

Water Rock Interaction [WRI 14]

Geochemical and isotopic investigations to study the origin of mineralization of the coastal aquifer of Sousse, Tunisia

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Abstract

In the Tunisian Sahel near one of the seaside resorts, the water quantity and quality are an even greater problem than in southern/central Tunisia. The groundwater of the Oued Laya aquifer system occurs mainly at two levels, a shallow aquifer at depths to about 60 m whose reservoir is mainly formed by Mio-Pliocene sediments (with gypsum lenses dispersed within the geological formations), and a deep aquifer situated between 100 and 250 m depth, located in the Miocene sandstone formations. The results of geochemical and isotopic studies have shown that groundwater salinity does not seem to be linked with increasing water well extraction. Rather, water mineralization seems to be acquired by dissolution of minerals in the aquifer system, especially halite and gypsum. Moreover, ion exchange processes also play an important role in groundwater mineralization. The stable isotope data do not support the hypothesis of mixing with seawater.

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1. Introduction

In the Tunisian Sahel near one of the seaside resorts, the water quantity and quality are a major problem. The Oued Laya coastal aquifer system is no exception. It is located in a coastal saline wetland along the Mediterranean Sea in the surroundings of the city of Sousse, about 140 km south of Tunis (eastern Tunisia). This water reservoir is mainly characterized for presenting bad quality groundwater resources with high salinity content in comparison with the neighbour's aquifers.

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The landscape is a coastal plain slightly sloping (3%) towards the sea. The groundwater of the Oued Laya aquifer system occurs mainly at two levels, a shallow aquifer up to depths of about 60 m whose reservoir is mainly formed by Mio-Pliocene sediments (with some gypsum lenses dispersed within the geological formations) and a deep aquifer, situated between 100 and 250 m depth, located in the Miocene sandstone formations. As a consequence of the climate and geological formations there are no perennial rivers in this region. Many small rivers carry water intermittently as floods, and intense storms occasionally cause surface runoff, which is discharged by the oueds. Oued Laya is the major oued reaching the coast. The others discharge into sebkhas (salty lakes).

2. Methodology

This work aims to characterize the geometry of the badly known Oued Laya aquifer system and to identify the geochemical processes responsible for the salty groundwater. With this goal, geochemical, isotopic and geophysical techniques were used in order to characterize and identify the main processes occurring within the aquifer and responsible for the water mineralization increase. To better understand the hydrodynamic processes taking place and flow regime as well as the origin of salinity of the groundwater, sampling campaign was performed, during 2009 and 2010, on thirty points (dug wells and boreholes). Different methodologies / approaches using geochemistry (ions Na^+ , Cl^- , SO_4^{2-} , Ca^{2+} , Mg^{2+} , Br^-), stable isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$) were compared with the hydrodynamic information [2] for identifying the main processes involved in the increase of mineralization. This work uses also a monitoring network set up in the Sahel of Sousse in the 1980s by the Water Resources Departmental of the Ministry of Agriculture, Tunisia.

The superficial aquifer, representing the shallow groundwater mean dry residuum concentrations of 4420 mg/L (mean values). Towards more deep values the groundwater mineralization increases, i.e., the confined aquifer is even more salty, reaching salinization values improper to be used for human supply, agriculture or even industry. The confined aquifer of this delta shows high values of electrical conductivity rising from the north (4 mS/cm) to the shoreline (14 mS/cm).

3. Results

3.1. The Na^+/Cl^- correlation

Chlorine is strongly correlated with sodium for the majority of the shallow groundwater samples. The positive correlation between Na and Cl contents (Fig. 1) indicates the contribution of halite (NaCl) dissolution to groundwater mineralization. The Na/Cl ratio obtained in the groundwater samples, suggests that the predominance of sodium and chlorine cannot be explained only by the proximity of the sea, by a straightforward seawater intrusion, even for samples taken near the sea line, since the Na^+/Cl^- molar relationship differ significantly from that of the Mediterranean ($r^2=0.86$) [3], a strong enrichment in the sodium content is observed in some of the most mineralized groundwater samples and also in part of the water samples lower salinization. Two parallel trend lines can be identify in Fig. 1, one to halite dissolution and another one with Na/Cl higher than the marine ratio reflecting an income of sodium to the system, which could be related to water rock interaction and ion exchange ($\text{Na}-\text{Ca}$). Ion exchange processes involves transfers from mass between solid matter and the solution very common in deltaic areas, where clay minerals and organic matter are abundant.

3.2. The Br⁻/Cl⁻ relationship

The Br⁻/Cl⁻ relationship is an important hydrological tool in order to identify the possibility of seawater intrusion since it is relatively constant (1.5×10^{-3}) in the seawater, considering the extremely long residence time in the oceanic masses [3]. In the Mio-Pliocene aquifer, the Br⁻/Cl⁻ relationship is not distinctive (Fig. 2): more than two thirds of the shallow groundwater points are within a range of 20% from the seawater relationship. This proximity can be explained both by continental waters mixing with seawater, and also by an influence of the spray marine on the infiltrated rain waters. The shallow groundwater points ascribed to Br⁻/Cl⁻ ratios plotted over to the sea water dilution line are related with sampling sites located outside of the likely seawater intrusion area.

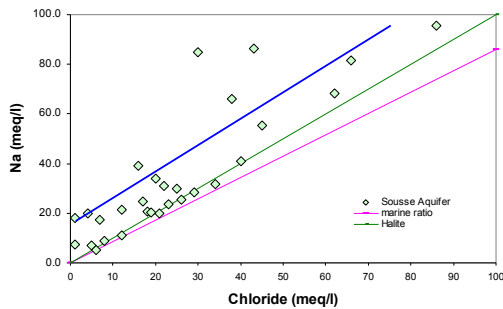


Fig. 1. Correlation between Na⁺ and Cl⁻

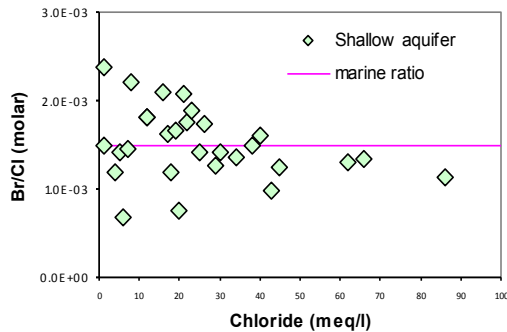


Fig. 2. Relationship between Br⁻/Cl⁻ ratio and Cl⁻

3.3. Stable Isotopes ($\delta^{18}\text{O}$, $\delta^2\text{H}$)

A separate study of ionic relationships and stable isotopes is not able to identify the origin of the water precisely. The combination of these two approaches is more explicit and in most cases even crucial. The observation of the plots $\delta^{18}\text{O}$ vs. $\delta^2\text{H}$ (Fig.3) and Cl⁻ vs. $\delta^{18}\text{O}$ (Fig. 4) for the Mio-Pliocene aquifer of Sousse shows that the isotopic composition ($\delta^{18}\text{O}$) in the groundwater can be divided in two groups (Fig. 3). In the first one the composition of $\delta^{18}\text{O}$ varies between -3.8 and -4.91 ‰: This group was formed by some water samples enriched in ¹⁸O and ²H, which aligned on the mixing line of seawater, indicating a probable marine contamination. The other samples of this group are located between the global meteoric water line (GMWL) and the local water line (LMWL) of Tunis Carthage. The hypothesis of an important contribution of the present-day precipitation to the recharge is the most probable. The second group is composed by the wells showing $\delta^{18}\text{O}$ values ranging between -4.91 and -5.39 ‰. These values are relatively far different from the weighted average mean of the precipitation water of the Tunis Carthage station (-4.4 ‰). Considering this isotopic difference of about 1 ‰ (mean values) in the oxygen-18 content, another explanation must be added to characterize the groundwater system. From the geographic and altitude point of view the region “did not change”, so to explain the depletion found in the groundwater system, one should call for other climatic conditions during the recharge and very different from those observed in the region in nowadays. Studies performed in groundwaters from United Kingdom and from western and central Europe recharged during the last glaciation are also depleted in both ¹⁸O and ²H in comparison with modern precipitation in the region [4]; [1]; [5], due to the colder climate during recharge, so Mio-Pliocene aquifer of Sousse show signs of an isotopic fingerprint characteristic of old water probably recharge during the last glacial maximum. On the other hand, plotting the isotopic composition (¹⁸O) as a function of Cl⁻ (Fig. 4), some indication of mixing between fresh groundwater and seawater can be found. An isotopic shift is observed in the plot, i.e. some isotopic

enrichment in the groundwater samples towards seawater composition is found. So, face to the probably presence of relationship between the isotopic composition and the mineralization, the marine origin of salinity can not be excluded (Fig. 4). Furthermore, one possible explanation for the enrichment detected in the other points that present “heavy isotopic content” and smaller mineralization, this situation punctually can be explained by groundwater evaporation in the borehole or during the sample collection.

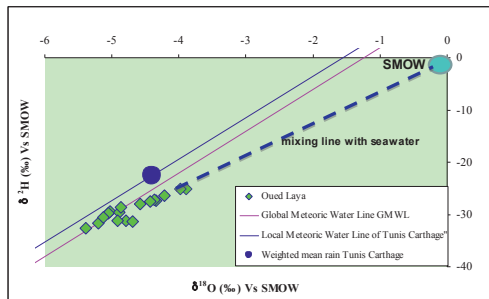


Fig. 3. Plot of $\delta^2\text{H} \text{‰}$ Vs. $\delta^{18}\text{O} \text{‰}$ (V-SMOW)

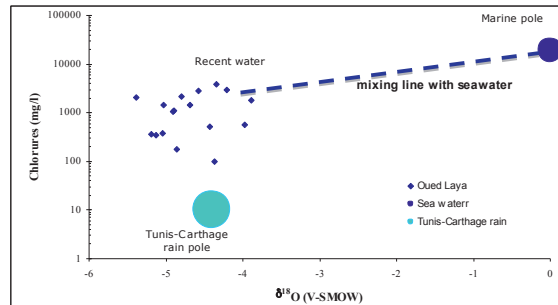


Fig. 4. Plot of Cl- Vs. $\delta^{18}\text{O} \text{‰}$ (V-SMOW)

4. Conclusions

The results of geochemical and isotopic studies have shown that the salinity of the studied shallow groundwater seems not to be linked with the increasing water well's abstraction, as in the major part of coastal aquifers in the Mediterranean area. In contrast, water mineralization seems to be acquired by dissolution of minerals in the aquifer system especially halite and gypsum. Besides ion exchange processes play also an important role in the groundwater mineralization. Therefore, it clearly appears that several sources might contribute with different mineralization to the salinization of the aquifer through the natural recharge and also through the return of water irrigation that remains to be confirmed by other analytical approaches such as stable isotope of ^{15}N coupled with the nitrate contents. The contamination of the Mio-Pliocene shallow aquifer by a mixture with seawater is probable and the stable isotopes data support the hypothesis of mixing with seawater.

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