

A hydrochemical and isotopic investigation of the groundwater mineralization under irrigated land in the Hammamet-Nabeul coastal plain, Cap Bon peninsula, North-eastern Tunisia

Prof. Kamel ZOUARI

Introduction:

During the last two decades, groundwater resources have played a fundamental role to confront the challenge of growing water scarcity and facilitate economic development in most arid and semi-arid region from North Africa. Currently, in the Hammamet-Nabeul district, Cap Bon Peninsula, north eastern Tunisia, shallow groundwater is the only dependable source for agriculture production and accounts for approximately 80% of all irrigation supply. Moreover, the long-term withdraw from these resources has engendered several deleterious problems such as generalized water-level decline and groundwater quality deterioration. In fact, agricultural production, which are based essentially on intensive irrigation and fertilization to improve the soils, represent a long-term risk of groundwater degradation by excess fertilizers, salts and pesticides leached downward. Therefore, groundwater resources will need to be carefully assessed and managed if even a modest increase in irrigation by groundwater is to be sustainable.

It is within this framework that is undertaken the present hydrochemical and isotopic investigation, which aims to provide relevant information concerning the natural and anthropogenic processes, controlling the groundwater mineralization, which will contribute to the sustainable management of groundwater resources in the study area.

Study area

The study district, which belongs to the Cap Bon peninsula, North-eastern Tunisia, covers an areas extent of approximately 450 Km². It is limited to the south by the Gulf of Hammamet, to the west by the Bouficha basin, to the north by the Grombalia basin and to the east by the oriental coastal plain (Fig.1). The climate is Mediterranean with a mean annual rainfall ranging from about 500 mm at the hill zones to less than 200 mm in the valley zones. The mean annual potential evapotranspiration and temperature exceeds 1,350 mm/year and 25 °C, respectively. The Hammamet-Nabeul basin is distinguished by a very dense surface drainage network, which is constituted by several non perennial Wadis that collects surface runoff from the surrounding hills toward the Gulf of Hammamet.

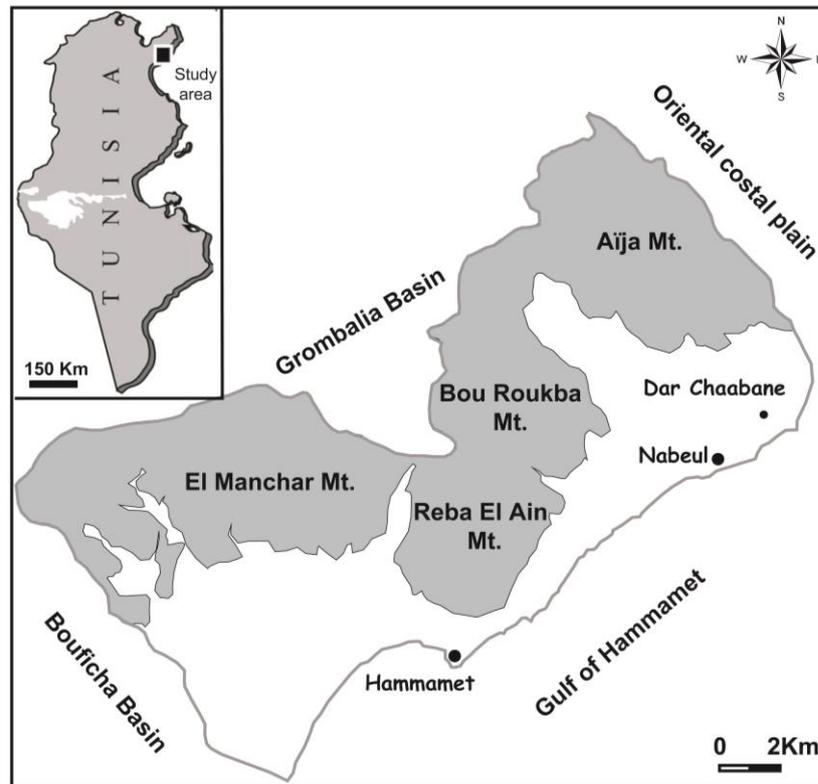


Fig. 1: Location map

Hydrogeology

Hydrogeologically, the shallow, unconfined aquifer of Hammamet-Nabeul is hosted in the Plio-Quaternary detrital deposits (Fig.2). It consists mainly of sands, sandstones, clay and evaporates. This unconfined aquifer represents the largest water-producer likely due to its high hydraulic conductivity. It is tapped by high number private and state owned wells, located in the costal and the central part of the basin. The bedrock of the Hammamet-Nabeul unconfined aquifer is constituted by the Miocene clayey deposits that separates this groundwater reservoir from the underling confined aquifer of the Oligocene. Groundwater flow in the shallow water-table takes place towards the Gulf of Hammamet. The principal flow directions converge NW-SE and S-N from the bordering high lands toward the Gulf of Hammamet, which constitutes the natural discharge area. This highlights that the recharge of the studied unconfined aquifer occurs in the foot of the Mountains, limiting the basin in its northern part.

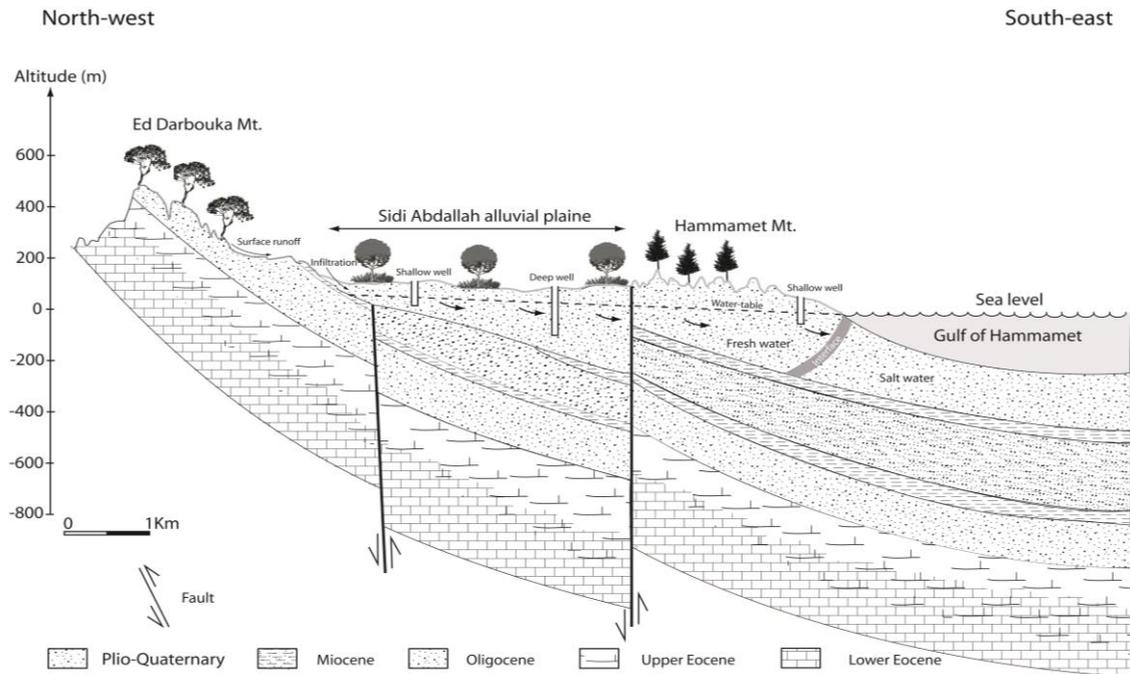


Fig.2: Hydrogeological cross section in the Hammamet-Nabeul unconfined aquifer

Hydrochemical investigation:

In order to precisely determine the origins of the major ions and the processes that control their concentrations in Hammamet-Nabeul groundwaters, several bivariate diagrams were completed. In the Na vs Cl diagram, the majority of samples display a well-defined relationship, suggesting the same origin of sodium and chloride likely related to the halite dissolution (Fig. 3a). On the other hand, the majority of groundwater samples are in equilibrium with respect to calcite and dolomite, suggesting that these minerals are not likely to dissolve. However, all groundwater samples are undersaturated with respect to gypsum and anhydrite, indicating the eventual dissolution of these sulphate minerals (Fig. 3b). On the other hand, some samples display a deficiency of Ca^{2+} versus SO_4^{2-} which is compensated by an excess of Na^+ with respect to Cl^- , suggesting supplementary modification by cation exchange process.

Nitrate content

In the Hammamet-Nabeul unconfined aquifer, about 75% of samples have nitrate concentration that exceeds the drinking-water standards of 50 mg/l (WHO, 2006). The average value of nitrate in the whole groundwater samples is 120 mg/l. These high nitrate concentrations provide evidence to the significance of the return flow waters contribution in the recharge of the unconfined aquifer. Indeed, ammonium nitrate, liquid fertilizer and other commercial complex nitrogen fertilizers are used at large-scale in the agricultural regions,

where flood irrigation is applied. In these regions, NO_3 contents are up to 300 mg/l (Fig. 4). The excessive use of $\text{Ca}(\text{NO}_3)_2$ -fertilizers is verified through the well-defined relationship between NO_3^- and Ca^{2+} (Stigter et al. 2006) (Fig. 5a). Similarly, the well-defined relationships in the plots of NO_3 versus SO_4 and Mg versus SO_4 suggest that N and S are used in the study area in the form of $(\text{NH}_4)_2\text{SO}_4$ and MgSO_4 -fertilizers (Gi-Tak et al. 2004) (Fig. 5 b,c).

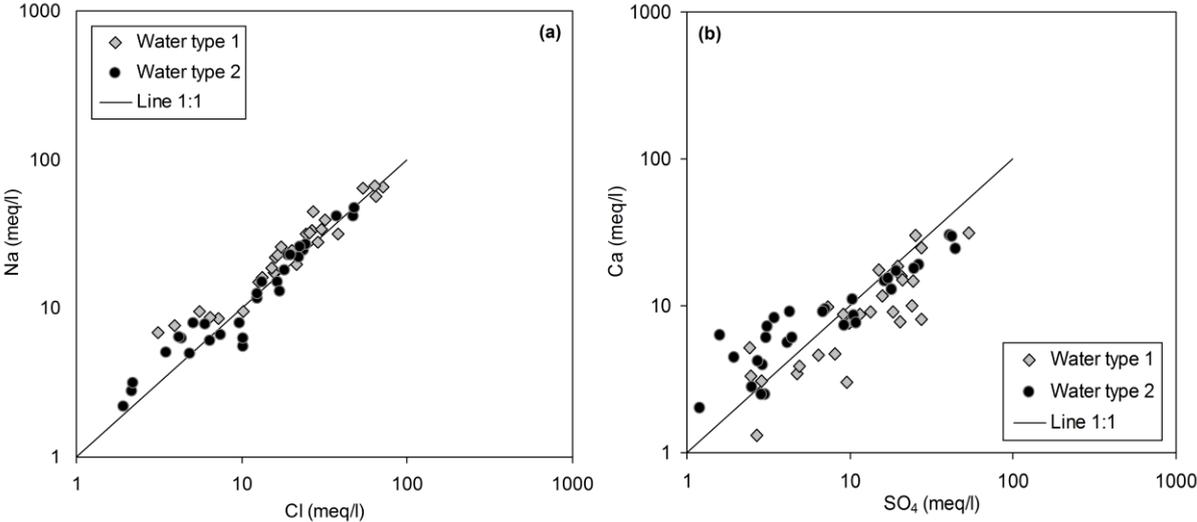


Fig.3: Plots of Na vs Cl (a) and Ca vs SO_4 (b)

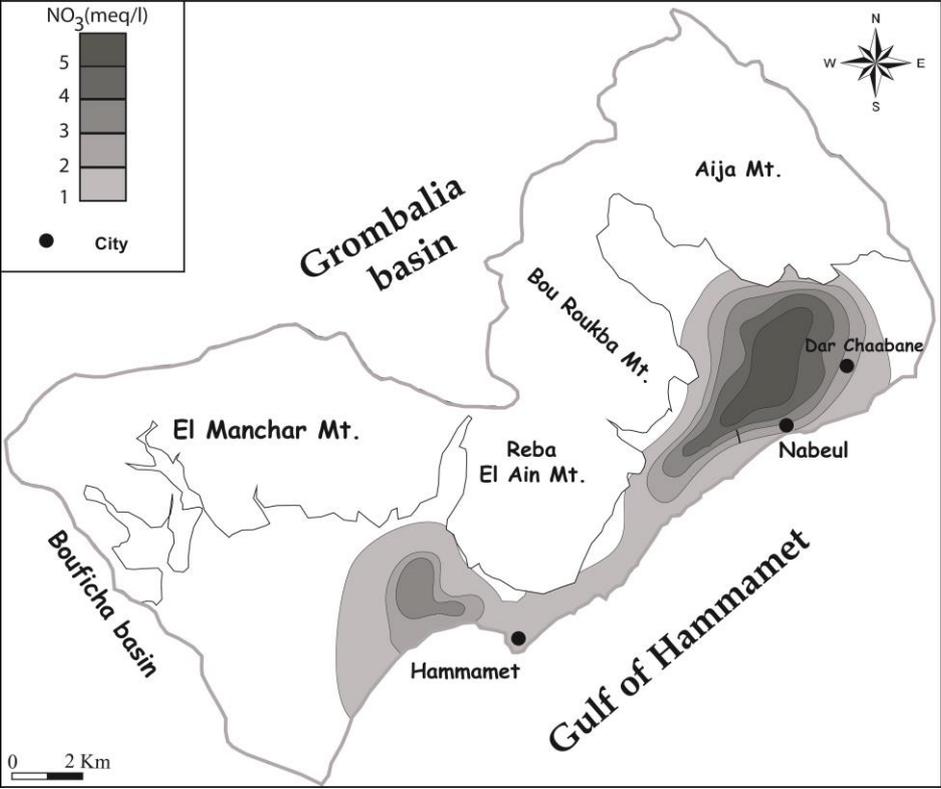


Fig.4: Spatial distribution of nitrate

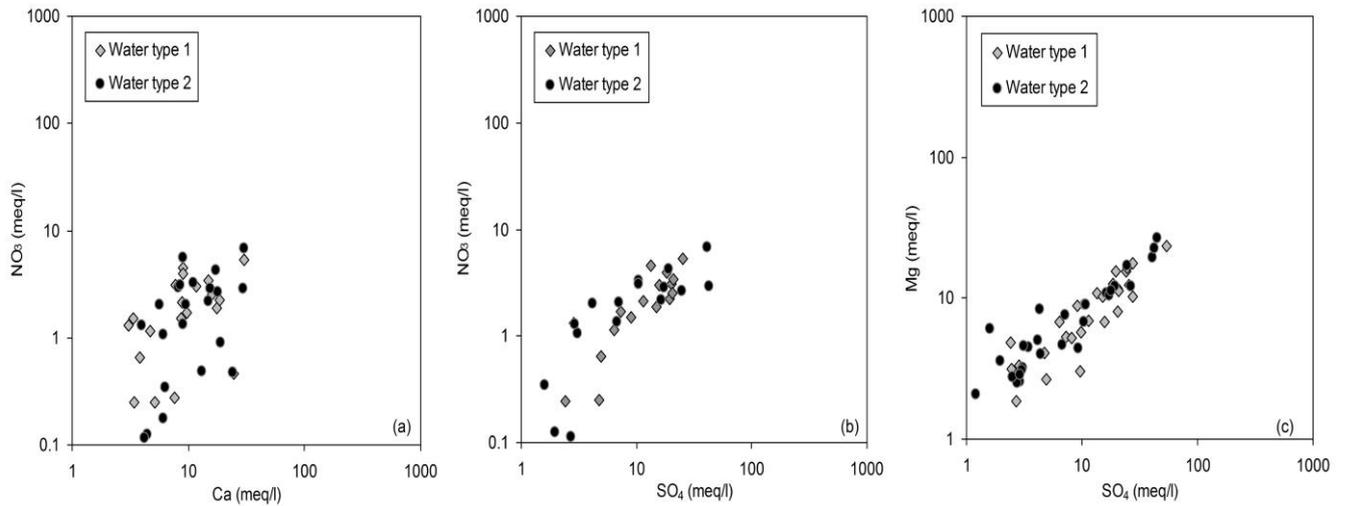


Fig.5: Plots of Ca^{2+} vs NO_3^- (a), SO_4^{2-} vs NO_3^- (b) and Mg^{2+} vs SO_4^{2-} (c)

Isotopic investigation:

The $\delta^{18}\text{O}$ and $\delta^2\text{H}$ compositions of the Hammamet-Nabeul shallow groundwater range from -5.5 ‰ to -3.3 ‰ and from -31.9 ‰ to -22 ‰, respectively. In the conventional diagram of $\delta^{18}\text{O}$ vs. $\delta^2\text{H}$ (Fig. 6), the whole groundwater samples plot globally on and below the RMWL, suggesting that they derive from Mediterranean origin rainfall. However, when examined in the detail, these groundwater samples can be divided into two groups. The first group, includes 14 samples (about 40%) presenting a relatively wide range of $\delta^{18}\text{O}$ and $\delta^2\text{H}$ values, varying from -5.22 to -4.6‰ and from -28.95 to -23.5‰, respectively. This range of variation suggests that this group originate from direct condensation from atmospheric moisture (Craig, 1961) and lends support to the modern origin of these groundwaters. The second groundwater group comprises 22 samples (about 60%) that plot below the RMWL with a regression line of $\delta^2\text{H} = 5.7 \delta^{18}\text{O} - 0.92$ ($R^2 = 0.87$). The low values of the slop and the intercept of this regression line provide insight to the evaporation of this groundwater samples form the group 2. This evaporation is likely in relation with the return flow process relatively abundant in these zones where flood irrigation is applied at large-scale. In these zones, the long-term practice of flood irrigation causes infiltration of water that largely fractionates in the ground surface and in the irrigation channels due to their long exposure to the atmosphere.

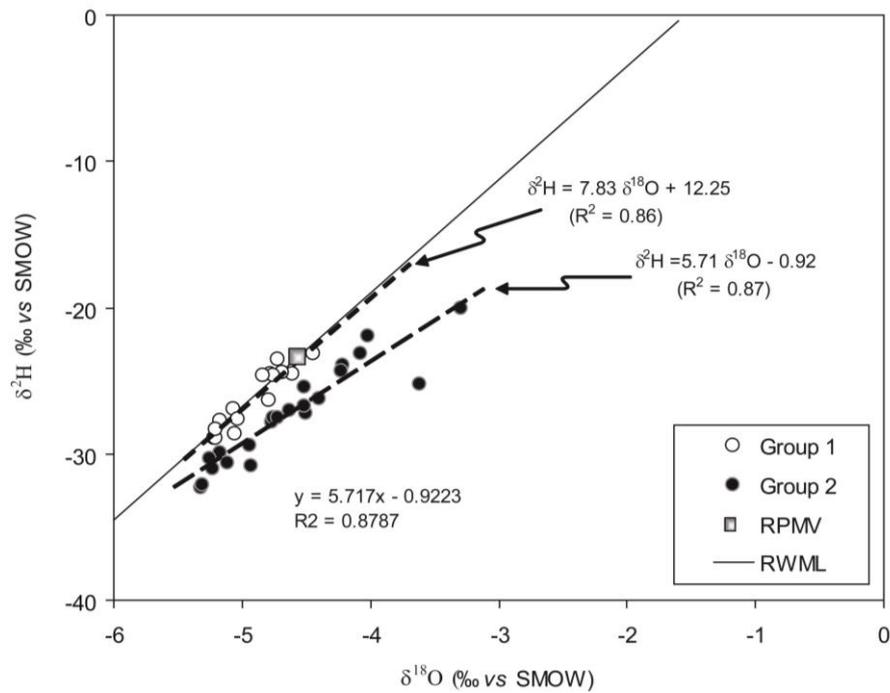


Fig.14: $\delta^{18}\text{O}/\delta^2\text{H}$ diagram

Conclusion

The geochemical exploration shows the dominance of Na-Cl and Ca-SO₄-Cl water types resulting from the dissolution of halite and gypsum and the cation-exchange process. Additionally, the return flow process in relation with the long-term flood irrigation practice contributes to the mineralization by producing high amounts of nitrate. The stable isotope signatures reveal the existence of two groundwater groups. The non-evaporated groundwaters with relatively depleted contents, reflecting modern recharge at higher altitudes; and, evaporated groundwaters with enriched contents highlighting the influence of return flow of irrigation waters.

References:

- Craig H (1961) Isotopic variations in meteoric waters. *Science* 133 : 1702–1803
- Stigter TY, Carvalho AM, Ribeiro L, Reis E (2006) A Impact of the shift from groundwater to surface water irrigation on aquifer dynamics and hydrochemistry in a semi-arid region in the south of Portugal. *Agricultural water management* 85: 121–132
- WHO (2006) World Health Organization. *Guidelines for drinking water quality*, 3rd edn, incorporating first addendum.
- Gi-Tak C, Kangjoo K, Seong T, Kyoung H, Soon O, Byoung Y, Hyoung S, Chul W (2004) Hydrogeochemistry of alluvial groundwaters in an agricultural area: an implication for groundwater contamination susceptibility. *Chemosphere* 55: 369-378