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Analyzing groundwater resources availability using multivariate analysis in the Selva Basin (NE Spain)

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Abstract

Groundwater availability depends on its accessibility, as well as on its quality. A principal component analysis (PCA) has been used to link the occurrence of natural (fluoride) and human (nitrate) pollutants with the hydrological dynamics in the Selva Basin (NE Spain) as a means to analyze quality problems and provide strategies for water resources exploitation. Statistical results show that both pollutants are independent, and they are related to groundwater fluxes of different spatial scales. Fluoride is linked to regional groundwater systems, while nitrate is related to local recharge produced within the basin. PCA thus permits relating a potential occurrence of pollutants to specific characteristics of the hydrogeological system. It also becomes an approach to assess its vulnerability by identifying key parameters related to pollution. Such a statistical outcome is of interest for water resources planning with the aim to avoid locating production wells in areas that show hydrogeological or hydrochemical features associated with either type of pollution.

Keywords: groundwater availability; principal component analysis; nitrate pollution; fluoride pollution; Selva basin.

1. Introduction

Water resources availability depends on the accessibility of this resource, as well as on its quality. Pollution can deteriorate surface and ground water, hindering in some cases its convenience for human and environmental needs. The forecast of potential pollution threads is then of interest. Hydrogeological

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and hydrochemical data can provide a necessary background to evaluate the suitability of a given location for non-polluted groundwater withdrawal.

In the Selva Basin different kinds of groundwater pollution have been described. On the one hand, high nitrate concentrations have been detected in shallow and deep wells (over 50 mg/l), mainly caused by agriculture and livestock activities. On the other hand, some deep wells show high fluoride content caused by natural sources (over 1.5 mg/l; [1-3]). These two quality problems limit groundwater uses in this area.

Principal component analysis (PCA) has been widely used in hydrogeological studies to identify relationships between variables and to reduce the complexity of large-scale data sets. Some of these studies have used PCA to analyze the relationship between a pollutant and other physicochemical parameters, (e.g. [4] and [5]), or to describe the characteristics of a hydrogeological system ([6] and [7]).

In this context, a PCA has been conducted using the hydrochemical, isotopic and potentiometric data for the Selva Basin [1-3], with the aim of identifying the origin and fate of these two pollutants by comparing its statistical inference with other variables that are known to describe the hydrogeological flow system of the Selva basin. In this way, statistical associations relate pollutant occurrence to flow dynamics under development conditions. This should permit evaluating non-polluted groundwater potential availability according to hydrogeological and hydrochemical variables.

1.1. Study area

The Selva Basin is located about 100 km NE of Barcelona (Spain). This tectonic graben, of approximately 600 km^2, surrounded by mountain ranges of 500-1200 m maximum height.

From a hydrogeological point of view, three main formations can be distinguished in the study area: the granitic and metamorphic rocks found in the surrounding ranges and in the basement of the tectonic basin; the Neogene sedimentary infilling of this basin, mainly composed of layers of arkosic conglomerates, sandstones and gravel, alternating with layers of clay and silt; and recent alluvial formations composed of loamy and fine sands in the Onyar River area, and of sand and gravel in the Santa Coloma stream.

In the Selva basin, recent industrial and urban growth, together with intense agricultural and livestock production, has resulted in high water demand (27.1 hm^3/year) and wastewater production (5.5 hm^3/year [8]). These demands have been historically supplied using groundwater resources, but nitrate and fluoride contents are causing groundwater availability problems in this area.

2. Methodology

A hydrochemical and isotopic survey was conducted in May 2006. Thirty one wells (from 7-150 m deep) were sampled. These wells were part of a large observation net used for seven potentiometric surveys from 2000 to 2006.

Analytical methods for hydrochemical and isotopic data are referred in [1], [2] and [3].

The SPSS program (version 19, 2010, SPSS INC.) was used to perform a principal component analysis, based on the hydrochemical, isotopic and potentiometric data of the 31 wells considered. As regards potentiometric data, the variable used to represent the different hydrologic responses was the head level difference between two surveys. The surveys taken into account in the PCA were those considered as the best examples of dry and wet conditions (May 2004 and October 2004).

3. Results and discussion

Results obtained by the application of the PCA analysis show that variables were correlated, but not orthogonal, with a value of 351.1 for the Bartlett chi-square statistic (for 66 degrees of freedom and a minimum significance level <0.001). In order to obtain higher values in the measure of sampling adequacy (MSA) based on the Kaiser-Meyer-Olkin measure, Cl^- and K^+ were ruled out, since they presented the lowest correlations with the rest of the variables considered. Thus, the value for the MSA was increased to 0.65. In addition, a varimax rotation was conducted to reduce the overlap of the original variables in the different varifactors.

In this analysis, the total variance explained by the three resulting varifactors (VF) was 77.4%. Results of this PCA after rotation are summarized in Table 1 and Figure 1, and are interpreted as follows:

- VF1: was the varifactor with the highest loading of F^-. This varifactor was also participated by pH, HCO_3^- and Na^+, parameters that have been described to be related to regional, large-scale fluxes in the Selva Basin ([1], [2] and [3]).
- VF2: was interpreted as representative of the altitude of the recharge area, since it was mainly participated by $\delta^{18}O$ and δD, and also Ca^{2+} and Mg^{2+} that are characteristic from low evolved groundwater in this area ([1], [2] and [3]).
- VF3: was representative of NO_3^- concentration, originated in local recharge within the basin, and spreads from infiltration towards the subsurface, as well as of those ions related to this kind of pollution (Ca^{2+} and SO_4^{2-}), since nitrate has a high loading of 0.839 in this varifactor.

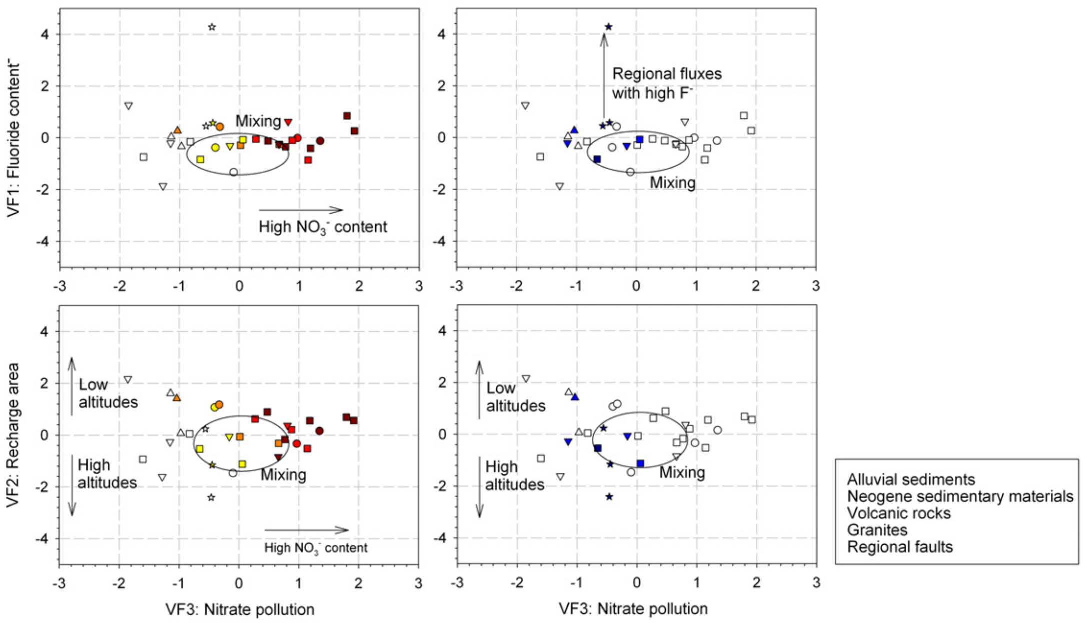

Fig. 1. Distribution of groundwater samples according to their scores for VF1 (groundwater fluxes with high F-), VF2 (recharge area) and VF3 (nitrate pollution). Complementary legend: yellow infilling, 25-50 mg NO_3^-/l; orange 50-75 mg NO_3^-/l; red, 75-100 mg NO_3^-/l and dark red >100 mg NO_3^-/l; blue 0.7-1 mg F^-/l; dark blue >1 mg F^-/l.

Thus, PCA analysis indicates that groundwater fluxes with high fluoride content are independent to those with high nitrate concentrations (Figure 1). The occurrence of both pollutants was only detected in wells that exploit surface aquifer levels together with deep levels where mixing of both groundwater fluxes (regional and local) occur.

Table 1. Loadings of variables considered on 3 significant varifactors (VF). Underlined values represent relevant loadings. Legend: VF, varifactor; HHD, hydraulic head difference.

VF	HCO_3^-	Na^+	pH	EC	F^-	dD	^{18}O	Mg^{2+}	SO_4^{2-}	NO_3^-	Ca^{2+}	HHD	% Variance explained
VF1	0.895	0.885	0.825	0.796	0.777	-0.039	-0.001	0.027	-0.016	-0.073	-0.002	0.055	29.274
VF2	.0287	-0.395	0.097	0.127	-0.501	0.886	0.849	0.771	0.211	0.210	0.580	0.051	25.369
VF3	-0.037	-0.024	-0.212	0.537	-0.166	0.052	0.122	0.238	0.864	0.839	0.730	-0.562	22.796

4. Conclusions

Although the Selva basin does not have significant water resources quantity limitations [8], two distinct quality problems have been detected: high NO_3^- concentrations in surficial groundwater fluxes, and high F^- content linked to regional flow systems. PCA results allow us to determinate that these problems are independent. Only groundwater mixing associated with pumping activity allows the joint occurrence of both pollutants. This defines the vulnerability of the system to groundwater resources exploitation and the impact on its quality. From a management point of view, such statistical result is of interest for hydrological planning as it avoids locating production wells in areas that show hydrogeological or hydrochemical features associated to any of both types of pollution.

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