

WATER QUALITY OF AN AQUIFER SITUATED IN A SEMI ARID REGION EL-MALABIOD CASE STUDY (NE ALGERIA)

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ABSTRACT

The studied area is characterized by a semi arid climate with a high evapotranspiration. Analyses are carried out on water from an alluvial aquifer situated 5 to 6 meters below the surface soil. The results obtained indicate a high concentration particularly of chlorides and sulphates. The bicarbonates, however, show high contents only near the contacts where outcrop the limestone. This indicate that the aquifer is supplied through limestone formation. Otherwise, the nitrates present very high concentrations reaching 80 mg.l-1, showing that the water of the aquifer is unsuitable for consumption. This pollution is due mainly to the intensive and anarchic use of the fertilizers in this region. The spread of the nitrogenous pollution is produced by chase effect. It might be said, then, that the water of El-Malabiod in its actual state presents some problems with regard to its use. The result of thermodynamic application has shown that the chemical composition of water is due to water-rock interaction.

GEOGRAPHICAL SETTING (FIGURE 1)

The studied area belongs to the wilaya of Tebessa in the easternmost part of Algeria. It is situated at about 250 Km South of Annaba, zones of desert gates, and is limited to the South by Djebel Onk, to the East by the Algero-Tunisian border, and to the West by the wilaya of Biskra.

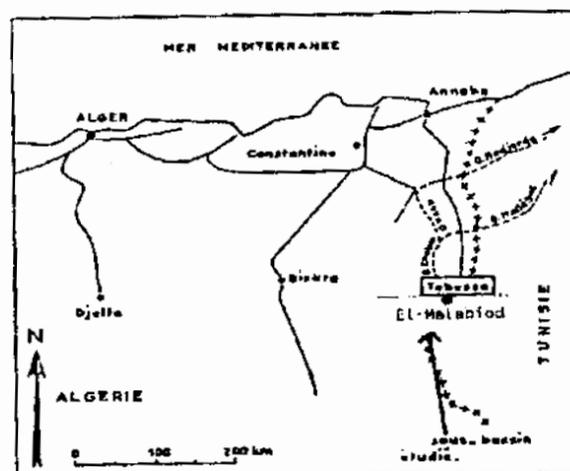


Figure 1: Geographical setting.

CLIMATOLOGY

The climatic study has shown that the region is characterized by a semi-arid climate. Aridity index (I) calculated, according to the method of Martonne ($I=P/T+10$), to be: $I=10.05$. This value falls within the range $10<I<20$ which characterize a semi-arid climate. The annual precipitation is 250 mm.

UNDERGROUND HYDROLOGY

Piezometric maps show an underground flow having a North-South direction. However, in the Western and Northern zones, the observed isopiestic spacing indicate a slow flowing.

GEOLOGICAL SETTING

The studied area is part of the Saharian Atlas. It consists of a smoothly sloping plain having as North and South boundaries several folds striking SW-NE. The Northern boundary constitute a watershed between the basin slope of Medjerrah and that of Chott Melhrir. The sedimentary cover of the studied basin is composed of:

- Epicontinental type sediments with variations in facies and thickness and generally striking SW-NE (Aptian to Maestrichtian).
- Sandstone and multicoloured clays of lower Miocene.
- Germanic-type Trias in a diapiric form.

The cretaceous strata have been affected by tectonic folding of SW-NE strike.

The studied basin shows two main units:

- The outcrops of the basin border, of cretaceous age, constitute the first unit.
- The second unit is composed of Miocene and quaternary formations which occupy the total surface of the basin.

These two units constitute an incomplete stratigraphic serie (lack of Eocene formations). The description of which is as follows:

Trias

Only the SP, from El-Malabiod to Djebel Dalaa Er-Rouail, shows a reduced outcrop in diapiric form. It is composed of a typical facies of the region:

- gypsum-bearing clays, limestones and dolomitic limestones. In the North-East and at Djebel Djebissa, triassic formation appear as diapir. Diverse elements are known: 1- red clays and gypsum, 2- thin layers of limestone and black dolomitic limestone.

HYDROCHEMISTRY

Ternary diagrams

Dynamic interpretation

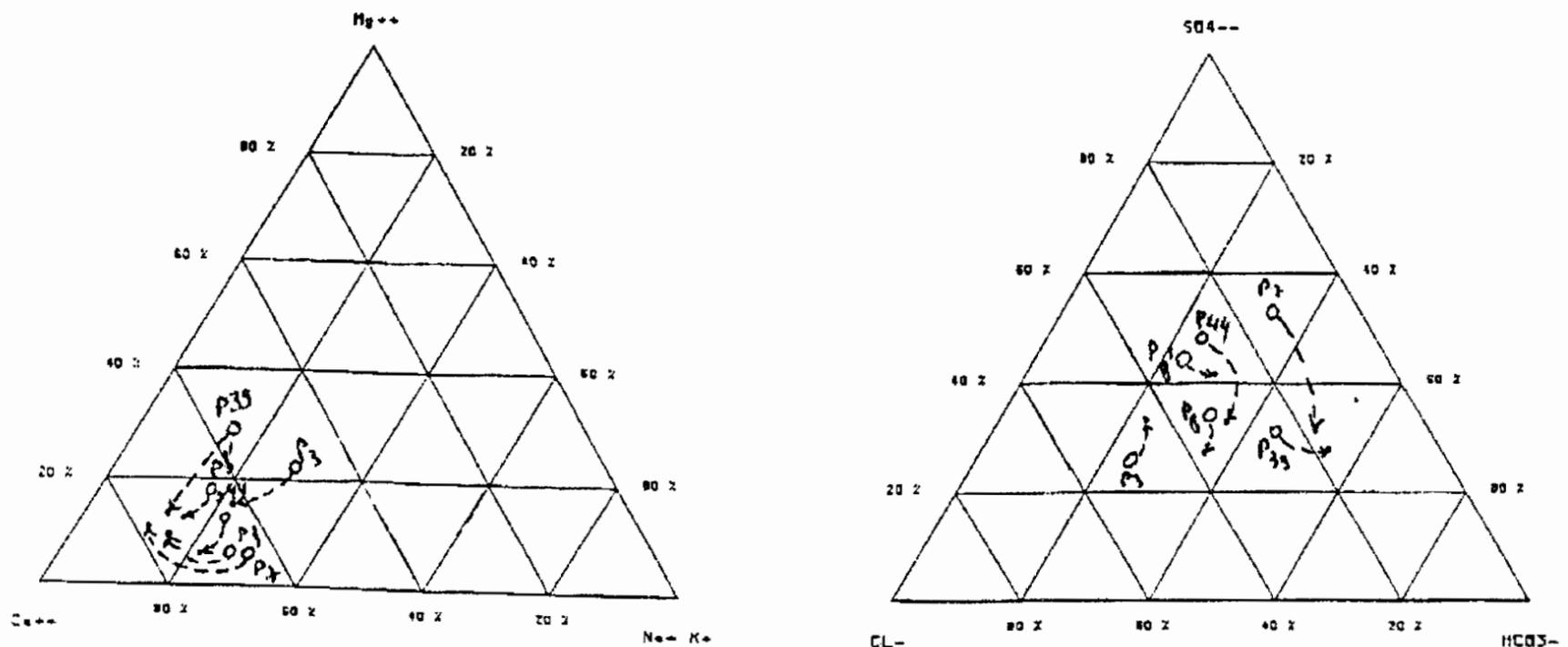
It fixes shifting and its incidence on the chemical facies. It will be carried out from high water period towards low water period.

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Upstream part (Figure 2)

* Displacement of cations: There is a tendency of calcium enrichment; this is accompanied by a decrease in sodium and magnesium contents.

* Displacement of anions: modifications are of low extent; chlorides enrichment has been recorded for the following samples: P7, P14, P8, wells P53 and P8, indicating an increase in bicarbonates whereas P3 shows sulphate-enrichment.



a- Ca^{2+} , Mg^{2+} , Na^+K^+ .

b- Cl^- , SO_4^{2-} , HCO_3^- .

Legend

- High water (upstream part)
- ▽ Low water (upstream part)

Figure 2: Ternary diagram.

Downstream part (figure 3)

* Displacement of cations: two tendencies seem to exist:

- Calcium enrichment regarding the following samples: P34, P31, P44 and M8. This evolution is accompanied by a decrease in magnesium concentrations.
- The second tendency shows a sodium enrichment and concerns wells P52 and P9. This is accompanied by a decrease in calcium and magnesium.

* Displacement of anions: The majority of the samples indicates sulphates-enrichment, only the well P44 shows an increase in bicarbonates.

Through the two sectors, the evolution are not the same; for instance, calcium accompanies chlorides in the upstream part whereas in the downstream part sulphates are accompanied by sodium. This fact may well be due to leaching.

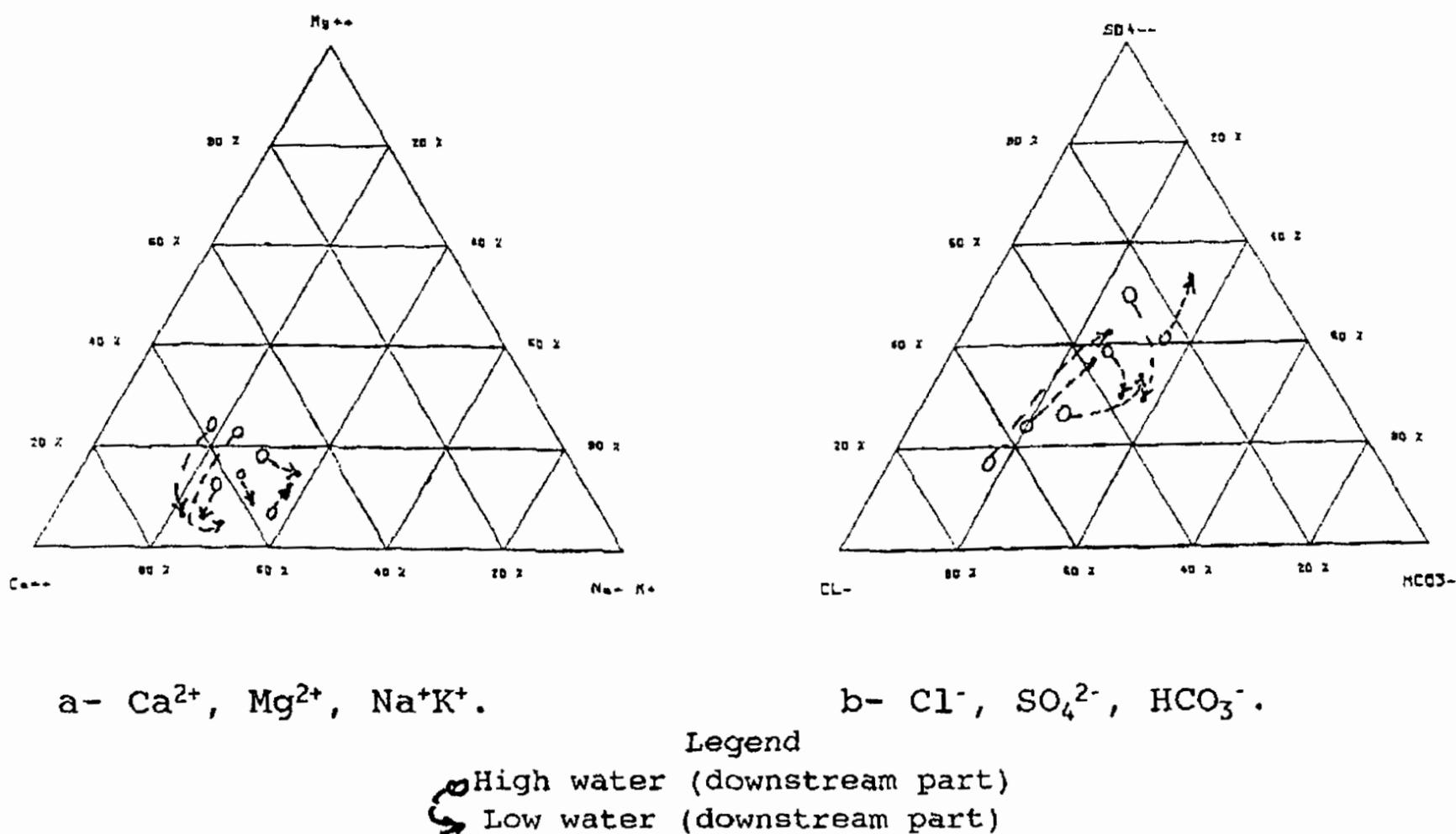


Figure 3: Ternary diagram.

Map of nitrates (figure 4)

In the major part of the studied area, contents are higher than the current norms. The highest concentrations are in the order of 90 mg/l, and are located in the central and Northwestern parts. They are probably due to the massive use of fertilizers because this studied area is of agricultural vocation. The excess of nitrate could be explained by the simplified diagram.

Soil bacteria may use gaseous nitrogen directly from the atmosphere. It is then incorporated in the biomass where a part will be transferred to roots. The organic matter which decays under the effect of bacteria and fungi oxidizes organic nitrogen to the radical forms NH_2 : Here is the process of ammonification which leads to the formation of NH_4 . The second process of nitrification deals with the re-use of ammoniac into two steps:

1st step: passage from NH_4 to NO_2 (action of bacteria "Nitrosomonas").

2nd step: passage from NO_2 (nitrites) to NO_3 (nitrates) (action of bacteria "Nitrobacter").

Nitrates are subject to three possible ways:

1. percolation towards the aquifer,
2. denitrification phenomenon: transformation of nitrates (NO_3) into gaseous nitrogen (N_2) by means of "Pseudomonas",
3. absorbed by plante roots.

The presence of nitrates in fresh water is cancerous: In the studied area, many cases of death due to generalized cancers have been recorded.

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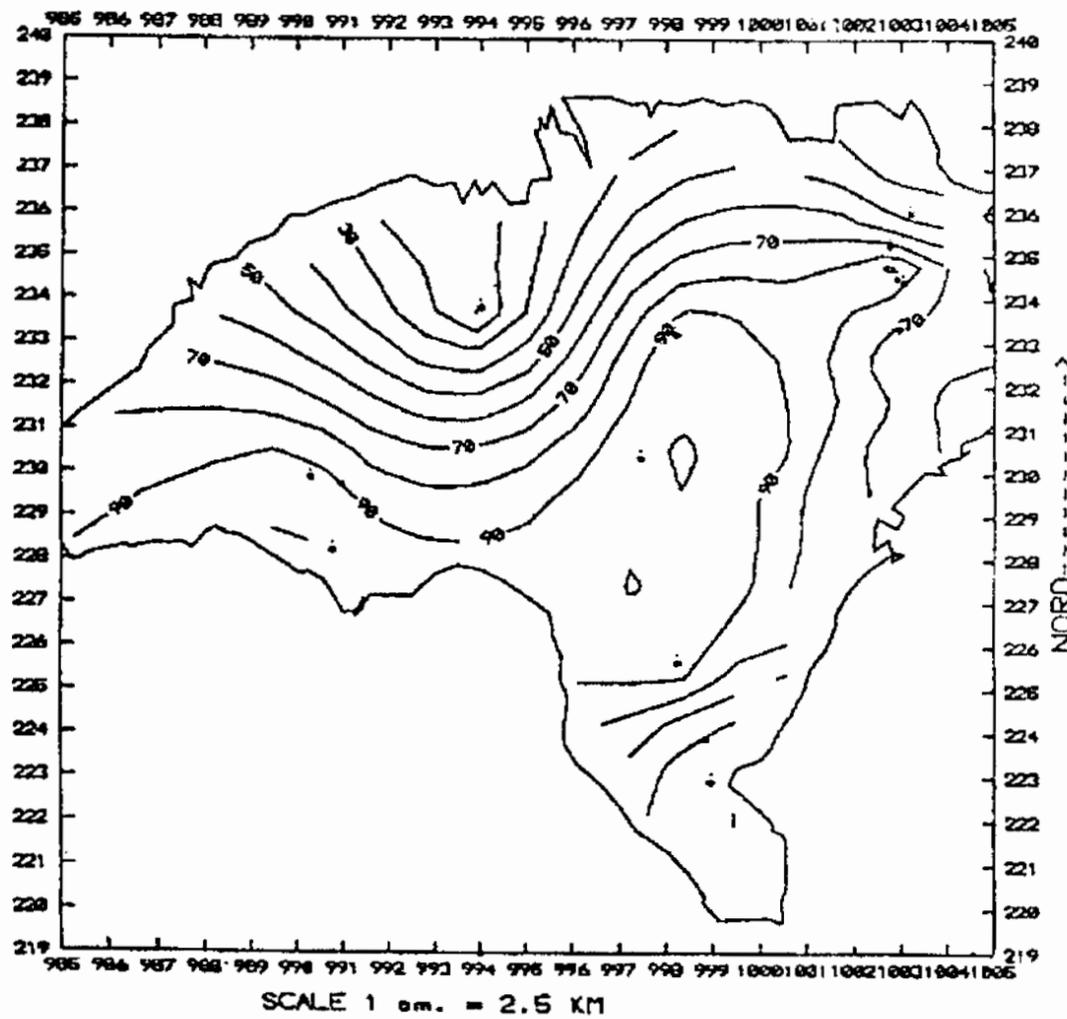


Figure 4: Map of nitrates.

The occurrence of nitrogen in water is in the form of either nitrogen-bearing minerals or as ions: ammonium ion, nitrate ion and nitrite ion. Among the principal causes of nitrogen occurrence in water are:

- nutritive substances lost from soil,
- excessive use of fertilizers which enables the acceleration of eutrophication phenomenon of surface water.

Among treatments which decrease or eliminate this element are:

a- Physico-chemical treatments: They give good results but still remain related to cost price which is expensive for some cases.

The following table shows the principal treatments:

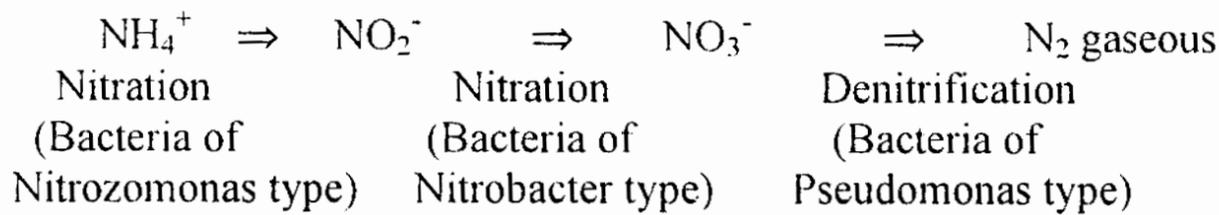
Elements	Treatments
Nitrogen	<ul style="list-style-type: none"> - Stripping - Exchanging ions resins - Electrodialysis - Electrochemical treatment - Chloration

b- Biological treatments: They are efficacious and less expensive.

The following table gives the principal procedures:

Elements	Treatments	Bacteria
Nitrogen	- Nitrification	Autotrophs
	- Denitrification	Autotrophs Heterotrophs

This biological treatment of nitrogen is represented by the following steps:



Among the measures taken to battle this pollution are to inform the direction of agricultural services whose role is to control farmers activities, and hence to take severe decisions regarding the use of fertilizers and to respect the norms in the agricultural areas. A permanent and continuous observation of chemical analyses is needed through the control network of the aquifer.

ANALYSIS PCA

Application

The treatment carried out deals with El-Ma-Labiod aquifer. Two different stages will be studied: the first abstracting the nitrates, the second will take them in consideration.

a- The case where the nitrates are not taken in consideration

The data matrix is composed of eight (08) variables and 109 individuals (U.S). For treatment, we have taken five axes which exhibit 94% of information.

Table 1

Axes	F1	F2	F3	F4	F5
Proper values	4,32	1,05	0,96	0,79	0,35
Contribution	54,1%	13,3%	12,1%	10,0%	4,5%

Correlation matrix

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Table 2: Correlation matrix without nitrates

	COND	NaK	Mg	Ca	Cl	SO4	HCO3	pH
COND	1							
NaK	0,38	1						
Mg	0,68	0,21	1					
Ca	0,86	0,22	0,77	1				
Cl	0,90	0,37	0,68	0,79	1			
SO4	0,78	0,42	0,64	0,65	0,73	1		
HCO3	0,25	0,07	0,06	0,27	0,16	0,06	1	
pH	-0,26	-0,04	-0,24	-0,32	-0,18	-0,18	-0,89	1

The previous table shows the different correlations between the variables pair to pair. The significant coefficient (r) is function of the treated number of individuals. For the actual case, $r=0.37$, which allows to bring out the following associations:

Analysis of PCA circles

Circle PCA (figure 5)

The interpretation is limited to the circle formed by the F1 and F2 axes, because it gives the maximum information (67.4%). The horizontal factor F1 exhibit 54.1% and oppose highly mineralized water, that is ion-rich (HCO₃, Ca, Mg, Cl, SO₄ and NaK) to poorly mineralized water characterized by a basic pH (pH>7). This latter correlate negatively in relation with other elements, which shows a reverse evolution and this allow us to say that when the pH is basic, water is mineralized and vice-versa, when the pH is acid, water is poorly mineralized. The vertical axis F2 exhibit 13.3% and oppose calcic bicarbonated water to sodic chlorided water or magnesium in one side or sodic sulphated water or magnesium in the other side. These four families of water straitly influence the pH, whereas calcic bicarbonated water are opposit to the pH (change inversely). Circles PCA2, PCA3, PCA4 and PCA5 confirm the discribed distribution.

The study of individuals (figure 6)

The graph shows up three families of water. The first bicarbonate-rich water oppose chlorideor sulphate-rich water. These waters are opposed to basic water according to F1 axis origin, which seams influencing the chemical composition. For instance, samples 47, 31, 58, 45, 44, 70, 72, 77 and 78 are located in limestones of the borders, which give bicarbonate-rich water. On the other hand, the other samples are situated within the plain, and hence show the observed difference in the chemical composition of water.

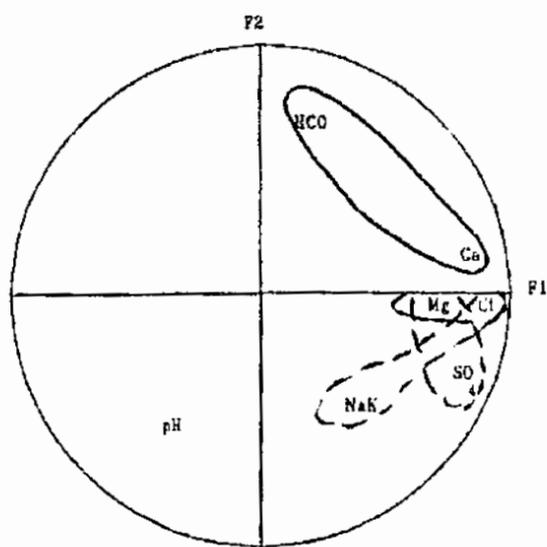


Figure 5: Circle of correlations - Case 1

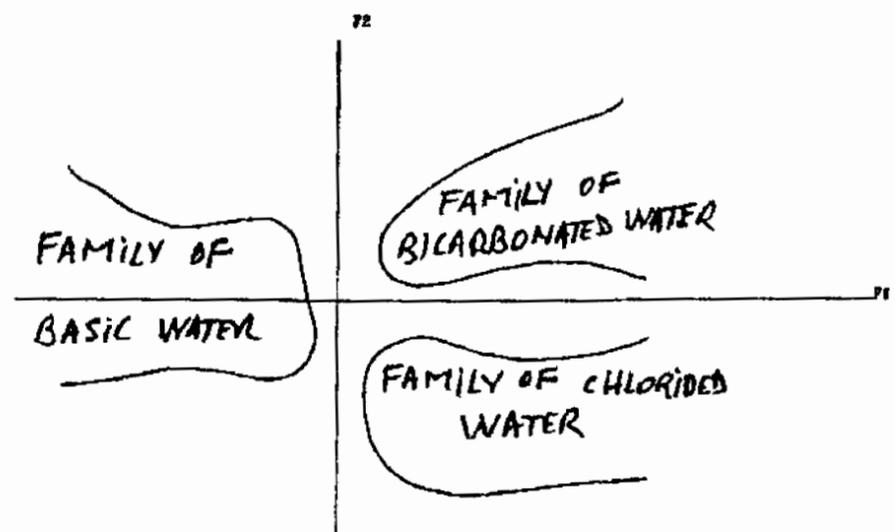


Figure 6: The study of individuals - Case 1

b- The case when nitrates are taken in consideration

The data matrix is composed of nine (09) variables and 60 individuals u.s. For treatment, five axes have been selected and exhibit 95.1% of information.

Table 3

Axes	F1	F2	F3	F4	F5
Proper values	4,78	1,31	1,09	0,90	0,45
Contribution	53,2%	14,7%	12,2%	10,0%	5,0%

Correlation matrix

Table 4: Correlation matrix with nitrates

	COND	NaK	Mg	Ca	Cl	SO4	HCO ₃	pH	NO ₃
COND	1								
NaK	0,87	1							
Mg	0,64	0,38	1						
Ca	0,90	0,67	0,53	1					
Cl	0,93	0,78	0,67	0,86	1				
SO ₄	0,82	0,81	0,63	0,65	0,70	1			
HCO ₃	0,38	0,38	-0,03	0,39	0,24	0,06	1		
pH	-0,12	-0,09	-0,01	-0,15	-0,19	-0,005	-0,05	1	
NO ₃	0,01	-0,20	0,09	0,20	0,02	-0,14	-0,14	-0,16	1

The previous table shows the different correlations between the variables pair to pair. The coefficient (r) is function of the treated number of individuals. For the actual case, $r=0.47$, which allows to bring out the following associations:

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Analysis of PCA circles (figure 7)

The interpretation is limited to circle PCA1 formed by the F1 and F2 axes, which gives the maximum information of 67.9%. The horizontal factor exhibit 53.2% of information and oppose highly mineralized water; that is ion-rich: HCO₃, Cl, SO₄, Ca, Mg and NaK, to poorly mineralized water with basic pH and polluted by nitrates. This pollution correlate negatively with respect to ions which indicate an exogeneous origin of nitrates. The pH shows a reverse evolution with respect to other elements. This will allow us to say that the basic water is highly mineralized compared to acidic water. The vertical F2 axis exhibit 14.7% of information, and oppose sodic bicarbonated or sodic sulphated water with basic pH to calcic chlorided or magnesian chlorided water polluted by nitrates. The pH itself is in opposition to these waters. In this case, waters will show an acid pH. Circles PCA2, PCA3, PCA4 and PCA5 confirm the observations described above.

The study of individuals (figure 8)

Four families of water are distinguished. They are opposed pair to pair. According to F1 axis bicarbonated and chlorided waters are opposed to basic and polluted waters by nitrates. Examining axis 2, we note an opposition between bicarbonated water with a basic pH and chlorided water which is polluted by nitrates. This interpretation shows that the chemical composition of water is straitly influenced by the geology; that is where limestones are outcropping water is bicarbonated. On the other hand, the enrichment in chlorides is linked with the existence of clays, sands, ... etc. This indicate the importance of leaching of geological formation by water. The pollution by nitrates is exogeneous and is due to the anarchic use of fertilizers.

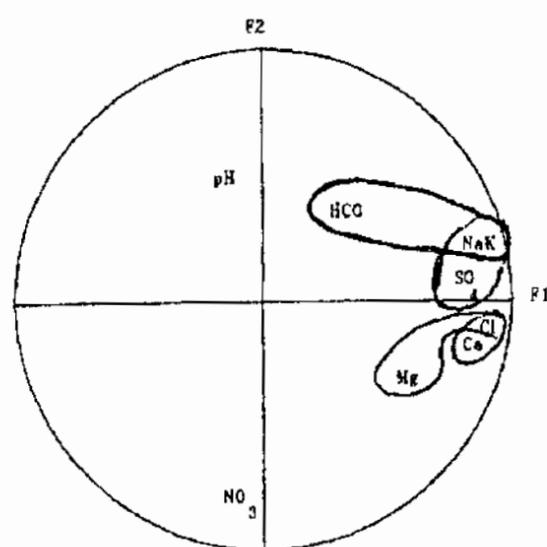


Figure 7: Circle of correlations - Case 2

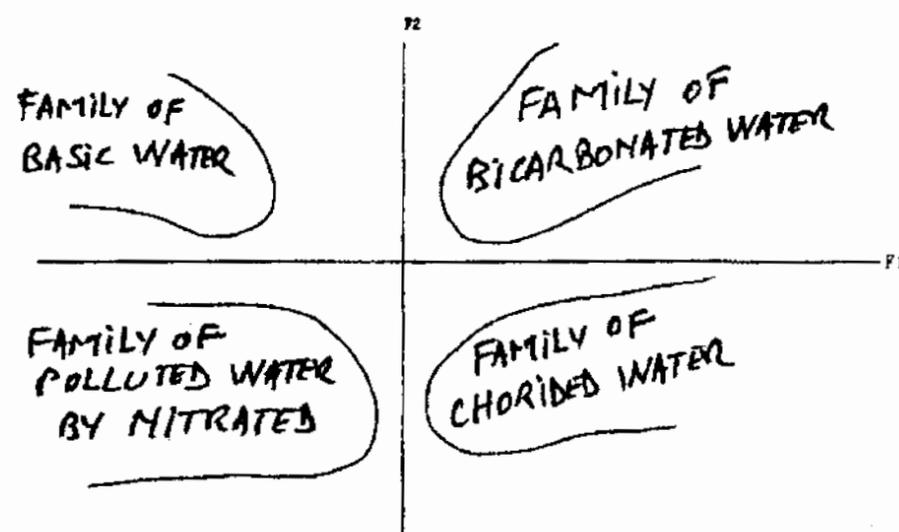


Figure 8: The study of individuals - Case 2

CONCLUSION

The study of principal components has elucidated the competition which seam existing between the ions. An opposition between bicarbonated water and chlorided water has been recorded. This distribution is closely related to the geological formations (some wells are situated in limestones whereas, others are located in the quaternary formations). This evolution is engendered by leaching of the geological formations. Elsewhere, a pollution of water by nitrates has been observed, and this is due mainly to the intensive use of fertilizers.

THERMODYNAMIQUE

The analyses carried out during this work have enabled the determination of the chemical composition of water. The major elements have been known, and this according to several criteria.

Relationship between activity and concentration

A solution is said to be ideal if it is composed of two species A and B, where the properties are such that, the interaction energy between the A molecules are similar to that between A and B or identical to that between two molecules B. The activities of two species of an ideal solution would be equal to their concentrations. Actually, these conditions could not be realized because of the electrostatic interactions between the charged ions and the water molecules arranged around them. In a real solution, the ionic interactions of water are the cause of a free energy which is different from that of ideal water, and hence different from the relationship between the free energy and the ionic activity. The activity of the solute and the solvent will be different from their concentrations. The ratio between the activity of the species and their concentrations define the activity coefficient. For the non-charged solutes, the activity coefficients could be represented in an approximative manner by the equation of (Plummer and Mackenzie, 1974):

$$\gamma = 100,1I$$

where I is the ionic power of the solution.

Application for the water of El-Ma-Labioud region

Using the previous thermodynamic calculations at temperature of 20 °C, the different factors which could affect the chemical composition of water could be determined. The calculations have been carried out using the program WATEQ B "Water Equilibrium Formulation" (Plummer et al., 1974).

The results obtained indicate the presence of many elements (18) with variable concentrations which could be important or nearly negligible. However, the following elements are among the principal constituents of water of the area: Anhydrite, Aragonite, Calcite, Dolomite and Gypsum. These elements show the importance of salts in water. This indicates that water of the area is quite charged. The values are in general lower than the unity, which indicate an undersaturation. However, aragonite, calcite and gypsum show values higher than the unity, thus indicating a supersaturation.

Saturation index

According to the mass law, when an aqueous solution is in equilibrium with a mineral, the product of the ionic activity for the mineral will be equal to the thermodynamic equilibrium constant. The degree of saturation of water could be represented by a saturation index (SI), which is the logarithm of the quotient of ionic activity product, divided by the equilibrium constant (K).

$$SI = \text{Log IAP/K}$$

where:

SI: saturation index

IAP: ionic activity product

K: equilibrium constant

The saturation index reaches a value of zero when the saturation is in equilibrium with a solid phase. A positive saturation index indicates a supersaturation, and a negative index indicates an undersaturation in relation with minerals. We have only a few minerals which affect the chemical composition of water:

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- Calcite: Only the water point P21 shows a negative SI (-0.025). The other wells show positive SI; this indicate that water is calcite-rich and so is the salinity of water.
- Dolomite: All samples show a positive SI; this is due to leaching of limestones which outcrop in the area.
- Gypsum: All analyses show a $SI < 0$. This undersaturation has a dissolution origin which enrich water in $CaSO_4$.
- Anhydrite: An undersaturation is shown with $SI < 0$. This explain the observed salinity. The increase of salinity is engendered by the dissolution. This show the extent of evaporitic formations in the area.
- Aragonite: Only four samples show a negative SI. The others indicate a high salinity.
- PCO_2 : The whole samples show low PCO_2 , which indicate that the corrosion of the matrix is not significant, which in turn explains a positive SI.

The results of calculations have shown positive saturation indexes, which explain the excess of constituent minerals and also explain the observed salinity. This latter is engendered by low PCO_2 too, which prevent an important corrosion of the matrix.

CONCLUSION

This piece of work has been carried in the area of El-Malabiod which is situated in the easternmost part of Algeria. This region is characterized by a semi-arid climate. The geological description along with the geophysical data indicate a heterogeneous aquifer. Precipitations are rather low; in the order of 300 mm/year. The piezometric maps show a convergent flow towards the South. The interpretation of ternary diagrams shows that calcium accompanies chlorides in the upstream part while sodium accompanies sulphates in the downstream sector. Hydrochemical mapping and principal component analyses indicate a pollution of water by nitrates due to P.K.N. Thermodynamic analysis has shown up an extensive dissolution indicating, to some extent, the observed concentrations.

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