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title: **Assessment of hydrogeochemical processes in a semi-arid region using factor analysis and speciation calculations (Bajo Almanzora, SE Spain)**

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ABSTRACT

The quality of the water supply of the Bajo Almanzora region for agricultural and domestic uses is mediocre. This region possesses very limited water resources that are variable in time and space, so the water requirement of the population and the agriculture activities has to aid on the use of underground resources.

The main materials that have aquifer behaviour are the quaternary and plio-quaternary conglomerates that fill in the depressions. During December 2004, waters from springs, galleries, wells and boreholes in the study area were sampled. The physical-chemical variability was interpreted in the conceptual framework of the hydrogeology and hydrogeochemistry of the area. Factor analysis and speciation calculations provided evidence of the different hydrogeochemical processes on this area: salinization, precipitation of carbonates, silica dissolution, eutrofization and exchange on clays.

INTRODUCTION

The river basin of the Almanzora River is located in the northern part of the Almeria province. The area of study of this investigation is framed within the Bajo Almanzora region, located to the East of the Almanzora river basin, and covers a surface of 700 km^2 (Fig. 1).

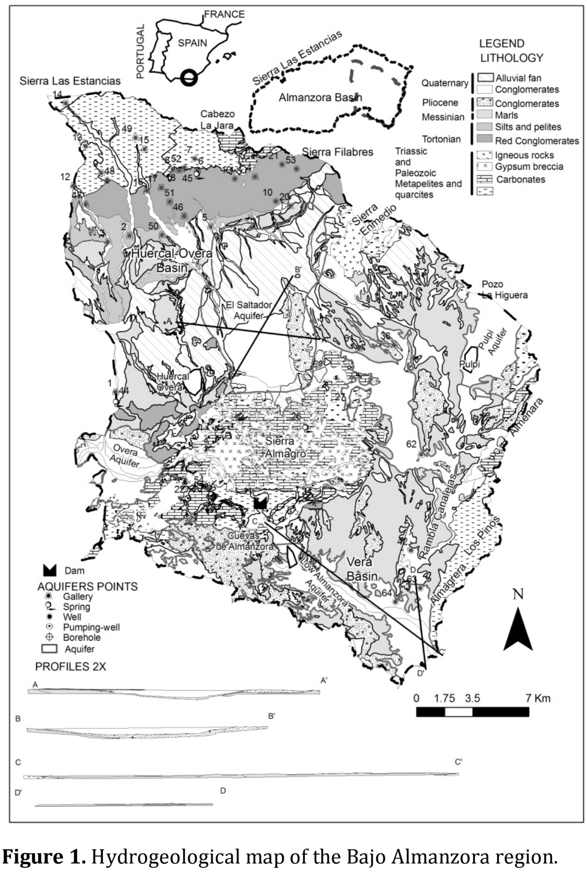

Figure 1. Hydrogeological map of the Bajo Almanzora region.

In a similar way to what occurs in other Mediterranean semi-arid zones, it possess very limited water resources that are variable in time and space and affected by droughts and floods (Martín-Rosales et al., 2007a). The degradation of the quality of the water is a common problem in the Mediterranean region, especially during the summer period (Iglesias et al., 2007). Hidalgo and Cruz-San Julián (2001) determined the main hydrogeochemical reactions that control the composition of the water reserves in a mediterranean detrital aquifer (Guadix-Baza) in an intra-betical basin. The principal aim of the present paper is to identify sources of physical-chemical variability, and to relate them to hydrogeochemical processes defined on the conceptual frame of the hydrogeology and hydrogeochemistry of the area.

The patterns of flow and the aquifer system were studied by sampling the hydrological components for chemical analysis in December of 2004. In order to recognize the patterns in the water quality, hydrogeochemical facies and their spatial distribution were studied aided with a Piper diagram. The study of hydrogeochemical processes that originate the water salinity was aided both in results of factor analysis and of chemical modelling.

STUDY AREA

Hydric resources and demand

Within the study area, the demand of water for domestic supply is 2.7 Mm^3/a. There is an extensive area of irrigated lands, where citruses, vegetables, olive trees, almond trees, and others, are cultivated. The demand for irrigation is estimated to range in between 61 and 88.5 Mm^3/a for the study area. Another point is water demand for animal farming, notably the water consumption of numerous pig farms.

The precipitation presents high inter-annual variability. For the set of the rain gauges of the zone, the value for a typical dry year is 131 mm/a and the value for a typical humid year is 396 mm/a. From thermometry and pluviosity data, it can be deduced that there is a useful volume of water of 20 Mm^3/a, on the average, for the aquifers and aquitards of the Bajo Almanzora region, with a 0.75 variation coefficient. The Almanzora River presents during a typical average year 5.4 Mm^3/a, although, during a typical dry year the run-off can be completely worthless. Two diversions from the Tajo River (14.4 Mm^3/a) and from the Negratín dam (32 Mm^3/a) provide water for agriculture.

Geology and hydrogeology

The study area is located geologically in the eastern part of the Betic Cordillera. It has been differentiated a betic substratum, which emerges at the mountain zones, and a sedimentary filling at the hollow areas (Fig. 1). Superposed tectonic units represent the materials of betic substratum, with micaschists, metapelites and dolomites-limestones members, from bottom to top. At the Sierra of Almagro, the contact between the metapelites and meta-sandstones formations and the carbonated formation folds, and it presents tectonic detachments (Sanz-de-Galdeano and García-Tortosa 2002). In the sedimentary filling, lithology and paleogeography are properly studied (Briend 1990, Mora 1993, Barragán 1997). The Huércal-Overa sedimentary basin is located to the North and to the West of Sierra Almagro, the Vera Basin is located to the Southeast of this mountainous elevation. Towards the end of the Pliocene, deltaic and continental conglomerates were deposited mainly at the Vera basin and the Pulpí Corridor. The

Huércal-Overa sedimentary basin was tilted recently, so that the northern margin was raised, generating several levels of alluvial fans (García-Meléndez et al., 2003). At the southern margin of the Sierra of Estancias carbonated crusts and travertines lay, which have formed during the current period.

The main materials that have aquifer behavior are the quaternary and plio-quaternary conglomerates that fill in the hollow areas. The plio-quaternary conglomerates are conferred heterogeneous transmissivities, normally between 40–75 m^2/day in border areas, and 500–800 m^2/day on the centre of the basins, and storage coefficients of 8-10% or 2-3% in siltier sections (Barragán-Alarcón, 2009). The alluvial materials of the Almanzora river measured between 8000-12000 m^2/day transmissivity; some karstificated carbonates outcrops that are located southeast of the Sierra of Almagro also show very high transmissivities.

At El Saltador, aquifer functions under a semi-confined aquifer regime, affected by the existence of intercalated clay and marl sections. At Overa, a non-confined layer (plio-quaternary conglomerate), well correlated with the Almanzora river flow, overlays a confined layer (tortonian conglomerates), separated by marls on its western half. At Pulpí the aquifer is very depleted of groundwater, the same occurs at the delta of the Almanzora river.

The aquifers at the mountains receive an important part of the recharge due to rainwater, especially at the Cabezo La Jara, which presents the highest elevation on the area. The discharges of these aquifers pour into the detritic aquifers in the depressed areas. All these aquifers are interconnected, working as an aquifer system. The main aquifers are connected by little superficial aquifers (alluvials, fans, plio-quaternary rocks). The interrelations between aquifers have been increasing with the use of irrigation waters of external basins and with the implementation of global management of the underground waters in the area, with the union of the irrigators associations.

METHODOLOGY

For the study of the hydrogeochemical processes, the recharge areas were underlined, because the assessment of them was easier on these ones, and they weren't so affected by overexploitation as the detritic neogene aquifers. The sampling carried out in December 2004 mainly focused on wells and galleries near of the betic substratum, supplied with underground waters of karstic and fractured aquifers (Table 1). A rainwater sample was taken on November 2006, which may be representative of rainwater on winter.

Electrical conductivity (EC), pH, temperature, and redox potential (Eh) were measured *in situ* with a WTW measurement instrument with interchangeable probes, previously calibrated. The alkalinity was measured *in situ* by titration using 1/50 N hydrochloric acid. The samples were filtered at 45 μm and, afterwards, maintained at four degrees until its subsequent analysis. The samples were analyzed searching for major ions, nitrate, and strontium by using HPLC with an ionic chromatograph DIONEX DX-120 at the University of Almería. Silica was measured by photometry at 690 nm with methylene blue after reduction of silicomolybdic acid. The obtained values are presented in Table 2. Isotopic deviations of ^{18}O and ^{2}H were measured with mass spectrometry on some samples in the Zaidín Stable Isotopic Lab of Spanish CSIC. These data were included in Table 2, too.

Table 1. Aquifer points sampled on December of 2004. Some calculated chemical parameters are included, like Balance error (%), dpH, CO_2 (mg/L on equilibrium). Isotopic deviations of ^{18}O and ^{2}H (‰) are included.

ID	Height	Name	Type	Use	Balance	dpH	CO_2	$(N^{+}+K^{+})/Cl^{-}$	$\delta^{18}O$	$\delta^{2}H$
1	305	Almajalejo	Gallery	Irrigation and regulation	-0.8	0.70	0.0520	1.523		
2	596	Las Minas	Gallery	Irrigation and regulation	1.6	0.62	0.0875	1.524		
3	580	La Hoya	Gallery	Irrigation and regulation	-0.6	0.69	0.0937	1.602		
4	709	El Cabezo	Gallery	Irrigation	-0.1	0.83	0.1267	1.377		
5	569	Fuente Nueva	Gallery	Riego	0.0	0.69	0.1578	1.428		
6	785	Zimbra de Erre	Zimbra	Mill	0.5	0.49	0.1647	1.879		
7	835	Erre	Well		-0.6	0.22	0.4880	2.068		
8	815	Fuensanta	Well		-34.8			0.551		
9	847	Los Toscanos	Zimbra		-1.7	0.84	0.0521	2.397	-5.71	-44.67
10	581	Goñar 1	Well		-1.5	1.00	0.0836	1.056	-2.64	-41.92
11	149	Presa	Superficial	Irrigation and regulation	-1.3	0.93	0.0426	1.213	-4.55	-43.04
12	776	La Casica	Zimbra		-2.0	0.70	0.0729	1.746	-6.13	-44.10
13	973	Las Vicarias	Well		0.2	0.25	0.3489	2.100	-6.21	-42.29
14	915	Los Cabrera	Gallery	Irrigation	-0.4	0.74	0.1200	2.047	-6.99	-44.96
15	824	La Pilica	Zimbra		-11.0			2.133	-6.02	-43.50
16	720	Fuente Amarga	Gallery		1.9	0.48	0.1664	1.676	-6.69	-54.06
17	751	Los Rizos	Zimbra		0.1	0.33	0.7921	1.340	-7.37	-45.56
18	782	Fuensanta	Zimbra		0.2	0.61	0.2371	3.235	-6.18	-43.73
19	714	El Almecico	Well		0.6	0.15	0.1635	0.738	-5.48	-39.34
20	518	Goñar	Gallery		0.3	0.68	0.1118	1.133	-6.57	-46.81
21	686	Derramadores Alto	Well		1.3	0.47	0.0929	1.025		
22	260	El Chaupí	Borehole	Supply	-1.5	0.14	0.0328	0.727		
23	308	Variegato	Zimbra		-25.6			1.114	-5.32	-27.89
24	207	Fuente Álamo	Zimbra		1.2	-0.05	0.2257	0.718		
25	519	La Rellana	Spring		1.0	0.20	0.9974	0.767	-5.88	-43.03
26	503	Poza del Pino	Spring		1.7	0.35	0.2954	0.972	-7.44	-45.94
27	378	Rambla de Mahoma	Well		5.1			0.856	-5.29	-23.34
36	250	Los Vizcaínos	Zimbra		-0.6	0.86	0.0580	0.784		
41	134	Canalejas	Well		-0.2	0.26	0.5961	1.051	-5.02	-38.52
42	45	La Mulería	Well	Wheel	-0.7	1.06	0.5533	1.433	-4.43	-32.60
44	290	Almajalejo Spring	Spring	Mill	1.6	0.22	0.6068	1.197		
45	760	Erre	Spring		-0.3	0.81	0.1174	2.011		
46	604	Los Arteros	Zimbra		-2.6	0.78	0.0610	1.348		
47	728	El Purión	Gallery		0.1	0.67	0.0887	1.574		
48	811	Los Toscanos	Well		-0.3	0.60	0.2026	1.785		
49	836	La Seca	Zimbra		-0.1	0.12	0.9312	1.526		
50	563	Algor	Gallery	Irrigation and regulation	0.9	0.60	0.1634	1.862		
51	691	Las Marianas	Zimbra		0.7	0.63	0.1538	1.607		
52	817	Fuensanta-Erre	Well		-1.0	0.37	0.2817	8.340		
53	641	Derramadores Bajo	Well		0.7	0.82	0.0780	1.161		
54	254	El Marqués	Spring		-0.2	0.38	0.3058	0.836		
61	271	Las Avestruces	Zimbra		0.4	0.86	0.0738	0.668		
62	155	La Perlita	Zimbra		2.4	0.23	0.6066	1.394		
63	27	Los Guiraos (Herrerías)	Well		-0.6	0.24	0.1758	1.323		
64	27	Herrerías-	Well		-0.1	0.45	0.2130	0.981		

Table 2. Concentration of major ions and hydrochemical parameters. (Conductivity:mS/cm, temperature: °C, concentrations: mg/L).

ID	EC	pH	TEMP	Eh	Cl	SO4	HCO_3	Na	K	Ca	Mg	Sr	NO_3	SiO_2
1c	1751	8.18	22	413	230.4	351.3	256.2	224.5	5.3	81.2	55.7	1.7	14.9	8.3
2c	1004	8.03	19.5	382	87.2	188.2	280.6	85.1	1.8	81.8	38.6	0.8	24.9	8.7
3c	1293	8.04	20.2	349	124.1	257.3	317.2	127	3.3	93.3	50.9	1	13.4	8.6
4c	1970	7.84	20.8	440	25.4	1004	292.8	21.1	2.7	310.7	120.9	12.3	0.4	14.2
5c	1067	7.93	19.4	341	96.1	131.6	402.6	87.8	2	98.2	40.7	2.2	5.3	13.6
6c	807	7.92	14.6	-31	60.1	60.3	366	72.6	1	66.3	28.8	1	0.3	22.4
7c	794	7.5	13.9	361	48.4	41.7	402.6	64.3	0.9	76.9	27.7	0.9	0.1	10
9c	1431	8.34	15	410	113.9	327.3	312.3	175.1	3.3	80.9	53.7	1.5	28.9	17.7
10c	4280	8.41	13.1	359	1095.5	326.2	617.3	739.6	17.5	99.1	142.6	4.6	4.1	42.2
11c	2520	8.31	9.5	240	280	880	231.8	211.7	14.4	221.3	124.5	6.4	4	0.6
12c	1278	8.13	17.9	380	99.4	254.7	292.8	109.5	5.2	85.6	53.1	0.7	6.6	11.1
13c	1050	7.6	13.7	416	87.9	127.5	366	117.5	3.6	77.7	30.3	1	30.9	25.4
14c	931	8.06	16	458	48.3	154.8	390.4	63.2	1.6	91.6	45.8	1.1	3.2	15.5
16c	1061	7.8	17.7	400	73.5	256.7	305	78.1	3.1	100.1	49.3	2.2	36.7	14.4
17c	1495	7.38	14.2	390	118.7	260.2	524.6	102.9	0.4	146.9	66.8	1.6	0.1	14.9
18c	861	7.89	15.2	378	38.3	22.1	500.2	80.3	0.2	81.6	25.9	1	0	21.9
19c	1448	7.63	14.6	395	153.6	417.2	195.2	67.8	9.8	112.8	89.5	11.1	9.8	11.4
20c	2680	7.9	17.2	397	371.5	671.7	280.6	264.3	14.8	200.3	113.9	9.7	145.4	25
21c	891	8.01	14.5	411	95.5	112	256.2	61.1	4.1	66.5	37.9	3.9	13.2	4.5
22c	514	8.12	18.7	378	85.4	20.6	122	39.1	2	31.7	22.9	1	14.5	9.4
24c	777	7.5	20.1	293	98.3	90.8	207.4	44.2	2.7	51.4	40.4	5	0.4	10.1
25c	3630	7.06	10.8	-10	198.0	1980.9	329.4	96.9	2.8	605.9	203.0		14.1	15.1
26c	2700	7.43	7.8	360	62.9	1677	207.4	34.7	8.5	595.4	89	9.7	0.7	11.6
36c	5250	8.08	18.9	412	1211.5	961.5	250.1	607.9	14.2	264.5	243.5	21.4	67.5	6.8
41c	11510	7.22	12.6	421	2262	3890	341.6	1515	46.4	649	647.1	39.1	100.4	13.6
42c	7630	7.84	20.4	-130	1281.2	1901.2	1451.8	1174.8	26.4	348.7	385.0		20.6	11.5
44c	3160	7.27	18.6	443	540.6	920.0	359.9	414.8	8.3	221.4	120.8	15.0	5.8	
45c	919	8.10	15.1	431	56.6	102.5	398.9	72.6	2.1	96.3	28.2		2.5	4.4
46c	1047	8.34	12.4	358	145.9	49.8	339.2	126.7	1.5	60.5	33.6	1.3	2.9	12.4
47c	1244	8.05	18.8	434	108.6	250.5	298.9	108.5	4	92.1	48.6	1	17.4	5.1
48c	1785	7.9	8.9	386	150.1	404.9	402.6	171.7	3.5	136.7	65.6	1.4	24.8	8.4
49c	1247	7.19	17.4	459	91.5	235.7	414.8	89.3	2.1	120.8	53.8	1.3	4.7	10.4
50c	1137	7.84	19.5	400	71.2	268.3	341.6	83.8	3.6	112.5	50.8	2.3	36	13.2
51c	1044	7.96	15.5	311	82.8	140.7	390.4	85.9	0.8	88.9	40.4	3	0.3	10.6
52c	820	7.74	14.8	315	13.3	102.3	414.8	70.9	1.5	68.2	36.2	1.2	1.5	21.9
53c	1495	8.16	12.3	388	126.7	428.7	311.1	93	4.1	138.4	79.5	8.8	15.9	5.6
54c	929	7.75	8.3	444	88.7	26.4	402.6	46.8	2.3	84.3	41.2	5	0	10.4
61c	5990	8.08	12	442	1628	1036	286.7	698.9	10.3	313.9	326.6	28.1	98.5	17.8
62c	8160	7.16	21.1	452	1698	2086	317.2	1499	61.1	348.3	143.5	6.8	262.4	10.8
63c	5540	7.58	16.5	381	944.7	1762	219.6	795.3	25.5	233.5	262.8	6.1	51.5	6.4
64c	3630	7.58	16.4	419	602.5	1111	256.2	368.5	25.3	302.8	161	7.7	38.9	6.9
Pe	328	7.91	19.4		38.2	56.5	48.4	33.3	1.6	19.1	9.4	7.2		1.1

The hydrogeochemical facies were assigned based on Piper diagram. Factor analysis was used to synthesize the largest possible portion of physical-chemical variability on uncorrelated factors. Factor analysis is commonly used in hydrogeochemical studies. Glynn and Plummer (2005) criticized the use of factor analysis to assess the degree of conservative mixing between end-member solutions compositions, while ignoring the reactions that could cause the precipitation/dissolution of the elements.

The data matrix doesn't adjust to the multivariate normal distribution; thus, the optimal conditions for the application of the factor analysis are not fulfilled. Dreher (2003) advise not to use log-transformations because they modify ionic ratios. To add more complexity to this, some variables are near logarithmic (like chlorine), others are near normal (like bicarbonate), and others don't fit any distribution properly (like Eh). The chosen method of factor analysis is PCA. It is a widely extended erroneous practice to apply Varimax rotation when the aim is to study observation values for the different samples. It was preferred not to apply any rotation to preserve the orthogonality of the vectors of loadings, and at the same time, to preserve the uncorrelation of the scores (Jolliffe 1995). Maps of the scores of the factors were obtained.

To reinforce the hydrogeochemical knowledge, saturation indexes of some mineral phases and dominant phase diagrams were calculated with PHREEQC v2.0 and WATEQF.

RESULTS AND DISCUSSION

Hydrogeological model

Water descends from the Sierra of Estancias and pours into the Saltador aquifer. One net of parallel streams, following a direction SE from the sierra between 1000 and 600 m a.s.l, with slopes of 10–15%. It's expected that these streams download an average of 3–3.5 Mm^3/a. At Sierra Almagro, waters keep stored in carbonated and evaporitic aquifers, and just in a small portion (1-1.5 Mm^3/a as an average) pour into the Saltador aquifer by the N (<400 m a.s.l.) and towards Pulpí corridor to the E (<300 m a.s.l.). To the South the ramblas that descend to the alluvial of Almanzora river (<200 m a.s.l.) pour very little water.

Waters transferred from Negratín and from Tajo-Segura are distributed at Saltador, at Overa, at Pulpí and at Cuevas. The waters of Palomares desalination plant are used to irrigate (3–4 Mm^3/a) on the Almanzora river alluvial and on quaternary deposits on Pulpí corridor. The global management of the aquifer system trends to buffer excessive exploitation of the aquifers effects, distributing the weights of extractions to less over-exploited aquifers. Recently, the drawdowns were near constants at El Saltador, between 3–3.5 m/a, although at borehole 33 were higher, near to 8 m/a. On September 2006 the piezometric level was at 203–209 m a.s.l. on the centre of the depression. On Pulpí aquifer a minimum piezometric level was reached on January of 2005 at 204–209 m a.s.l. on the centre of the depression.

Water classification

High electrical conductivity gradients (EC) are observed in ramblas to the North (>1mS/cm/km) and to the South of the Sierra Almagro (1.8 mS/cm/km in April 2007), that denote the importance of the processes of saline dissolution at these ramblas. This dissolution relates to two causes: the first one is the entry of waters that flow in contact with marine pliocene marls; the second one, waters returning after its use in irrigation, that come highly contaminated with agricultural wastes. The points with the highest EC are located at the Bajo Almanzora aquifer and at the Canalejas rambla.

In Fig. 2A, the collected samples are represented on Piper diagrams. An important group of bicarbonated waters is observed: 6, 7, 8, 13, 14, 15, 17, 18, 21, 23, 45, 51, 52, the majority of them with calcium-magnesium composition. Generally they distribute spatially linked to phyllites, micaschists and limestones, the same as to clayey sections where the surface of contact water-rock is large. On the southern flank of Sierra de Las Estancias it can be observed that lots of points corresponds to this class. Other classes of sulphatated waters at points 11, 19, 25, 26, 27, 41, 63 y 64, of calcic-magnesic composition, are affected by gypsum dissolution and evaporitic salts on the betic substrate and on tertiary deposits. Just on two cases chlorinated waters were found (10, 36), that were linked to evaporation affection. Anyway, water progressively assimilates chlorine and reach very high absolute concentrations.

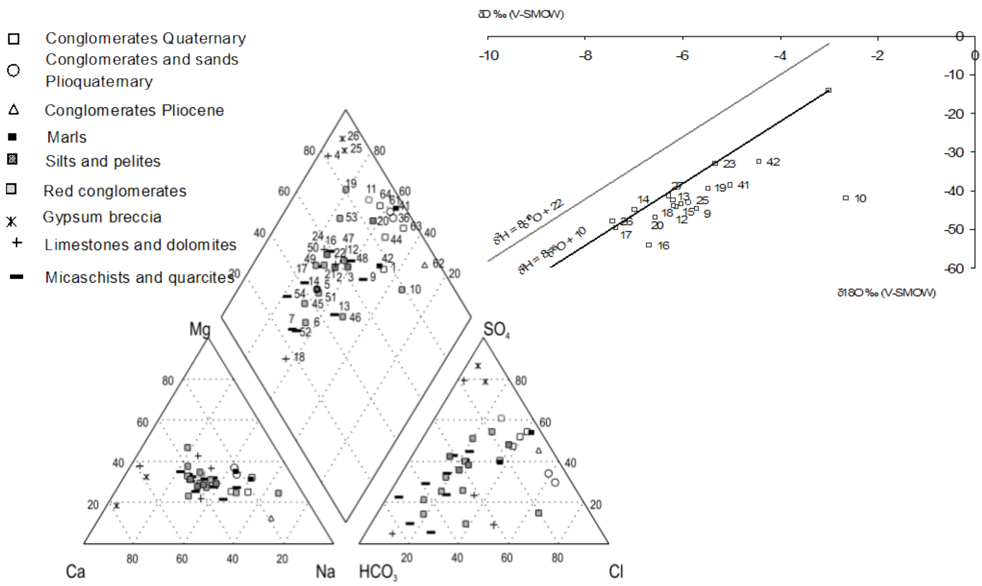

Figure 2. Piper Diagrams for the sampling period (A) and isotopic deviations on the sampled waters (B).

The majority of waters are calcic-magnesic but calcic waters are frequent, too: 25, 26, 4, 8 on gypsum and carbonates, or sodic waters on tertiary deposits and recent conglomerates: 1, 10, 42, 46, 62, 63. Rainwater may present sodic composition, too.

Isotopic deviations permit to figure out the degree of fractionation due to evaporation. Unfortunately there are no rainwater data in this area. All the ground waters are isotopically enriched in relation to a line representing the original rainwater (Fig. 2B). Well 10 presents the higher $\delta^{18}O$, which is registered as the higher degree of evaporation.

Factor analysis

The vectors of loadings are tabulated in Table 3. Factor 1 is related to EC, sulphate and chloride, it characterizes the influence of sulphatated and chlorinated salts in the waters, and of its draining by ramblas in sub-superficial fluxes. This factor explains 53.2% of the variability. Factor 2 is related on the shallow sections to bicarbonate and silica and inversely to temperature and Eh. It characterizes higher dissolution of limestones in underground waters of higher CO_2 content, deep thermal samples were not considered in the sampling or data matrix. It is related, too, with higher silica dissolution, at high pH waters. This factor explains 12.6 % of the variability.

Factor 3 includes nitrate, temperature and Eh versus calcium; it differentiates an organic contribution in superficial environments.

Table 3. Vectors of loadings for the factor analysis.

		Temp	CE	Eh	pH	Cl	SO_4	HCO_3	Na	K	Ca	Mg	Sr	NO_3	SiO_2	% Var
Dec 2004	F1	-0.05	0.99	0.28	-0.42	0.94	0.95	-0.15	0.93	0.9	0.84	0.91	0.83	0.73	-0.02	53.2
	F2	0.42	-0.09	0.23	-0.1	-0.16	0.09	-0.85	-0.15	0.03	0.07	-0.08	-0.01	0.09	-0.85	12.6
	F3	-0.74	-0.02	-0.29	0.08	-0.09	0.17	-0.19	-0.23	-0.24	0.34	0.23	0.33	-0.48	-0.25	9.95
	F4	0.19	0.08	-0.39	0.78	0.19	-0.07	-0.28	0.11	0	-0.18	0.12	0.14	0.05	0.08	7.2

Maps of the scores are presented in Fig. 3. For factor 1, the points that higher scores reached are points 41, 62 and 61, generally the factor increases in the flow path and on the top of marly deposits. Factor 2 finds a minimum at point 10, followed by 6, 52, 18 y 17; all of them are located to the South and Southwest of the Cabezo La Jara, respectively, near sub-actual deposits of travertines and calcretes which cover the apex of the fans. For factor 3, there is a minimum at point 62, followed by 20, 10, 1 and 50; all of them locate at ramblas that present high vulnerability to nitrate pollution. Intensive agriculture, pasturing and growth of almond trees in plowed fields favor this vulnerability.

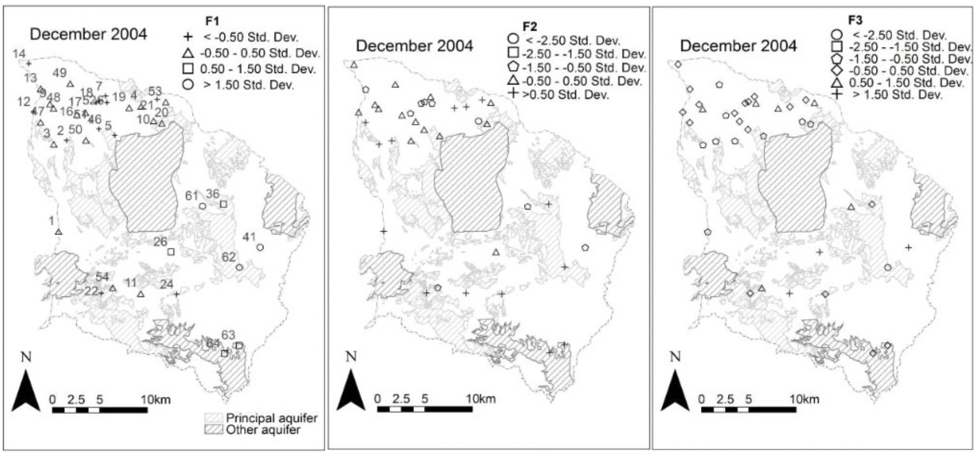

Figure 3. Maps of the scores of the factor analysis on the three factors.

Speciation and hydrogeochemical processes

In Fig. 4 the saturation indexes of calcite, dolomite, strontianite, CO_2, gypsum and quartz are plotted. Halite is always sub-saturated in waters at Bajo Almanzora region. Gypsum usually presents light sub-saturation. Dolomite is always saturated, except in the rainwater sample which has a SI = -1.88. The importance of this rainwater chemistry implies that dedolomitization is a constant in the surface. Gypsum is always under-saturated, except at 41 (SI= 0.06, in a rambla environment at Pulpí corridor) or at 25 and 26 (on evaporitic gypsum). Quartz SI is a bit higher (+0.45) than chalcedony SI; waters over-saturated in quartz are still under-saturated in chalcedony. The high pH values at dolomite-limestone aquifers could have been a factor enhancing silica solubility according to the observations of Knauss and Wolery (1988). The saturation indexes of calcite depict the ability of the waters to precipitate carbonates presenting samples 42, 10, 45 and 11 $SI_{calcite}>1$.

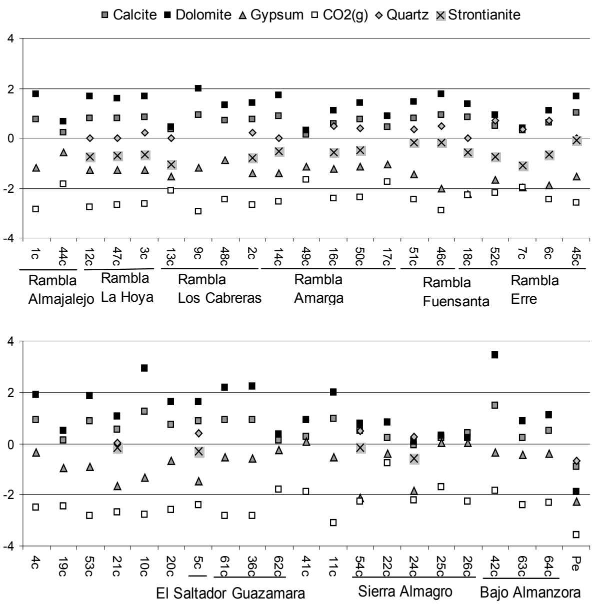

Figure 4. Saturation indexes in some species for the waters of the Low Almanzora region.

Another hydrogeochemical process of considerable importance in the area is cationic exchange. This process is more difficult of quantify considering exchange constant, but can be identified by the low $(Na^{+}+K^{+})/Cl^{-}$ ratios, in meq/L, that are lower than 1 in one of every three points sampled.

CONCLUSIONS

Factor analysis can be used to identify sources of physical-chemical variability, and to relate them to hydrogeochemical processes. Salinization, carbonate dissolution and eutrofization are the most underlined processes in the Bajo Almanzora ground waters. Sodification of soils and clayey sections is a normal process. Good Agricultural Practices have not been sufficiently implemented, and there is a generalized contamination due to nitrates and fertilizers. The kind of contamination is incremented in highly saline regions, such as the Bajo Almanzora aquifer or the Pulpí corridor, since high salinity hinders denitrification. The possible incorporation of the Bajo Almanzora water mass within the registry of Specially Protected Areas under the Nitrate Directive of the European Community can be proposed as a restoration measure.

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