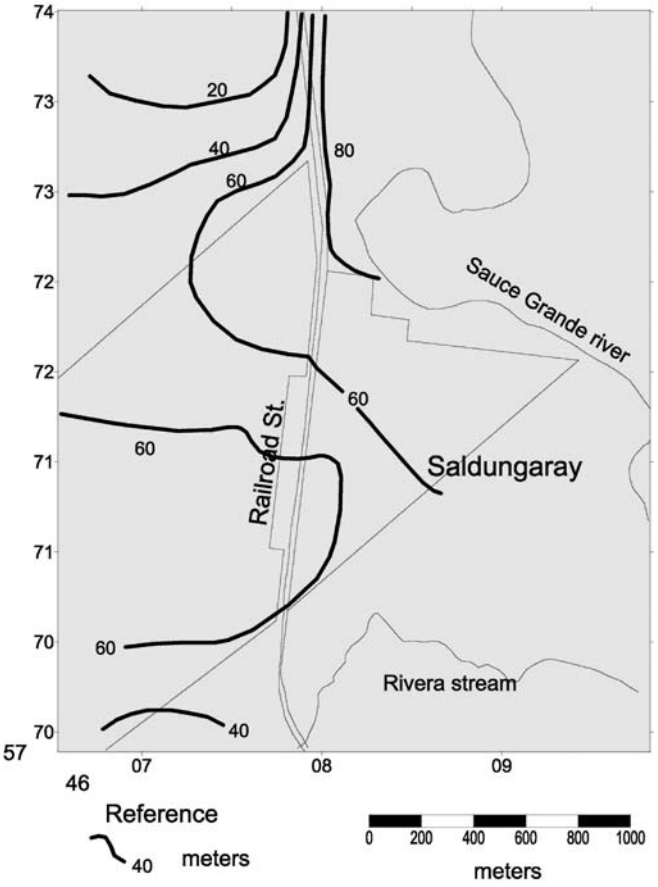

Fig. 2
Thickness of Pampean sediment

Groundwater

Dynamic aspects

The characteristics of groundwater movement and its behavior within the sediment unit with primary permeability can be established from the water-table morphology. The general direction of groundwater flow coincides with the topography, although it has a lower gradient (Fig. 3).
The natural process for groundwater recharge to the aquifer is the infiltration of excess rainfall. Regional hydraulic gradients are about 0.4%, with values increasing in the headwater region (west of the city) and decreasing towards the river.
The groundwater discharge area is the Sauce Grande River. The water table is deeper than 20 m to the west of the city, and 18 m near the railroad station. To the east near the river, the depth decreases to 10 m (Fig. 4).

Hydrochemical aspects

Groundwater has a low salinity (dissolved solids 400 to 800 mg/l). The water is of the calcium bicarbonate type. The lowest values of bicarbonate (200–250 mg/l) and calcium (20–40 mg/l) are to the west of the city, and contents increase with the flow direction. The chloride concentration varies from 40 to 150 mg/l, and the values increase with the flow direction. Sulfates vary between 10 and

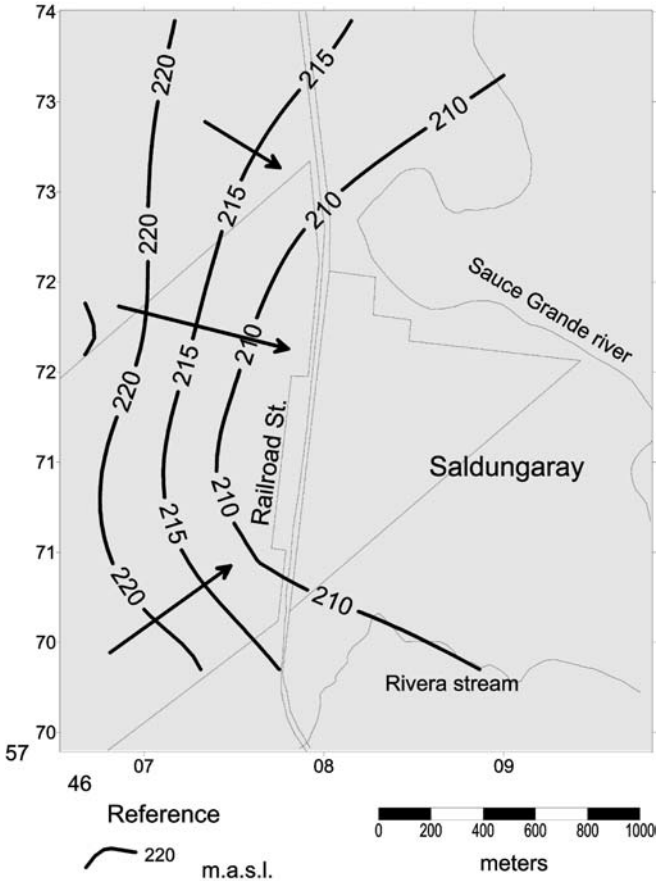

Fig. 3
Groundwater flow

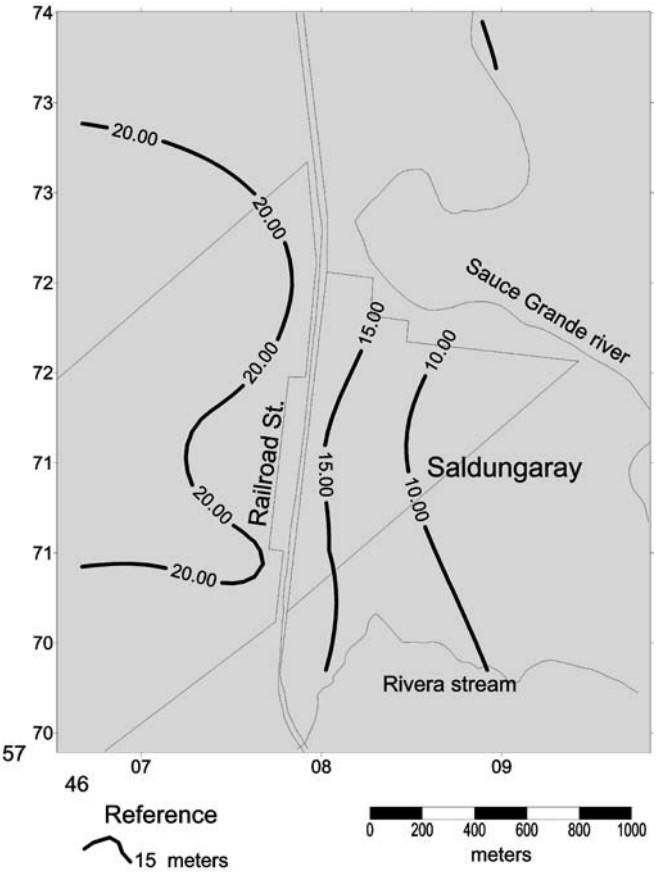

Fig. 4
Depth to water table

20 mg/l. The major ion concentrations do not impair the quality of the water supply. The same applies to heavy metals. High values of nitrate (40 mg/l) at some isolated sites are associated with contamination due to human activities.

Fluoride concentrations

The fluoride concentration varies from 0.2 (only one well) to 5 mg/l. The values typically range between 2 and 4 mg/l for over 90% of the data. The fluoride concentration is a limit to using the water for human supply. The fluoride concentration shows a tendency to decrease with the direction of the groundwater flow (Fig. 5). Values ranging from 1 to 2 mg/l appear in the groundwater discharge area (Sauce Grande River).
The highest fluoride areas are found to be coincidental with the lowest calcium and bicarbonate values.
The highest values of the fluoride concentration (above 3 mg/l) appear with the increase of the sediment thickness (60 m) to the west of the city. Also, this area has the deepest water table (greater than 20 m). Although this area includes rural activities, there is no use of phosphate fertilizers.
The relation between spatial variations of fluoride concentrations with groundwater flow and hydrogeological characteristics shows the increase in fluoride content to be associated with natural processes. Fluoride dissolution can

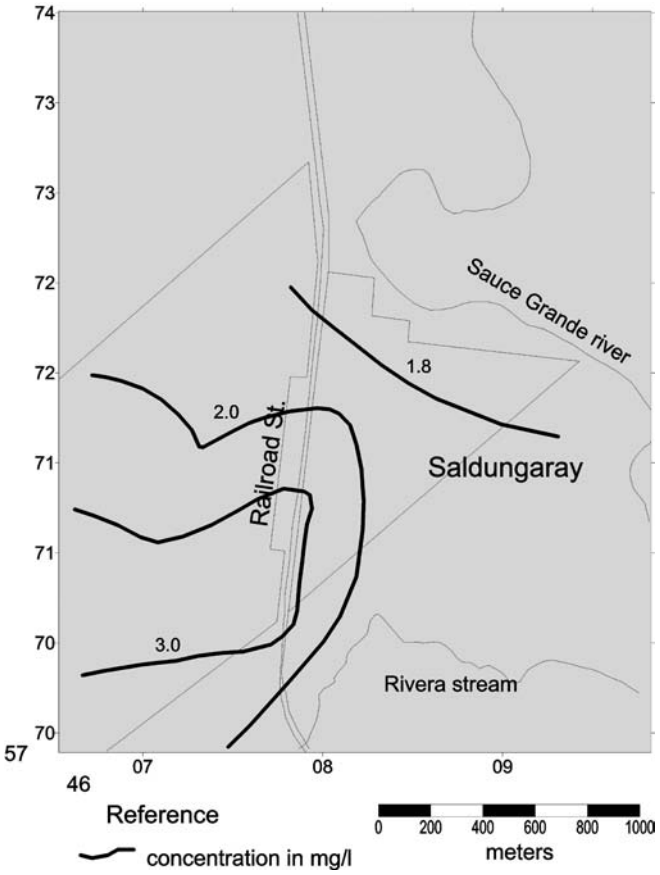

Fig. 5
Fluoride concentration in mg/l

be related to vitroclasts derived from volcanic ash distributed in the sediment unit.
In the area of the highest values of fluoride concentration, the water-table depth (20 m) is located in the middle level of mineralogical zones of the sediment unit in which there is the greatest percentage of volcanic ash. The fluoride concentration is smaller in the area where the water-table depth is less than 10 m, coinciding with the superior level of the mineralogical zones with low vitroclast percentage. The calcium content increases and the fluoride concentration decreases with the direction of the groundwater flow. On the other hand, the infiltration is significant in the region and increases to the east of the city, where the topographic slopes are less. In this area the fluoride concentration diminishes and there exists an addition of infiltration water which can produce a dilution in the fluoride content. The increase of bicarbonate concentration with the flow direction reflects the importance of the infiltration.

Conclusions

The fluoride concentrations in the Saldungaray groundwater varied in the range 2–4 mg/l. Spatial variations are shown to be decreased along the groundwater flow path. The highest fluoride concentration area is found to coincide with the lowest calcium values. In this area the thickness of the aquifer system is greater (60 m), and the water-table depth coincides with the level of the sediment unit where the percentage of vitroclasts is greater (15–50% of the mineralogical composition).
The fluoride concentration is smaller in the area where the water-table depth is less than 10 m, coinciding with the level of the sediment unit with low vitroclast percentage. In this area the fluoride concentration diminishes and there exists an addition of infiltration water which can produce a dilution in the fluoride content.

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