The origin of water salinity on the Annaba coast (NE Algeria)

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Abstract Water wells located on the Annaba City coast are characterized by high salinity. The origin of this may be attributed to several factors such as the geological features of the region, the climate and the salted bevel. A number of analyses were carried out during October 1990, November 1998, December 1998, January 1999 and February 1999, in order to locate the origin of this high salinity. Principal component analyses show that the chloride-rich, Na-rich water is located near the sea. This indicates that seawater is the most likely contaminant of freshwater and that the sand can contribute highly to the observed high chloride contents. Our results also show that the salinity increases steadily when approaching the sea, and indicates the influence of marine water. Away from the coast, the observed Sr/Ca ratios (< 1) is due to the absence of the evaporitic formation which outcrops further south of the region.

Key words Algeria; climatic changes; dryness; geology; geophysical; hydrochemical; interface; Mediterranean Sea; salt level

INTRODUCTION

Water wells located on the Annaba City coast are characterized by high salinity. This may be attributed to several factors such as the geological features of the region, the climate and the salted bevel. The Annaba plain is located in the north-eastern part of Algeria (Fig. 1). It is bordered by the Mediterranean Sea to the north, the Belelieta Massif (287 m) and Boukhadra (152 m) to the west, the oriental Numidian Chain (1411 m) to the south, and the Bounamoussa River to the east.

GEOLOGY AND HYDROGEOLOGY

The lower plain of Annaba, the Seybouse plain, shows two superimposed aquifers (Nouacer, 1993). The upper aquifer (the surface nappe) is mainly composed of a sandy-clay formation, whereas the lower aquifer (the deep nappe) consists of gravels cemented by sandy-clay materials (Fig. 2). These two aquifers are separated by a clay formation which has a thickness decreasing from 50 to 0 m from north to south where the two aquifers meet. The clay formation which has a vertical permeability of 10^{-9} to 10^{-8} m s^{-1}, isolates the two aquifers. The gravels aquifer is deeper in the northern part (50–80 m) than in the northern part of the plain (5–20 m), where a lateral contact with

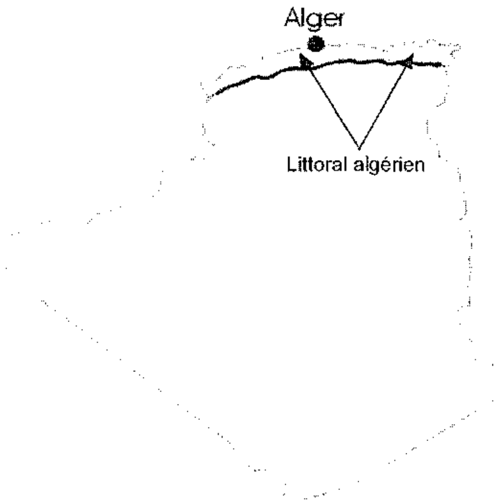

Fig. 1 Geographical situation.

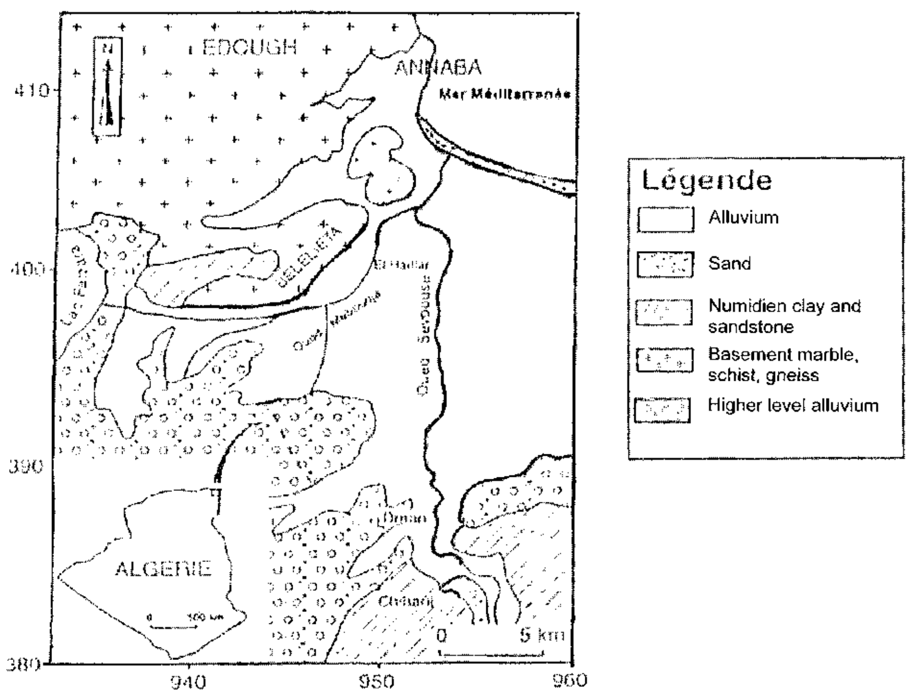

Fig. 2 Geographical map.

the surface aquifer exists. The east–west extension of this contact is about 25 km. The general flow of groundwater in the gravel aquifer is south-north directed, with an important gradient of 6.10^{-4} upstream and a lowest gradient of 4.10^{-4}. The mean permeability coefficient of the overall aquifer is 4.10^{-4} m s^{-1}.

MATERIALS AND METHODS

This study was carried out using chemical data obtained from analyses of samples collected over five months (50 samples every month): November 1999, December 1999, January 2000, February 2000 and March 2000. Physico-chemical parameters (pH, temperature, conductivity) have been measured *in situ* using a WTW multi-parameter device. Chemical analysis has been carried using Atomic Absorption for cations and colorimetry for anions.

METHODOLOGY

The climate

The climate is typically Mediterranean with two main seasons: dry and wet. The precipitation history shows a marked fall, from 1000 mm $year^{-1}$ to 500 mm $year^{-1}$.

Geophysics

The interpretation of electric soundings (CGG) reveals two aquifers of unequal extension: one superficial and the other deep.

Interpretation of the piezometric map

The piezometric map (Fig. 3) shows a general north–south flow with a mixed relationship river-nape (Hani, 2000). A north-south flow is also observed; that is, from the sea towards the aquifer. This is related to the topographic changes (Daghoussa mound) which facilitates marine intrusion. Hydrochemical data have been subject to statistical analyses. Principal component analysis carried out for each period of sampling (Fig. 4) shows a competition between NaCl and $CaSO_4$, giving a high salinity to water. The partition map of the analysed samples (Fig. 5) shows that NaCl-rich waters are close to the sea. Several sources have been tested to identify the origin of this salinity.

The effects of evaporitic formation (Triassic)

In order to show the effects of the evaporitic formation on the observed high salinity, mapping (Fig. 6) of Sr/Ca ratios has been carried out. The resulting map shows that Sr/Ca values range from 0.1% to 9.2%. However, in the vicinity of the sea, the Sr/Ca ratios do not exceed 2%. Therefore, the influence of the evaporitic formation on the high salinity observed in this zone is ruled out.

The evolution of chloride and sodium contents

Debieche (2002) has pointed out in his study that there is an increase of chloride and sodium content when approaching the sea. This trend confirms our results obtained using principal component analysis.

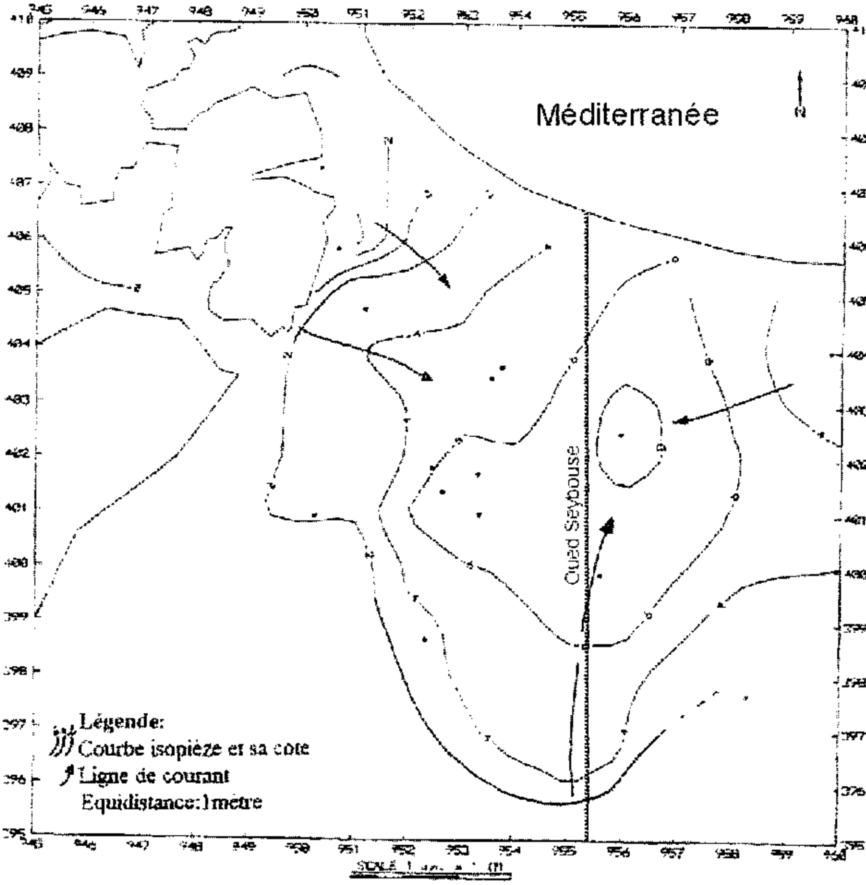

Fig. 3 Piezometric map.

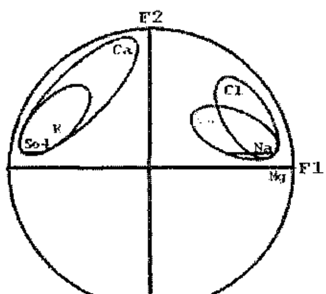

Fig. 4 Principal component analysis circle.

The contribution of Br/Cl ratios

On recommendation of J. Mudry, variations of Br/Cl have been considered in this study. The analysed samples show the presence of bromide in water. Calculated Br/Cl ratios gave values ranging between 0.3 and 3.4. This variation indicates the influence

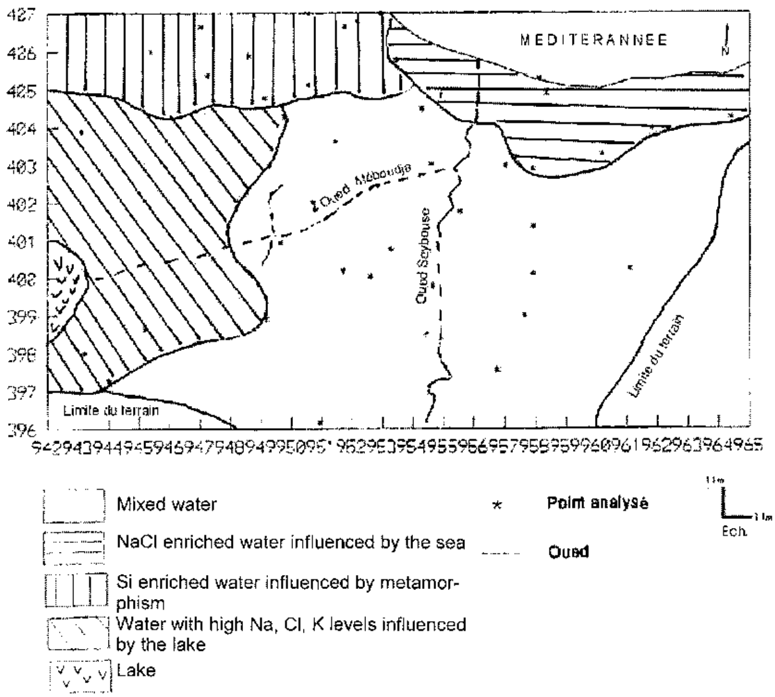

Fig. 5 Partition map of analysed samples.

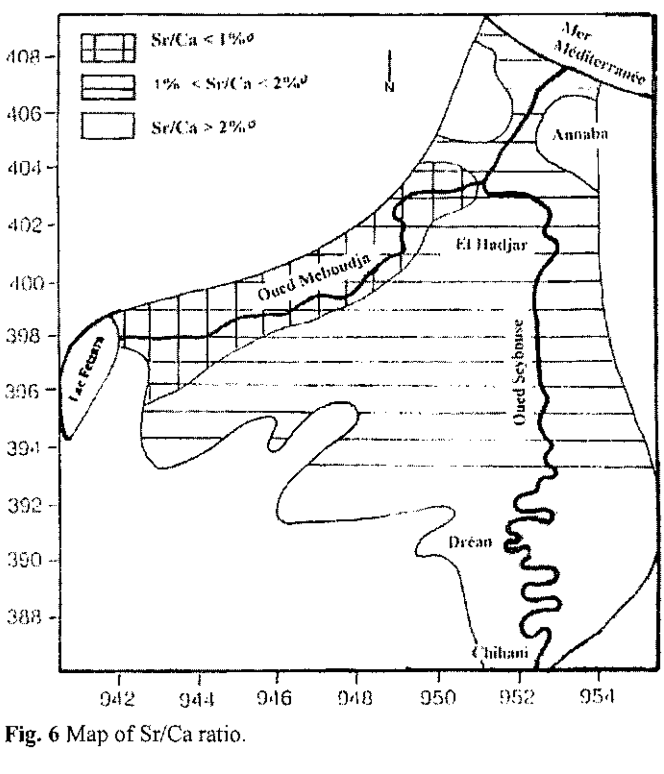

Fig. 6 Map of Sr/Ca ratio.

Table 1 Br/Cl ratio for eight sample locations.

Point number	Br/Cl ratio
P_1	1.2
P_2	0.3
P_5	2.16
P_6	1.15
F_1	0.43
F_2	3.4
F_5	1.15
F_{13}	0.03

of seawater, but could also be a result of marine sprays. For more precision, several representative samples of the whole area have been analysed. The results are shown on in Table 1.

Table 2 Oxygen and tritium isotopic composition.

Points d'eau	Origin of water	Aquifer type	Total mineralization	$d^{18}O_{SMOW}$ (%)	$d^{2}H_{SMOW}$ (%)	Tritium UT	
1–Well before Chihani	O	Numidian sandstone	1708	–5.85	–39.3	16.1	2.1
2–Well at Chihani	O		1678	–5.31	–35.2	10.6	1.6
3–Seybouse at Drean	O		1724	–5.75	–30.1	9.3	1.5
4–Waste of ECOTEC	R_i		3630	–4.21	–27.6	24.5	3.2
5–Seybouse at Drean	O		1872	–5.71	–38.7	8.0	1.5
6–Seybouse at Chbaïta	O		1779	–6.0	–36.6	10.1	1.4
7–Seybouse at El–Hadjar	O		1736	–5.63	–34.5	11.6	1.5
8–Seybouse at Oasis	O		1980	–5.55	–37.7	11.1	1.5
9–Meboudja at Pont Bouchet	O		2100	–2.24	–22.1	6.1	1.2
10–Seybouse Sidi Salem	O		6500	–4.54	–29.0	10.4	1.4
11–Waste of SN METAL	R_i		6250	–3.48	–23	9.0	1.4
12–Waste of ORELAIT	R_i		1020	–6.5	–42.6	9.1	1.4
13–Meboudja at Hadjar Diss	O		2730	+0.12	–18.3	6.8	1.3
14–1st waste SNS	R_i					11.1	1.5
15–2nd waste SNS	R_i		1350	–5.60	–50.3	8.0	1.4
16–Meboudja after SNS	O		2120	–1.82	–13.2	7.9	1.4
17–Industrial area Sidi Amar	R_i		2120	–2.26	–20.6	8.8	1.4

Contribution of the isotopes

Seventeen samples (Djabri, 1996) were collected from the Seybouse and Meboudja rivers, from wells and wastes, and analysed for their oxygen and tritium isotopic compositions (^{18}O and UT). In this study, we are going to focus on tritium isotopes since they give the absolute age of waters. All the analysed samples gave a value of UT greater than 6 (Table 2), which indicates that the water is rather recent and we have, therefore, a neo-salinity. Combined results obtained by the different methods show that high salinity is most likely a result of marine intrusion.

CONCLUSIONS

The data and results obtained in this study show the marked decrease of water reservoirs in Algeria during the past two decades. The water crisis has incited the deciding authority over this period to seek solutions that satisfy the population. However, the proposed solutions might have negative consequences on the aquifers, as is seen in this study; the over-exploitation of the coastal aquifers exposes the latter to marine intrusion. To recover the freshwater–saline water equilibrium, it is more appropriate to carry out a complete hydrogeological study over the whole coast, and estimate the exact water resources. A scenario of better exploitation of water may then be possible.

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