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title: **Water quality in the Bou Areg plain and the Lagoon of Nador (Morocco): the land use connection and groundwater pollution**

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INTRODUCTION

The coastal Plain of Bou Areg, is located in the Mediterranean shore of Morocco, close to the Spanish enclave of Melilla (Fig. 1). This aquifer covers a surface of about 190 Km^2 (Dakki, 2003) and consists in two sedimentary formations of Plio-Quaternary age. The upper layer is made of fine silts and the lower one is made of coarse silts with sand and gravels (El Yaouti et al., 2009). The thickness of the aquifer ranges from environs 40 m at Kebdana to 1 m next to the shore.

The aquifer communicates with the lagoon of Nador, which represents its main outlet.

Several *oueds* are present in the area, also contributing to freshwater input of the lagoon of Nador; but only few have a permanent regime and most of them also have human contribution such as sewage and wastewaters.

The alimentation of the Bou Areg aquifer is given by groundwater from the Gareb confining aquifer, rainwater, freshwater from the Selouane River (as the main surface drainage), and irrigation waters (El Yaouti et al., 2009).

Aquifer salinization is widely recognized (Dakki, 2003), making the groundwater of the plain not diffusely used for agricultural purposes. If on the one hand the high salinity can be related to the soil nature, on the other the increase in salt content (e.g.14-10gL^{-1} in the area close to the City of Nador) could be associated to a local saline water (and lagoon water) intrusion (Dakki, 2003).

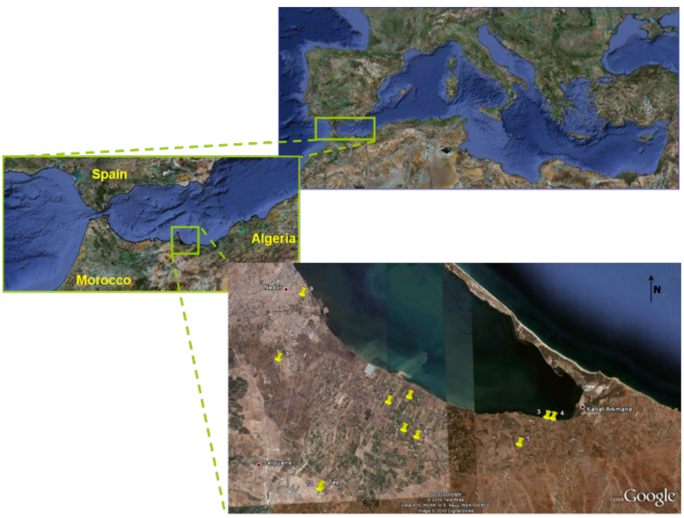

Figure 1. Location of the Bou Areg plain and the Lagoon of Nador. Sampling sites.

As in most of the coastal zones in the Mediterranean area, and worldwide, the increase in urban development in the Grand Nador area is negatively affecting natural resources quality through uncontrolled liquid and solid wastes discharge.

This catchment contains a mix of arable farming, grazing industries and urban settlements, whose combined action is damaging the natural environment especially due to the by-products of those human activities. Moreover the increase in use of phytosanitary products and synthetic fertilizers, contributing to the decrease of groundwater quality, is also affecting lagoon quality, resulting from surface runoff and groundwater discharge.

Understanding and quantifying the origin of groundwater pollution and salinization, as well as assessing the interactions between the aquifer and the lagoon is the firs step for performing adequate management practices. Therefore the main goals of the present work are to contribute to the provision of specific and reliable data on groundwater quality in the Bou Areg coastal plain and to define and quantify the interactions between the Bou Areg Costal Plain and the Lagoon of Nador.

Moreover, as this work is framed within the Strategic Partnership for Mediterranean Sea Large Marine, Ecosystem, UNESCO-IHP Sub-Component: "Management of Coastal Aquifer and Groundwater", this pilot case study will be assumed as an example of the application of hydro-geochemical and hydrogeological tools to support long term science based management practices and Integrated Water Resource Management in transition zone in coastal aquifers.

MATERIALS AND METHODS

In order to restrict the sources and the processes of salinization and to discriminate among different contribution to groundwater pollution in the Bou Areg aquifer, groundwater samples have been collected in 10 dug wells spread across the coastal aquifer (Fig. 1). This first field activity, performed in November 2009, represented the preliminary mission of the project aimed to obtain information on the status of the aquifer quality, and to identify the potential sampling sites for the subsequent missions (June 2010 and November 2010). *In situ* measurements have been performed to determine pH, Electrical Conductivity, Salinity, groundwater and air temperature. Hydrochemistry of major and minor elements (e.g. B, Br, Li, Si, Sr), together with the environmental stable isotopes of water molecule ($\delta^{18}O$ and $\delta^{2}H$) and $\delta^{13}C$ has been used to restrict the sources and the processes of salinization and trace the origin of groundwater recharge.

Moreover, as the area is mainly exploited for agricultural activities, the natural abundance $\delta^{15}N_{\_NO3}$ was investigated to trace the main sources of NO_3^-, as a fundamental step to prevent the plain from further contamination. The $\delta^{18}O$ composition of nitrate adds some more information on the origin of NO_3^-, and it allows distinguishing between synthetic and natural fertilizers (Clark and Fritz, 1997).

RESULTS AND DISCUSSION

In situ measurements pH has a mean value of 7.7, with values ranging between 7.4 and 8.3, showing neutral or slightly basic nature. Electrical conductivity suggests the presence of exceedingly mineralized waters, with an average of 4,780 μScm^{-1}, and a maximum of 8,120 μScm^{-1} in well 4. Water temperature of collected samples varies between 15.4°C and 22.3°C, with an average of 20.6 °C, these values are typical of cold-hypothermal waters.

The abundance of major ions, especially of nitrates, chlorides and sulphates (Figure 3 and 4) suggest an elevated alteration of physical-chemical properties in fresh water resources, and thus an increased risk for public health. Mineralization processes are relevant and concern areas where farming and rural or urban life can affect the groundwater quality.

GROUNDWATER RECHARGE

The δ18O and δ2H values for groundwater sampled in the Bou Areg plain, were plotted and compared with the Global Meteoric Water Line (GMWL: $\delta^2H = 8.13\ \delta^{18}O+10.8$; Craig, 1961; Figure 2A).

Due to the absence of rain measurements for the studied area, data were compared to the dataset of the closest available station, also considering that the main sources of precipitations are Atlantic driven precipitations. Therefore, obtained values were also compared with the Local Meteoric Water Line (LMWL: $\delta^2H = 8\ \delta^{18}O+13.7$) provided by Ouda et al. (2005). Deviations from both the global and the local meteoric water line, with an average slope of 6.7, suggest the occurrence of evaporative processes and mixing with saline sources. The evaporative enrichment and the deviation even from the LMMWL reflect the evaporative loss of the aquifer (Clark and Fritz, 1997). This is also confirmed by the comparison between the isotopic signal of oxygen-18 and chloride (Figure 2B).

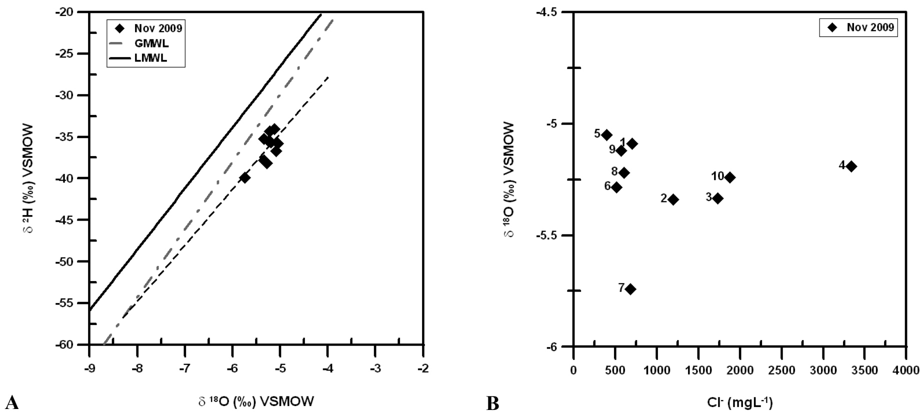

Figure 2. Delta Deuterium and oxygen-18 variations in groundwater from the Bou Areg coastal plain (A), [Dashed green line: Fit linear data NOV 2009; Grey dashed line:Global Meteoric Water (GMWL; Craig, 1961; Clark and Fritz, 1997); Plain line: Local Meteoric Water Line (LMWL; Ouda et al. 2005)]; Delta oxygen- 18 vs chloride.

SALINIZATION

Based on this preliminary analysis, and according to the results of several authors (Chaouni et al., 1999; El Mandour et al., 2008; El Yaouti et al., 2008; El Yaouti et al., 2009) it is clear that groundwater in the Bou Areg aquifer are affected by salinization problems. El Mandour et al.(2008) among the others pointed out the possible interaction of different sources of groundwater salinization: seawater intrusion, the influence of marly gypsum-bearing terrains and the influence of anthropogenic products as the agricultural fertilizers.

In fact if we plot Na concentration versus Cl concentration (Figure 3A) we can observe that almost all the samples have quite high concentrations in both Na and Cl, confirming the possible salinization processes affecting the aquifer. In particular only two samples (4 and 10) have a composition coherent with the progressive dilution with sea water, while all the others plot above the dilution line. This enrichment could indicate water-aquifer interaction, and cation exchange reactions between the silicates fractions of the aquifer and groundwater rich in dissolved calcium; therefore in first approximation we could assume that the circulation is slow, facilitating the exchange with silicates, with liberation of Na^+ (El Yaouti et al., 2009) and a possible associated decrease in Ca^+. However by plotting Ca versus Cl, (Figure 3B) an increase in Ca^+, is observed, possibly indicating the occurrence of carbonates or gypsum dissolution. The highest value of Ca concentration for well 10 (Figure 3 B) could be representative of its origin, therefore associated to its baseline conditions.

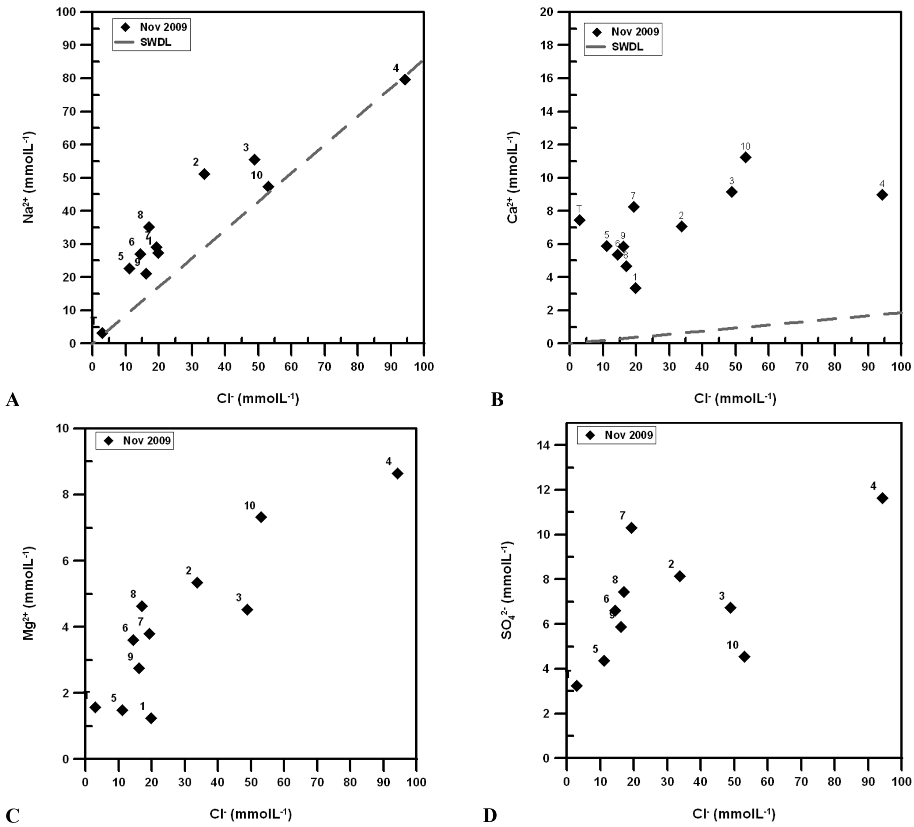

Figure 3. Plots of dissolved species versus chloride concentration (in mmolL-1). (A) Na vs. Cl; (B) Ca vs Cl; Mg vs Cl; (D) SO_4 vs Cl; dashed lines represent Seawater Dilution Line (SWDL).

WATER POLLUTION

In order to identify the different sources of nitrate, the isotopic composition for nitrogen and oxygen have been studied. Intensive human activity in this area has resulted in pollutant loads, in some cases exceeding drinking water standards, in particular, for nitrate and Boron (Fig. 4) For this reason, in order to build up the correct policy for groundwater management, the identification of the different sources of nitrogen pollution is required.

Considering the isotopic composition of the wells, (Figure 5 and 6) the samples lay within the ranges consistent with an origin from soil organic matter and, manure or septic system effluents

(10-15‰), as expected if considering the position and the social situation of the region. In fact in rural areas and in over inhabited region, the main impact on groundwater is represented by the combined action of fertilizers and septic effluents, thus confirmed by $\delta^{13}C$.

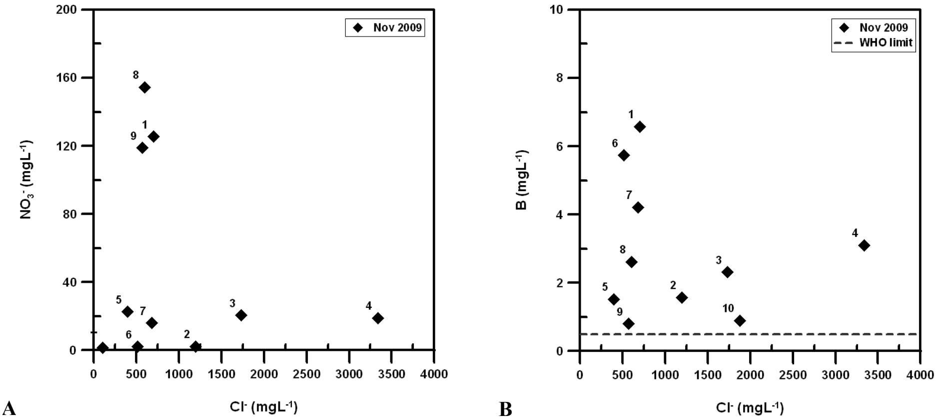

Figure 4. Nitrates concentration versus chloride (A); Boron concentration vs chloride (B). Dashed Line represents the WHO drinking limit for B (B= 0.5 mgL-1).

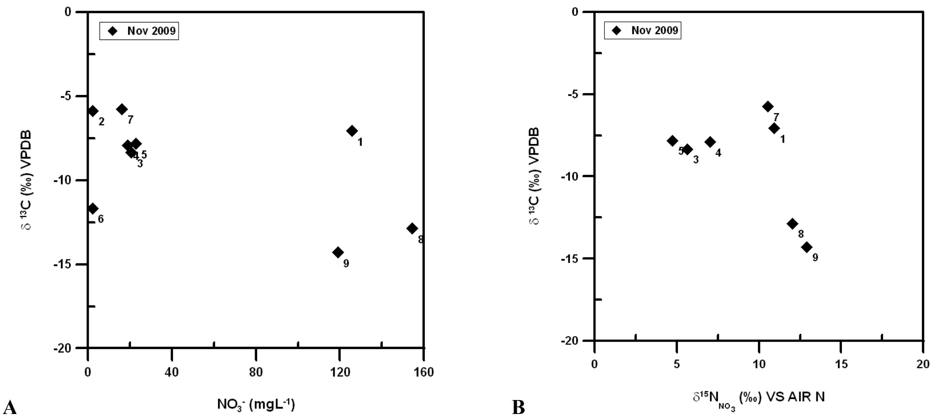

Figure 5. Delta carbon 13 (‰) versus nitrates concentrations (A) and delta 15 nitrogen (‰; B).

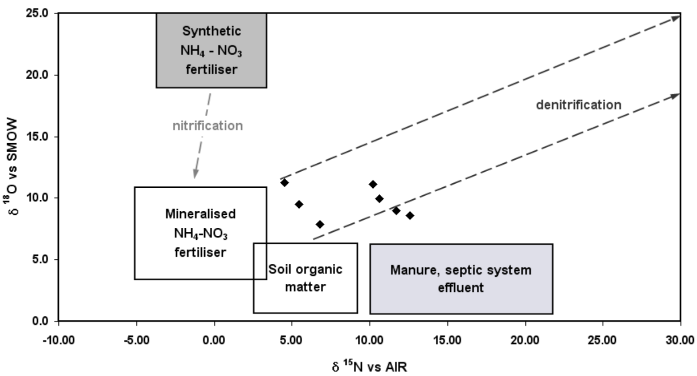

Figure 6. Isotopic composition of Nitrates for the Bou Areg coastal plain.

Moreover, considering the isotopic signal for carbon-13 in Dissolved Inorganic Carbon (DIC), few wells (6, 8, 9) have a signature coherent with the recharge in a open system , while the others have a composition coherent with the mineralogical matrix (Figure 5).

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