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Hydrochemistry of groundwater salinity sources in the shallow aquifer: Case of Annaba plain (Ne Algeria)

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Key words: Annaba Gulf, Coastal aquifer, Groundwater salinity, Seawater intrusion, Anthropogenic pollution.

Abstract

The growth of population and expanding agricultural and industrial sectors in the recent years, have created an increase in demand. However the overexploitation of the coastal aquifer of Annaba Gulf (North-East Algeria). These heavy demands have caused a degradation of groundwater hydrochemical quality (salinization). To identify the origin of groundwater salinity; hydrochimical and physical parameters information has been examined and to interpret the processes of the mineralization. Electrical conductivity values varied between 838 and 10600µS/cm. Chloride concentration attained 1850mg/L and the proportion of seawater intrusion in the extreme north of the plain was 8.58% calculated by seawater fraction formal, showing the intense seawater intrusion. Cation-exchange reactions and water–rock interactions related to the dissolution of evaporitic formation and calcite occurred by ionic relationships during seawater intrusion. Nitrate values ranged from 0 to 11.4mg/L under the drinking water standards. Therefore, the main origin of groundwater salinization was attributed to seawater intrusion with the contribution of anthropogenic pollution.

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Introduction

A general feature of coastal areas is their large water demand, because of the fact that they are usually densely populated and subject to intensive agriculture and tourism. The intensive exploitation of coastal aquifers in an attempt to satisfy this demand may generate problems. One of these problems is presented in our case study as a degradation of the groundwater hydrochimistry by salinization in Annaba Gulf. Groundwater salinization in coastal areas occurs in many aquifers around the world (Barlow, P.M., 2003; Bear, J., Cheng, A.H.-D *et al.,* 1999) and in numerous Mediterranean countries (Benavente, J., Larabi, A *et al.,* 2004; Cost Environment Action 621, 2005). Understanding the spatial variations in the chemical composition of groundwater is helpful to identify the different pollution sources (Mahesha, A., Nagaraja, SH., 1996), delimit and fight it, in order to preserve for future generations. In the previous studies, seawater intrusion is presented as the major cause and origin of groundwater quality degradation (Xiao, G., Yang, J *et al.,* 2014; Zhang, B., Song, X *et al.,* 2013), which observed in the case of unconfined aquifer connected to the sea where a strong demand in water resources induced a decrease of piezometric level (Veronique de Montety *et al.*, 2008).

Farmland, factories and tourist areas are located on the coastal area, where the economy is developing rapidly. Agriculture depends on intensive irrigation and fertilization to improve the soil efficiency. However excessive amounts of fertilizers infiltrate into the groundwater with the irrigation return flow. Waste water emissions from factories can cause deterioration of the groundwater. Also, domestic sewage makes a contribution to groundwater salinization. These anthropogenic contaminations may result in high nitrate concentrations in the groundwater (Xianfang Song *et al.*, 2016). Summer is the period of water ressources scarcity. Furthermore; the cultivated crops in this saison are mainly tomatoes, melon and water melon. These crops need intense irrigation that causes an increased request for groundwater. To satisfy water demand, farmers intensifly pump water from wells and drillings which imbalances freshwater–saltwater interface (Larbi Djabri *et al.*, 2013). The objective of this study is to determine the salinization sources (seawater intrusion; anthropogenic sources) in the shallow coastal aquifer depending on groundwater hydrochemical characteristics.

Material and methods

Geographic and geological situation

The studied region is located in the North-East of Algeria (Fig.1). It is bordered by the Mediterranean Sea from the North, by Drean town from the South,by Mafragh River from the East and by Fetzara Lake from the West. The plain is supplied from the West by the river coming from the Edough mount, and from the South by the upstreams coming from Ain Berda and Guelma mounts. The studied area is characterized by the outcrop of a sedimentary and a metamorphic formations (Fig.2). These formations date from the Paleozoic to the Quaternary. The metamorphic formations which outcrop in the western part date from the Paleozoic. They form the Edough, Belilieta and Boukhadra massif, constituted mainly of gneiss. The sedimentary formations age go from the Mesozoic to the Quaternary. This latter is constituted of alluvial sediments forming the reservoir rock. We distinguish the old Quaternary (high terraces) containing the alluvial aquifer, where the material is made of sand, clay and gravels. The recent Quaternary correspond to the low and the average terraces. The actual Quaternary: the alluvial fans are actual bed deposits of the river; they are formed of sand and gravels. (Larbi Djabri *et al.*, 2013).

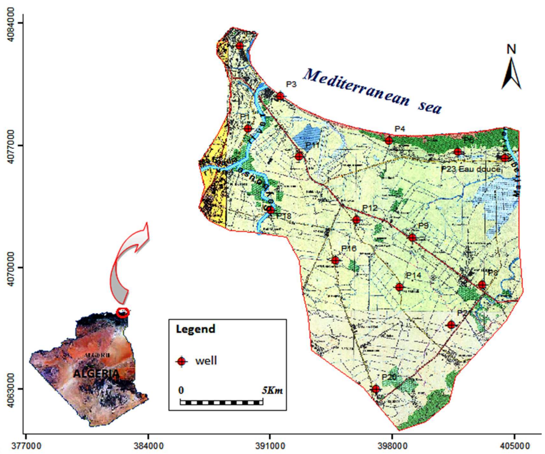

Fig. 1. Location of the study area and sampling sites.

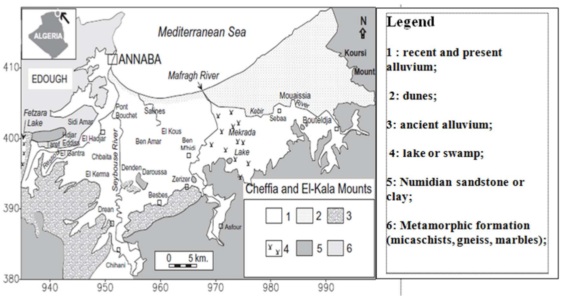

Fig. 2. Geologic characteristics of the study area.

Hydrogeology

The ground of Annaba plain receive an important aquifer possibilities, where two hydrogeologic layers are superposed the upper one called free, in which the wells are implanted, and the deep one is captive becomes free in its southern part (Drean region) (Fig.3) (Larbi Djabri *et al.*, 2013).

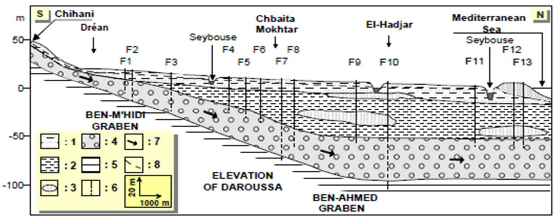

Fig. 3. geological cross section through the aquifer system.

1: clayey sand (shallow aquifer); 2: detritic clay; 3: sand; 4: stons and gravels (deep aquifer); 5: numidian clay; 6: borehole; 7: flow line; 8: piezometric level of the deep aquifer.

Sample collection and treatment

Fifteen groundwater samples were taken from domestic wells, and one seawater sample from the Mediterranean sea in the periode of November2016. Wells location (Fig.1) and piezometric level were recorded when sampled. Electrical conductivity (EC), pH and water temperature (T) were measured in situ via (WTW Multiparameter device). The major ions of the water samples were treated and analyzed in the physical and chemical analysis laboratory.

Seawater fraction

The seawater fraction in groundwater was estimated using chloride concentration as this ion has been considered as a conservative tracer (Custodio, E., Bruggeman, GA., 1987), not affected by ion exchange. It is calculated as follows (Appelo, CAJ., Postma, D., 2005):

$$fsea = (Ccl, sample - Ccl, fresh)/(Ccl, sea - Ccl, fresh)$$

Where $fsea$ is the seawater fraction, $Ccl, sample$ is the chloride concentration of the sample, Ccl, sea is the chloride concentration of the Medeterranean sea, and $Ccl, fresh$ represents the chloride concentration of the freshwater. The freshwater sample was chosen considering the lowest measured value of the electrical conductivity (EC) (Slama, F., Bouhlila, R *et al.*, 2010). The only inputs are either from the aquifer matrix salts or from a salinization source like seawater intrusion.

Ionic deltas

Based on the seawater fraction, the theoretical concentration of each ion i resulting from the conservative mixing of seawater and freshwater was calculated using:

$$Ci, mix = fsea \times Ci, sea + (1 - fsea) \times Ci, fresh$$

where Ci, sea and $Ci, fresh$ are the concentration of the ion i of the seawater and freshwater respectively. For each ion i, the difference between the concentration of the conservative mixing Ci, mix and the measured one $Ci, sample$ simply represents the ionic deltas resulting from any chemical reaction occurring with mixing:

$$\Delta Ci = Ci, sample - Ci, mix$$

When ΔCi is positive, groundwater is getting enriched for ion i, whereas a negative value of ΔCi indicates a depletion of the ion i compared to the theoretical mixing (Andersen, MS., Nyvang, V *et al.*, 2005).

Results and discussion

Interpretation of piezometric map (November 2016)

The groundwater map (Fig. 4) shows that there is a general south–north flow. However, at the Daroussa mount we notice a change of the flow direction. This latter is from the sea to the continent. This tendency with the high depressions localized on the central and southern part of the map; pointing out probably a penetration of seawater.

The map shows also an interlink between the sea, rivers and aquifer. These elements certainly affect the water chemistry (Larbi Djabri *et al.*, 2013).

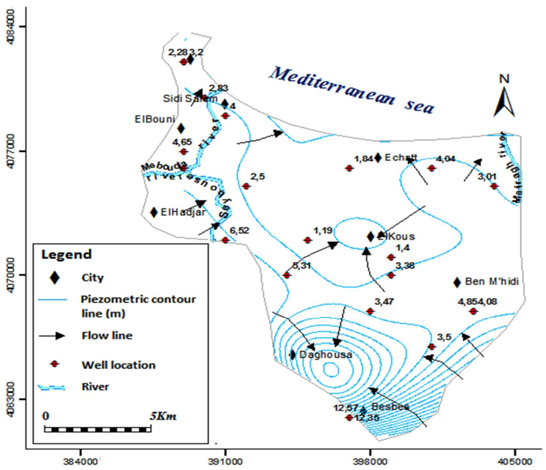

Fig. 4. Piezometric map of the shallow aquifer (November 2016).

The characteristics of groundwater salinity

The salinity of the groundwater is determined by EC (Bouchaou, L *et al.*, 2008; Gime´nez, E., Morell, I., 1997). which was chosen as an index to evaluate the extent of groundwater salinity (Fig.5). The main contributors to the groundwater salinity are Cl^-, Na^+, Mg^{2+}, Ca^{2+}, K^+, SO_4^{2-}, HCO_3^- and NO_3^-. EC values in the groundwater ranged from 838 to 10600µS/cm, with an average of 5916.86µS/cm. The highest values were measured in the area extended from northwest to southest of the plain. Where the high concentrations are possibly the results of seawater intrusion into the aquifer system, and the other high ones inside the plain either from human activities such as agriculture, industry or from the developement of seawater-freshwater interface.

Seawater intrusion processes

The extent of seawater intrusion is shown in (Fig.6 a,b). The trend of the chloride distribution is consistent with the seawater fraction. The most serious seawater intrusion area is located in the line where the cities ELBouni, ELHadjar on the Est to ELKous and south of Ben M'hidi; with a highest chloride concentration of 1850mg/L and a seawater proportion of 8.58%.

The drawdown from overexploitation of groundwater has caused seawater intrusion.

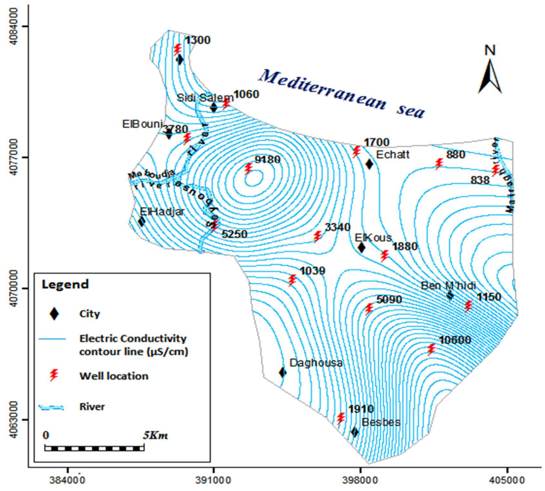

Fig. 5. Spatial distribution of electric conductivity (EC).

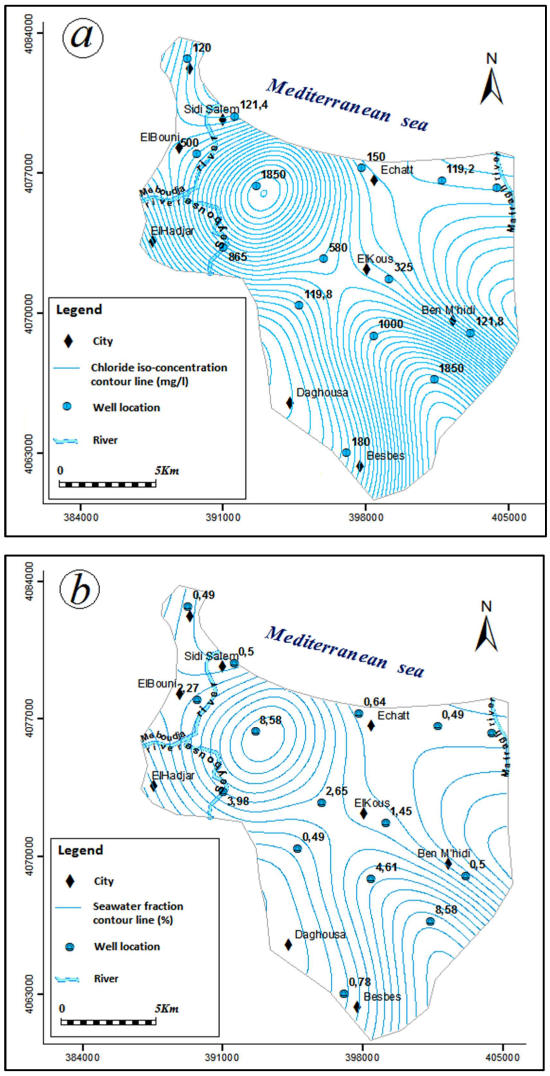

Fig. 6. Spatial distribution of chloride concentration (a) and seawater percentage (b).

The bivariate diagram (Fig.7a) reveals good correlation for most samples between the electrical conductivity and the chloride concentration. All of the samples are located in the chloride-depleted domain (above the mixing line). The mixing line join seawater sample with freshwater sample. (Fig.7 b) shows the relationship between sodium and chloride. The samples distribute around the mixing line. A few of samples are adjusting the mixing line and under it. But the majority of samples are located in the chloride-depleted domaine indicate that sodium is enriched in the aquifer. However, a big part of samples (Fig.7c) concentrated in the chloride-depleted domain, means that calcium enriched in the groundwater, generally samples scatter near the mixing line. When a good correlation observed between magnisium and chloride (Fig.7d). According to (Fig.7a,b,c,d), the enrichment of sodium and the depletion of calcium and magnisium at some wells suggests that there is a possibility of salinization from the processes of the evaporitic formations dissolution. Furthermore (Fig.7e), shows the sulfate enrichment of the half sampls. In order to completely understand the processes that the theoretical content variation indicates, and to find out more about the behavior of the cations, the ionic delta was plotted for sodium, calcium, magnesium and sulphate (Xianfang Song *et al.*, 2016), (Fig.7 f). The great majority of the samples are enriched in calcium and magnisium, a few of samples depleted in sulphite when a big part of sampls are depleted in sodium. This suggests that the probability of seawater intrusion is insufisant (El Yaouti, F., El Mandour A *et al.*, 2009). However, the excess of calcium, magnisium and sulfite, indicates the existence of other sources contributing to the enrichment of groundwater. Fertilizers can be considered as potential sources of Ca^{2+}, Mg^{2+} and SO_4^{2-} (Milnes, E., Renard, P., 2004).

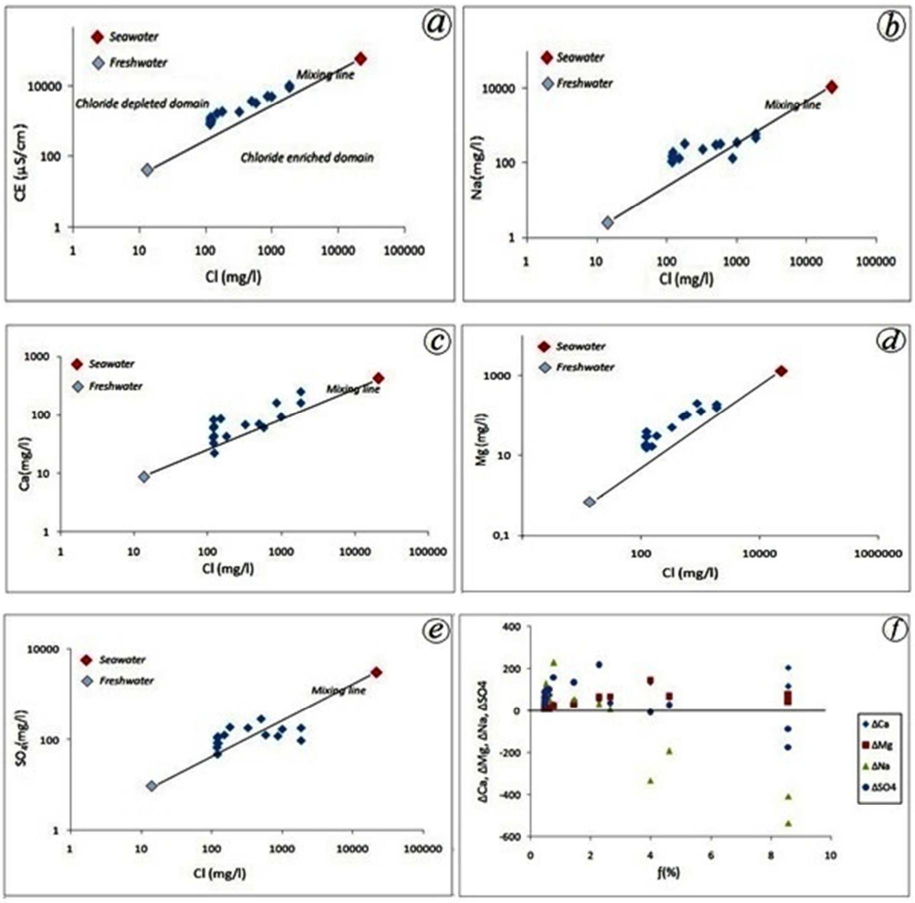

Fig. 7. The bivariate diagram of (a): electrical conductivity/Cl relationship; (b): Na/Cl relationship; (c): Ca/Cl relationships; (d): Mg/Cl relationships; (e): SO4/ Cl relationships; (f): Δ(Na, Ca, Mg and SO4) versus seawater percentage of groundwater samples.

Pollution by human activities

Due to the joint development of industry and agriculture, groundwater is under enormous pressure in the study area. Contamination by nitrate occurred. The spatial distribution of the nitrate pollution is shown in (Fig. 8). Nitrate concentrations range between 0 and11.4 mg/L. Then all sampls are under the drinking water standard (50 mg/L).

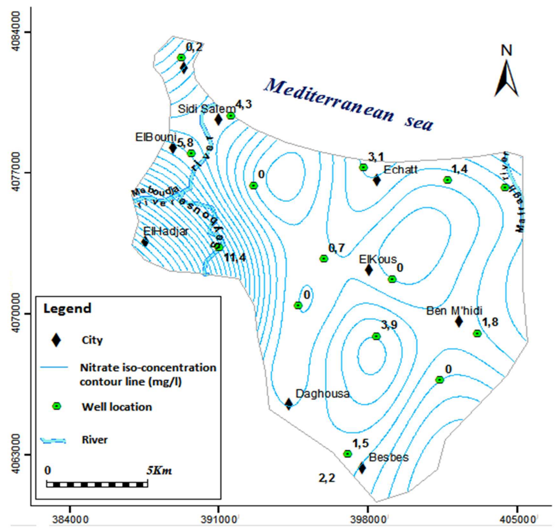

Fig. 8. Spatial distributions of nitrate (NO3).

The relationship between nitrate contamination and seawater intrusion is shown in (Fig.9), which reveals high nitrate concentrations at low seawater fraction. This indicates that the nitrate contamination has no relation to seawater intrusion. Instead, nitrate contamination can be attributed to human activities including abuse of fertilizers, industrial wastewater and domestic sewage.

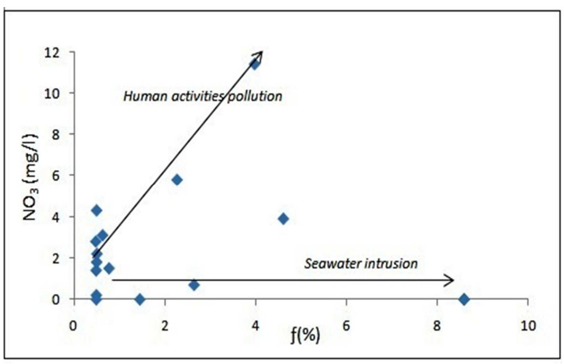

Fig. 9. The bivariate diagram of seawater fraction versus NO3.

Conclusion

The study method used reveals that electrical conductivity values varied between 838 and 10600 µS/cm. Chloride concentration attained 1850 mg/l and the proportion of seawater intrusion in the extreme north of the plain was 8.54%, showing the intense seawater intrusion. Nitrate values ranged from 0 to 11.4 mg/l which it is the drinking water standards 50 mg/l; where there is very low possibility of anthropogenic pollution. Therefore, the main origin of groundwater salinization was attributed to seawater intrusion with the contribution of anthropogenic pollution.

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References

Andersen MS, Nyvang V, Jakobsen R, Postma D. 2005. Geochemical processes and solute transport at the seawater/freshwater interface of a sandy aquifer. Geochimica et Cosmochimica Acta **69,** 3979-3994. DOI: 10.1016/j.gca.2005.03.017

Appelo CAJ, Postma D. 2005. Geochemistry, groundwater and pollution, seconded. Balkema, Rotterdam.

Barlow PM. 2003. Ground Water in Freshwater–Saltwater Environments of the Atlantic Coast, US Geological Survey.

Bear J, Cheng AHD, Sorek S, Ouazar DHI. 1999. Seawater Intrusion in Coastal Aquifers-Concepts, Methods, and Practices. Kluwer Academic Publishers, Dordrecht/ Boston/ London.

Benavente, J., Larabi, A., El Mabrouki, K. 2004. Monitoring, modeling and management of coastal aquifers. Water Research Institute, University of Granada.

Bouchaou L. 2008. Application of multiple isotopic and geochemical tracers for investigation of recharge, salinization, and residence time of water in the Souss–Massa aquifer, southwest of Morocco. Journal of Hydrology **352,** 267-287.
DOI: 10.1016/j. jhydrol. 2008.01.022

Chae GT. 2004. Hydrogeochemistry of alluvial groundwaters in an agricultural area: an implication for groundwater contamination susceptibility. Chemosphere **55,** 369-378.
DOI: 10.1016/j. Chemos phere.2003.11.001

Cost Environment Action 621. 2005. Groundwater management of karstic coastal aquifers. European Communities, Luxembourg.

Custodio E, Bruggeman GA. 1987. Hydrogeochemistry and tracers.In: Custodio E (ed) Groundwater problems in coastal areas studies and reports in hydrology, vol 45. UNESCO, Paris pp. 213-269.

El Yaouti F, El Mandour A, Khattach D, Benavente J, Kaufmann O. 2009. Salinization processes in the unconfined aquifer of Bou- Areg (NE Morocco): a geostatistical, geochemical, and tomographic study. Appllied Geochemistry **24,** 16-31.
DOI: 10.1016/j.apgeo chem.2008.10.005

Gime´nez E, Morell I. 1997. Hydrogeochemical analysis of salinization processes in the coastal aquifer of Oropesa (Castellon, Spain). Environmental Geology **29,**118-131.

Khaska M. 2013. Origin of groundwater salinity (current seawater vs. saline deep water) in a coastal karst aquifer based on Sr and Cl isotopes. Case study of the La Clape massif (southern France). Appllied Geochemistry **37,** 212-227.
DOI: 10.1016/j. apgeochem. 2013.07.006

Larbi Djabri. 2013. Impacts of morphological factors on the marine intrusion in Annaba region (east of Algeria). Taylor & Francis 2151-2156.
DOI: 10.1080/19443994.2013.808585.

Mahesha A, Nagaraja SH. 1996. Effect of natural recharge on sea water intrusion in coastal aquifers. Journal of Hydrology 174, 211-220.

Milnes E, Renard P. 2004. The problem of salt recycling and seawater intrusion in coastal irrigated plains: an example from the Kiti aquifer (Southern Cyprus). Journal of Hydrology **288,** 327-343. DOI:10.1016/j.jhydrol.2003.10.010

Moussa AB, Zouari K, Oueslati N. 2008. Geochemical study of groundwater mineralization in the Grombalia shallow aquifer, north-eastern Tunisia: implication of irrigation and industrial waste water accounting. Environmental Geology **58,** 555-566. DOI: 10.1007/ s00254-008-1530-7

Pablo Pulido-Leboeuf. 2003. Strontium, SO4 2−/Cl− and Mg2+/Ca2+ ratios as tracers for the evolution of seawater into coastal aquifers: the example of Castell de Ferro aquifer (SE Spain). Compts Rendus Geoscience **335(2003),** 1039-1048.

Park SC, Yun ST, Chae GT, Yoo IS, Shin KS, Heo CH, Lee SK. 2005. Regional hydrochemical study on salinization of coastal aquifers, western coastal area of South Korea. Journal of Hydrology **313,** 182-194.
DOI: 10.1016/j.jhydrol.2005.03.001

Slama F, Bouhlila R, Renard P. 2010. Identification of groundwater salinization sources using experimental, multivariate statistical analysis and numerical modelling tools: case of Korba coastal aquifer (Tunisia). Congress, groundwater quality sustainability, Krakow 12-17. Sept.

Stigter TY, Dill AMMC, Ribeiro L, Reis E. 2006. 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. Agricultral Water Managment **85,** 121-132.
DOI: 10. 1016/j.agwat. 2006.04.004.

Taha-Hocine Debieche. 2002. Evolution de la qualité des eaux (salinite, azote et métaux lourds) sous l'éffet de la pollution saline, agricole et industrielle; U. F. R. des Sciences et Techniques de l'Université de Franche-Comté Ecole Doctorale Homme, Environnement, Santé; thesis (2002).

Veronique de Montety. 2008. Origin of groundwater salinity and hydrogeochemical processes in a confined coastal aquifer: Case of the Rhône delta (Southern France). Applied Geochemistry **23(2008),** 2337-2349.
DOI: 10.1016/j.apgeo chem.2008.03.011

Xianfang Song. 2016. Origin of groundwater salinity and hydrochemical processes in an unconfined aquifer: case of Yang-Dai River basin in Qinhuangdao (China). Environmental Earth Sciences (2016) **75,** 54.
DOI: 10.1007/ s12665-015-4825-5

Xiao G, Yang J, Hu Y, Du D. 2014. Hydrogeochemical recognition of seawater intrusion processes in Yang River and Dai River coastal plain of Qinhuangdao City. Saf Environ Eng **21,** 30-39.

Zghibi A, Tarhouni J, Zouhri L. 2013. Assessment of seawater intrusion and nitrate contamination on the groundwater quality in the Korba coastal plain of Cap-Bon (North-east of Tunisia). Journal of African Earth Sciences **87,** 1-12.
DOI: 10.1016/j.jafrearsci.2013.07.009

Zhang B, Song X, Guo Z, Zhao X. 2013. Investigation of the origin and evolution of groundwater in Yang-Dai River Plain by chlorine, oxygen 18 and deuterium. Acta Clientage Circumstantiate **33,** 2965-2972.