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The impact of irrigation water returns on the water quality of Annaba El Tarf aquifers (Northeastern Algeria)

Samir Lekoui*[1], Djorfi Saadane[1], Foufou Atif[2], Imad Eddine Bouznad[2]

[1]*Department of Geology, Faculty of Earth Sciences, Badji Mokhtar University, Annaba, Algeria*

[2]*Department of Earth & univers Sciences, Ziane Achour University, Djelfa, Algeria*

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Abstract

In the North Eastern part of Algeria, The plain of Annaba El-Tarf, constitutes a privileged sector in agricultural activity, characterized by piezometric levels very close to those of a soil generally fertile, several modes of irrigation are practiced in which the gravitational one is the most used, This use causes significant loss of water pumped and groundwater pollution by irrigation return waters concentrated by evaporation and leaching. The aim of this study is to focus on the impact of irrigation return waters on the quality of groundwater in the irrigated perimeter of Bounamoussa and for this purpose, sampling campaign and hydro chemical analysis was carried out through wells and boreholes of the study area, The physicochemical analysis by different methods (Piper diagram, PCA, AHC, Richard diagram) showed the presence, first, high mineralization producing a high salinity due to high concentrations of major elements (Calcium, magnesium, chloride) which are due to the leaching of geological formations, second pollution by nitrogen elements (nitrates, nitrites, ammonium) and phosphates which are due to the intensive use of agricultural fertilizers and domestic discharges.

***Corresponding Author:** Samir Lekoui ✉ samirlekoui@yahoo.fr

Introduction

The intensity of agricultural practices and the implementation of several irrigation Systems have caused an impact on groundwater quality, especially those returning to the aquifer after irrigation. These return waters transit through agricultural soils and an unsaturated zone rich in salts of various origins which have been leached by the irrigation water loaded with chemical elements and brought to the water table. The re-infiltration of irrigation water is a potential source of degradation of groundwater quality, mainly in areas where the water table circulates at shallow depths of the soil surface. Salinity may cause harmful effects because of the fixation of sodium chloride salts by soil colloids. Sodium has a harmful effect on vegetation, indirectly by degrading the physical properties of the soil. As a result, soils become compact and asphyxiating to plants (Todd 1980). When the concentration of Na^{+} ions in a soluble state in soil is important, these ions frequently replacing Ca^{2+} cations in the absorbent complex. Water loaded with salts can cause this effect. The risk is Determined from the value of the absorbable sodium, "Sodium Absorption Ratio: SAR". For the same conductivity, the risk is much greater when the coefficient is higher. Several studies carried out in the region (Debièche, 2002, L. Djabri, 1996, A, Hani, 2003, N. Khérici, 1993, A. Belhamra, 2001, S. Djorfi, 2008) allowed following the hydrochemistry water to highlight the influence of industrial and urban discharges as well as agricultural activity on the hydrochemistry of aquifer waters.

The aim of this work is to take stock of the impact of irrigation water returns on the quality of surface and underground water in the irrigated area of Bounamoussa, the treatment of chemical data allow to analyze the mechanisms that control the transfer of pollution to groundwater and identify the origin and genesis of some pollution contaminants.

Materials and methods

Geographical location

The perimeter of Bounamoussa occupies a total area of 16,200ha, of which 14,800ha represents the net irrigable area. It belongs to the series of coastal plains of eastern Algeria. It is administratively attached to the two cities with a percentage of 80% for the city of El Tarf and 20% for the city of Annaba; it is an alluvial plain with a center of gravity located 15km southeast of the city of Annaba. It is located on both sides of the national road n°82 connecting Annaba to the city of Bouhadjar. Limited to the North by a massif dune which separates it from the sea and encumbers the flow of rivers. South and southeast by the foothills of the mountains of Chaffia, from where comes the Bounamoussa river on which was built the dam of the Cheffia; To the west by the primary mass of Edough, then by the ridges which separate it from Fetzara Lake; To the east by the ridges that separate it from the swamps of Mekrada.

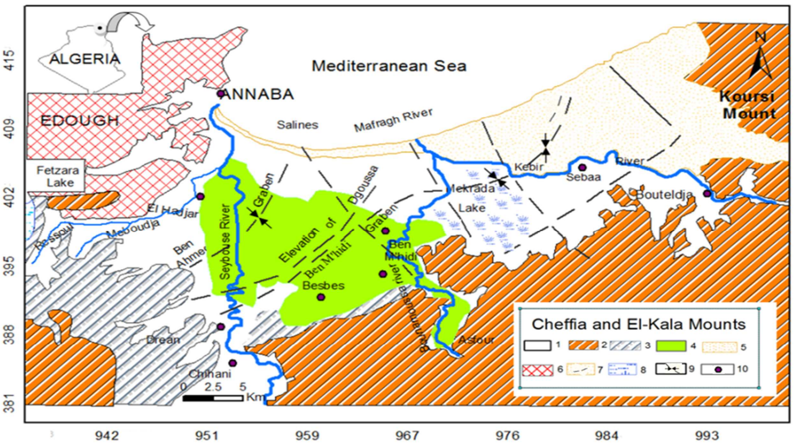

Fig. 1. Geological situation of the plains of the Annaba-Bouteldja region.

(1) Recent and present alluvium; (2) Numidian sandstone or clay; (3) ancient alluvium; (4) irrigated perimeter; (5) massif dunes; (6) metamorphic formation (micaschists, gneiss, marbles); (7) fault; (8) lake or swamp; (9) graben axis ;(10) urban area.

Climatology and hydrology

The study area has a Mediterranean climate, fresh and humid in winter and hot and dry in summer, receiving an annual average of rain which varies between 603 mm and 703 mm with an average temperature of 18°C. The origin of the perimeter irrigation water is the surface waters of the Cheffia dam located at a distance of twenty kilometers (20km) upstream from the study area; hence the water supply system is part of a large group of facilities for the irrigation of the perimeter, approximately 15,000 hectares located in the lower valleys of Bounamoussa and Seybouse (plain of Annaba).

Geology and Hydrogeology

The study area is part of the geological complex of the Tell Algerian Nord Oriental (L'Edough massif), presents metamorphic rocks in borders (gneiss, schists, micaschists, marbles, and metamorphic limestone), which constitute areas of feeds for water table of alluvial sediments potentially aquiferous of Mio-Plio-quaternary that form the major part of the plain. The hydrodynamic study allows to distinguish two different aquifers, with unequal quantitative and qualitative importance regarding the extent. The one superficial (free); consisting of fine sand and gravel with a thickness of 10 to 15 meters. The other deep; semi-captive becomes captive in the West, has a depth which varies from 12 to 80 meters (Fig. 2).

Sampling and hydrochemistry analysis

The samples were collected in polyethylene bottles, rinsed with distilled water, then with the water to be sampled, closed and kept at 4°C, through ten wells, three boreholes, four samples along Bounamoussa River and two along Seybousse River in the period of low water October 2017.

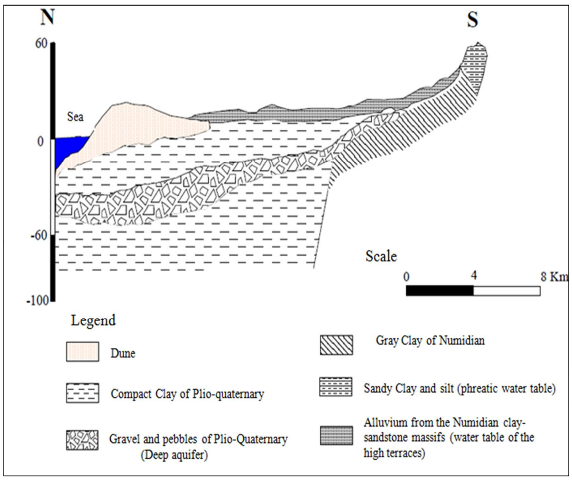

Fig. 2. Geological section showing the different water levels through Annaba plain.

The analyzes focused on the following variables: Three physicochemical parameters (T°C, pH, conductivity and levels of water table) are measured in situ directly after sample collection using a multi-parameter device WTW brand. The chemical elements analysis were performed by spectrophotometry method for anions and atomic absorption flame for major cations, The concentration of nitrate (NO^{3-}), nitrite (NO^{2-}), ammonium (NH_4^+) and phosphate (PO_4^{3-}) was measured using the UV spectrophotometric filtering method.

Results and discussion

The results obtained are illustrated in the following statistical table n°01.

Table.01. Water analysis basic statistics of the irrigated perimeter of Bounamoussa (October 2017).

Variable	Minimum	Maximum	Mean	Std. deviation
T C°	18.3	23.4	21.12	1.57
PH	6.51	8.4	7.46	0.53
CE µs/cm	448	970	2849.21	2707.84
O2	0.700	8.10	2.69	2.19
Ca^{2+}	53.410	521	193.23	127.61
Mg^{2+}	17.000	403	84.22	90.85
Na^+	41.000	322	160.94	75.32
K^+	2.000	21	10.63	5.49
Cl^-	28.200	513	226.57	138.63
SO_4^{2-}	31.000	613	202.29	129.45
HCO_3^-	151.240	541	358.74	130.86
PO_4^{3-}	0.200	3.30	0.84	0.73
NO_3^-	0.200	87	10.89	23.16
NH_4^+	0.000	5.11	0.47	1.14
NO_2^-	0.000	0.73	0.28	0.24

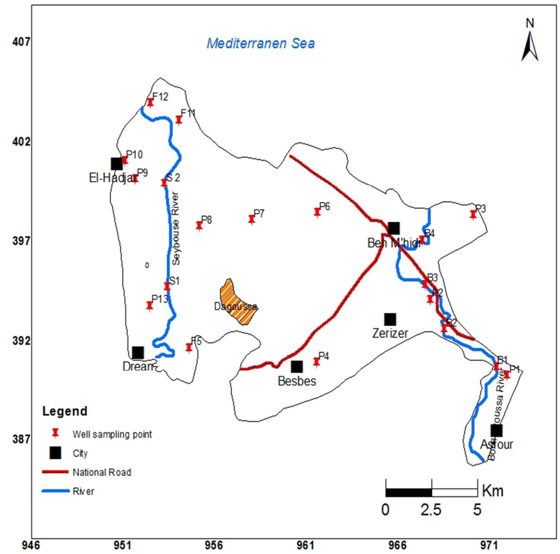

Fig. 3. Sampling inventory map.

Interpretation of the piezometric map

The general appearance of isopièzes curves shows that the water table follows the topographic model, the direction of flow is from upstream to downstream (South North) constituting the accumulation area of all groundwater, we note the presence of two cones of depression along Seybouse river, the curves are convergent and tight indicating a high hydraulic gradient and a feeding of the river by the water table, another depression near ben M'hidi along bounamoussa river, These cones are due to the effect of intensive pumping which lowers the piezometric level of the water table.

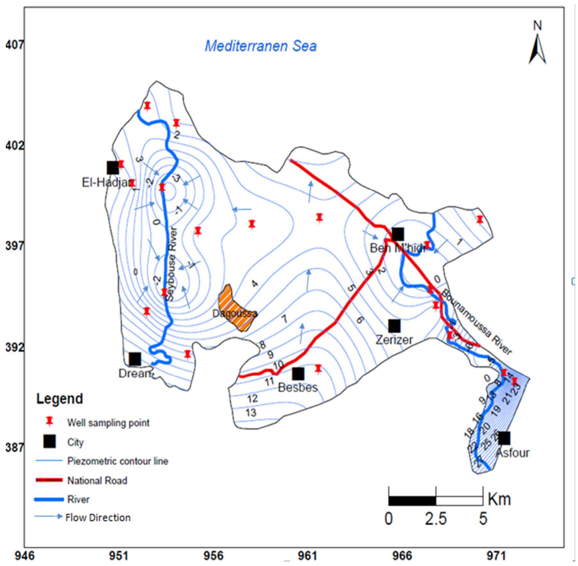

Fig. 4. Piezometric map of the irrigated perimeter (October 2017).

The chemical facies

Piper diagram was wrong in the Anions triangle,I suggest the corrected text and I put the correct diagram Fig.05 as follow:

The chemical facies

The Piper diagram (Fig.05) shows the presence of three major chemical facies, The most common is chlorinated and sulphated calcium in almost all sampling points (P1, P2, P3, P4, P7, P8, P10, P13, F5, P6, F12, S1, S2 and B4). The predominance of this facies is due to the dissolution of the evaporitic formations existing upstream of the rivers (Djabri, 1996) such as halite (NaCl) and dissolution of gypsum lenses ($CaSO_4$).

The second facies is magnesium calcium bicarbonate in the surface waters of Bounamoussa river (B1, B2 and B3) and in borehole F11 (in the deep ground water).The presence of this facies is related to the dissolution of carbonate formations such as cipolin, limestone ($CaCO_3$), by water charged with carbon dioxide and also the dissolution of carbonate gypsum ($CaSO_4$) formations with high magnesium contents such as Magnesite ($MgCO_3$), Dolomite $CaMg(CO_3)_2$.

The third facies is sodium chloride and potassium, represented by a single point (P9) in the surface water table in the plain of El-Hadjar. Its origin is mainly related to the dissolution of salt formations and the effect of marine salinity.

The dissolution of the saliferous minerals is done according to the following relation: $NaCl = Na^+ + Cl^-$

The presence of potasium in these waters is due either to the use of chemical fertilizers or to clay formations rich in potassium.

Nitrates NO_3^-

With high solubility, nitrates represent the form of the most oxygenated nitrogen, the maximum concentrations are observed at the wells P13, P12 and P11 with 87mg/l, 61mg/l and 21mg/l respectively). However, the concentrations do not exceed 2mg/l in most of the perimeter; the presence of nitrates is linked to the intensive use of chemical fertilizers.

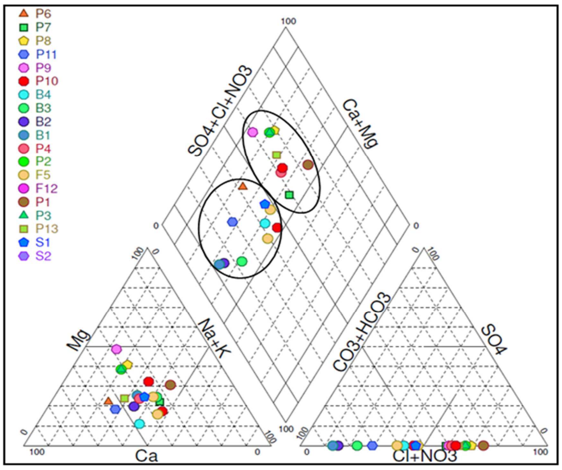

Fig. 5. Piper diagram showing the chemical facies of the waters in the study area (October 2017).

Spatial variations of nitrate, nitrite and ammonium concentrations

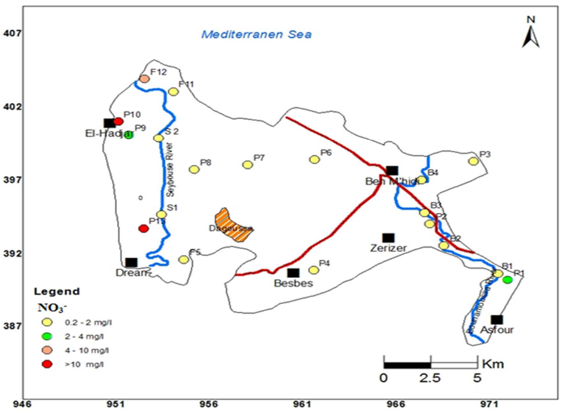

Fig. 6. Nitrate spatial concentration map (October 2017).

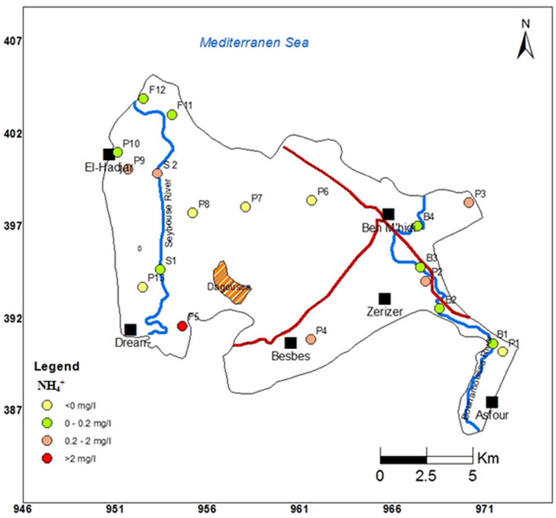

Fig. 7. Ammonium spatial concentration map (October 2017).

Ammonium (NH_4^+)

High concentrations are observed near the Drean, Besbes, El-hadjar and also in the surface waters of rivers, concentrations sometimes exceed 2mg/l. Ammonium is the most toxic form of nitrogen, its presence in the water is linked either to the urban and industrial discharges in rivers or by reduction of nitrogen forms (nitrate and nitrite) in reduced conditions.

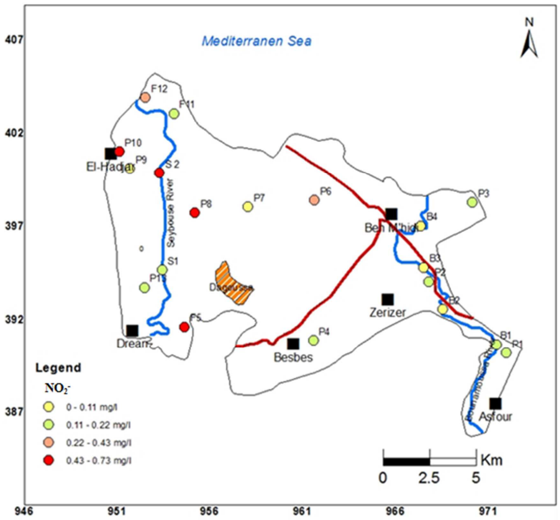

Fig. 8. Nitrites spatial concentration map (October 2017).

Nitrites NO_2^-

A toxic form, it represents the form of the passage between nitrates and ammonium, the highest values are observed downstream of the seybousse river and near El-Hadjar city with (0.77mg/l and 0.66mg/l respectively). They are due to the effect of the oxidation of the ammonium form.

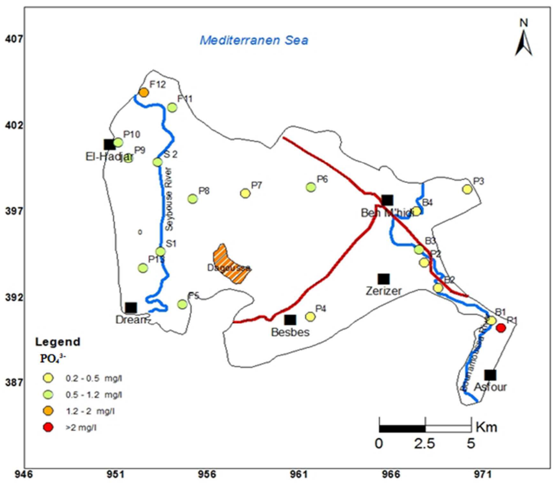

Fig. 9. Phosphate spatial concentration map (October 2017).

Phosphate (PO_4^{3-})

In Deep groundwater concentrations range is from 0.5 to 1.2mg/l but in water table and surface waters the values are minimum and do not exceed 1.2mg/l with the exception of P1 in the plain of El-Asfour where the concentration is maximum 3.3mg/l, The presence of phosphate is related to the effect of urban discharges and the impact of stagnant water in the rivers.

The Analysis in Principal Components (ACP)

This analysis takes into account all the water points. The projection of the variables and individuals was carried out on 4 axes, which represents 53.57% of the total variance (Fig. 10). on axis I (36% of the variance), it presents the pole of salinity (Na^{2+}, Cl^-) Indicating a marine origin (P13), negatively correlated with the potassium elements (K^+) projected on point F11 due to the alteration of silicate formations (gneiss, shale, potassic clays) potassic clays, and the dissolution of chemical fertilizers. Axis II (17% of the variance), There were two groups a different origin, on the positive axis we have the evaporitic carbonate elements (P9, P8, P6), on the negative axis the nitrogen and bicarbonate elements (F5).

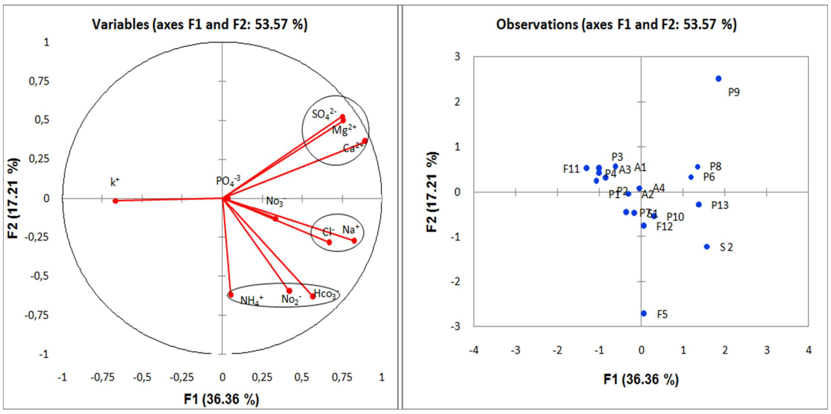

Fig. 10. Projection of the variables according F1.F2

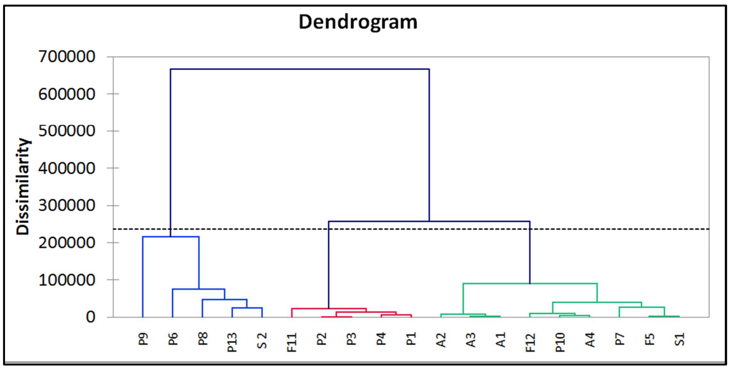

Fig. 11. Dendrogram of classification of water points.

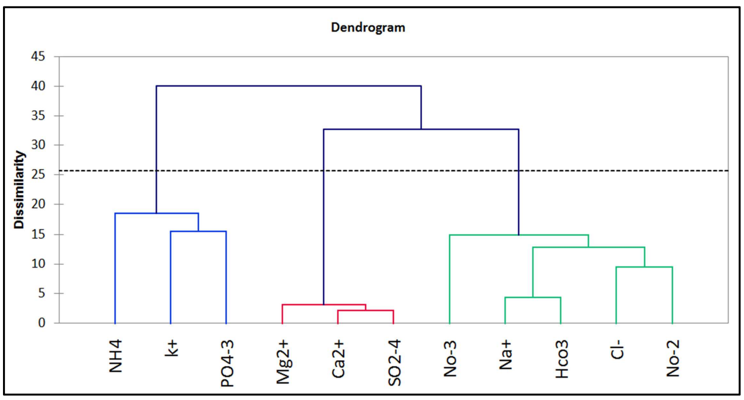

Fig. 12. Dendrogram of classification of variables.

Ascendant Hierarchic Classification (AHC)

The dendrogram of hierarchical classification of water in the irrigated perimeter of Bounamoussa (Fig.11 and Fig.12) highlights the existence of three groups. The first group represents the potassium phosphatic elements with the pollutant element (Ammonium) in points P9, P6, P8, P13 and S2 being located along the Seybouse which is the receiver of all urban discharges. The second represents the carbonates and sulfated elements (F11, P2, P3, P4, and P1) which are from geological origin (the dissolution of carbonate and gypsum formations).

The third is sodium chloride (Na+, Cl-) of marine origin which affects the deep water table in the downstream part near the sea, combining with nitrogen elements (NO_2^-, NO_3^-) which are the result of intensive use of agricultural fertilizers.

Water quality for Irrigation

It is conventionally known that irrigation water is rich in sodium element; this latter has an influence on permeability and soil infiltration. The presence of Na^+ has harmful effects on the soil structure by clay deflocculation. This effect is interpreted by different authors by calculating several parameters including the most common "SAR", obtained by the following formula:

$$SAR=\frac{Na^{+}}{\sqrt{(r\,Ca^{+}+r\,Na^{++})}}$$

SAR values and conductivities are projected on the classification diagram of irrigation water (Fig.13 and 14) which includes the following subdivisions:

SAR <10: Water used with little risk of alkalization

10 <SAR <18: Water used with an appreciable alkalizing hazard

SAR> 26: Water presenting a very high risk of alkalization

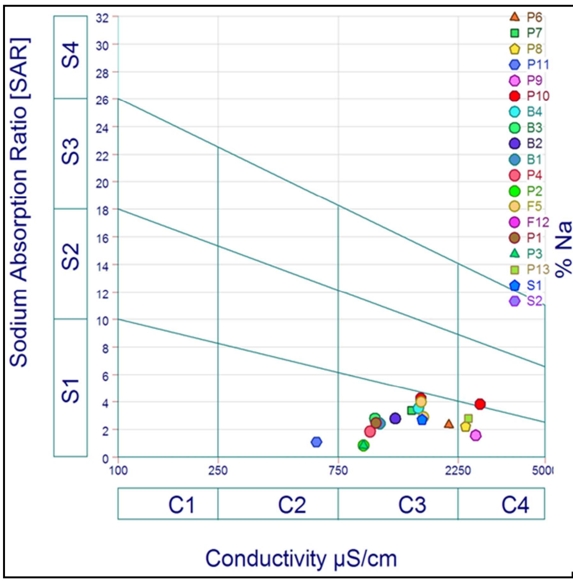

Fig. 13. Richards diagram SAR (USSLS 1954).

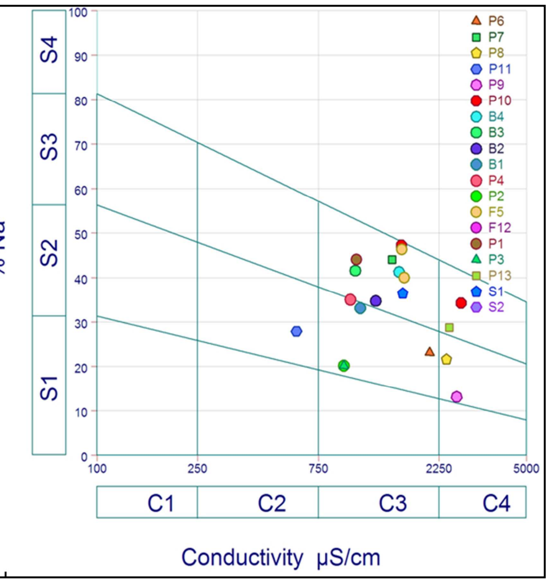

Fig. 14. Richards diagram (% Na^+) (USSLS 1954).

Waters classification according to their abilities to irrigation revealed three classes:

Class C3S1: Represents 73.68% of samples, characterized by high conductivity and low SAR, so this water is acceptable for the irrigation of salt-tolerant crops on well-drained soils and where the evolution of salinity should be well controlled.

Class C4S1: Represents 26.31% of the samples, unusable water, highly mineralized, it is presented by a high salinity and a high conductivity. These waters are not suitable for irrigation, but can be used under certain conditions: very permeable soils (well drained), good leaching and plants very tolerant to salts.

Class C2S1: Represents 5.26% of samples, is good for irrigation and can be used, but waters of this class can cause problems for clay soils.

The primary effect of total salinity is to reduce crop growth and production. It is usually expressed by mineralization or electrical conductivity (EC), the classification of irrigation water taking into account this parameter should be as follows:

- Conductivity in µS/cm less than 700, there is no restriction for irrigation;
- Conductivity ranging between 700 and 3000 µS/cm, the restriction for irrigation is light to medium.
- Conductivity higher than 3000 µS/cm, the restriction for irrigation is high.

Generally, according to these limits our study area shows a restriction for irrigation light to medium with the exception of downstream waters of the seybouse which represent a high restriction to irrigation.

Conclusion

From maps, profiles, The Analysis in Principal Components (PCA), Ascendant Hierarchic Classification (AHC) and Water quality for Irrigation we can conclude that:

The high mineralization producing high salinity is due to high concentrations of major elements (Ca^{2+},Mg^{2+}, SO_4^{2-}, Na^+, K^+, Cl^-..) themselves are due to leaching of geological formations.

The impact of agricultural activity is reflected by the presence of nitrogen and phosphate elements (NO_2^-, NO_3^-, PO_4^{3-}) which are due to the intensive use of agricultural fertilizers.

The risks of salinization and alkalization are not independent. The risk is greater when salinity is important. Richard diagram classifies the waters according to their ability for irrigation. Three classes can be presented; C2S1 waters can be used on almost any soil and for any crop, Those of C3S1 class should be used with caution, while those in the C4S1 category must almost always be rejected.

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