

NATURAL TRACERS AND ISOTOPE TECHNIQUES TO DEFINE GROUNDWATER RECHARGE AND SALINIZATION IN THE BOU AREG COASTAL AQUIFER (NORTH MOROCCO)

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Abstract

The geochemical and isotopic ($\delta^2\text{H}$, $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, $\delta^{15}\text{N}_{\text{NO}_3}$, $\delta^{18}\text{O}_{\text{NO}_3}$) characterization of the Bou Areg aquifer (North Morocco) based on samples collected during two surveys in November 2009 and June 2010 allowed the identification of runoff from the mountain regions and agricultural return flows as the main sources of aquifer recharge. The high salinization of the aquifer is not only due to the intensive agricultural activities but it is also associated with the natural quality of the catchment. The isotopic signal of dissolved nitrates allowed for the identification of two main sources of nitrogen in the system: (i) fertilizers and (ii) manure and septic effluents. The study, framed within the UNESCO-IHP sub component of the Strategic Partnership for the Mediterranean Large Marine Ecosystem, represents the first isotopic investigation of the area and will serve as a basis for the promotion of robust science based management practices in the region.

1. INTRODUCTION

Urban and coastal areas in arid and semi arid regions mainly rely on groundwater resources. The continuous utilization of coastal aquifers to respond to human needs can give rise to a deterioration of natural ecosystems, already threatened by climate changes, with possible severe effects on human health and wellbeing. In particular, incessant withdrawal can lead to overexploitation problems (if abstraction exceeds natural replenishment rates) and possible associated saline water encroachment. In addition, salinization problems might be related to other potential sources that must be defined and understood with the aid of appropriate hydrogeochemical techniques [1] to design a sustainable groundwater management programme in the long term.

Within the Strategic Partnership for the Mediterranean Large Marine Ecosystem, UNESCO-IHP subcomponent (Management of Coastal Aquifer and Groundwater), this work applies hydrogeochemical and isotopic tracers to define groundwater recharge and salinization in the pilot case study of the Bou-Areg aquifer [2]. The results will provide criteria to support science based water management practices.

2. SITE DESCRIPTION

The Bou-Areg coastal plain is located on the Mediterranean shore of Morocco, close to the Spanish enclave of Melilla. The climate of the region is mainly semi arid, but with a general high level of humidity due to the proximity to the sea. The dominant winds have a W-SW direction from November to May and an E-NE direction from May to October [3]. There is no regular rainy season, and regional precipitations are mainly related to Atlantic perturbations, with an average of about 300 mm/a [4].

The catchment area covers a surface of about 190 km², and it is limited by the Gourougou volcanic massif (NW), the Beni-Bou-Iffrou volcanic massif and the Kbdana range (SE). The area is also characterized by the presence of the so-called lagoon of Nador, which covers a surface of about 115 km². The lagoon is located in the Plio-Quaternary catchment basin of Meilla-Nador. The northern part of the plain is dominated by the presence of minerals such as calcium plagioclase, silica, olivine and pyroxene coming from the Gourougou mountain, while the soils of the southern part are rich in quartz, calcite and clays. In particular, the clay fraction is dominated by illite and chlorite [5], which generally characterize areas at weak pedologic evolution, as young soils or, as in this case, arid and semi arid regions.

The hydrological network is constituted by numerous rivers with temporary flow (*oueds*) and only few permanent ones (the most important of which is the Selouane *oued*). Some *oueds* directly discharge in the lagoon of Nador contributing, together with the underground water flow, to its freshwater and sediment inputs, while all the others do not reach the lagoon because of flow reduction due to evaporative

loss or infiltration in the aquifer. In addition to surface water contribution, sewage and wastewater inputs are also present and are mainly associated with the urban and suburban settlements on the lagoon shore (SE: Kariat Arekman; NW: Beni-Enzar).

3. METHODS

Two sampling campaigns performed in November 2009 and June 2010 allowed for the collection of 40 groundwater samples from private wells in the Bou-Areg aquifer and of two spring samples located close to the lagoon shore. *In situ* measurement involved pH, Eh, Electrical Conductivity, groundwater temperature and alkalinity. Chemical analyses of water samples were performed at the hydrochemical laboratory of CNR-IGAG (Montelibretti, Italy) (November 2009 campaign), and at the hydrochemistry laboratory of the Earth Sciences Department of the University of Pavia, Italy (June 2010 campaign), using ion chromatography. Trace elements analyses (B, Li, Sr) were performed at the Earth Sciences Department of the Pavia University, Italy, using an ICP-AES Jobyn Yvon 24. Br analyses were performed at the CNR-IGG (Pisa) using ion chromatography (Dionex 100). Samples for stable isotope analysis were collected and prepared according to standard procedures [6]. All gases were analysed on a Finningan™ MAT 250 Mass Spectrometer at ISO4 s.n.c., Turin, Italy.

4. HYDROGEOCHEMICAL RESULTS AND DISCUSSION

Groundwater samples in the Bou-Areg area are mainly classified as the sodium-chloride type, with the more enriched waters located in the downstream area, close to the lagoon. The two springs show a chemical composition close to that of groundwater, but with a clear influence of lagoon water, suggesting the occurrence of mixing processes. In addition, the groundwater chemical composition is also influenced by water-rock interaction processes. High alkalinity values registered for most of the wells might reflect elevated concentrations of dissolved inorganic carbon in the aquifer, typical of open system conditions.

All the samples collected in the Bou-Areg aquifer show strong salinization, confirmed by the high concentrations of both Na and Cl (Fig. 1). As a general feature, aquifer salinity increased from November 2009 to June 2010, possibly because of higher leaching of the unsaturated zone, thus recharging the underground system with more dissolved salts [7]. In fact, the salts remobilization from the unsaturated zone is a phenomenon of particular relevance in arid and semi-arid regions, where, after heavy rain episodes, the infiltration is more rapid and stronger.

The chemical composition of dissolved salts in groundwater is slightly different from that of seawater, due to differences in the hydrochemical processes occurring

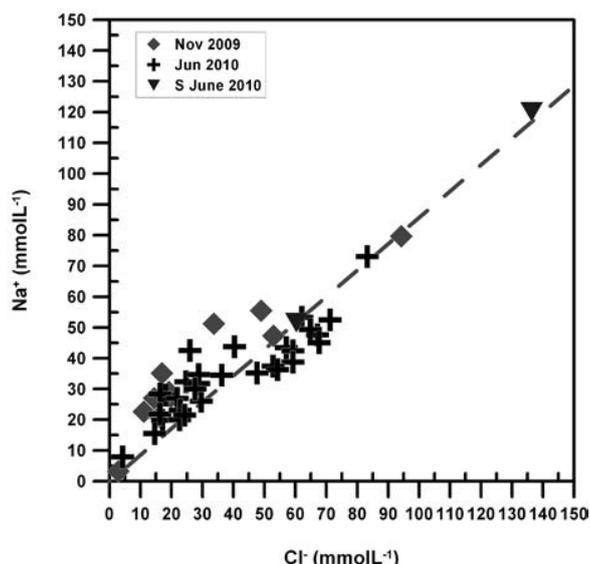


FIG. 1. Plots of sodium versus chloride concentration (in mmol/L) for the samples collected in the Bou-Areg aquifer. The dashed grey line represents the seawater dilution trend.

in those systems. This explains why most of the samples plot above the freshwater–seawater dilution line (Fig. 1). Only few samples have a composition coherent with the progressive dilution with seawater, thus suggesting the possible existence of old seawater intrusion or presence of connate water [4, 8] interacting with the recent recharge in this sector of the aquifer. The aquifer appears to be mainly recharged by mountain runoff. Besides, other sources of local recharge are altering the chemical composition of the studied groundwater, creating a complex system where apportioning natural processes and anthropogenic perturbation is difficult. In this case, isotopes can help to better define the origin of recharge and salinity.

4.1. Groundwater recharge

Stable isotopes of water molecules (Fig. 2) deviate from both the Global Meteoric Water Line (GMWL, [9]) and the Local Meteoric Water Line (LMWL, [10]) suggesting the occurrence of evaporative processes prior to recharge and mixing with external saline sources [6]. The samples that are more enriched in $\delta^{18}\text{O}$ ($> -5\text{‰}$) also show relatively higher concentrations of chloride (> 1000 mg/L) and dissolved nitrates (> 50 mg/L). This, associated to the extensive agricultural practices in the area, suggest that agricultural return flows is another important recharge source in

the aquifer [11]. On the other hand, wells with relatively high oxygen-18 values and low chloride concentrations might be associated with mixing with an already evaporated solution (e.g. the irrigation channel water).

4.2. Groundwater salinization

To better understand the pollution sources in the aquifer and the associated recharge process, $\delta^{13}\text{C}$ was studied. By comparing carbon-13 and oxygen-18 (Fig. 3) one can notice that the isotopic signal of the oxygen is more uniform, meaning that the waters are affected by the same fractionation processes (evaporation in the aquifer, evaporation during the irrigation processes and water recycling), whereas the carbon isotopic signature is more variable due to interaction with the carbonates system, soil organic matter or pollutants. Two groups of samples can be distinguished: (i) wells of group A (Fig. 3) have a more negative isotopic signal, typical of local recharge remobilizing pollutants in the unsaturated zone, thus changing the isotopic composition of carbon-13, and (ii) wells of group B, showing a tendency towards more positive carbon-13 values. This can be coherent with processes of carbonate dissolution ($\delta^{13}\text{C}$ of marine carbonate $\sim 0\text{‰}$) in intensively irrigated areas; in fact, as carbonate is dissolved, $\delta^{13}\text{C}_{\text{DIC}}$ will evolve to more enriched values. Of course, how far it evolves and the rate of carbonate dissolution depends on the 'openness' of the system, therefore on the soil CO_2 , and possible interaction of photosynthetic uptake (fixation of CO_2 by C3 or C4 plants [6]). For example, C4 plants (e.g. common

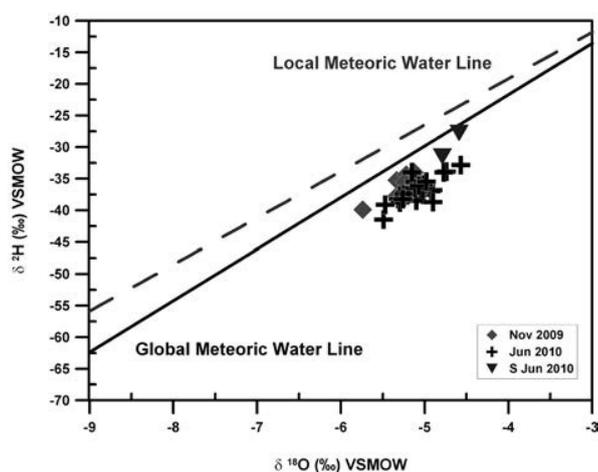


FIG. 2. Water stable isotope content in the Bou-Areg aquifer. Triangles highlight the isotopic composition of the two spring samples. Black and dashed grey lines represent the Global Meteoric Water Line [9] and the Local Meteoric Water Line [10] respectively.

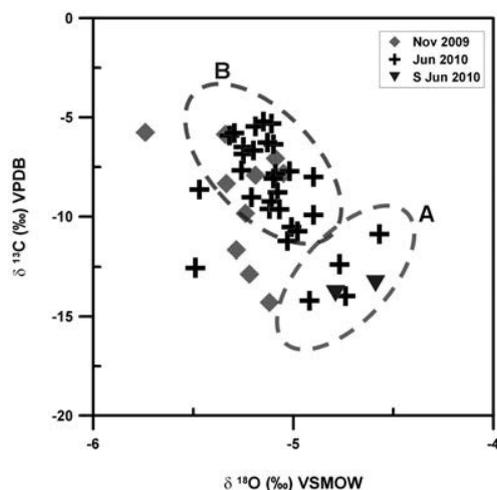


FIG. 3. Isotopic signal of the groundwater in the Bou-Areg aquifer. Plot of $\delta^{13}\text{C}$ (‰) versus $\delta^{18}\text{O}$ (‰). See text for explanation.

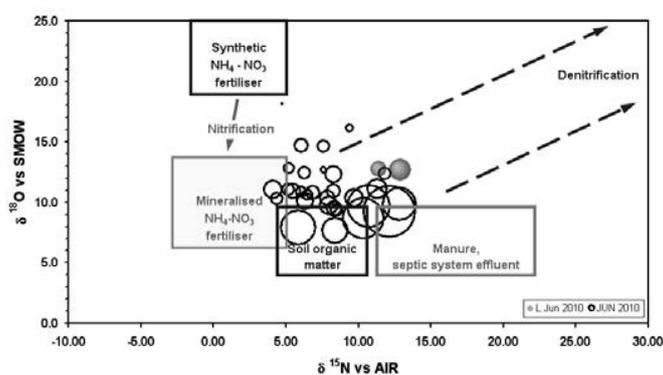


FIG. 4. Isotopic composition of dissolved nitrates $\delta^{15}\text{N}$ (‰) for groundwater and spring water samples in the Bou-Areg aquifer. Bubbles dimensions are proportional to the concentration of dissolved nitrate (modified after Ref. [12]).

agricultural plants like sugar cane, corn and sorghum) have $\delta^{13}\text{C}$ ranging from -10 to -16‰ , thus coherent with the signal of the Bou Areg water samples.

Experimental findings confirm that for most of the samples the high salinity is given by the coexistence of dissolution processes of evaporative rocks and carbonates from Miocene substratum water–rock interactions, and human impacts due to agricultural return flows. The latter represent the main contribution to groundwater salinization, especially in the central part of the aquifer, as well as one of the main causes of the general increase in nitrate concentrations.

By comparing the obtained isotopic data for groundwater of the Bou-Areg aquifer (Fig. 4), with the isotopic composition of $\delta^{15}\text{N}_{\text{NO}_3}$ in manure, septic system effluents (10–15‰) in soil organic matter (~5‰) and fertilizers (~0‰, [6]), two main sources of nitrogen input to groundwater can be distinguished. Two wells, located in the suburbs of the city of Nador and showing the highest dissolved nitrates concentrations appear to be clearly affected by pollution from manure and septic effluents systems (~+12‰), while the other two, located in the central part of the plain, have a signal coherent with mineral fertilizers (~+4‰), thus explaining their high potassium concentrations. As a general feature, most of the wells appear to be a mixing between these two main sources. Despite the fact that their isotopic signal is compatible with the one of soil organic matter ($\delta^{15}\text{N} \sim +4$ to $+10\text{‰}$), the mixing origin is more coherent with nitrates concentration quite above the 50 mg/L [6]. For the other wells, mixing processes seem to occur thus affecting the isotopic signal of dissolved nitrate, and the same process appears evident for the two springs.

5. CONCLUSIONS

Multi-tracer investigation of the Bou-Areg coastal aquifer allowed for a clearer definition of the main sources of groundwater recharge and salinization. Results from this work confirm that human activities are strongly altering the natural characteristics of the Bou-Areg coastal aquifer. This is mainly associated with groundwater exploitation for irrigation practices, and the combined pollution of fertilizers, manure and septic effluents. The improvement of groundwater exploitation, together with the enhancement of sanitation structures and wastewater disposal, will allow the considerable amelioration the quality of the subsurface waters and a better response to climatic and environmental changes in the area.

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