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Quality of the Fetzara Lake groundwater from north-east Algeria

[1]Fadila FEKRACHE, [2]Rachid DJAMAI and [3]Cherif ABDENNOUR

[1,2]Laboratory of Soil and Sustainable Development, Department of Biology, University Badji-Mokhtar-Annaba, BP 12 Annaba 23000, Algeria.
[3]Laboratory of Animal Ecophysiology, Department of Biology, University Badji-Mokhtar-Annaba, BP 12 Annaba 23000, Algeria.

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A B S T R A C T

Waters of Fetzara Lake is supplied by three rivers (Ziyed, El Hout and Mellah), small streams, the catchment area and also the rain falling directly on the Lake. The diverse alluvial terraces and the dunes which line the Lake contain a little deep groundwater. Thus, the duration of flood of this Lake is a function of the annual pluviometry. Groundwater catchment of Fetzara Lake represents a major resource for farmland irrigation and animal rearing of Annaba region. This water is exposed to strong exploitation by the presence of traditional wells and undergo the constraints of the repeated and long periods of drought provoking a degradation of its quality, which is generally expressed by salinisation. The salinisation process determination of Fetzara Lake groundwater was approached from the study of the major (Na^{+}, Ca^{++}, Mg^{++}, Cl^{-}, SO_4^{--}, CO_3^{--}, HCO_3^{-}) and minor (Br^{-}) elements. Water electric conductivity showed important variations between different sites, which arranged from 0.45 mS/cm to 3.5 mS/cm. Total mineralization is mainly determined by the ions of chlorides, sodium and sulfates, which showed a positive correlation with the electric conductivity. Data interpretation was realised by using the diagram of Piper, Durov and the calculation of the saturation index of different chemicals. Results' projection in the diagram of Durov showed two chemical facies; sodium-chlorides and sodium-bicarbonate. The study revealed the origin and the process of salinisation and the different types of waters; this phenomenon is mainly due to the dissolution/precipitation of minerals from the reservoir formation. The use of Br^{-}/Cl^{-} ratio has allowed eliminating the hypothesis of a marine intrusion in this aquifer.

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INTRODUCTION

North Africa is a typically semi-arid region where water resources may evolve spectacularly under the influence of the climatic fluctuations or the anthropological actions [4]. These changes can often reduce groudwater quantity and quality [13,16,2].

The chemical composition of wells' waters is mainly originated from water penetration through the sol and its residence in the undergound reservoirs. As a results, water acquires mineral load characteristics of the crossed sols and rocks. The elements present in solution are informative on the nature of the crossed aquifer [11].

Fetzara Lake is a seasonal lagoon situated in a climatic zone with big pluviometric variability. The climate of the region presents an important pluviometric deficit (Evaporation > pluviometry) [7]. Besides, the temporal structure of the hydric balance sheet of this lake is more complicated. The rainfull and especially the evaporation present annual cyclic variations with an indisputable seasonality, it is a characteristic of the dry climates, this usually leads to the concentration of the soluble elements in the soils being translated by the salinisation of the latter. However, rains can be important for certain years, where the balance sheet becomes more positive, so favoring the refill of the groundwater reservoirs and the washing up of the soluble elements towards the latter [7].

All the hydraulic and pedological studies made on the region of the Fetzara Lake demonstrated that the causes limiting the agricultural development of the zone are due to the hydromorphy, the irregularity of rains and especially the salinity [15].

The aim of actual work realised in the region of Fetzara Lake is to study from a geochemical approach the major mechanisms having contributed directly to the evolution of water salinity. Also, a particular attention is focused to the study of Br^{-}/Cl^{-} ratio to confirm the origin of such salinity.

Corresponding Author: Fadila FEKRACHE, Laboratory of Soil and Sustainable Development, Department of Biology, University Badji-Mokhtar-Annaba, BP 12 Annaba 23000, Algeria.
E-mail: ffekrache@yahoo.fr

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MATERIALS AND METHODS

Characteristics of the region of study:

Fetzara Lake is situated 14 km southward of the Mediterranean Sea and 18 km in the Southwest of Annaba city. It is represented by a wide depression with a length, from east to west, of 17 km, and a width, from north to south, of 13 km. It is limited to the North by the massif of Edough, to the South by hills and bordered by dunes in the East and the West. The easily flooded part of the lake is situated in the center of the zone and covers a surface area of 13000 hectare. This lake is partially flooded in winter in spite of the presence of a main channel crossing it from west to east [10]. Such channel is insufficien to evacuate all waters, which lead to increase its surface area and distribute more salts on the surrounded grazing lands.

The geological formations of the studied zone contain the following [14]:

The alluvial plain is constituted of silt, sand, gravel and travertine. The reliefs of the northwest massifs and the South zone is made mainly of quartz and reddish, alternating with beds of clay, dated to the upper Eocene associated with outcrops of marl with pyritic ammonites of the lower Cretaceous as well as the limestone of Trias. The north zone is formed with eruptive and metamorphic rocks (crystalline and granitelike schists). Some outcrops of limestone and phosphatic limestone of the middle and lower Eocene are also found in this zone.

The climate of the region is of Mediterranean type; it is moderate and characterized by a cold-wet winter and a hot-dry summer.

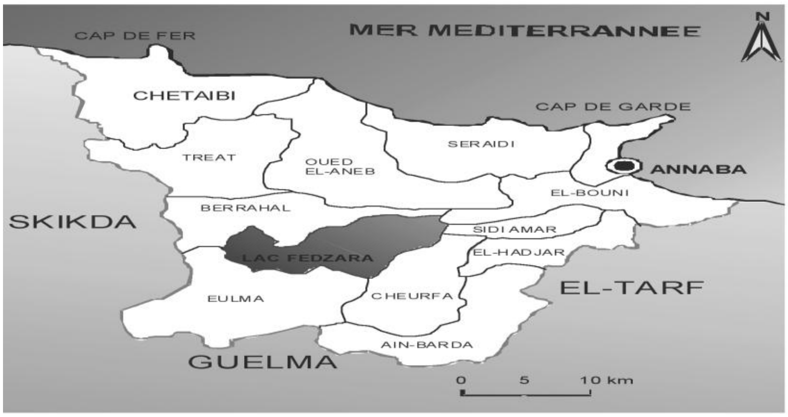

Fig. 1: Geographical location of the Fetzara Lake.

The total surface of the catchment area of Fetzara Lake covers 500.5 km^2 [15] (fig 2). Waters of the lake are collected from the three main rivers (Zied, El-Hout and Melah). The river Zied (1008 m) is situated in the Northeast of the lake with a catchment area of 19 Km^2, but that of El-Hout (795 m) is considered as being the biggest river in the Southeast, with a catchment area of 81 km^2. The Melah is situated on the West of the lake and its catchment area is 47 km^2 [8].

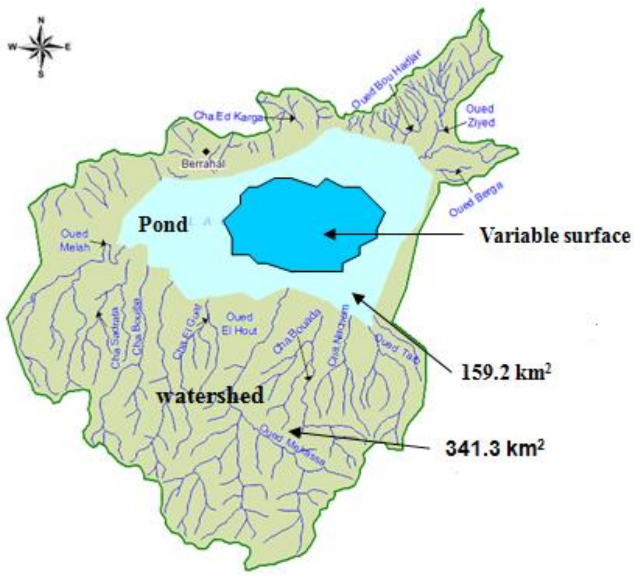

Fig. 2: The catchment area of Fetzara Lake [15].

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Used analytique methods:

Samples were taken from 25 wells in state of exploitation (used for irrigation) with depths varying between 4 and 10 m during the month of January, 2011, which coincides with the period of acquifer refill. The parameters measured were the pH, Eh (potential redox), temperature (T °Cy) and the electric conductivity (EC), which directly measured on samples of raw water in the field.

The analyses of the major (Na^+, Ca^{++}, Mg^{++}, Cl^-, SO_4^{--}, CO_3^{--}, HCO_3^-) and the minor (Br^-) elements were realised in the laboratory by titrimetry for Cl^-, HCO_3^-, CO_3^{--}, Mg^{++} and Ca^{++}, by spectrophotometry for SO_4^{--} and Br^- and by flame spectrophotometry for Na^+ and K^+.

The analysis of the correlation matrix was made by means of the software XLSTAT to determine the relations between the physico-chemical and the chemical elements.

The diagram DUROV which determines the chemical facies of waters was realised by means of the software “ROCKWORKS15", while the saturation index (IS) of minerals dissolved in water was calculated by by the software "DIAGRAM".

RESULTS AND DISCUSSION

Salinity:

Total dissolved solids (TDS) is a good indicator of the global quality of groundwater. The total mineralization or the TDS is expressed by mg/l, where it corresponds to the sum of the cations and the anions. The values of mineralization oscillate between a minimal value of 471.2 mg/l and a maximal one of 2318.8 mg/l, with an average of the order of 1142.03 mg/l. The salinity varies in notables proportions in the zone of study. Altogether, it is rather low on borders of the North of the lake and it increases in the South and Southeast. The mineralization is essentially related to chlorides, sodium and calcium. The contribution of sulfates is negligible compared to the other elements, while bicarbonates have no determining role in the mineralization of waters.

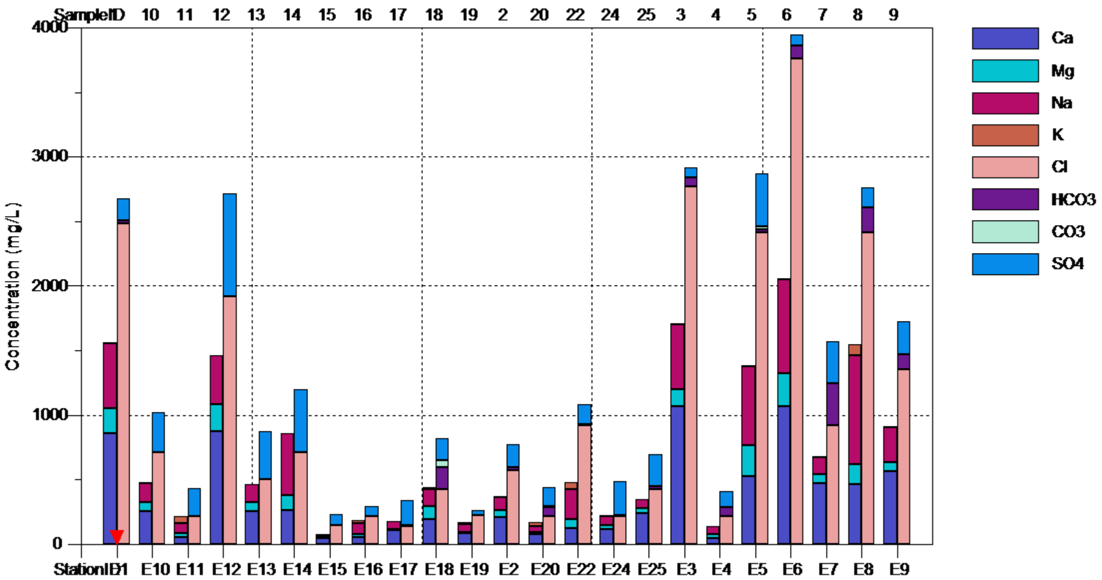

Fig. 3: Total mineralization of Fetzara lake groundwaters.

Interpretative diagrams:

The interpretation of the major elements in terms of chemical facies turns out precious when it comes to distinguish groups of water of chimisme and mineralization within an aquifer. The tool most frequently used is the diagram of Piper, based on the relative and equivalent concentrations (meq/l) with regard to the sum of the cations even anions. The representation of the major element concentrations on the diagram of Piper (fig.4), shows that sampled waters are generally of the sodic chlorinated to sodic-bicarbonated type. The sodic-chlorinated facies, is frequent in the milieu rich on evaporites (as the halite [NaCl]). However, the sodic-bicarbonated facie is found in certain aquifers of the sedimentary basins and shows interactions water-rock (exchange Ca^{++} vs. Na^+ on clays) [3].

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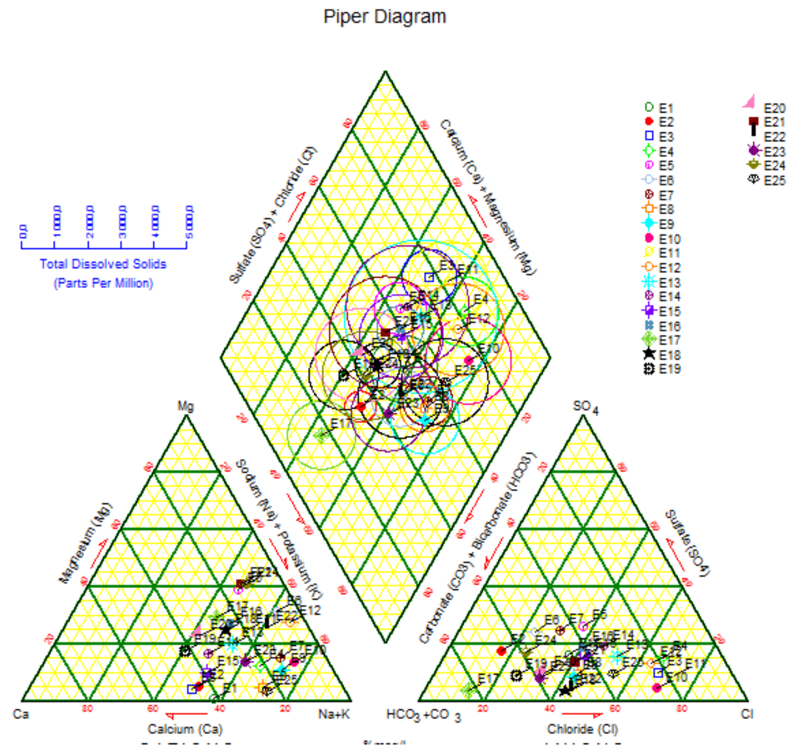

Fig. 4: Diagram of Piper representing the major element concentrations of Fetzara groundwaters.

The diagram of Durov, built on the basis of the relative contents (meq/l) of major ions in solution allows visualising the distribution of sample compositions. The latter has for axes of braided two diagrams of Piper, respectively anions and cations. Thus, for every sample, we represent its composition in cations and anions on the corresponding axis. The intersection of the projection of the two coordinates obtained gives the representative point of the sample in the diagram of Durov. This diagram allows to distinguish easily the samples of (Na^{+}-Ca^{++})-$HCO_3^{-}$from those of type (Na^{+}-Ca^{++})-Cl^{-}, respectively named the type bicarbonated and the chlorinated type. This distinction is often used on the literature to distinguish groundwaters, the signature of which gets closer to those to high salinity (chlorinated type), to those whose signature gets closer to some water of refill (type bicarbonated) [12,17].

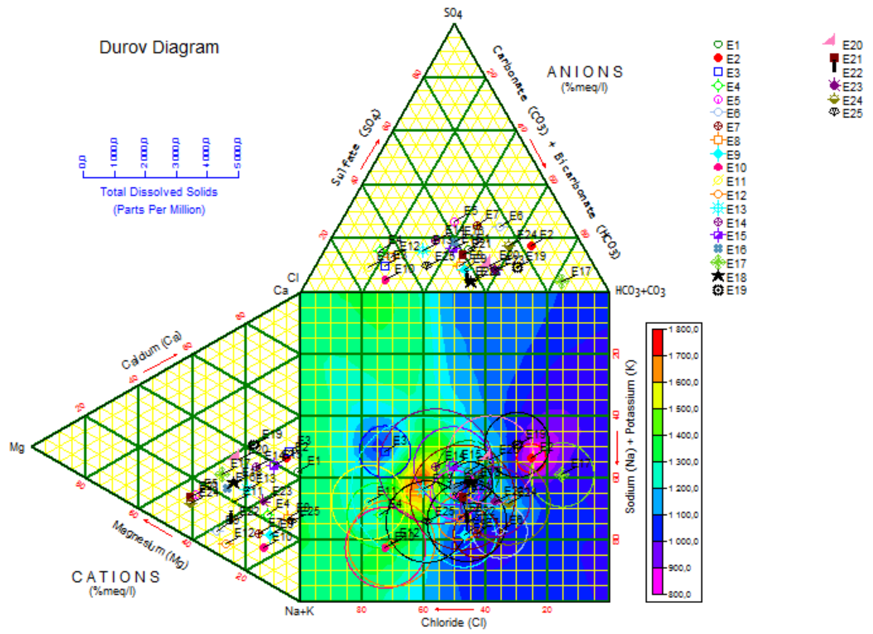

Fig. 5: Diagram of Durov representing the major element concentrations of Fetzara groundwaters.

Index of saturation (IS):

The balance of waters with the matrix is often expressed either by the rate of saturation (= (PAI/Ks)*100), or by the saturation index (IS=log (PAI/Ks)), where PAI is the activity product of the concerned ions and Ks is the produc of mineral solubility considered. The saturation index is the mostly used shape for groundwater [2].

The degree of saturation, sub-saturation or the state of balance of a solution towards a mineral is estimated only if we can compare the product of solubility with the product of ionic activity of the reference ions in solution [5,6]. Water is balanced with the mineral when IS = 0, it is sub-saturated when IS < 0 and supersaturated when IS >0 .When a solution is sub-saturated towards a mineral, this one will tend to dissolve [2].

The obtained results indicate a light sub-saturation with regard to the halite (NaCl), and a sub-saturation with regard to the gypsum ($CaSO_4$, $2H_2O$) and the aragonite ($CaCO_3$), the dolomite (Ca^{++}, Mg^{++})$(CO_3)_2$ and of the anhydrite (CaSO4) in all the watershed (Tab.1). The majority of samples show a sub-saturation towards the calcite ($CaCO_3$), with the exception of site 1, 3, 13, 14, 20 which are supersaturated. Consequently a possible dissolution of these minerals can contribute to the acquisition of the salt load in the groundwaters.

Table 1: Index of saturation of Fetzara Lake groundwater towards some minerals.

Samples	IS Anhydrite	IS Aragonite	IS Calcite	IS Dolomite	IS Gyps	IS Halite
E1	-1.71	-0.10	0.05	-1.63	-1.47	-6.10
E2	-2.18	-0.34	-0.20	-1.28	-1.95	-7.19
E3	-1.92	-0.08	0.07	-0.86	-1.68	-5.95
E4	-1.87	-0.39	-0.24	-0.68	-1.63	-5.67
E5	-2.02	-0.71	-0.57	-0.66	-1.78	-6.27
E6	-2.34	-1.16	-1.01	-1.32	-2.10	-6.36
E7	-2.15	-0.94	-0.79	-1.55	-1.90	-6.45
E8	-2.28	-0.58	-0.43	-1.57	-2.04	-6.15
E9	-2.36	-0.20	-0.05	-0.25	-2.11	-6.00
E10	-2.59	-0.72	-0.57	-1.01	-2.35	-5.42
E11	-2.06	-0.67	-0.52	-0.88	-1.82	-5.52
E12	-2.42	-0.84	-0.69	-0.63	-2.17	-5.41
E13	-1.37	0.00	0.15	0.21	-1.13	-5.20
E14	-1.30	-0.12	0.03	-0.21	-1.06	-5.49
E15	-1.56	-0.21	-0.06	-0.67	-1.32	-5.81
E16	-2.08	-1.20	-1.06	-1.97	-1.84	-6.31
E17	-2.58	-0.57	-0.42	-0.78	-2.33	-6.72
E18	-2.79	-0.69	-0.54	-1.12	-2.54	-6.33
E19	-1.97	-0.51	-0.36	-1.06	-1.72	-6.40
E20	-1.79	-0.11	0.04	-0.09	-1.54	-5.92
E21	-1.95	-0.52	-0.37	-0.22	-1.70	-5.68
E22	-2.66	-0.81	-0.66	-1.00	-2.41	-5.76
E23	-2.18	-0.67	-0.52	-1.29	-1.93	-6.07
E24	-2.11	-0.81	-0.66	-0.74	-1.86	-6.14
E25	-2.00	-0.58	-0.43	-0.43	-1.68	-1.71

The Br^-/Cl^- ratio:

Chlorides and bromides are among the best preserved species, they do not participate in water-rock interactions and their ratio is an indication of origin and a tracer of mixtures. The ratio of these two species, compared with current seawater and/or with that of seawater in various stages of salt precipitations, can be used to characterize the origin of the chlorine, and thus indirectly the origin of water and its mineralization. The ratio Br^-/Cl^- helps to identify a possible contribution of marine water because it is relatively constant ($1.5.\ 10^{-3}$) [1]. The analysed wateres presented a bromide concentration between 0.0089 and 0.0973 mg/l. Such concentration is considered very low compared to that of seawater. The graph shows a dispersion of points indicating that the two elements have different origins (fig.6), thus there is no marine intrusion into groundwater of Fetzara Lake.

Conclusions:

The aquifer of Fetzara lake knows a degradation of its water quality. The electric conductivity showed important fluctuations in a point to another and oscillates between 0.45 and 3.5 mS/cm. The strong conductivities concentrate essentially at the Northeast and Southeast zones of the pond, so following the gradient of water flow. This salinity is principally controlled by chlorides, sulfates and sodium. The climatological study shows that the concentration of solutions under the influence of intense evaporation, which characterises the region in summer, is the main process of salinisation. However, two other processes are certainly responsible on the evolution of Fetzara lake salt dynamics. It is on one hand the phenomenon of ionic exchanges between waters and rocks. On the other hand, the strong variability of the anoxia conditions and the partial pressure of CO_2 engendered by the clogging of the environment by water, are promoting the oxydo-reduction reaction affecting probably the sulfate contents. Moreover, groundwaters of this lake are characterised by two types of chemical facies, sodic-bicarbonated and especially sodic-chlorinated, which suggest the presence of avaporative deposits, leading to the dissolution of halite in these waters. The use of the approach Br^- /Cl^- ratio has allowed to exclude the hypothesis of an increase of water salinity by marine intrusion.

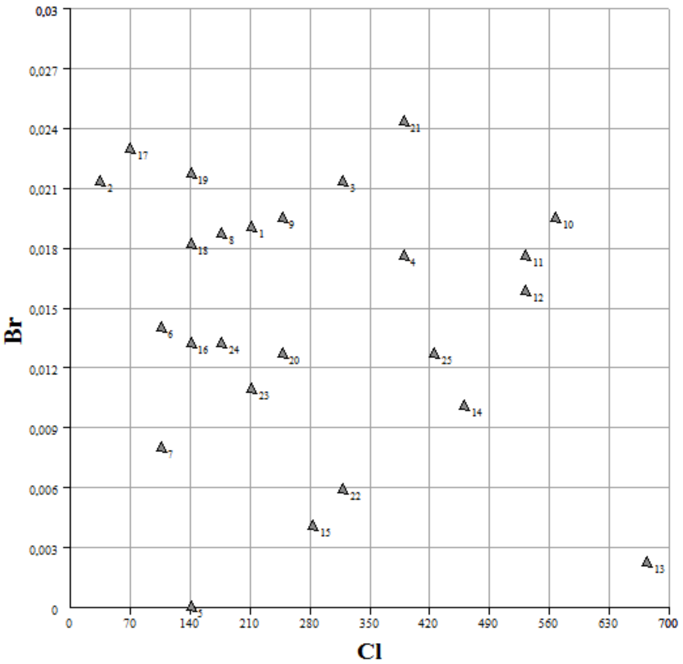

Fig. 6: Variation of Br^- according to Cl^- concentration in Fetzara Lake groundwaters.

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