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Assessment of groundwater salinity mechanisms in the coastal aquifer of El Haouaria, Northern Tunisia

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Abstract

In the El Haouaria region (N.E. Tunisia), our hydrodynamic survey revealed a decrease in unconfined groundwater reserves of approximately 11% over the last 30 years due to the abstraction of water. Over that same time period, the groundwater table displayed a natural decrease of about 10 m in depth over an area of 230 km². Hydrogeological investigations have shown that two aquifers which vertically integrate all of the permeable zones in the region can be distinguished: a shallow aquifer formed by filling the Quaternary and another deeper one in the Pliocene. These two aquifers are separated by a semi-permeable layer through which vertical exchange by seepage is possible. Different methods using geochemistry (Na⁺, Cl⁻, Br⁻) and stable isotopes (¹⁸O, ²H) are compared with the hydrodynamic information for identifying the main processes involved in the salinization and recharge. Forty groundwater wells were sampled to obtain additional information on the hydrochemical and isotopic characteristics of the groundwater defined in previous studies.

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1. Introduction

The El Haouaria aquifer is a relatively small aquifer located in northeastern Tunisia, characterized by a semi-arid climate and located on the Cap Bon peninsula. This study aims to integrate hydrogeological data with major ion geochemistry and the isotopic signatures of groundwater in order to identify the major hydrochemical processes responsible for groundwater mineralization. Here we measured stable isotopes and major ion chemistry (Na^+ , Cl^- , Br^-) in 40 groundwater samples from the El Haouaria aquifer. Much of the available water in the plain is used for irrigation to further agricultural development of the region. The El Haouaria plain is 12 km wide and 16 km long and is exposed to the sea on the east and west sides. The North and the South are bordered by clay Miocene outcrops with intercalations of sandstone. The surface area of the quaternary water table is 230 km². Water resources in this region rely heavily on its pluviometric potential and the atmosphere's evaporation potential, which takes back the majority of the precipitation. The El Haouaria water table benefits from wet conditions with an average rainfall of 568 mm/year, a natural depression which forms a basin for collecting run-off water, and a sandy, very permeable dunal mantle that ensures the best conditions for rain infiltration. The average annual temperature varies from 17 to 19 °C. The wettest months are November and March, and the driest are July and August. Potential evapotranspiration exceeds 1100 mm/year. Few previous studies have been done on the isotopic characterization of the El Haouaria aquifer [1].

2. Local geology and hydrogeology

The El Haouaria plain forms a depression facing east-west and is bordered by the sea on both sides, with outcrops of the Oum Douil formation in the north and south. The reservoir of the El Haouaria groundwater is composed of an overburden of quaternary sediment 50 meters deep and a dunal cap under which rests a large Pliocene deposit 200 meters deep making up the central filling of this depression. According to the geological cross sections done on boreholes in the region, the quaternary deposits are made up of intercalations of sandy layers and clay with travertin and tuff located at the summit. These two aquifer levels are separated by a semi-permeable layer of clay 10 to 15 meters thick, which fills the deep aquifer located in the Pliocene deposits, as opposed to the groundwater table made up of quaternary sediments (Fig. 1). Hydrogeological investigations have shown that two aquifers, which vertically integrate all of the permeable zones, can be distinguished: one groundwater table formed during the quaternary and a deeper aquifer formed during the Pliocene. These two aquifers are separated by a semi-permeable layer through which vertical exchange by seepage is possible. Our hydrogeological study showed that interconnection exists between the groundwater towards the deep aquifer at Dar Chichou and another one in the opposite direction at Gareât El Haouaria (a salty lake located in the center of the plain), where the deep aquifer supplies the groundwater. Examining the changes in piezometry from 1972 to 2004 revealed a continual decrease, which varied from 1 to more than 14 m in some places. Compared to 1972 values, an average decrease of 3.38 m was observed in 2001 across the El Haouaria plain.

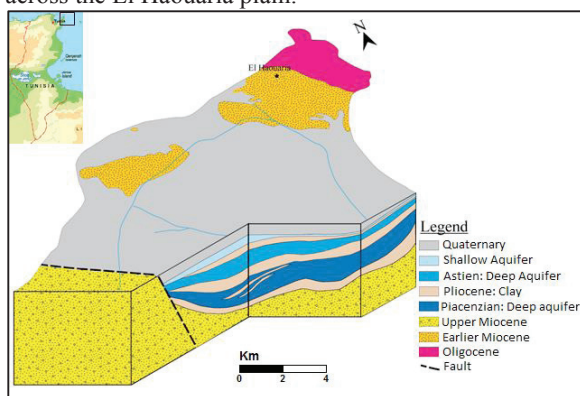


Fig. 1. Location of the study area and Bloc Diagram of El Haouaria region

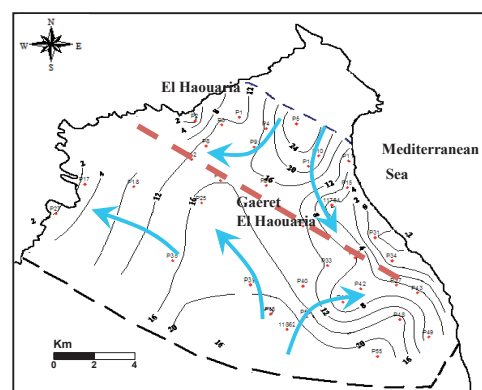


Fig. 2. Piezometric map of El Haouaria shallow aquifer

This decrease lessened to 1.4 m in 2006, such that there was a decrease of 11% since 2001 and 4.6% since 2006 for the total depth of the groundwater estimated at 30 m. These two aquifers have more than 200 m of depth in the plain characterized by an active fault of Azmour located in the southern part of the study area. Depth of the groundwater table varies across the region. The piezometric map established in 2006 shows that the aquifer is characterized by a groundwater divide (Fig. 2). In the southern part of the aquifer, the groundwater flows towards the Garet El Haouaria (salty lake), located in the center of the plain, then flows towards the sea, located to the East and West. Groundwater flow coming from the north is also flowing towards the sea located in the East and West.

3. Chemical investigation

The salinity of the groundwater is determined by the total dissolved solids (TDS) and ranges from 3 to 8 g/l (the highest values are measured in the shallow aquifer). The strong correlation ($r^2 = 0.94$) (Fig. 3. a) in the Na^+/Cl^- relationship suggests that these two elements have the same origin. Even for samples taken far from the sea, the molar relationship Na^+/Cl^- does not differ very significantly from that of the Mediterranean sea (0.86) [2]. The geographical location of the study area (peninsula) gives several hypotheses on the origin of salinity. First, the predominance of sodium and chloride can be explained by the proximity to the sea, via the spray caused by prevailing winds from the sea contributing to chloride and sodium concentrations. Secondly, the development of agriculture and corresponding irrigation, in the El Haouaria region, will increase the concentration of salts. This is accentuated by evaporation of irrigated water which will increase soil salinity, and therefore, the contribution of these salts to the aquifer through the excess of water irrigation. Finally, the excessive use of fertilizers enriched in Na and Cl in this region will result in a systematic and additional presence of Na and Cl in the groundwater. The processes of dissolution, precipitation and cation-exchange are actively taking place within the groundwater system. Results indicate that groundwater is oversaturated with regarding several mineral phases (calcite, aragonite and dolomite). However most of the groundwater is unsaturated with respect to gypsum and anhydrite. The Br-/Cl-relationship helps to identify the possibility of seawater intrusion [3] since it is relatively constant (1.5×10^{-3}) in the seawater considering the extremely long residence time of oceanic masses. Because of this, particular attention to the Br/Cl ratio (Fig. 3.b) was paid to sampling points near the Mediterranean Sea on both the east and west side of the El Haouaria plain. The water samples whose Br/Cl ratios are lower than the marine molar ratio (around 0.5×10^{-3}) point to a different mineralization origin. Alternatively, samples whose molar Br/Cl ratios are above the sea water dilution line are not affected by seawater intrusion. In this case, the salinization of the groundwater would be expected to result from the ionic concentrations increasing due to both the evaporation of recharge waters and the effects of interactions between the groundwater and the geological formations.

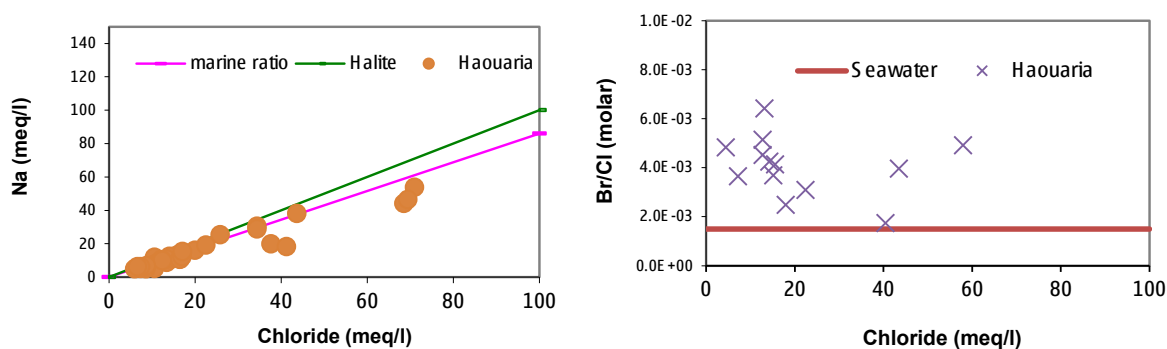
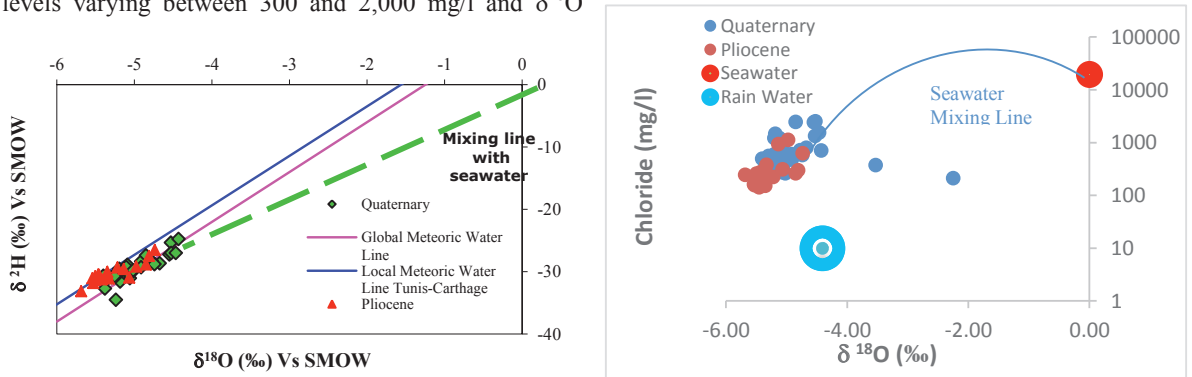


Fig. 3. (a) Na Vs Cl Relationship; (b) Br/Cl Vs Cl Relationship.

4. Stable isotopes

The Deuterium - Oxygen 18 diagram shows two groups (Fig 4.a). In the first group (^{18}O between -5.4 and -4.43 ‰ V-SMOW), points are located between the global meteoric water line (GMWL) and the local meteoric water line of Tunis-Carthage station ($\delta^2\text{H} = 8\delta^{18}\text{O} + 12.4$) [4]. The location of these water points, often near rivers, is compatible

with recharge from recent rain storms. The second group is mainly composed of deep Pliocene groundwater whose ^{18}O contents vary between -5.69 and -4.74 ‰, thus less than -4.41 ‰, the weighted average of rain in Tunis-Carthage. The quaternary waters of this group could result from a mixture of new and older waters [1]. There is no indication of presence of water enriched in ^{18}O and ^2H falling on the mixing line with seawater. For the other points situated below the mixing line with seawater, they are under the influence of evaporation. A separate study of ionic relationships and stable isotopes is not able to identify the origin of the water precisely [3], [5]. The combination of these two parameters is more explicit, especially the Cl^- Vs. ^{18}O graph (Fig. 4.b) that places the samples between different end-members. The first end-member, around 10 mg/l for Cl^- and 4.41 ‰ V-SMOW for $\delta^{18}\text{O}$, is defined from the rainwater samples at Tunis-Carthage located about 40 km east of the study area and at practically the same altitude. The second end-member is represented by Mediterranean waters, having a $\delta^{18}\text{O}$ content around $(0$ ‰) and a Cl^- content of about 19500 mg/l. The third end-member is the water from the Pliocene aquifer, with lower mineralization than the Quaternary water and more depleted ^{18}O content. The other Quaternary points have Cl^- levels varying between 300 and $2,000$ mg/l and $\delta^{18}\text{O}$



levels from -5.5 to -4.0 ‰ V-SMOW. Their sometimes heavy mineralization cannot be understood from only one rainwater–seawater dipole.

Fig. 4. (a) Plot of $\delta^2\text{H}$ ‰ Vs. $\delta^{18}\text{O}$ ‰ (V-SMOW); (b) Plot of Cl^- Vs. $\delta^{18}\text{O}$ ‰ (V-SMOW).

5. Conclusion

In the El Haouaria aquifer, irrigation development that induces leaching of soils with dissolution of evaporate rocks (gypsum and halite minerals) was identified as the main source of mineralization contributing the qualitative degradation as the salinity of the groundwater. The stable isotopic (^{18}O , ^2H) results highlight the recharge of the shallow aquifer from current rain water. There is no indication of presence of water enriched in ^{18}O and ^2H with the exception of evaporated water, and results don't show mixing with seawater. However special attention has been given to the problem of possible future seawater intrusion into the wells due to their proximity to the Mediterranean Sea.

Acknowledgements

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References

1. Ben Hamouda, M.F., Hydrogeological, geochemical and Isotopic Approach of the Coastal Aquifers Systems of Cap Bon: Case of the Eastern coastal and El Haouaria aquifer, Tunisia, 2008. PhD in Agronomic Sciences of the National Agronomic Institute of Tunisia [in french].
2. Jones BF, Vengosh A, Rosenthal E, Yechieli Y. Geochemical investigations. In: Bear J et al (eds) Seawater intrusion in Coastal aquifers. Kluwer Academic Publisher, Dordrecht; 1999: 51–71.
3. Vengosh, A., Salinization and Saline Environments, Reference Module in Earth Systems and Environmental Sciences, Treatise on Geochemistry (Second Edition), Volume 11, 2014, 325-378.
4. Celle-Jeanton H, Zouari K, Travi Y, Daoud A Isotopic characterisation of the precipitation in Tunisia. Variations of the stable isotope

compositions of rainfall events related to the origin of air masses. C.R. Acad. Sc. Series IIA - Earth and Planetary Science. 2001;**333**:625-631.
5. Negrel P, Petelet-Giraud E. Isotopes in groundwater as indicators of climate changes. Trends in Analytical Chemistry 2011; **30**:1279-1290.