DOI: 10.2478/jwld-2018-0006

JOURNAL OF WATER AND LAND DEVELOPMENT
2018, No. 36 (I–III): 57–65
PL ISSN 1429–7426

Available (PDF): http://www.itp.edu.pl/wydawnictwo/journal; http://www.degruyter.com/view/j/jwld

Received 05.06.2017
Reviewed 04.08.2017
Accepted 14.09.2017

A – study design
B – data collection
C – statistical analysis
D – data interpretation
E – manuscript preparation
F – literature search

Assessment of groundwater salinity and risk of soil degradation in Quaternary aquifer system. Example: Annaba plain, Algeria N-E

Samia HALIMI[1,2] ABCDEF ✉, Hicham RECHACHI[1) F], Sofia BAHROUN[2) E], Nour Elhouda MIZANE[1) F], Tarek DAIFALLAH[1,2) E]

[1)] Khenchela University, Department of Ecology and Environment, N32, El Hamma, 40000, Algeria; e-mail: samia1_halimi@yahoo.fr
[2)] Annaba University, Department of Geology, Algeria

For citation: Halimi S., Rechachi H., Bahroun S., Mizane N.E., Daifallah T. 2018. Assessment of groundwater salinity and risk of soil degradation in Quaternary aquifer system. Example: Annaba plain, Algeria N-E. Journal of Water and Land Development. No. 36 p. 57–65. DOI: 10.2478/jwld-2018-0006.

Abstract

Quality of water resources in Annaba plain (North East) of Algeria is facing a serious challenge due to industrialisation and excessive exploitation of water. Therefore, 29 groundwater samples were collected from this area to assess their hydrogeochemistry and suitability for irrigation purposes. The groundwater samples were analysed for distribution of chemical elements Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}. It also includes pH, electrical conductivity.

The hydrochimical study has shown that the facieses are changing between a pole calcium-chloride-sulphate and sodium-chloride types. The results also showed that the salinity is the major problem with water for irrigation use (58% of samples fall into C3S1 class). As a result, the quality of the groundwater is not suitable for sustainable crop production and soil health without appropriate remediation.

Key words: *Annaba plain, hydrogeochemistry, irrigation, quality, water resources, water salinization*

INTRODUCTION

Groundwater potential and quality are of major concern to researchers because of increasing demand for fresh water coupled with climate change effects. Large amount of effluents generated from urban population, industries and agricultural activities may pollute soil and groundwater. Groundwater recharge and distribution depend on the underlying geological formations, surface expression, local and regional climate settings [SHIRAZI *et al.* 2015].

Water as a resource is very important in all facets of human life including plants cultivation. Not only it must be available, but also it must be of ample quality. [MARAL 2010] defines water quality as characteristics of a water supply that will influence its suitability for a specific use and how well the quality meets the needs of the user, and this quality is determined by certain physical, chemical and biological factors. By defining irrigation water quality, the chemical and physical characteristics of water must be prominent [AYERS *et al.* 1994]. Water used for irrigation varies in quality, depending on type and quantity of salts dissolved in it as a result of the sources and/or the path that water has travelled. Generally, the quantity of salt dissolved in irrigation water is relatively small, but its effect is very significant. The suitability or quality of irrigation water is judged not only on the quantity and 13 kinds of dissolved salts, but also on the potential effects of its long-term use.

In the lower plain of Seybouse, the chemical composition of water is often influenced by the impact of dissolution of geological formations, industrial discharges and agricultural activities ATTOUI *et al.* [2016]; HABES [2013]; DEBIECHE [2002]; HANI [2003]; LEKOUI [2010]; ZENATI [2010]. Thus, it is required to periodically check the water quality changes over time and space, depending on the variation of its physicochemical parameters.

This study is a preliminary reflection on monitoring of waters physicochemical quality and contaminants transfer within aquifers of Annaba plain (N-E of Algeria). It aims to understand the mechanisms of water flow transfer and the hydrogeochimical processes controlling waters mineralization. In order to control the quality of groundwater in Annaba plain, a total of 29 samples were collected during December 2013 from the Quaternary aquifer, geochemical methods have been applied on physicochemical data obtained during sampling campaign (wet season). As regards Piper's diagram and the saturation index (obtained with PHREEQC model) were applied to include chemical specifities of classes and water renewal processes.

GEOGRAPHIC LOCATION

Annaba plain is situated in the north-eastern part of Algeria (Fig. 1).

The area is subject to a Mediterranean climate defined by a cold and rainy winter and a hot, dry summer (Fig. 2, 3). The average annual rainfall, actual evapotranspiration and recharge are respectively 700, 500 and 80 mm [HALIMI *et al* 2016].

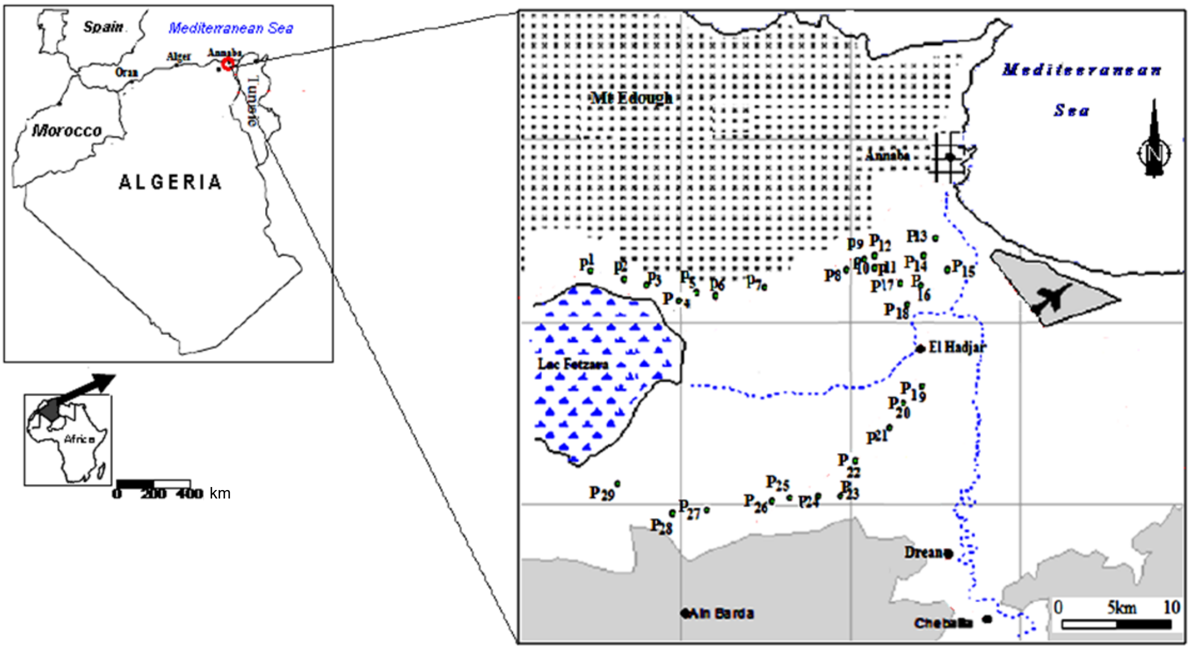

Fig. 1. Location map of the study area; source: own study

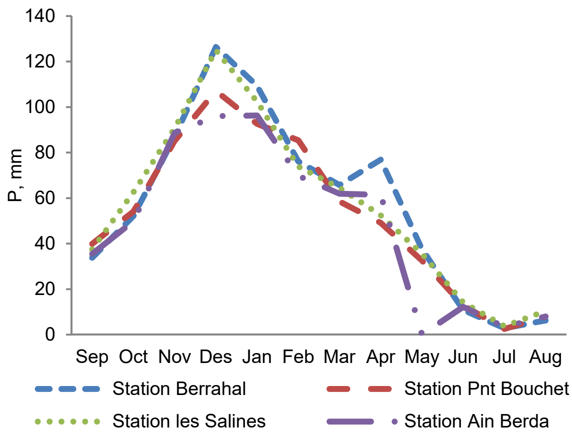

Fig. 2. Average monthly variations of rainfall (*P*) in study area; source: own study

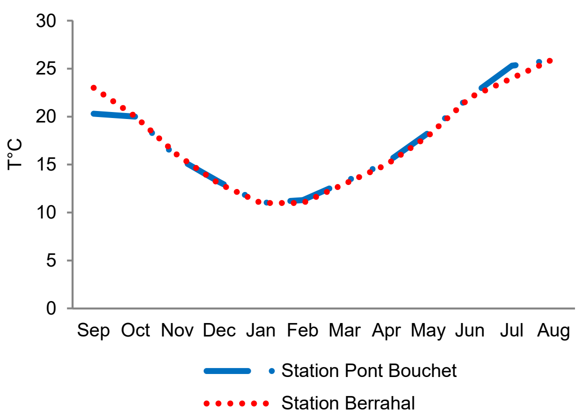

Fig. 3. Average monthly variations of temperature (*T*) in study area; source: own study

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The region of Annaba has been object of several geological studies, including that of JOLEAUD [1936], HILLY [1962], VILA [1980], LAHONDÈRE [1987] and LAOUAR *et al*. [2002]. These studies indicate the existence of two types of section, one is sedimentary and the other is metamorphic (Fig. 4, 5). The stratigraphic column of this land is distributed from Primary to Quaternary:

a) **The primary pedestal**: flush in the West in the Massif of Edough, Belelieta and Bouhamra, cristallophyllian rocks;
b) **The secondary plinth:** flush apart from the study region, in the southern part, at the level of the region of Guelma and Bouchegouf, 20–50 km south of the study area
c) **The Tertiary plinth:** presents an important thickness in the study area with three systems: lower Eocene, Oligocene and Mio-Pliocene;
d) **The Quaternary:** three levels are distinguished: Early Quaternary constituted by alluvial formations (clay, silt, sand, gravel and pebbles), Middle Quaternary corresponding to the lower terrace of 20 to 50 m, constituted by clays and sands and finally Late Quaternary corresponding to sand dune ridges and alluvial silts of Seybouse watershed.

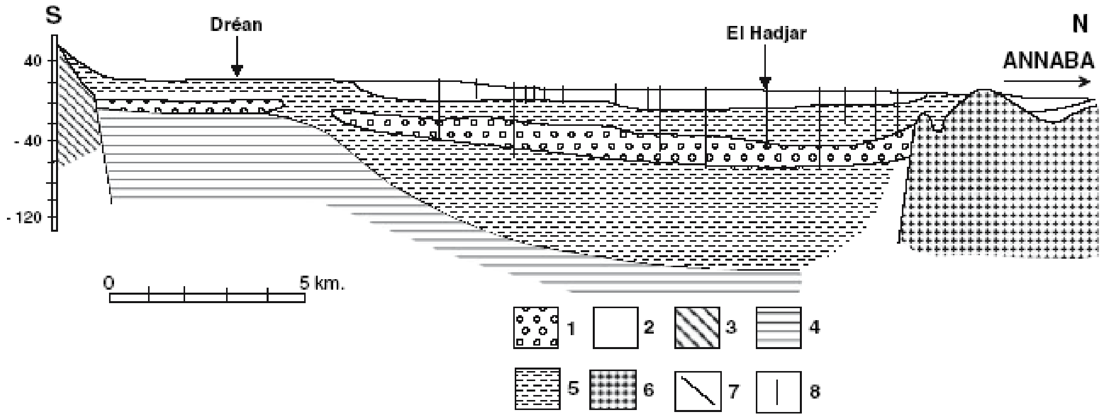

Fig. 4. Geological cross sections of study area; *1* = pebbles and gravels, *2* = sand, *3* = Numidian clay, *4* = Cenomanian marl and marly limestone, *5* = Plio-Quaternary detrital clays, *6* = metamorphic formations, *7* = fault, *8* = drilling; Source: ROUABHIA [2010]

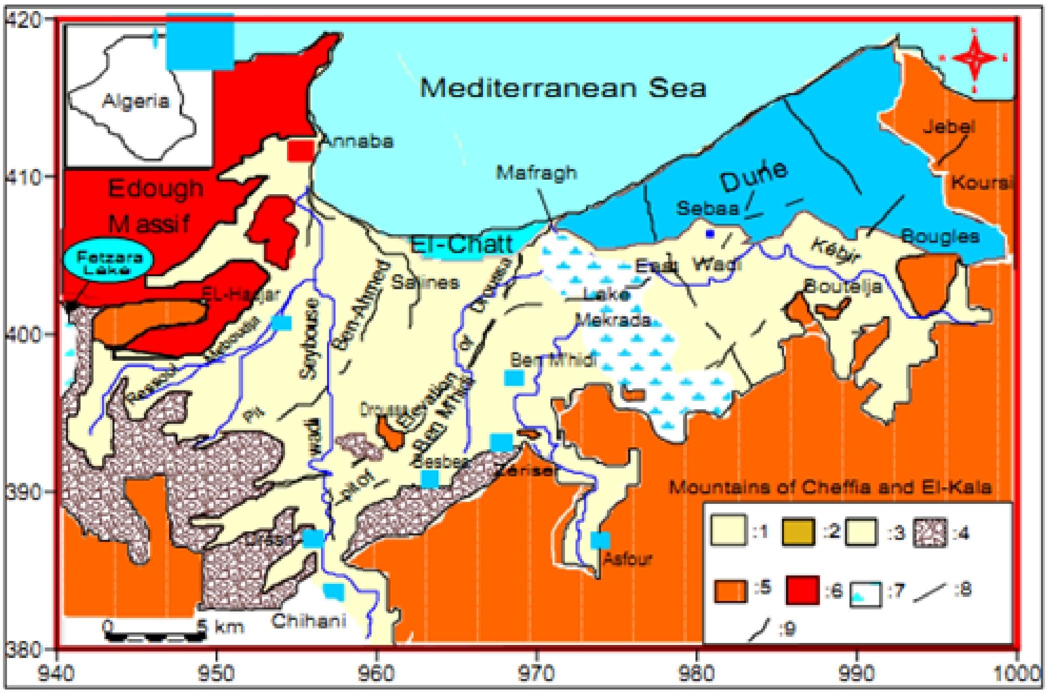

Fig. 5. Extent of different aquifers in Annaba Bouteldja plains; *1* = shallow aquifer; *2* = aquifer of massive dune of Bouteldja; *3* = unconfined aquifer of the dune; *4* = aquifer alluvium high level; *5* = Numidian sandstones and clays; *6* = metamorphic formations (aquifer of marbles); *7* = swamp; *8* = faults; *9* = septic; source: GAUD [1976], amended, 2009

MATERIALS AND METHODS

To achieve these objectives, it is important to make a monitoring (groundwater), with a comprehensive analysis of physicochemical parameters to explain the origin and evolution of each element.

The study has been carried out in Annaba plain (December 2013), 29 samples have been collected from the Quaternary aquifer (i.e., 1 dm^3 for the analysis of standard anions and cations). All samples have been filtered (0.45 μm) and stored at 4°C in polyethylene bottles until analysis. The pH and temperature (WTW-pH330) and electrical conductivity (*EC*) (WTW-EC330) measurements have been conducted in the field with portable instruments. Cation analyses have been performed with ICP-MS in ACME Laboratories (Mass Spectrometer ICP-MS) Laboratories (France). Chloride and bicarbonate ions have been analysed with titrimetric methods (EPA 325.3 and SM 2320). All anion analyses have been conducted with standard procedures with 2% analytical error. Diagram v2.0 computer program has been used to conduct primary computations of water chemistry and correlation analysis between the parameters.

RESULTS AND DISCUSSION

IDENTIFICATION OF WATER CHEMICAL FACIESES

The study of the groundwater's chemical composition has for goal to identify its chemical facieses, its portability potential use as well as their suitability for irrigation purposes.

The data of the major ions carried over the Piper and Stiff diagrams allowed demonstrating the evolution of chemical facies water. The enrichment by chlorides and sulphates of groundwater of Annaba plain is very clear for all samples this reflects the acquisition mode (dominant) of chemistry: chlorides and sulfates have relatively high levels. Cations have the same scenario; magnesium and sodium are domi-

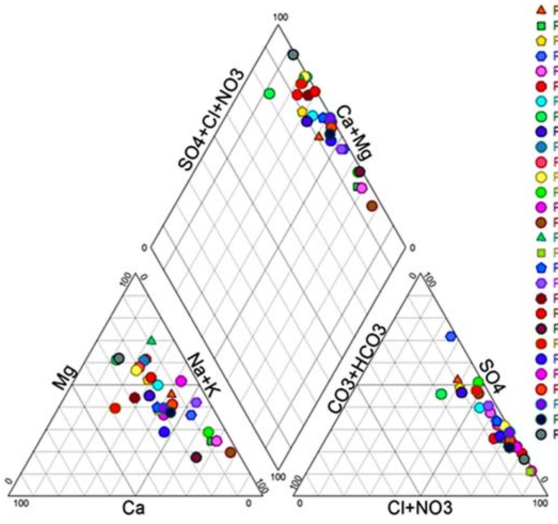

Fig. 6. Piper diagram; P1–P29 = sampling points as in Fig. 1; source: own study

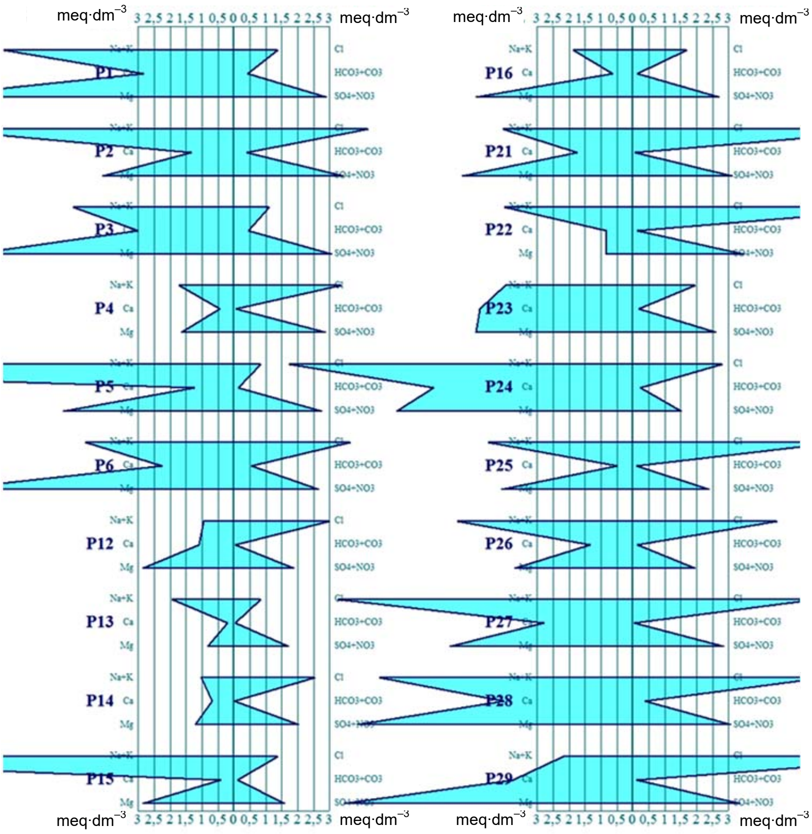

Fig. 7. Stiff diagram; P1–P29 = sampling points as in Fig. 1; source: own study

nant this shows and confirms the impact of geology on the water quality. Bicarbonates are derived from boundary formations while sulfates and chlorides are related to anthropogenic activities (Fig. 6, 7).

CORRELATION BETWEEN MAJOR ELEMENTS AND TOTAL DISSOLVED SOLIDS

For better spatial and temporal characterization of groundwater salinization in quaternary aquifer, we studied the different correlations between TDS (total dissolved solids) and major elements values (Cl^-, SO_4^{-2}, HCO_3^-, Ca^{+2}, Na^+ and Mg^{+2}).

Indeed, chlorides has a positive linear correlation with the TDS (R^2 = 0,61) confirming halite dissolution, an excess of chloride may be come from the dissolution of salts, infiltration of wastewater and recycled water for irrigation. As the calcium excess is accompanied by a sodium deficiency, it can be explained by the basic exchange associated with clay minerals, which fix Na ion after the liberation of Ca, on the other hand, sulphates correlate with the TDS (R^2 = 0.3), showing a possible dissolution of gypsum and /or anhydrite as indicated by the saturation index to wards these minerals; this proves the origin of mineralization by dissolving some minerals of the reservoir rock during the transit of water (Fig. 8).

The values of chloride concentrations and total dissolved solids levels in the ground waters of Annaba plain are increase from South to North (Fig. 9a, b) due to dissolution, industrial discharges and the invasion of marine waters (keep the direction of flow). The high concentration of sulphates may be due to the solubility of gypsum rocks, the oxidation of pyrite and other metal sulphides (Fig. 9c).

SATURATION INDEX

To assess the geochemical processes responsible for the groundwater mineralization in Annaba plain, particular attention is paid to the chemical composition and the saturation index (*SI*) of water with respect to certain minerals. The calculation of the saturation index (*SI*) was performed with the PHREEQC software (USGS).

The calculated saturation index indicates that only carbonate minerals tend to precipitate, particularly in the form of dolomite. The relationship between the saturation index and the carbonate minerals shows that most of the waters are oversaturated with calcite,

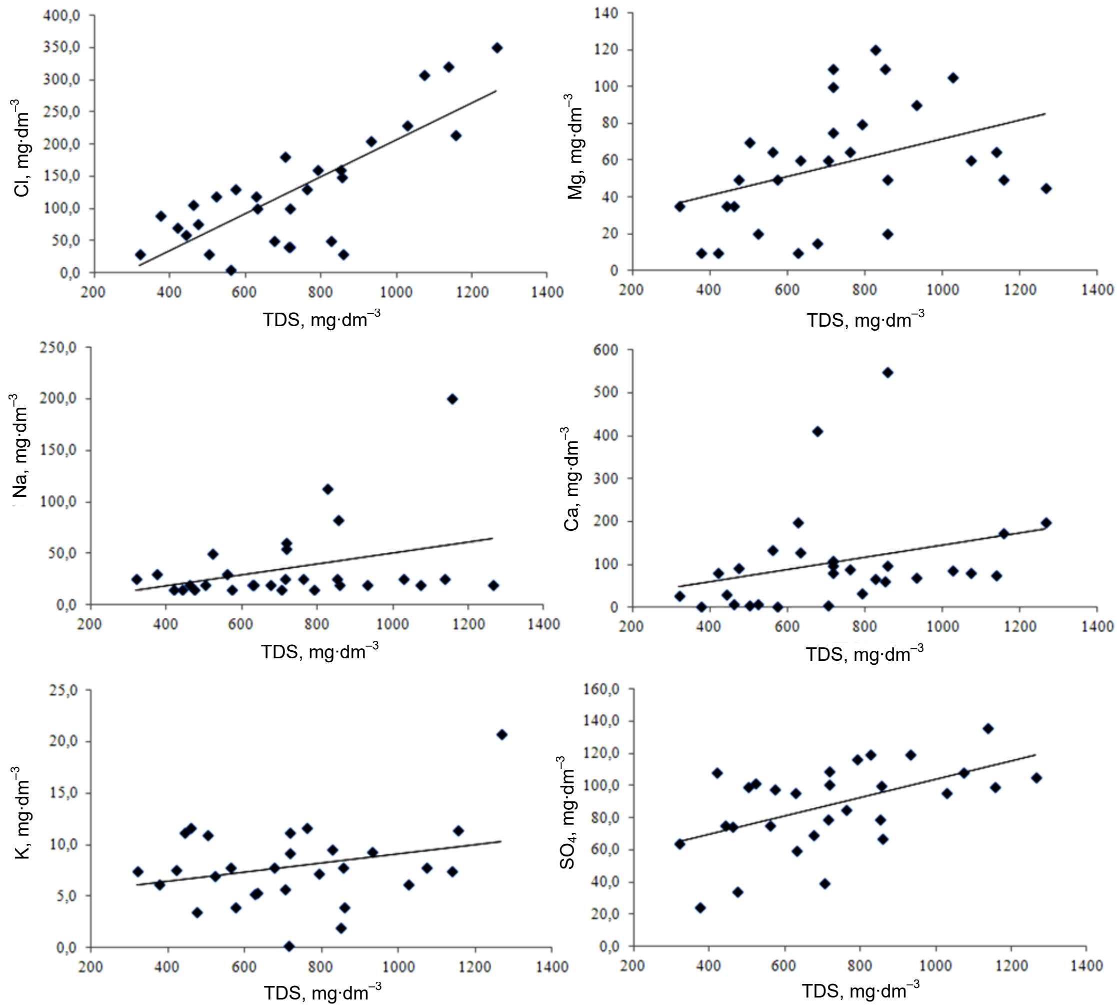

Fig. 8. Correlation between major elements and total dissolved solids (TDS); source: own study

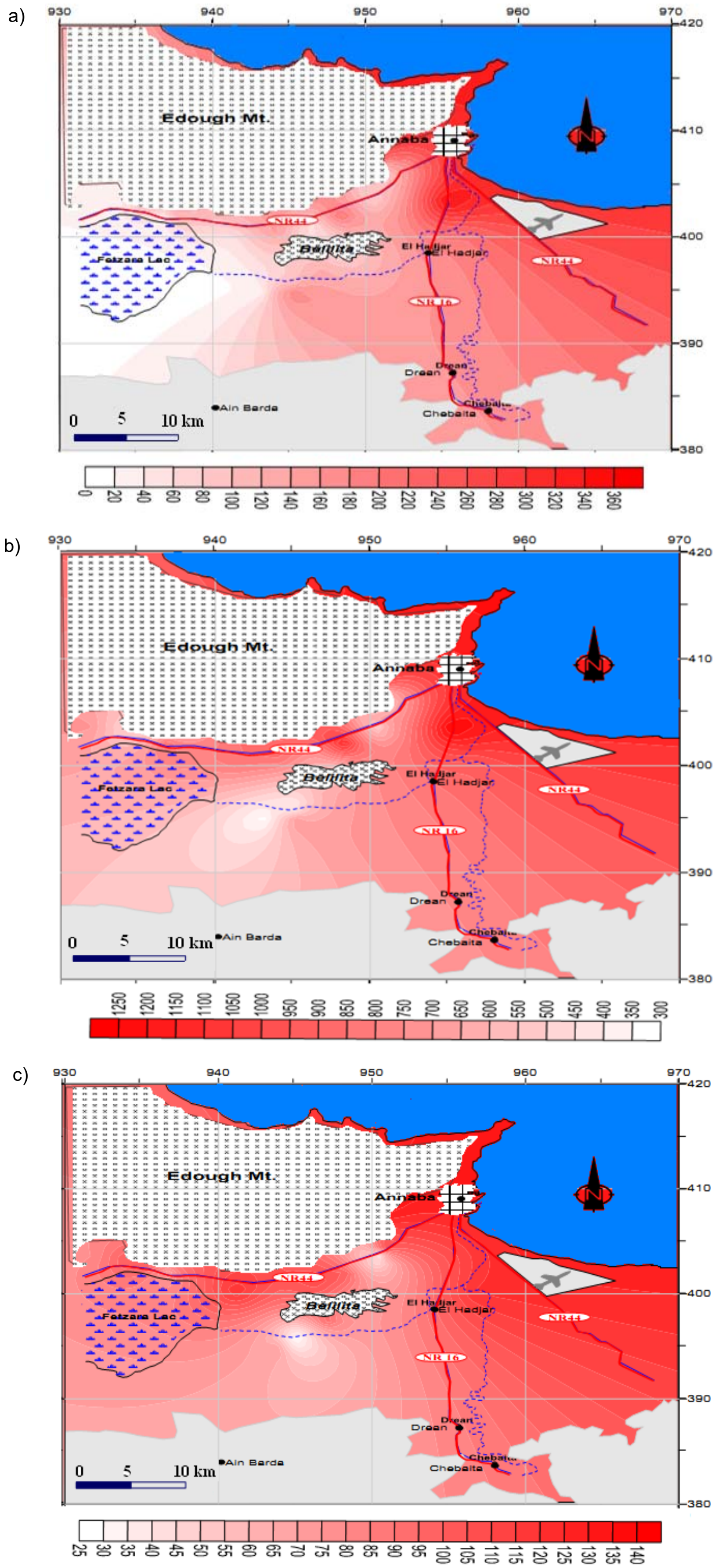

Fig. 9. Spatial distribution in groundwater of Annaba plain: a) of chloride, b) of total dissolved solids (TDS), c) of sulphate; source: own study

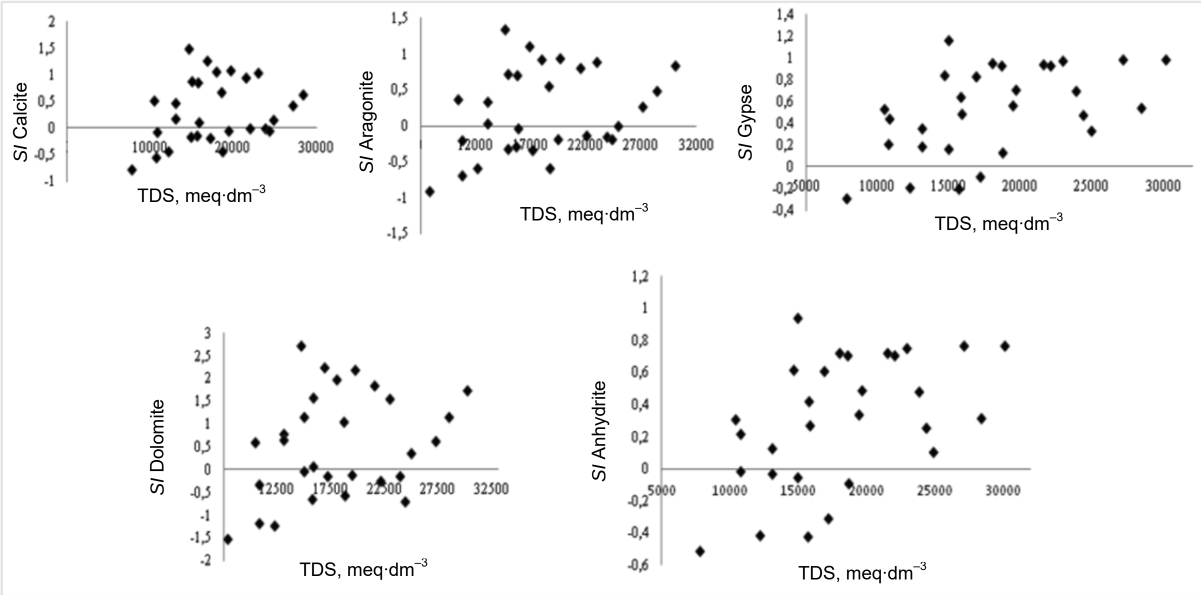

Fig. 10. Relationship between saturation index (*SI*) and total dissolved solids (TDS); source: own study

aragonite and dolomite. Indeed, the relationship between the saturation index of evaporated minerals and TDS shows that the waters of the plain are almost in balance with evaporated minerals: gypsum and anhydrite (Fig. 10).

CLASSIFICATION OF IRRIGATION WATER

Irrigation plays a dominant role in agriculture because of degrading water resources and variant distribution of the rainfalls in Mediterranean region throughout the year. Farmers need to save water and make judicious use of it, especially during the dry season [ZARE *et al.* 2014]. Irrigation water salinity affects the evapotranspiration depends on the soil physical characteristics, soil moisture and crop canopy [ABEDINPOUR 2017].

Several measurements are used to classify the suitability of water for irrigation, including *EC*, total dissolved solids (TDS) and sodium adsorption ratio (*SAR*). Some permissible limits for classes of irrigation water are given in Figure 11. Both *EC* and *SAR* are commonly used to classify salt-affected soils.

RISK DETERMINATION OF SOIL STRUCTURE DEGRADATION CAUSED BY IRRIGATION WATER QUALITY

Sodium adsorption rate (*SAR*) is calculated and used (with *EC*) to predict the stability of the structure of the soil in relation to irrigation water. *SAR* value

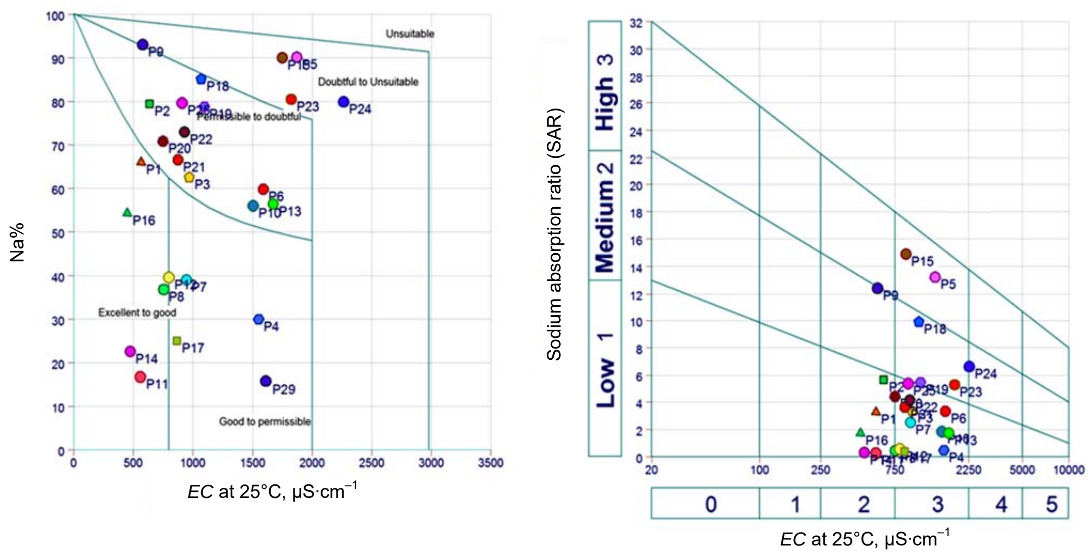

Fig. 11. Wilcox diagram: classification of irrigation water in the study area; *EC* = electrical conductivity; source: own study

measures the relative concentration of sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}), and can be calculated from the following equation:

$$SAR = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca+Mg}}{2}}} \qquad (1)$$

The sodium percentage (Na%) is calculated using the formula given below where all the concentrations are expressed in miliequivalents per dm^3:

$$\mathrm{Na}\% = \frac{\mathrm{Na+K}}{(\mathrm{Ca+Mg+Na+K})}\ 100 \qquad (2)$$

These parameters can be combined or separately, involved in the classification of irrigation water; four classes appear: excellent, good, poor and permissible. The groundwater quality degradation in the study area reflects a change in the water quality.

Wilcox diagram (Fig. 11), relating sodium percentage (Na%) to electrical conductivity (*EC*) show that most of the groundwater samples (20.7%) fall into excellent to good, 17.25% of samples good to permissible categories, 44.82% of samples fall into permissible to doubtful category; fact (17.24%) samples are in the doubtful category improper for irrigation, suggesting the involvement of human activities.

The representations of SAR to electrical conductivity (EC) show that the groundwater is found mainly in four classes:

1) C2S1 (P1, P2, P11, P14 and P16) where the salinity is medium and alkalinity is low;
2) C3S1 (high salinity and low alkalinity) over 55% of samples fall in this class, this water is suitable for agricultural purposes;
3) C2S3: four samples (P18, P19, P23 and P24) fall into this class where the salinity is high and must be checked, these waters considered acceptable for agricultural use;
4) C3S3: two samples (P5 and P15) are in the area of poor water quality so it is unusable for agriculture.

CONCLUSIONS

This study compared the geochemical characteristics of groundwater from samples obtained in Annaba plain. The *SAR* (sodium adsorption ratio), sodium (%) (Sodium percentage), were evaluated using the concentration distribution of ions.

The water in the study area shows enrichment by sodium and magnesium among cations, chlorides and sulphates among anions. Based on the patterns we observed, it can be concluded that all the groundwater of quaternary aquifer of Annaba presents the important variations of mineralization particularly controlled by chlorides and sodium, which becomes more marked in the direction of flow.

SAR values suggest suitability of groundwater from the study area for irrigation. This research may serve as a preliminary study to provide baseline information that may direct future water quality assessment studies in the study area.

REFERENCES

ABEDINPOUR M. 2017. Wheat water use and yield under different salinity of irrigation water. Journal of Water and Land Development. No. 33 p. 3–9. DOI 10.1515/jwld-2017-0013.

ATTOUI B., TOUMI N., MESSAOUDI S., BENRABAH S. 2016. Degradation of water quality: the case of plain west of Annaba (northeast of Algeria). Journal of Water and Land Development. No. 31 p. 3–10. DOI 10.1515/jwld-2016-0031.

AYERS R.S., WESTCOT D.W. 1994. Water quality for agriculture [online]. FAO Handbook 29. [Access 01.02.2012]. Available at http://www.fao.org/docrep/003/t0234e/t0234e00.htm

DEBIECHE T.H. 2002. Evolution of water quality (salinity, nitrogen and heavy metals) due to salt pollution, agricultural and industrial. Application to low plain of the Algerian Seybouse Northeast. PhD Thesis. Besançon. Univ. Franche-Comte pp. 235.

GAUD B. 1976. Etude hydrogéologique du système aquifère d'Annaba–Bouteldja. [Hydro geological study of Annaba – Bouteldja aquifer system]. Rapport de l'ANRH, Algérie pp. 151.

HABES S. 2013. Caractéristiques chimiques d'un lac appartenant aux écosystèmes humides du Nord de l'Algérie; Cas: Lac Fetzara Nord-Est Algérien [Chemical characteristics of a lake belonging to wetland ecosystems in northern Algeria; Case: Lake Fetzara, North-East Algerian]. PhD thesis. Annaba University pp. 211.

HALIMI S., BAALI F., KHERICI N, ZAIRI M. 2016. Irrigation and risk of saline pollution. Example: groundwater of Annaba plain (north east of Algeria). European Scientific Journal. Vol. 12. No 6 p. 241–254.

HANI A. 2003. Methodological examination of anthropological structure and process, application for Mediterranean coastal basin. PhD Thesis. Annaba. Univ. of Annaba pp. 213

HILLY J. 1962. Etude géologique du massif de l'Edough et du Cap de Fer (Est-Constantinois) [Geological study of the Edough Massif and the Iron Cape (East-Constantinois)]. Publications of the Geological Map Service in Algeria. Bulletin. No. 19 pp. 408.

JOLEAUD L. 1936. Etude géologique de la région de Bône et de la Calle-pub [Geological survey of the Bône region and the Calle-pub Geological map service]. Algeria No. 12. Service carte géologique. Algérie No. 12.

LAHONDERE J.C. 1987. La série ultra tellienne d'Algérie Nord orientale et les formations environnantes dans leur cadre structural [The ultra tellienne series of North Eastern Algeria and surrounding formations in their structural framework]. PhD Thesis. Montpellier. Univ. of Montpellier pp. 238.

LAOUAR R., BOYCE A.J., AHMAD Said Y., OUABADI A. 2002. Stable isotope study of the igneous, metamorphic and mineralized rocks of the Edough complex, Annaba, Northeast Algeria. Journal of African Earth Sciences. Vol. 35. Iss. 2 p. 271–283.

LEKOUI S. 2010. Evaluation du risque lié aux sites pollués en milieu urbain et industriel, cas d'Annaba, Nord Est Algérien [Risk assessment of polluted sites in urban and industrial areas, case of Annaba, North East Algeria]. MSc Thesis. Univ. of Annaba pp. 138.

MARAL N. 2010. Soil and water analysis techniques for agricultural production. MSc Thesis. Durham. Middle East Technical University pp. 108.

MORIN G., SLIVITZKY M. 1992. Impacts des changements climatiques sur le régime hydrologique: Le cas de la rivière Moisie [Impacts of Climat Change on the Hydrological Regime: The Case of the Moisie River]. Journal of Water Sciences. Vol. 5. No. 02 p. 179–195.

MUDRY J. 1991. L'analyse discriminante, un puissant moyen de validation des hypothèses hydrogéologiques [Discriminant analysis, a powerful means of validation hydrogeological hypotheses]. Journal of Water Sciences. Flight. Vol. 4 p. 19–37.

RICHARDS L.A. (ed.) 1954. Diagnosis and improvement of saline and alkali soils. Handbook 60. Washington. U.S. Department of Agriculture pp. 159.

ROUABHIA A., DJABRI L., REHAB H., HANI A. 2010. Geochemical characterization of groundwater from shallow aquifer surrounding Fetzara Lake N. E. Algeria. Arabian Journal of Geosciences. Vol. 5 (1) p. 1–13. DOI 10.1007/s12517 -010-0202-6.

SHIIRAZI S.M., ADHAM M.I., ZARDARI N.H., ISMAIL Z., IMRAN H.M., MANGRIO M.A. 2015. Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia. Journal of Water and Land Development. No. 24 p. 11–19.

VILA JM. 1980. Algerian mountain chain and the Algerian–Tunisian confines. PhD Thesis. Paris 6. Pierre and Marie Curie Univ. pp. 665.

WILCOX L.V. 1955. Classification and use of irrigation waters. Circular. No 969. Washington, D.C. U.S. Department of Agriculture pp. 28.

ZARE N., KHALEDIAN M., MAILHOL J-C. 2014. Using water and agrochemicals in the soil, crop and Vadose Environment (WAVE) model to interpret nitrogen balance and soil water reserve under different tillage managements. Journal of Water and Land Development. No. 22 p. 33–39.

ZENATI N. 2010. Pollution de l'environnement aquatique: Diagnostic et Proposition. Région de Annaba. [Pollution of the aquatic environment: Diagnosis and Proposal. Region of Annaba]. Annaba. University of Annaba pp. 289.

Samia HALIMI, Hicham RECHACHI, Sofia BAHROUN, N. Elhouda MIZANE, Tarek DAIFALLAH

Ocena zasolenia wód gruntowych i ryzyko degradacji gleb w czwartorzędowym poziomie wodonośnym: Przykład z równiny Annaba w północnowschodniej Algierii

STRESZCZENIE

Jakość zasobów wodnych na równinie Annaba w północnej Algierii jest poważnie zagrożona wskutek industrializacji i nadmiernej eksploatacji wody. Było to motywem do podjęcia badań prezentowanych w niniejszej pracy. Pobrano 29 próbek wody gruntowej z tego obszaru, aby ocenić jej właściwości hydrogeochemiczne i przydatność do nawodnień. Próbki wody gruntowej analizowano pod kątem stężenia Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-} i SO_4^{2-} oraz pH i przewodnictwa elektrolitycznego.

Badania hydrochemiczne wykazały, że skład wody zmienia się od typu wapniowo-chlorkowo-siarczanowego do sodowo-chlorkowego. Wyniki analiz dowodzą, że zasolenie wód stanowi poważny problem ze względu na ich zastosowanie do nawodnień (58% próbek mieściło się w klasie C3S1). Uznano, że jakość wód gruntowych bez wstępnych zabiegów remediacyjnych nie jest odpowiednia do produkcji roślinnej i utrzymywania właściwego stanu gleb.

Słowa kluczowe: *hydrogeochemia, jakość wody, nawodnienia, równina Annaba, zasoby wody, zasolenie wód*