Hydrochemical processes at the seawater/freshwater interface as indicators of seawater intrusion evolution: case of Korba coastal plain (Tunisia)

F. Slama[1,2], **R. Bouhlila**[1] and J. Tarhouni[3]

[1] Laboratoire de Modélisation en Hydraulique et Environnement, Ecole Nationale d'Ingénieurs de Tunis, BP 37 Le Belvédère 1002, Tunis, Tunisia
fairouz.slama@unine.ch
[2] Centre of Hydrogeology (CHY), University of Neuchâtel,
11, rue Emile-Argand. CH – 2007, Neuchâtel, Switzerland
[3] Institut National Agronomique de Tunisie (INAT),
43, Avenue Charles Nicolle 1082 -Tunis- Mahrajène Tunisia

ABSTRACT

Groundwater samples were taken from Korba coastal aquifer from June 2006 to March 2008. The sampling was performed in two transects perpendicular to the sea and following a flow path. Seawater fractions and ionic deltas were estimated for all samples. Results show that direct and inverse cation exchange processes are taking place respectively in the first transect touched by seawater intrusion and the second one where the flow is still seaward. The presence of these processes indicates that seawater intrusion is still acting as a source of salinization in the first transect.

INTRODUCTION

Seawater intrusion is a principal cause of fresh groundwater salinization in many regions of the world (Bear *et al.*, 1999). Fresh groundwater in arid and semi-arid regions, like the Mediterranean basin, is even more threatened by this type of contamination. In deed, such regions are characterised by a constant increase of water demand, especially for agricultural purposes, contrasting with the limited possibility of natural recharge and the high rates of evapotranspiration. Geochemical, geophysical, hydrodynamic and modelling tools have been used to study seawater/freshwater interaction along the transition zone. In this work we are applying geochemical methods to identify processes accompanying seawater/freshwater mixing in Korba coastal plain, located in the North-East of Tunisia. These hydrochemical processes can be considered as indicators of the evolution of seawater intrusion (Custodio and Bruggeman, 1987).

METHODS

Field experiment was carried out in Korba coastal aquifer along two transects perpendicular to the sea. The first transect is located in a piezometric depression and it is affected by seawater intrusion. In the second transect, the flow is still seaward. Groundwater was sampled at different periods from June 2006 to March 2008 in 50 observation wells along the two transects. Water types were determined, for each transect, using the conventional Piper diagram (Appelo and Postma, 2005). The Piper diagram was also used to identify geochemical processes occurring in the groundwater. The seawater fraction in the groundwater was estimated using

chloride concentration (Custodio and Bruggeman, 1987). The seawater fraction of a conservative mixing is calculated as follows (Appelo and Postma, 2005):

$$f_{sea} = \frac{m_{Cl^-,sample} - m_{Cl^-,fresh}}{m_{Cl^-,sea} - m_{Cl^-,fresh}}$$

Where $m_{Cl^-,sample}$ is the Cl$^-$ concentration of the sample, $m_{Cl^-,sea}$ is the Cl$^-$ concentration of the Mediterranean Sea (value taken from the literature (De Montety Veronique $et\ al.$, 2008)) and $m_{Cl^-,fresh}$ represents the Cl$^-$ concentration of the fresh water. In this study, the fresh water sample will be chosen considering the lowest measured value of the electrical conductivity. Once calculated, the seawater fraction is used for determining the concentration of each ion i resulting from the conservative mixing of seawater and the fresh water:

$$m_{i,mix} = f_{sea} m_{i,sea} + (1 - f_{sea}).m_{i,fresh}$$

Where $m_{i,sea}$ and $m_{i,fresh}$ are the concentration of the ion i of respectively seawater, and fresh water. For each ion i, the difference between the concentration of the conservative mixing $m_{i,mix}$ and the measured one $m_{i,sample}$ simply represents the concentration resulting from any chemical reaction occurring with mixing:

$$m_{i,react} = m_{i,sample} - m_{i,mix}$$

Those potential deviations from the simply mixed composition results from various chemical processes are also known as the ionic deltas (Ghabayen $et\ al.$, 2006; Grassi $et\ al.$, 2007; Pulido-Leboeuf, 2004). When $m_{i,react}$ is positive, groundwater is getting enriched for ion i whereas a negative value of $m_{i,react}$ indicates a depletion of the ion i compared to the theoretical mixing (Andersen $et\ al.$, 2005). Besides the calculation of seawater fraction and ionic deltas, we used PHREEQC to generate 20 solutions issued from the conservative seawater fresh water mixing with fractions ranging from 100% to 0.1 %.

RESULTS

Plotted in a Piper diagram (Figure 1) the majority of samples in both transects are Na-Ca-Cl type. The diagram also shows that a number of wells plot on the Theoretical Mixing Line indicating that mixing processes are taking place. Figure 2 illustrates the calculated ionic deltas versus chloride for both transects at different seasons. The majority of samples in transect S1 are depleted in Na$^+$ and enriched in Ca^{2+} and Mg^{2+}. The loss of Na$^+$ and gain of Ca^{2+} and Mg^{2+} suggests a direct cation exchange usually observed in similar situations when the seawater is replacing fresh water (Appelo and Postma, 2005; Cardona $et\ al.$, 2004; De Montety $et\ al.$, 2008; Yaouti $et\ al.$, 2009).
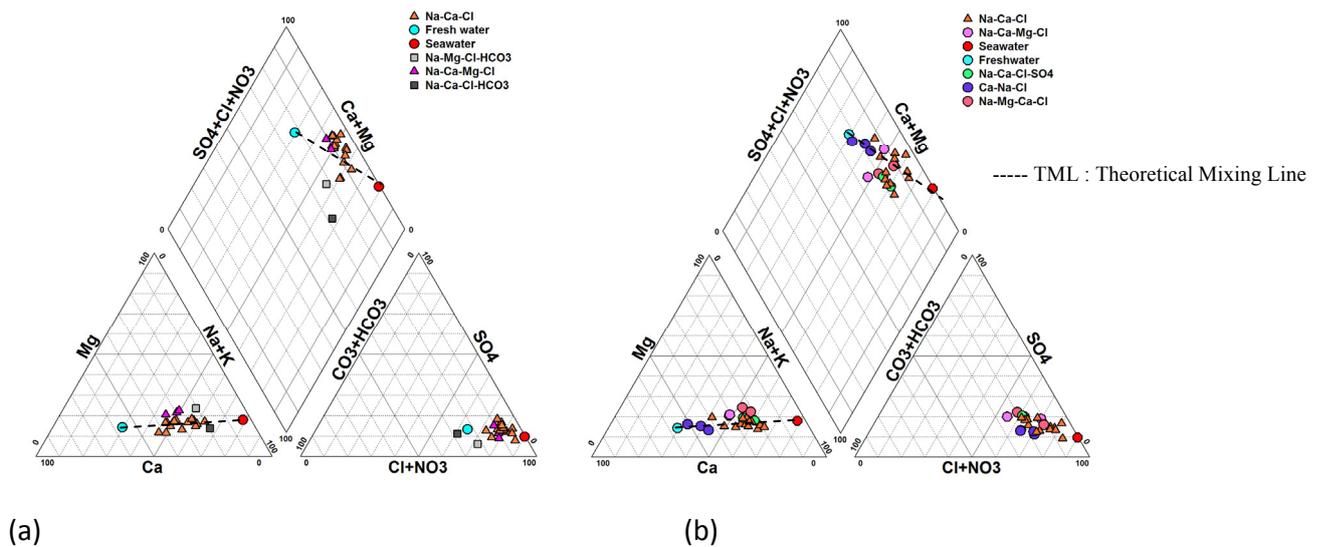
Figure 1. Piper diagram for (a) Transect S1 (b) transect S2

However, some samples are always or seasonally depleted in Mg^{2+} and enriched in Ca^{2+} indicating a possible exchange between these two cations. Custodio and Bruggeman (1987), explain that cation exchange processes take place in the seawater/freshwater interface until the exchange capacity of the exchanger is satisfied except in the sandy aquifers and in the case of a dynamic interface announcing a progressing seawater contamination. These explanations suit this transect of korba aquifer as it is mainly constituted of quaternary sands and as the inversion of the flow landward was reported since the seventies (Ennabli, 1980). Inversely, samples of transects S2 are enriched in Na^+ and in Ca^{2+}. As the flow is seaward in this transect, one can suggest that inverse cation exchange is taking place indicating the flushing of freshwater into seawater. However, the excess of Ca^{2+} suggests the existence of other sources contributing to the enrichment of groundwater. In this case, gypsum dissolution due to dedolomitization as well as fertilizers can be cited as potential sources of Ca^{2+} .
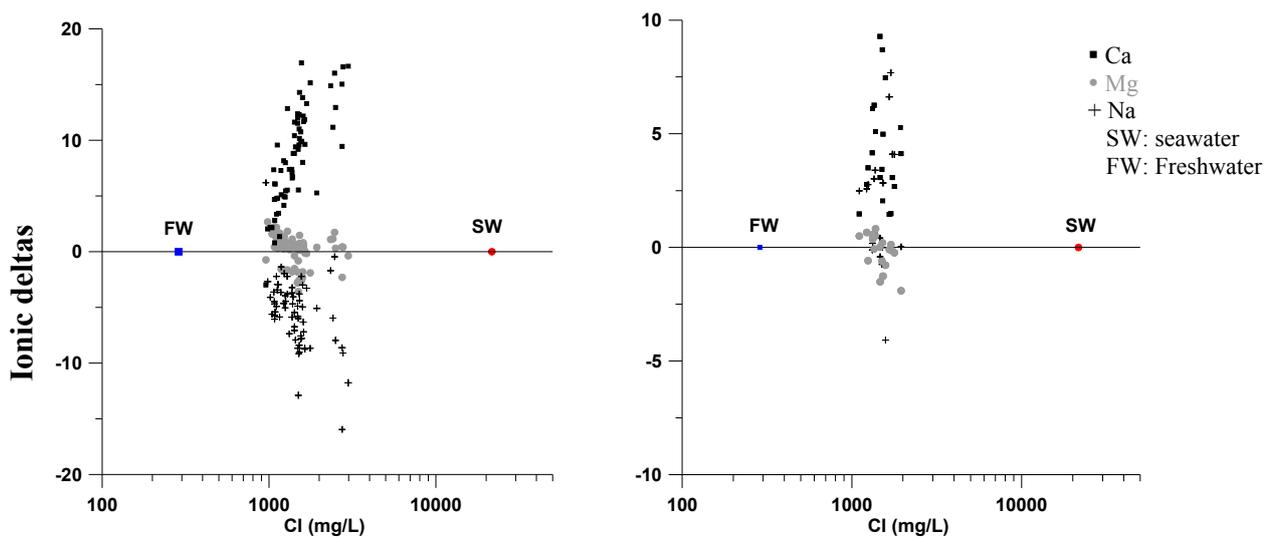

Figure 2. Ionic deltas of Na, Ca and Mg versus Chloride for (a) Transect S1 (b) Transect S2

13

DISCUSSION AND CONCLUSIONS

Hydrochemical processes, mainly direct and inverse cation exchange were observed in sampled wells at different periods of the year. These results indicate that seawater/freshwater interface is in a continuous evolution probably because of the permanent heavy pumping.

REFERENCES

Andersen, M.S., Nyvang, V., Jakobsen, R. and Postma, D., 2005. Geochemical processes and solute transport at the seawater/freshwater interface of a sandy aquifer. *Geochimica et Cosmochimica Acta* 69(16): 3979-3994.

Appelo, C.A.J. and Postma, D., 2005. Geochemistry, Groundwater and Pollution, second ed. Balkema, Rotterdam.

Bear, J., Cheng A.H.D., SorekK, S., Ouazar, D. and Herrera, I., 1999. Seawater Intrusion in Coastal Aquifers - Concepts, Methods and Practices. Kluwer Academic Publishers, Dordrecht.

Cardona, A., Carrillo-Rivera, J., Huizar-Alvarez, R. and Garniel-Castro, E., 2004. Salinization in coastal aquifers of arid zones: an example from Santo Domingo, Baja California Sur, Mexico. *Environmental Geology*, 45: 350-366.

Custodio, E. and Bruggeman, K.A., 1987. Groundwater Problems in Coastal Areas UNESCO, Paris.

De Montety, V. *et al.*, 2008. Origin of groundwater salinity and hydrogeochemical processes in a confined coastal aquifer: Case of the Rhône delta (Southern France). Applied Geochemistry, 23: 2337–2349.

Ennabli, M., 1980. Etude hydrogéologique des aquifères du nord-est de la Tunisie pour une gestion intégrée des ressources en eau. Doctorat d'Etat Thesis, Ministère de l'agriculture. République Tunisienne.

Ghabayen, S.M.S., McKee, M. and Kemblowski, M., 2006. Ionic and isotopic ratios for identification of salinity sources and missing data in the Gaza aquifer. *Journal of Hydrology*, 318: 360-373.

Grassi, S., Cortecci, G. and Squarci, P., 2007. Groundwater resource degradation in coastal plains: The example of the Cecina area (Tuscany - Central Italy). *Applied geochemistry*, 22: 2273-2289.

Pulido-Leboeuf, P., 2004. Seawater intrusion and associated processes in a small coastal complex aquifer (Castell de Ferro, Spain). *Applied geochemistry*, 19: 1517–1527.

Yaouti, F.E., Mandour, A.E., Khattach, D., Benavente, J. and Kaufmann, O., 2009. Salinization processes in the unconfined aquifer of Bou-Areg (NE Morocco): A geostatistical, geochemical, and tomographic study. *Applied geochemistry*, 24 16-31.