INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 11, No. 6, p. 132-140, 2017
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Contributions of environmental isotopes to identification of lateral transfers and drainage in a coastal aquifer system, Annaba-Bouteldja (North-East Algeria)

Imen Aichouri[1,2], Samir Hani[2], Nabil Bougherira[2], lamine Sayad[2], Nassima Sedrati[2], Larbi Djabri[2], Hicham Chaffai[*2]

[1]*National School of Mines and Metallurgy ENSMM, Annaba, ex CEFOS Chaiba, Annaba, Algeria*

[2]*Faculty of Earth Sciences, Laboratory of Water Resource and Sustainable Development (REED), Annaba University, Algeria*

Article published on December 30, 2017

Key words: Hydrogeological conceptual model, Salinity, Tritium, Principal component analysis, Flow paths, Annaba-Bouteldja.

Abstract

A new approach was applied to the Annaba–Bouteldja aquifers (northeastern Algeria) in order to understand better the hydrogeology of the complex aquifers despite the scarcity of the available data. Statistical techniques are used to combine various disciplinary data in order to identify chemical and isotopic groups, which are in turn used to define groundwater flow paths. The results of this research agree with the generally accepted hydrogeological conceptual scheme of the aquifers. Additionally, we obtained new results using the PCA method: (1) identification of the complex flow system by grouping various qualitative and quantitative parameters; (2) the description and characterization of the main groundwater flow paths from their sources to the discharge areas. These flow paths are characterized by their water categories, which are represented by salinity and origin of groundwater. This approach is useful for analysing aquifers despite the lack of important database and may also be helpful for studying other complex groundwater basins.

***Corresponding Author:** Hicham Chaffai ✉ hichamchaffai@yahoo.fr

Introduction

The shortage of available fresh water has become a crucial problem for many countries. This is accompanied by various anthropogenic and others sources of pollution, especially for near-surface aquifers (Amarasinghe *et al.,* 2005; Falkenmark and Lannerstad, 2005; Fan *et al.,* 2006; Dalina *et al.,* 2012). Deep groundwater, mostly in confined aquifers, in many arid and semi-arid areas is less exposed to surface pollution (Burgess *et al.*, 2010).

Nevertheless, hydrological data in such aquifer-hosted basins are generally scarce, and exploitation is expensive compared with that of shallow groundwater. Optimal management of the aquifer may reduce these costs. But even with a small database, multidisciplinary studies are needed, such as chemical element distribution and isotopic and physical properties (Burger, 1972; Fontes, 1976; Gilbert, 1991) that must be processed simultaneously.

In contrast to other methods, the principal component analysis (PCA) technique develops comprehensive linear constructions even with a small database, and easily shows some aspects of hydrological problems (Laffite, 1972; Davis, 1984). It can also be useful to identify and explain groundwater evolution processes (Deverel, 1989; Melloul *et* Collin, 1991; Melloul, 1992; Melloul, 1995).

In this research, the PCA technique is used as a tool to process chemical data in order to assess the nature of the Annaba-Bouteldja deep aquifers that have previously been the subject to many research studies (Chaffai *et al.*, 2005; Lamouroux *et al.*, 2006; Aoun-Sebaiti *et al.*, 2013; Sedrati *et al.*, 2016). The objectives are: (1) to develop a hydrogeological conceptual scheme; (2) to identify the flow paths and the rates of recharge; (3) to explain the hydrogeological aspects of the aquifers and the processes that affect water quality in the basins.

Material and methods

Conceptual model

The aquifer system is limited in the west by the Edough metamorphic complex (Fig. 1), in the south by Fetzara Lake and the eastern extension of the Cheffia Numidian mounts, in the north by the Mediterranean Sea and finally in the east by the Bouteldja Numidian massifs. The aquifer formation is composed of Mio-Pliocene and Quaternary sediments of Ben-M'Hidi and Ben-Ahmed graben. The deposits are heterogeneous with numerous alternations of sandy clays, sands and gravels levels. Three main aquifers are observed:

- a surface aquifer that extends over the whole plain of Annaba and flows through the surface silts;
- a gravel aquifer, which covers the entire study area and shows better hydraulic properties;
- a dune aquifer of the Bouteldja massif, which lies on the eastern limit of the whole aquifer system and is considered as a significant water reservoir.

The first two of these aquifers are separated by a semi-permeable and/or impermeable intermediate layer and, thus, constitute a single aquifer of two levels.

From piezometric maps at low watertable (October 2014), the following points arise (Fig. 2):

- The aquifer system, composed of the gravel and the surface aquifers, is characterized by a north–south-trending flow showing an isopiezis depression around the confining field of the Salines sector. Easterly, piezometric observations show a continuous flow in both dune and gravel aquifers. The discharge is carried out by superficial flow and by groundwater flow towards the sea. The aquifer is supplied by rainfall and infiltration of the Seybouse River water further south in the Daroussa Horst.
- The dune aquifer is characterized by a north-directed flow towards the sea and towards the gravel aquifer in the south. This water outflow is compensated by rainfall and surface water infiltration through the Numidian sandstone.

Step 1: collection of data

The first step is based on collecting data related to the study areas. These data include geological maps, complete descriptions of the lithologies and the structural features of the aquifers and any information obtained from the existing observation wells.

The data should also comprise chemical variables, such as concentrations of calcium, magnesium, sodium, etc., isotope data (deuterium, oxygen-18, tritium, etc.) and any other hydrogeological information, such as water levels (Idrotecno, 1979; Progress, 1999; Moula *et* Guendouz, 2004).

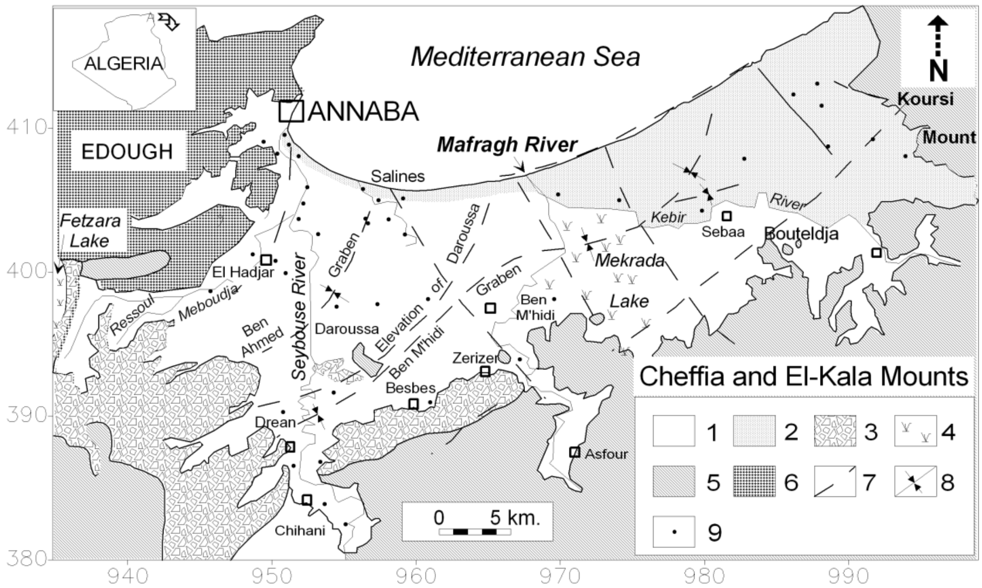

Fig. 1. Geological sketch map of the plains of the Annaba–Bouteldja region: (1) recent and present alluvium; (2) dunes; (3) ancient alluvium; (4) lake or swamp; (5) Numidian sandstone or clay; (6) metamorphic formation (micaschists, gneiss, marbles); (7) fault; (8) graben axis; (9) sampling points.

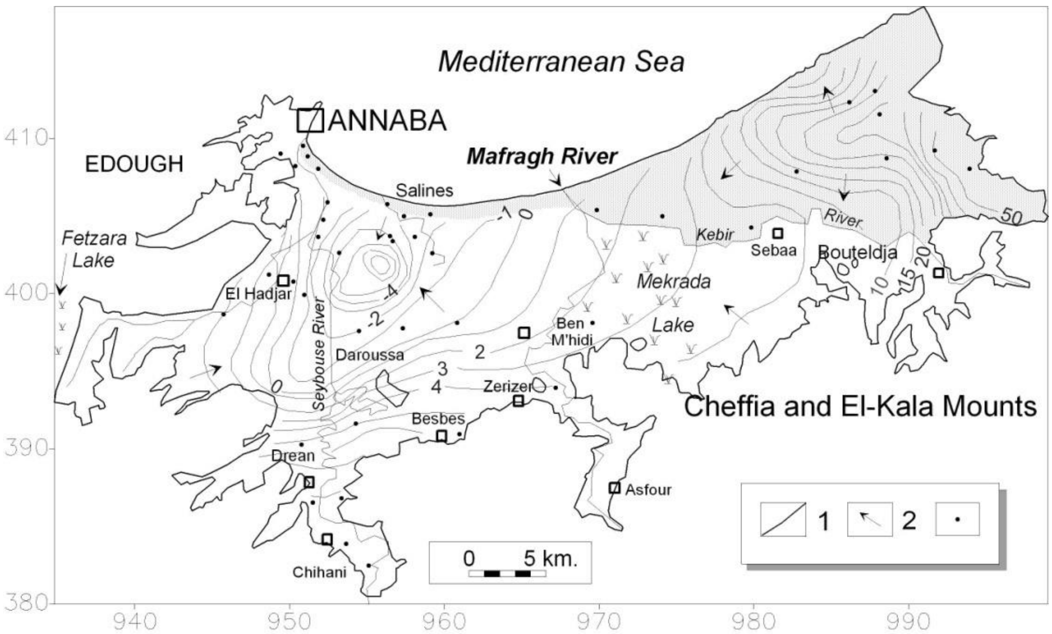

Fig. 2. Hydrogeology and major groundwater flow paths in the Annaba region: (1) potentiometric surface of gravel and dune aquifers (m); (2) flows paths; (3) wells sampling.

Methodology

The present methodology combines various multidisciplinary data in order to explain mechanisms occurring in groundwater flow systems using restricted data sets. Chemical groups are characterized by PCA in combination with classical methods. There are four steps in the proposed methodology to develop a conceptual model (Fig. 3).

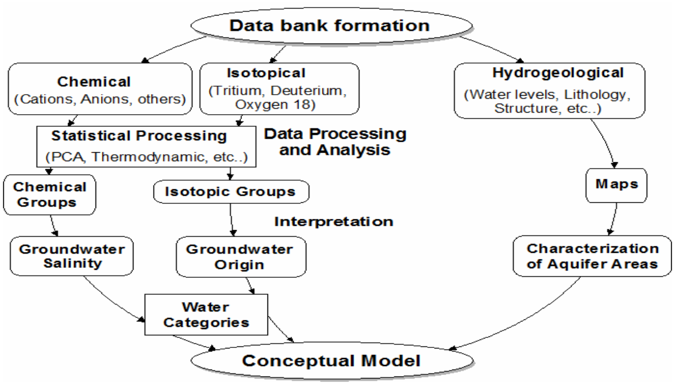

Fig. 3. Methodology diagram.

Step 2: processing, data analysis and group identification

The second step involves the identification of the relationships between chemical and physical data in the different sectors of the aquifer. The principal component analysis is used to process the available chemical data sets obtained from each of the observation wells. In the case of isotopic variables with incomplete sets of available data, only the classical graphical representation of deuterium versus oxygen-18 was used to explain the origin of groundwater; carbon-14 (observed in samples from only a few wells) was used only in special cases to estimate water age. Additional information from hydrological and geological maps, showing such features as water table configurations, hydraulic parameters and lithology, was used in the final stages of this methodology to augment the existing data.

Step 3: interpretation of the results

Water categories

Groundwater categories are jointly defined by their quality and origin. The quality of a given groundwater is affected by changes in chemical constituents due to the processes that can occur in the aquifer, such as water–rock interaction, groundwater evaporation, and interaction between fresh and saline and recent and fossil waters. Isotopic variables can define the origin of water and differentiate between water that was recharged during cooler climates that prevailed thousands of years ago and water that was recharged during a more recent warmer period. Groundwater-quality groups obtained from major chemical ionic data and water groups of different origin determined by isotopic properties are graphically combined to show water categories. This grouping is helpful in the development of the next methodology step.

Aquifer zones

Aquifer zones delineate phreatic, confined and recharge zones of an aquifer. The lithological and structural data obtained from geological maps and the combination of water samples from observation wells depicted in PCA groups are very helpful in defining various aquifer zones of the basin. For instance, low-salinity water and relatively recent water, which can be determined by the PCA and isotopic properties respectively, are of importance in defining the recharge areas. Similarly, PCA groups of saline and old water, obtained from relatively deep wells in the same aquifer, contribute to the identification of the discharge or transition zones that are little affected by recent groundwater recharge.

Step 4: hydrogeological conceptual model of groundwater flow

In this final step, the data and their interpretation help in the development of a hydrogeological conceptual model of groundwater flow. This consists of an interpretation of groundwater flow patterns in relation to various areas and zones of the aquifer.

The flow pattern in the aquifer represents the major flow directions of groundwater whose properties change in space between the recharge and the discharge zones. These changes may be explained simultaneously by the quality, origin, and age of water.

The recharge zones are represented by specific categories of groundwater, characterizing some segments of the flow. In addition an undisturbed aquifer with no fault or leakage would have the youngest groundwater (C) and the lowest salinity (II). On the other hand, the discharge zones are represented by water of other categories coming from elsewhere in the area. In this case, an undisturbed aquifer would have older groundwater (A) and higher salinity (III) than that of the recharge zones.

We assume that there is a relationship between water coming from the recharge zone and water arriving at the discharge zone. A groundwater basin composed of a confined aquifer that is partly recharged from a phreatic aquifer, where the water level is higher than the discharge zones, is characterized by two water categories.

The first category comes from the phreatic zone and involves fresh and more recent water, whereas the second category includes saline and older water in its discharge zones. Complex flow includes leakage from neighbouring aquifers, evaporation, mixing of entrapped saline and fossil waters, etc. In this case, more water categories must be added to explain whole flow properties. As above, additional data were used in the final stages of this methodology to augment the existing data.

Results and discussion

Chemical groups

Fig. 4 shows the quality of groundwater on the basis of major chemical ion contents, such as magnesium, calcium, potassium, sodium, and chlorides. The major variables that are closer to axis 2 are bicarbonates and sulphates (Fig. 4).

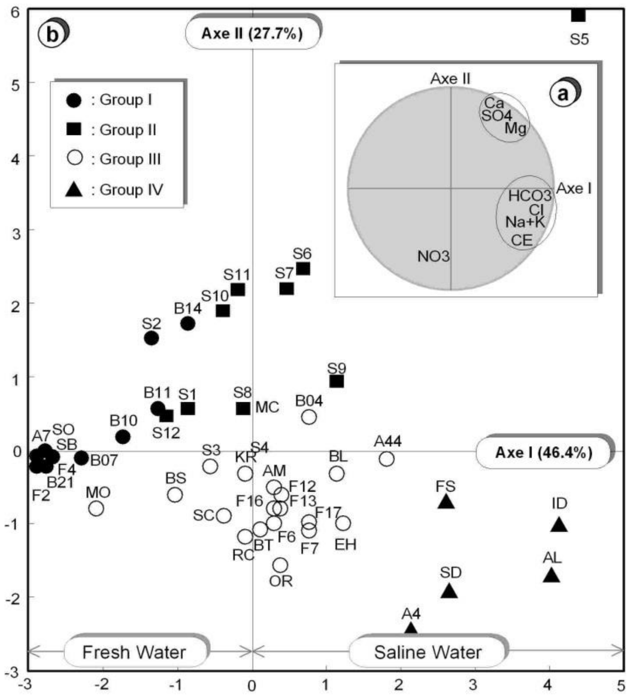

Fig. 4. PCA results: (a) circle of variables (plane I–II); (b) diagram of individuals (plane I–II).

The boundaries between various chemical groups shown in Table 1 are chosen randomly. All these data refer to the two main PCA axes, which explain almost 74% of the total variance.

The chemical characteristics of each of these groundwater groups are as follows:

- I and II groups represent relatively 'fresh' water. I water groups have conductivity values lower than 1200µS cm^{-1} (S indicates Siemens) and II water groups have conductivity values ranging between 1590 and 2120µS cm^{-1}. These groups include samples from the Bouteldja dune and the Seybouse alluvial aquifers (Table 1).

- The III and IV groups represent saline waters. The conductivity increases from the III group (2500 to 6500µS cm^{-1}) to the IV group (>6500 µS cm^{-1}). These water groups are located in the gravel aquifer and the strong salinities are due to base exchanges, marine water–freshwater interaction and infiltration of strongly saline surface water from Lake Fetzara and the River Seybouse (Djabri *et al.*, 2008; Djabri *et al.*, 2014).

Table 1. Chemical well groups.

Chemical group	Observation well	Conductivity range at 20°C (µS cm^{-1})
I	B10, B14, F2, B11, F4, SB, B21, A7, SO, S2, B07	< 1200
II	S7, S10, S9, S12, S11, S8, S1, S5, S6	588–2120
III	BS, MC, B04, KR, BL, BT, A44, SC, MO, F13, RC, EH, AM, F6, F7, F12, OR, F16, F17, S3, S4	500–6500
IV	FD, SD, A4, ID, AL	> 6600

Isotopic groups

Forty-six samples were analysed for their isotopic contents (tritium, oxygen-18 and deuterium). The deuterium was observed only in the superficial table. The tritium-richest waters present the less negative oxygen-18 contents (-5 to -2‰) and the tritium-poorest waters present the most negative oxygen-18 contents (-7 to -4‰). From these data, three isotopic groups of groundwater are identified: old (A), intermediate (B) and young (C) water (Table 2).

Table 2. Isotopic well groups.

Isotopic group	Observation well	Interpretation
A	SB, F16, F6, RC, BS, AM, SD, A44, B14, ID, A4, B04, F7, F17, BL, F12, F13, MO, SC, MC, BT, OR, EH, A7, AL, B10, S7	Tritium contents between 0 and 6 TU and the oxygen-18 values oscillate between -7 and -4‰
B	KR, S1, 6911, SO, Fd, S5, F2, S6, S3, B21, S2, S12, S4, S10, S8, S11, B07	Higher tritium contents (between 6 and 12 TU) and oxygen-18 contents (between -6 and -3‰)
C	F4, S9	This category has tritium contents higher than 12 TU and the less-negative oxygen-18 content (-5 and -2‰). These waters shows high deficits in deuterium versus oxygen-18

Group A

This water group is located at the confined part of the gravel aquifer in the plain of Annaba-Bouteldja and comprises tritium contents between 0 and 6 TU. Three wells (B14, MO and B10) reaching the confined part of the dunelike aquifer also belong to this category. The oxygen-18 values oscillate between -7 and -4‰.

Group B

This water group occurs in the three aquifers and shows higher tritium contents (between 6 and 12 TU) and oxygen-18 contents (between -6 and -3‰). Wells located far from the coast, in the Drean area, confirm the hydraulic interaction between the Seybouse surface water and the aquifer that was confirmed by differential measuring (Hani, 2003).

Group C

This last category occurs in the surface and the dunelike aquifers and has tritium contents higher than 12 TU and the less-negative oxygen-18 content (-5 and -2‰). These waters show high deficits in deuterium versus oxygen-18 (Djabri *et al.*, 1996).

Other data

Hydrogeological observations, such as water-table levels and lithology, are used to complete the above data in order to delineate phreatic areas and/or recharge zones of the aquifer.

Interpretation

Based on groundwater chemical and isotopic properties, five water categories are identified (Table 3): (1) old and low salinity water (C1); (2) old and high salinity water (C4); (3) old to young, low salinity water (C2); (4) old to young, high salinity water (C5); and (5) young and low salinity water (C3).

Groundwater categories and their respective geological contexts are used to characterize aquifer zones and groundwater flow. The hydrogeological conceptual model describes flow paths, major groundwater flow directions in the aquifer and the evolution of groundwater from the recharge to the discharge zones.

The spatial evolution of groundwater is determined by both water quality and water origin. Each aquifer zone is represented by one or more water categories.

Table 3. Water categories of Annaba-Bouteldja aquifers.

Water category	Chemical and isotopic groups	Observation well
C1	(I + II) A	B10, B14, SB, A7, S7
C2	(I + II) B	F2, B11, SO, S5, S6, B21, S2, S12, S10, S8, S11, B07, S1
C3	(I + II) C	F4, S9
C4	(III + IV) A	BS, MC, B04, BL, BT, A44, SC, MO, F13, RC, EH, AM, F6, F7, F12, OR, F16, F17, A4, OL, ID, SD
C5	(III + IV) B	KR, FD, S3, S4

In the Annaba–Bouteldja aquifer system, water categories show the evolution trends of the flux from the recharge zones to the discharge areas (Fig. 5). Water of the surface aquifer consists of four categories: C1, C2, C3 and C4. This indicates the preponderant influence of climatic features, such as evaporation and recharge, on water chemistry. The gravel aquifer is characterized by three water categories: C1, C4 and C5. C1 resulted from weakly charged water supply from the dune massif. C4 water is supplied from the River Seybouse in the Chihani, Dréan and Daroussa sectors. C5 represents water composition of the gravel aquifer in its confined part.

Water of the Bouteldja aquifer comprises four categories: C1, C2, C3 and C4. Again, the influence of evaporation in this unconfined aquifer tends to increase the ionic charge, whereas water dilution is caused by infiltration from rain (Hani *et al.*, 2006). The recharge zones, which are characterized by the recent waters and are not very mineralized, were located in the eastern corner, in the zone contact aquifer–sandstone. The alluvium aquifer to the south and the Mediterranean Sea to the north constitute the two main discharges of the aquifer. The discharge zones are characterized by highly charged old water. These results are consistent with piezometric map.

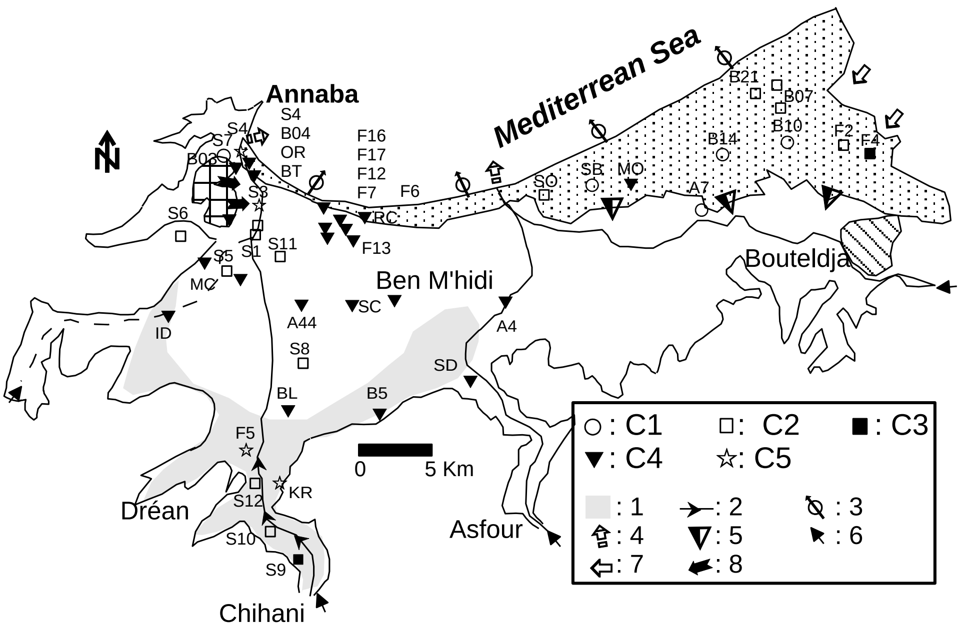

Fig. 5. Hydrogeology and major groundwater flow paths in the Annaba-Bouteldja region: (1) zone of weak thickness of the semi-permeable; (2) recharge zone of the aquifer; (3) groundwater toward the sea; (4) outflow toward the sea; (5) drainage of dune aquifer by the gravel aquifer; (6) contributions by rivers; (7) contributions from the Numidian rocks; (8) contributions from the metamorphic rocks.

Conclusions

The results obtained in this study and the proposed methodology has proved useful and is efficient at presenting a consistent hydrogeological conceptual model. Combined physicochemical and isotopic data reveal different categories of water. Incorporating these categories in the context of the aquifer system of Annaba-Bouteldja, such incorporation can show the evolution trends of the flux from recharging zones to discharging areas:

- Surface aquifer of Annaba. The circulating water in this unconfined aquifer belongs to four families of water (C1, C2, C3 and C4), which indicates the preponderant influence of climatic features (evaporation and recharge) on water chemistry.
- Gravel aquifer. This is characterized by three categories of water, namely C1, C4 and C5. C1 is due to water supply, weakly charged, of the dunelike massif. C4 is due to water supply from the Seybouse, in the sector located between Chihani, Drean and Daroussa. C5 represents the water composition of the gravel aquifer in its confined part.
- The aquifer of the Bouteldja sand dunes. Water of this aquifer belongs to four categories, namely C1, C2, C3 and C4. Here, with the aquifer also being free, on the one hand the influence of evaporation tends to enrich the ionic charge on one hand; on the other hand, the influence of local supply tends to dilute the water. However, several recharge zones can be located to the east in immediate contact with the Numidian sandstones and the discharge zones characterized by highly mineralized old water.

Consequently, the development of a hydrogeological conceptual model paves the way for delineating specific groundwater flow paths and it offers explanations regarding water quality and the recharge modalities of the aquifer. The present method is suitable for studying complex aquifers with various multidisciplinary data and may also be helpful for analysing other aquifers and does not require substantial investment.

Acknowledgments

The authors warmly thank Professor Azzedine Hani for these recommendations and his invaluable assistance in the preparation of this article before its submission.

References

Amarasinghe U., Giordano M, Liao Y, Shu Z. 2005. Water Supply, Water Demand and Agricultural Water Scarcity in China: A Basin Approach. Country Policy Support Programme (CPSP). Sustainable Economic Development Department, National Policy Environment Division, Government of the Netherlands.

Aoun-Sebaiti B, Hani A, Djabri L, Chaffai H, Aichouri I, Bougherira N. 2013. Simulation of water supply and water demand in the valley of Seybouse (East Algeria). Desalination and Water Treatment. DOI: 10.1080/19443994, 855662, 1-6.

Burger A. 1972. Chimie de la dissolution des roches carbonatées, Université de Neuchâtel, Switzerland.

Burgess WG, Hoque MA, Michael HA, Voss CI, Breit GN, Ahmed KM. 2010. Vulnerability of deep groundwater in the Bengal Aquifer System to contamination by arsenic. Nature Geoscience **3,** 83-87.

Chaffai H, Djabri L, Lamrous S. 2005. Réserves hydriques de la Wilaya de Annaba. Inventaire, évaluation et besoins futurs en ressources en eaux, LARHYSS Journal, ISSN 1112-3680, N° **4,** 31-36.

Dalina C, Konara M, Hanasaki N, Rinaldo A, Rodriguez-Iturbe I. 2012. Evolution of the Global Virtual Water Trade Network, Proceedings of the National Academy of Sciences, USA **109(16),** 5989-5994.

Davis JC. 1984. Statistics and Data Analysis in Geology, 2nd ed. Wiley: New York.

Deverel SJ. 1989. Geological and principal components analysis of groundwater chemistry and soil-salinity data, San Joaquin Valley, California. In Regional Characterization of Water Quality, Ragone S (Ed.). IAHS Publication, N° **182,** Wallingford 11-18.

Djabri L, Ghrieb L, Guezgouz N, Hani A, Bouhsina S. 2014. Impacts of morphological factors on the marine intrusion in Annaba region (East of Algeria), Desalination and Water Treatment, Volume **52,** Issue 10-12, 2151-2156.

Djabri L, Mania J, Messadi D, Hani A, Souag M. 1996. Apport des isotopes dans la connaissance des origines des eaux de la vallée de la Seybouse, Revue Hydrogeologia-Espagne **12,** 3-14.

Djabri L, Rouabhi A, Hani A, Lamouroux C, Pulido-Bosch A. 2008. Origin of water salinity in a lake and coastal aquifer system, Environmental Geology, Volume **54,** Issue 3, 565-573.

Falkenmark M, Lannerstad M. 2005. Consumptive Water Use to Feed Humanity: Curing a Blind Spot, Hydrology and Earth System Sciences **9,** 15-28.

Fan H, Huang H, Zeng T. 2006. Impacts of Anthropogenic Activity on the Recent Evolution of the Huang (Yellow) River Delta. Journal of Coastal Research **22(4),** 919-929.

Fontes JC. 1976. Les isotopes du milieu dans les eaux souterraines, La Houille Blanche **3,** 205-221.

Gilbert J. 1991. Vers une vision intégrée des eaux souterraines, résumé et recommendations, Journal d'Hydrogéologie **3,** 257-263.

Hani A, Lallahem S, Mania J, Djabri L. 2006. On the use of finite-difference and Neural network models to evaluate the impact of underground water overexploitation. Hydrol. Process **20,** 4381-4390.

Hani A. 2003. Analyse méthodologique de la structure et des processus anthropiques: Application aux ressources en eau d'un bassin côtier méditerranéen. PhD thesis, Université d'Annaba.

Idrotecno. 1979. Etude hydrogéologique de la région de Tindouf. Rapport final IDROGE/AO-623.

Laffite P, 1972. Traité d'Informatique Géologique. Edition Masson et Cie: Paris.

Lamouroux C, Hani A. 2006. Identification of groundwater flow paths in complex systems aquifer. Hydrol. Process **20,** 2971-2987.

Melloul A, Collin M. 1991. Water quality factor identification by the principal components statistical method. Water Sciences and Technology **24(11),** 41-50.

Melloul A. 1992. The principal components statistical method as a complementary approach to geochemical methods in water quality factor identification. Journal of Hydrology **140,** 49-73.

Melloul A. 1995. Use of principal components analysis for studying deep aquifers with scarce data-application to the Nubian sandstone aquifer, Egypt and Israel. Hydrogeology Journal **3(2),** 19-39.

Moulla AS, Guendouz A. 2004. Etude des ressources en eau souterraine en zones arides (Sahara algérien) par les méthodes isotopiques. Colloque international Terre et eau Annaba-Algérie 35-42.