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# Groundwater hydrochemistry of Aflou syncline, Central Saharan Atlas of Algeria

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**ABSTRACT**

The current paper sheds light on geochemical methods used to characterize water-rocks interaction. The concern is to assess the vulnerability of groundwater resources to contamination in Aflou, an area in central Saharan Atlas of Algeria. This study of hydrochemistry reveals lithological impact on hydrochemistry in Aflou syncline. Our study region is like a basin meaning that the important groundwater resources are located in the sandstones of the Intercalary Continental Aquifer (Barremian-Albian). This study marks a noticeable influence of evaporated minerals and ascents of Triassic materials, which are widely propagated along with different levels for several wells of Djebel Amour. Lithology influence on the hydrochemistry of this aquifer is very visible by evaporation contained essentially in the Triassic and in the marly intercalations of the Portlandian, the Barremian-Aptian-Albian and those of the Mio-Pliocene. For Aflou region, the lower Cretaceous (Portlandian) and Upper Jurassic (limestone) formations, the calcium sulfated facies, have very high levels of $SO_4^-$, $Cl^-$, $Ca^{2+}$, and $Na^+$. Integration of both graphical and Piper diagram, saturation index values (estimated by Phreeq-C method) and geographic information system tool was helpful not only to create the database for analysis of spatial variation in respective water quality parameters but also to decipher the hydrogeochemical process occurring in our study area. This study utilized the inverse distance weighted (IDW) interpolation method to interpolate and estimate cell values in Aflou syncline by averaging the values of sample data points in the neighborhood of each processing cell. IDW method has been used in establishing maps. The examination of iso-contents maps and the principal component analysis results show that the water composition was very closely related to the lithological nature of the different formations.

*Keywords:* Hydrochemistry; Conductivity; Evaporate; Saharan Atlas; Algeria

## 1. Introduction

Groundwater quality is generally influenced by water infiltration, topography, reservoir rocks geology, and anthropogenic factors [1,2]. For domestic, agricultural, and industrial needs, groundwater resources are very important factors if not a key in Algerian regions. These resources constitute the most available source of fresh water [3]. Due to the difficult climatic conditions, the permanent reservoirs of surface water are absent in Aflou. Groundwater resources in this region, namely Djebel Amour, Central Saharan Atlas depend on the Mio-Plio-Quaternary aquifers and the

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sandstone aquifer of the Continental Intercalary (Barremian-Albian). The upper Portlandian limestone aquifer directly affects the chemistry of the Barremian-Albian sandstone [4,5]. The aquifers links are generally very narrow. As far as regional groundwater systems of management are concerned. To better understanding groundwater systems, inter-aquifer leakage, and recharge mode are a fundamental key [6,7]. In all aquifers, water recharge, water-rock interactions, solute transport, are crucial factors that influence the chemical characteristics of groundwater and chemical processes occurring along the flow paths [8–13]. In groundwater, chemical composition origin can be determined by hydro-chemical processes. For this, several studies have been carried out to fully understand the responsible factor of this geochemical typology [3,14,15]. This study tends to evaluate the hydrochemistry of groundwater of study area, to explore the mode of recharging aquifers and the influence of lithology on the hydrochemistry of these waters. This hydro-chemical study of groundwater can help explain the behavior, the origin, and the evolution of the chemical elements described above, and thus, see the influence of evaporated minerals. Starting from the examination of iso-contents maps and based on a multidimensional statistical analysis, we tried to establish the links between water and the aquifers ensuring their conservation or their progression. In this work, we will consider the widely dispersed evaporated minerals influence at different wells positions, and at the same time, take into account the Triassic material at many points in the Aflou basin.

## 2. Study area

### *2.1. Geological and hydrogeological context*

The geology of highlands in Central Saharan Atlas (Djebel Amour) is characterized by a band of pleated land, forming a succession of anticlines and synclines oriented in a major North East-South West direction. The continental sandstone of the Barremian-Albian is crossed by drillings over several hundred meters. Rock is generally friable with calcic cement. These sandstones are largely cracked with two major directions: N 67°E and N 140°E. More than 600 wells, varying in depth from 3 to 850 m, intersected in these formations. The syncline center is occupied by the Mio-Plio-Quaternary formations, formed essentially of red clays, sand, and conglomerates; the thickness varies from few meters to more than 50 m at the level of the axis of the basin. The upper Cretaceous (Cenomanian-Turonian) lands form small perched syncline: Djebel Guern Arif, Oum El Gueddour, Sidi Okba, and Kef Gourou. The Cenomanian formations constituted by greenish gypsum marls, sometimes interspersed with banks of limestone of metric thickness, with a power of 200–250 m. The Turonian consists almost entirely of well-crystallized dolomitic limestone of a whitish color. The series with a power of 80 m is azoic at the level of this sector. Under the powerful sandstone series are yellowish limestones in small benches and the gypsum green marls of the Portlandian, the thickness is 200 m. The Triassic consists of a mix of brownish, purplish, or versicolored clays with intercalations of gypsum, halite, and intrusions of green rocks into dykes or packed in clays. It is located west of the Aflou Syncline and just west of Kef Guru (Fig. 1).

Several studies were elaborated to confirm the presence of a very important aquifer in the sandy formations of the Continental Intercalary [16]. The aquifer is close to the surface of the soil, it is very partitioned by the clay layers. Drilling discharge values between 20 and 60 L/s. The water is generally of good quality and has a dry residue which varies from 1 to more than 3 g/L. Aflou aquifer which is a multilayer system with mixed permeability where the cracking plays a very important key role in a water circulation: we can mention Portlandian aquifer

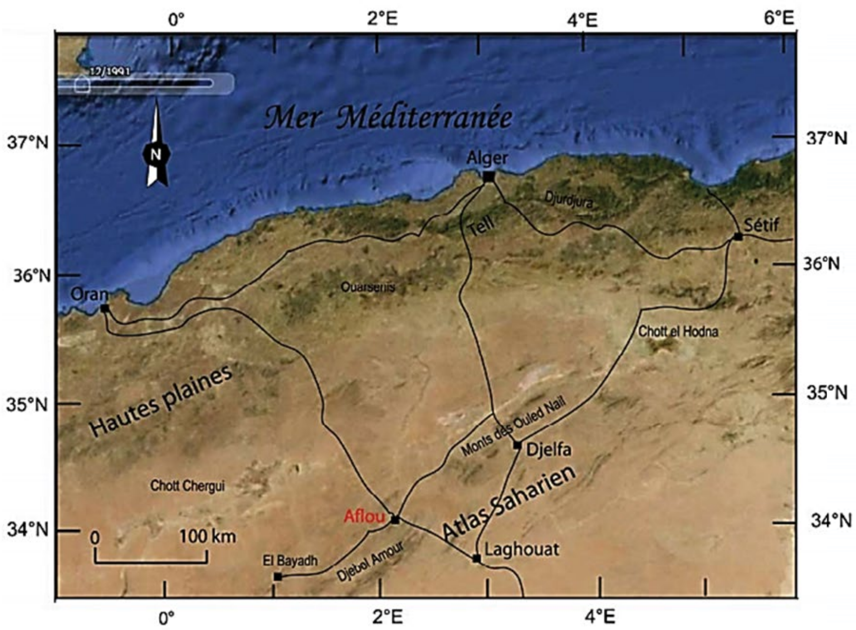


Fig. 1. Location of the study area.

and Mio-Plio-Quaternary aquifer [16]. Simplified geology and the well positions of the study area are shown in Fig. 2.

### *2.1.1. Lithology*

This point describes physical characteristics visible at outcrop in Aflou region (color, texture, grain size, and composition). In this study area, the major rock types are sediments. It is very important to know that orographic node is formed by Amour mountains. These constitute folds set and enclose a syncline basin in the center where Aflou city is located. In the north of syncline Aflou, Sidi Okba mountain is located with a 1,707 m of elevation whose summit is made of calcareous, in the south Zlag mountain is located with 1,580 m of elevation separates the syncline Aflou from Gaada plateau. In the Sahara, formed reliefs are leveled and the removed land is exported to the north and will fill the subsidy zones. During the secondary era, the sea covered the majority of Maghreb the great geosynclines of the Saharan atlas begin to be filled with sediment from the secondary era, shallow towards the north. At Cretaceous the sea will cover most of North Africa, it will evacuate at the beginning of the Tertiary. Terrigenous and chemical deposits offer remarkable sedimentation.

### *2.1.2. Piezometry*

The subsurface flow is generally in an SW-NE direction, with variations of the piezometric level between 1,440 and 1,320 m. Two large hydrogeological units can be distinguished from West to East [16]:

#### *2.1.2.1. Aflou unit*

The unexpected decreases (from 1,400 to 1,340 m) along the syncline gutter essentially constituted by the sandstone outcrops of the Continental Intercalary. The general flow runs from the South-West to the North-East, feeding from both sides of the syncline will also be noted, this denotes the canalization of the aquifer by the syncline. The general flow direction between southwest and northeast, it will also note a supply from two banks of the syncline, this indicates the channeling of the aquifer by the syncline. Existence of a cone depression in Aflou city would be in direct relation with the relatively important wells fields. In upstream (Aflou) the hydraulic gradient is 0.0005 and in downstream (Oeud Morra) its value is greater than 0.003 and linked to the permeability value (Fig. 3).

### *2.2. Hydrology and climatology*

Hydrographically, Djebel Amour ridges draw a water river which some of them join the catchments, Sebkhas and the Chotts of the high valley of Oran. In the case, the others are at the origin of the rivers which circulate on the Hamada before going to get lost along the sand of the Grand Erg. The majority of the Atlas rivers can be classified by Wadis since they are usually dry during the year. However, some wadis are regularly fed by the discharge of groundwater (Table 1).

Climatically, three main factors generate Djebel Amour regime:

- *Location*: The distance from the sea is 270 km, the region is located in the southern limit of the sector swept by

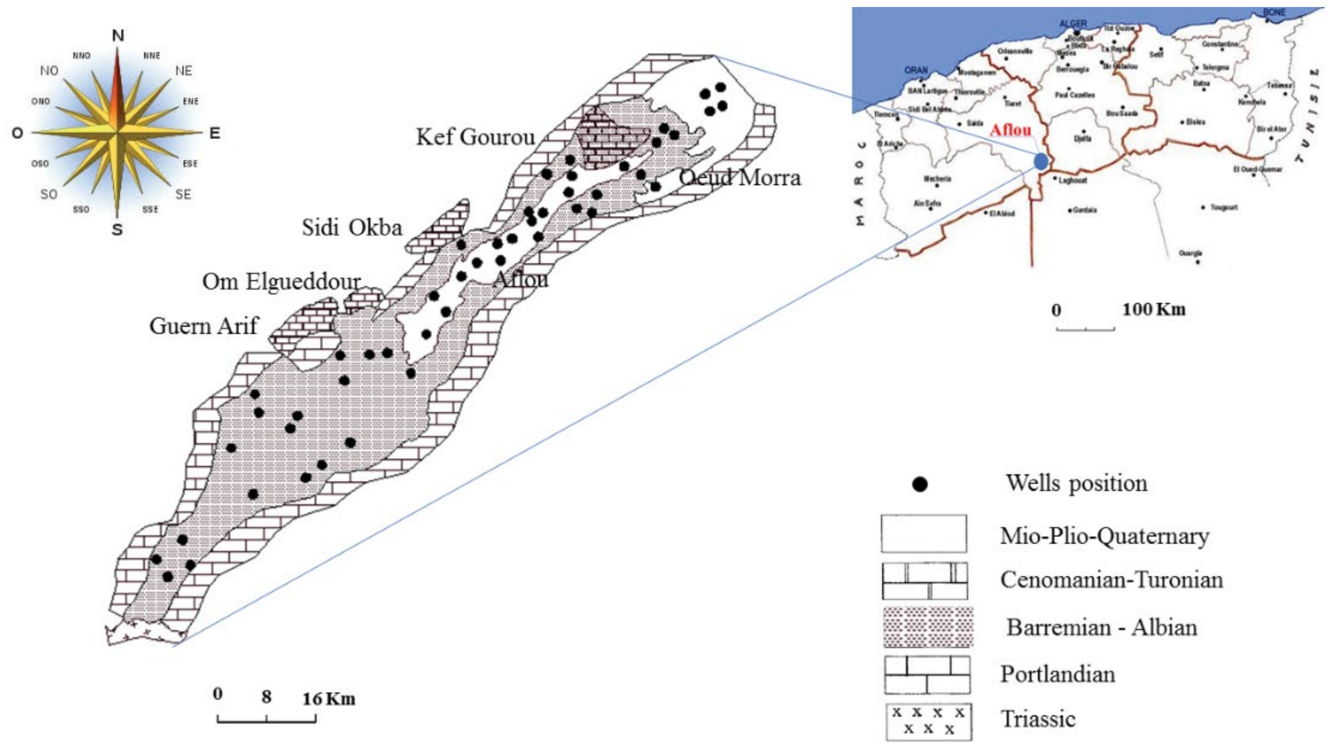


Fig. 2. Simplified geologic map of the study area [16].

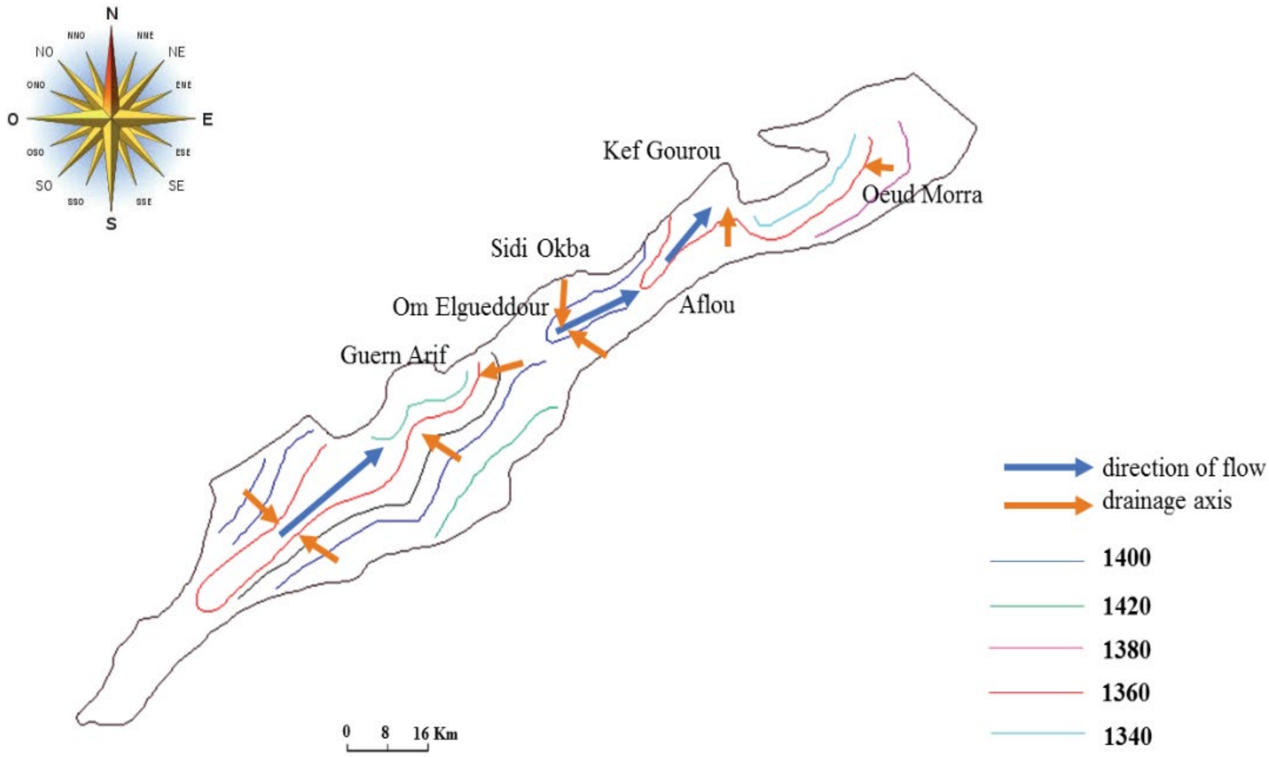


Fig. 3. Piezometric map of the study area [16].

Table 1
Hydrologic and climatic characterization of Aflou basin

| Oued | Area ($m^2$) | Flow (l/s) | Main flood ($m^3$) | Density of drainage ($km/km^2$) | Watercourse frequency ($km^2$) | Slope index (m/km) |
|---|---|---|---|---|---|---|
| Sebgag | 126.5 | 500 | 2.4 | 2.52 | 5.02 | 5.4 |
| Sekiafa | 775.57 | 300 | 8.66 | 1.58 | 2.47 | 8.79 |

the Polar Front and the derived Polar Front. As a result, the Atlantic-Mediterranean influences will be much degraded, while the Saharan grip is asserting itself as one move towards the South.

- *Altitude*: it compensates the effects partially those of the latitude; we noted an increase in the latter with altitude.
- Slopes orientations exposed to the rainy winds are wetter than their lapels. This orientation confirms the altitude effect with respect to precipitation values.

It is vital to know that the minimum rainfall in Amour mountain is 250 mm, and the maximum could reach 400 mm on the highest peaks. In Aflou, Sebgag, Oued Morra, and Brida cities, the registered annual precipitations are respectively 325, 260, 235, and 215 mm. The registered mean temperature is 18.5°C with a mean minimum of 3.50°C and a mean maximum of 23.8°C. The lowest temperature is registered during January is –2.3°C, the maximum value is 32.2°C registered in July. The climatic indices which we have calculated lead us to conclude that the basin of Aflou a semi-arid climate.

## 3. Materials and methods

### 3.1. Hydrochemical data

Hydrochemistry is a privileged means of investigation intervening both in the identification of aquifers and in understanding the rules governing the flow of water in underground aquifers [17,18]. One hundred and seventy-one samples were taken. The vast majority concern the Barremian-Albian aquifer at the Aflou basin. Electrical conductivity (EC), pH, and water temperature ($T$) were measured *in situ* via (multi parameter device). The main ions of the water samples were processed and analyzed in the physical and chemical analysis laboratory. Based on these data and on the basis of a statistical analysis, we sought to establish the links between the water and the aquifers that ensure their conservation or their progress [19]. The analysis results are summarized in (Table 2). The dispersion around the mean (m) of these elements is done using the standard deviation ($\sigma$) and coefficient of variation ($CV = \sigma/m$), it is estimated that the series is homogeneous when $CV < 50\%$ [20].

Table 2
Statistical characteristics of the physico-chemical parameters of water in the Aflou syncline

| Parameters (mg/L) | $T$ (°C) | pH | EC (μS/cm) | $Ca^{2+}$ (mg/L) | $Mg^{2+}$ (mg/L) | $Na^+$ (mg/L) | $K^+$ (mg/L) | $HCO_3^-$ (mg/L) | $SO_4^{-2}$ (mg/L) | $Cl^-$ (mg/L) | $NO_3^-$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum | 20 | 8.2 | 2,700 | 680 | 256 | 340 | 29 | 827 | 2,090 | 795 | 485 |
| Minimum | 15.1 | 7.4 | 400 | 40 | 6 | 5 | 0 | 60 | 0 | 10 | 0 |
| Average | 17.3 | 7.9 | 1,655 | 145.09 | 60.97 | 66.51 | 5.51 | 241.11 | 329.81 | 132.27 | 47.54 |
| SD | 1.13 | 0.20 | 927.2 | 91.42 | 46.25 | 61.18 | 4.33 | 94.04 | 327.30 | 124.45 | 59.28 |
| CV (%) | 6.46 | 2.67 | 58.78 | 62.72 | 65.98 | 91.94 | 78.39 | 39.02 | 99.13 | 94.23 | 117.90 |
| Standard WHO (2004) | | 6.5–8.5 | 2,000 | 200 | 150 | 200 | 12 | | 250 | 250 | 50 |

CV, coefficient of variation; SD, standard deviation.

### 3.2. Methodology and software

The study of the spatial distribution of facies is a chemical distribution study of parameters characterizing these facies. After data collection and chemical analyses in the laboratory, several computer tools, and software were used. Diagrams software were used to plot Piper and Schöeller Berkaloff diagrams. To explain the mineralization acquisition, Phreeq-C program was implemented to determine a saturation index of some specific minerals (calcite, aragonite, dolomite, gypsum, anhydrite, and halite). The same for maps, ArcGIS mapping software was used to consult maps.

### 3.3. Interpolation method (inverse distance weighted)

In space, points closer to each other have more correlations and similarities than the more distant ones. This theory presents the most important basis in the case where the interpolation methods are used. In the present work, we used the IDW interpolation method. Inverse distance weighted (IDW) is an interpolation technique that estimates cell values by balancing the values of sample data points in the neighborhood of each processing cell [21]. IDW method has been used to examine maps (Figs. 7–10) by Arc-GIS tool.

## 4. Results and discussion

### 4.1. Iso-contents maps

Figs. 4–7 show identical evolution of the conductivity. Three zones located respectively from West to East, Sidi Okba, Aflou, and Kef Gourou these zones characterize a strong zone. The evaporation of a both gypsiferous and saliferous intercalations in the Triassic formations at the eastern Aflou Syncline (Daia El Malha zone) explain these high concentrations which the maximum values closed on. In Aflou city, low peaks appear related by evaporates existence in Mio-Pliocene or marls of the Barremian-Aptian-Albien. In the South of Sidi Okba city, the high grades related by evaporate dissolution of Mio-Pliocene. The iso-contents curve close around a maximum and coincide with a watershed, and the concentration decreases as one move away from that line to a mixture with less mineralized waters. In the west of Aflou basin, the high Na+, $Cl^-$, and $SO_4^{2-}$ contents are related by presence of halite and gypsum in Triassic formations.

### 4.2. Conductivity

The registered electrical conductivity between 800 and 4,800 μS/cm. Conductivity values are 800 μS/cm as a minimum and 1,200 μS/cm as maximum, in the West of Aflou, but not at the center and East of the region. In the west, the highest values are registered near the outcrops of the Triassic. In Aflou region, the maximum of the conductivity is localized in the center where the curves have 3,400 μS/cm, progressively decreased in the East where other secondary maxima have not exceeded 2,000 μS/cm. High values are cited as flowing (Fig. 8):

- In agricultural regions, where chemical fertilizers and intense pumping are used, give a significant dissolution of evaporated minerals encompassed in marl of Mio-Pliocene and Barremian-Aptian-Albian (Aflou basin).
- Wastewater using for irrigation in the East of Aflou of Aflou.
- The direct lithology influence and evaporate formations of the Triassic (Kef Guru).
- At tectonics, the maximums coincide with faults (between Sebgag and Aflou), which allow us to admit the arrival of mineralized water coming from underlying aquifers.

### 4.3. Water families and characteristic formulas

#### 4.3.1. Diagrams of Schoeller-Berkaloff

The plot of data on Schoeller Berkaloff diagrams allows us to characterize a certain number of chemical facies (Fig. 9 and Table 3).

Fig. 9 and Table 3 shows the most representative analyzed waters by two types:

- Bicarbonated, sulfated, chlorinated with Ca > Mg > Na (II).
- Sulfated, chlorinated, bicarbonated with Ca > Mg > Nat (I).

To the west of Aflou city, the waters are generally type II. The bicarbonate character is related by the calcareous matrix of Barremian, Aptian, and Albian sandstones solutions. The Mio-Plio-Quaternary outcrops are relatively small, and as a result they have little effect on the chemistry of the water. Gypsum of the Triassic formations are origins of Sulfates.

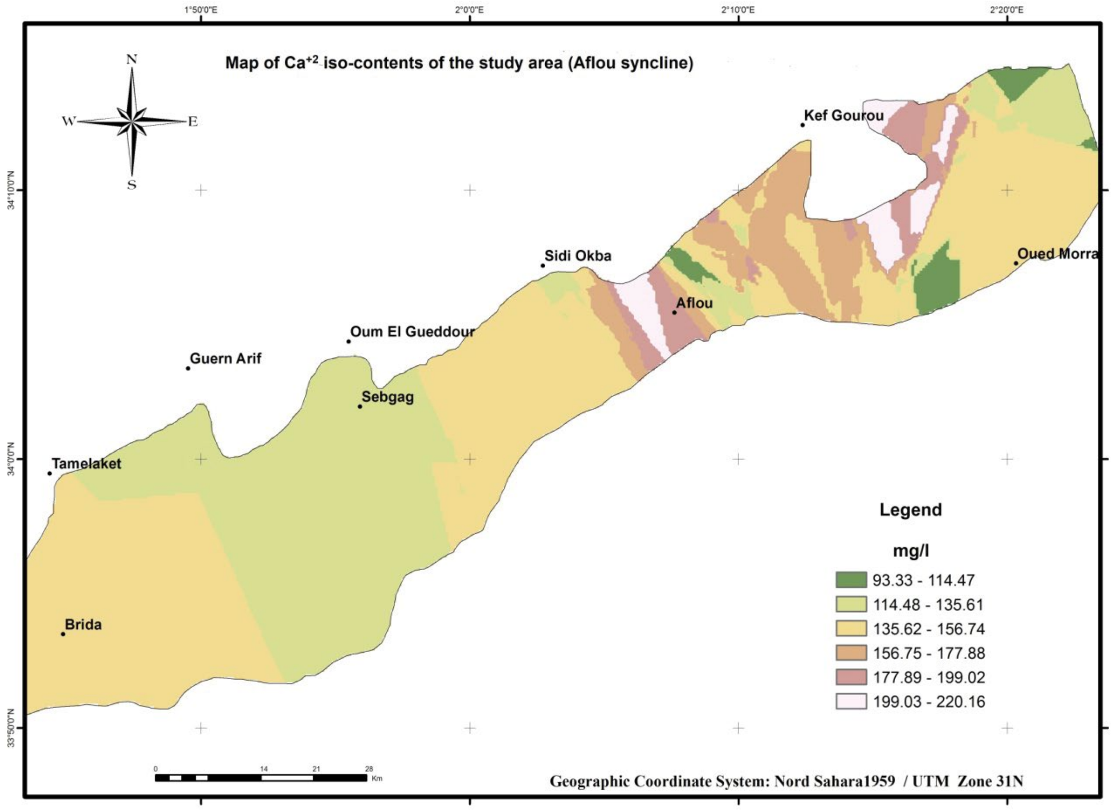


Fig. 4. Map of $Ca^{2+}$ iso-contents of the study area (Aflou syncline).

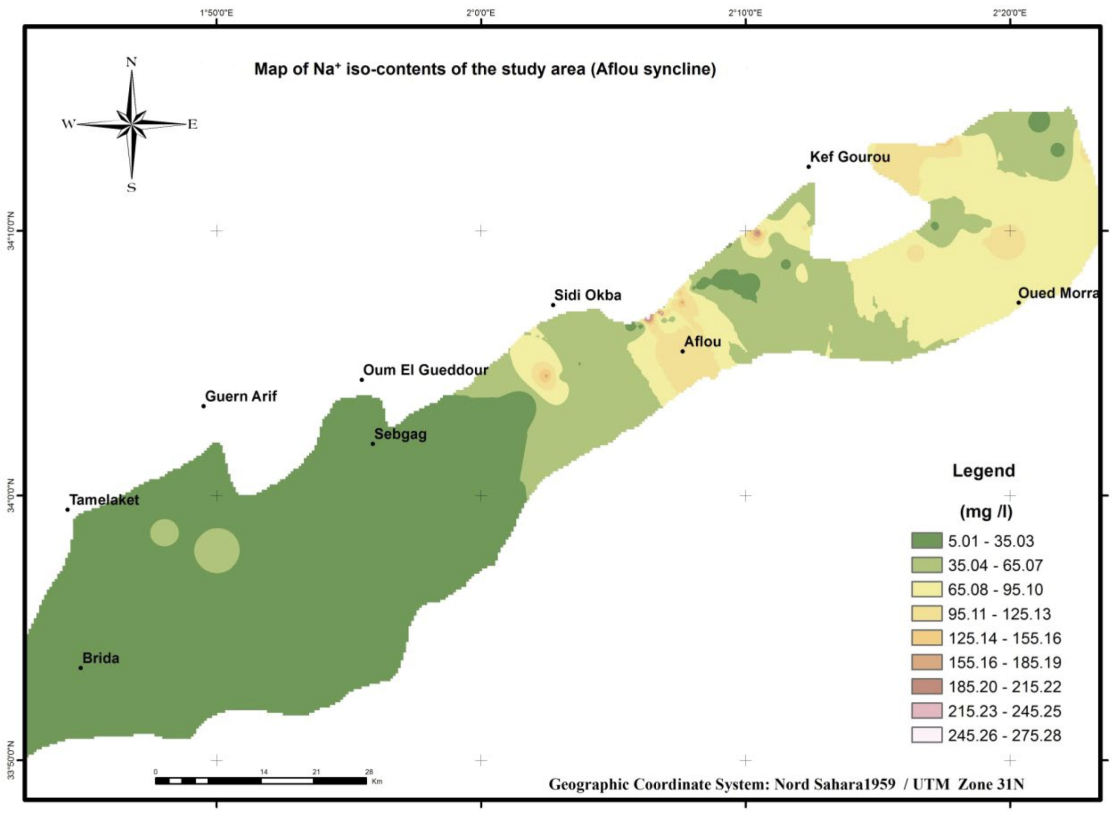


Fig. 5. Map of $Na^{+}$ iso-contents of the study area (Aflou syncline).

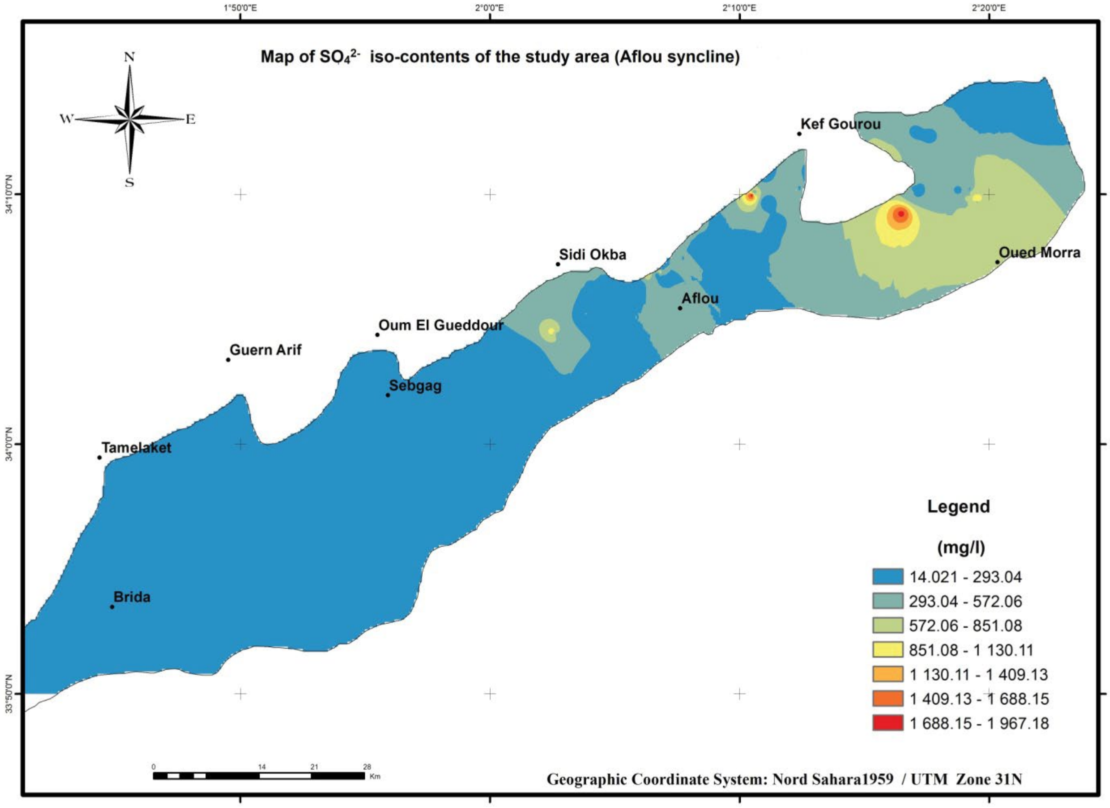


Fig. 6. Map of $SO_4^{2-}$ iso-contents of the study area (Aflou syncline).

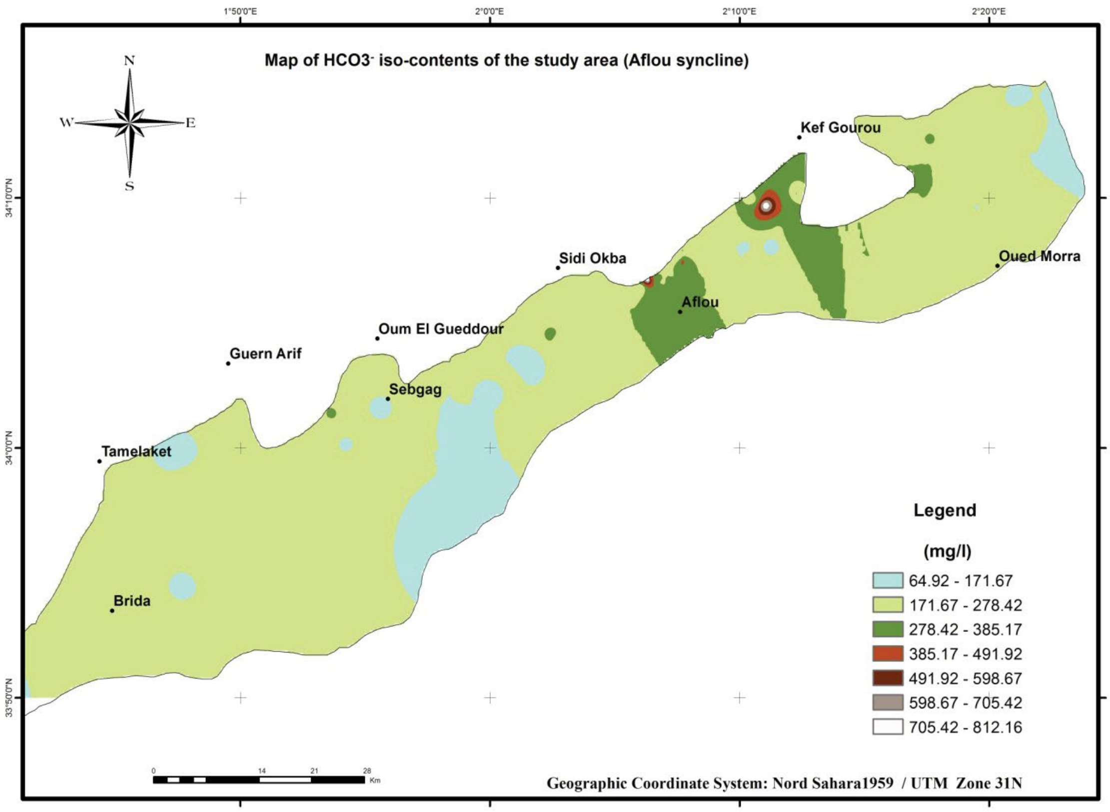


Fig. 7. Map of $HCO_3^-$ iso-contents of the study area (Aflou syncline).

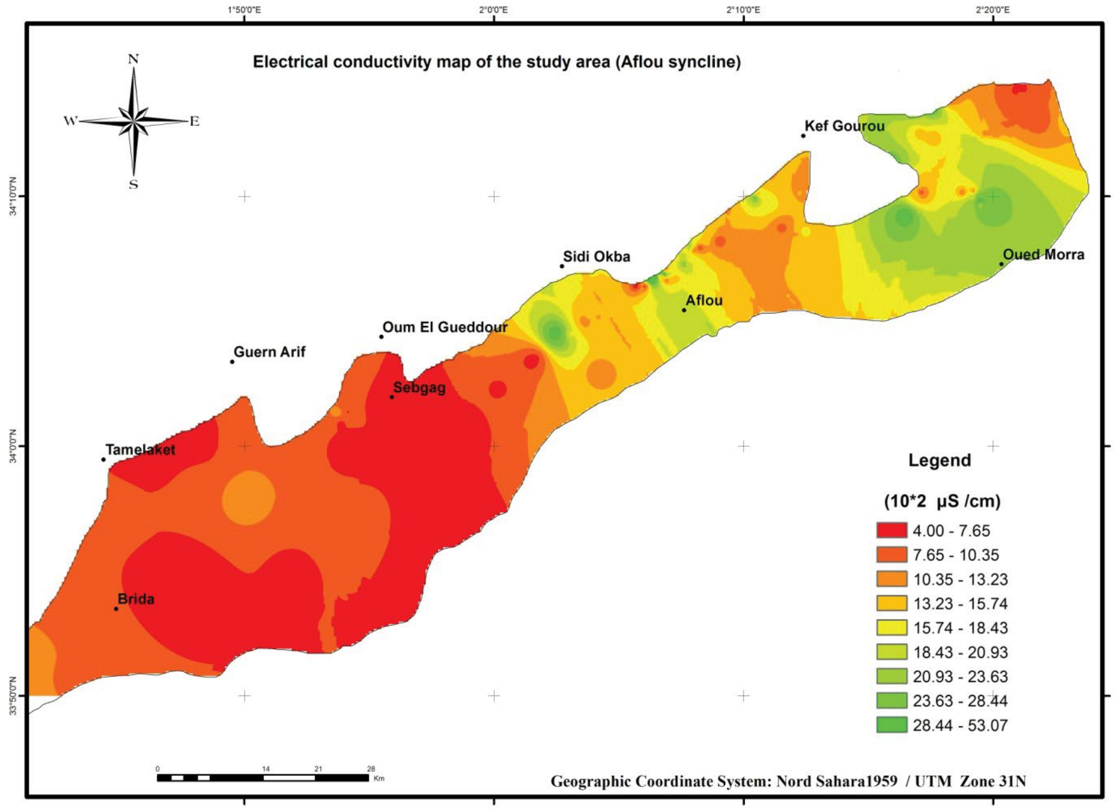


Fig. 8. Electrical conductivity map of the study area (Aflou syncline).

In the East of Aflou city, type I of facies characterizes a water quality. In Aflou city, the two types of facies (I and II) are found, but predominantly of the type II facies which generally characterize the Barremian Aptien, Albian sandstones. Gypsiferous of the Mio-Plio-Quaternary dissolution given Sulfates and Calcium.

*4.3.2. Piper diagram*

The presentation of chemical plotted on a Piper diagram (Fig. 10) provides a comprehensive approach to the chemical composition of groundwater [22]. Fig. 10 shows that the chemical composition of the groundwater is predominantly sulfates and bicarbonates anions so the captions are calcium and magnesium, which give sulfate types calcium and magnesium to the waters of the Aflou syncline. Four other hydrochemical facies appeared in the Piper and Schoeller-Berkaloff plot: calcium sulfate, calcium bicarbonate, magnesium sulfate, and calcium chloride. This was verified by the averages of the dominant contents of the following ions: $Ca^{2+}$ (7.81 meq/L); $Mg^{2+}$ (5.77 meq/L); $SO_4^{2-}$ (7.70 meq/L); $HCO_3^-$ (4.20 meq/L), and $Cl^-$ (4.14 meq/L). The predominant $SO_4$ anions with respect to $HCO_3$ and Cl, as well as the abundance of Ca and Mg cations, allow us to establish binary diagrams by the characteristic ratios: Ca/Mg vs. $SO_4$/Cl and Ca/Mg vs. $SO_4$/$HCO_3$ and Ca/Mg vs. $HCO_3$/Cl to explain geochemical evolution of facies encountered in Piper and Schoeller-Berkaloff diagrams.

Figs. 11–13 show that the Ca/Mg ratio is greater than unity, in 83% of the samples, indicating calcium enrichment and 17% of samples with values less than 1, indicating magnesium enrichment. For the $SO_4$/Cl ratio: 85% of the samples have values greater than one, indicating enrichment of Sulfate ion. On the other hand, 15% of these samples are less than unity and rich in chlorine ion. For the $HCO_3$/Cl ratio: 43% of the samples are less than unity indicating chlorine enrichment, whereas 57% are richer in bicarbonate. With respect to the $SO_4$/ $HCO_3$ ratio, about 62% have values greater than one that are rich in sulfate. The interpretation of these three diagrams showed the concentration of the ion ratios in four poles indicating the previously determined facies which characterize the Aflou syncline.

*4.4. Distribution of chemical facies*

The examination of distribution map in the groundwater facies of Aflou syncline shows lithology formation influence on facies types (Fig. 14). Calcareous matrix of Barremian, Aptian, Albian sandstones solutions are origins of bicarbonate-calcium facies. Calcium sulfate facies originated by gypsiferous levels of the Mio-Plio-Quaternaire and recharged by gypsum-laden runoff from the evaporite levels of the Neocomian formations.

*4.5. Evolution of water saturation indices in comparison of the preponderant minerals*

The saturation index of various minerals in water can be written mathematically as follows [23,24]:

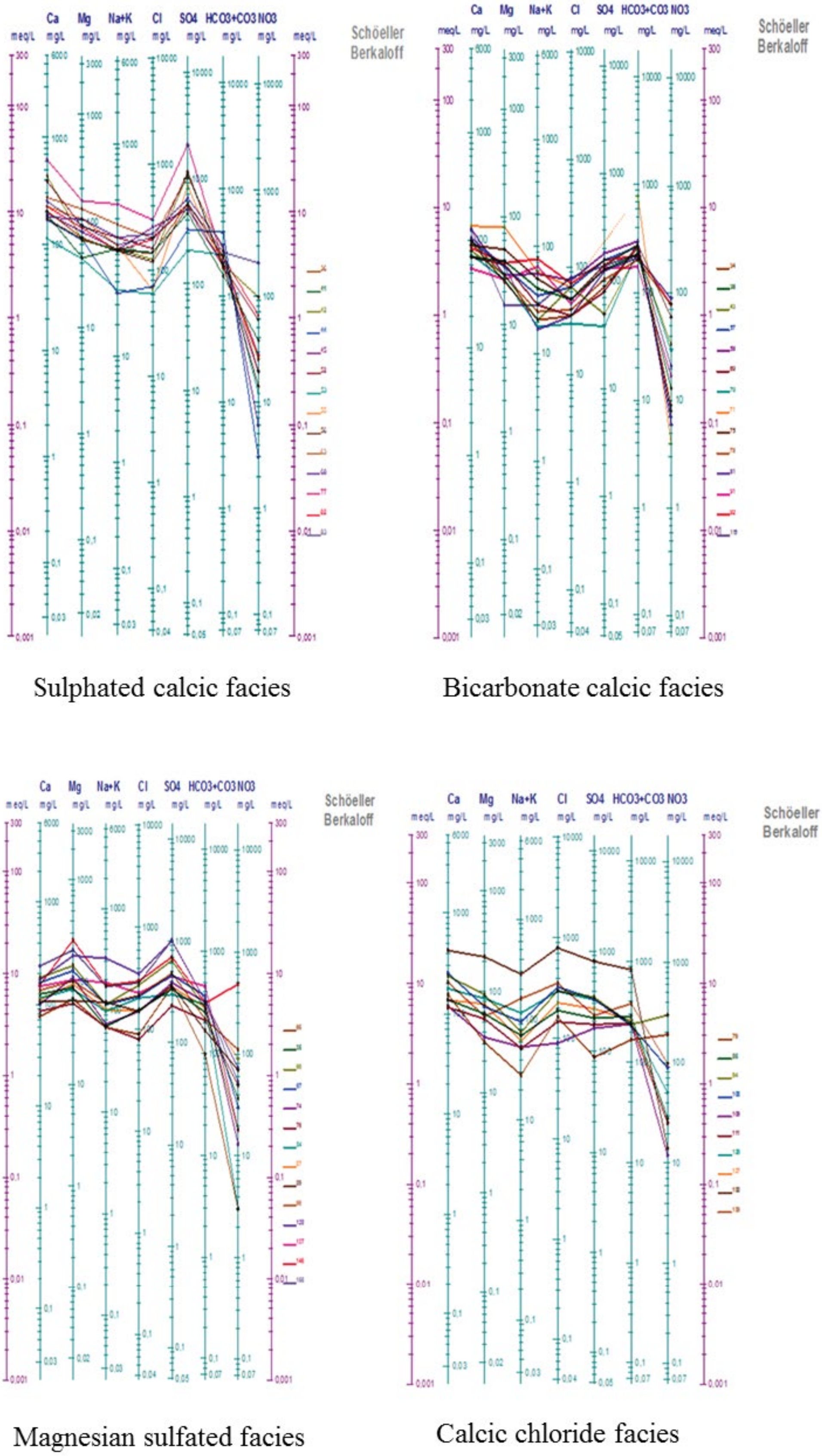


Fig. 9. Graphical representation of synclinal water analyzes of Aflou using Schoeller–Berkaloff diagram.

Table 3
Chemical facies of study area

| Calcium sulfated | | | |
|---|---|---|---|
| Sample | 68 | | |
| Percentage | 39.76% | | |
| | Sulfated, chlorinated, bicarbonated | Sulfated, bicarbonated, chlorinated | Sulfated, chlorinated, bicarbonated |
| $Mg^{2+}$ position | $Ca^{2+} > Mg^{2+} > Na^{+}$ | $Ca^{2+} > Mg^{2+} > Na^{+}$ | $Ca^{2+} > Na^{+} > Mg^{2+}$ |
| Sample | 40 | 24 | 3 |
| Percentage | 23.4% | 40% | 2.34% |
| **Bicarbonate, calcium** | | | |
| Sample | 66 | | |
| Percentage | 38.6% | | |
| | Bicarbonated, sulfated, chlorinated | Bicarbonated, chlorinated, sulfated | Bicarbonate, sulfate, chloride |
| $Mg^{2+}$ position | $Ca^{2+} > Mg^{2+} > Na^{+}$ | $Ca^{2+} > Mg^{2+} > Na^{+}$ | $Ca^{2+} > Na^{+} > Mg^{2+}$ |
| Sample | 56 | 6 | 4 |
| Percentage | 32.74% | 3.51% | 2.35% |
| **Sulfated, magnesian** | | | |
| Sample | 19 | | |
| Percentage | 11.11% | | |
| | Sulfated, chlorinated, bicarbonated | Sulfated, bicarbonated, chlorinated | Sulfated, chlorinated, bicarbonated |
| $Mg^{2+}$ position | $Mg^{2+} > Ca^{2+} > Na^{+}$ | $Mg^{2+} > Ca^{2+} > Na^{+}$ | $Mg^{2+} > Na^{+} > Ca^{2+}$ |
| Sample | 11 | 7 | 1 |
| Percentage | 6.43% | 4.09% | 0.6% |

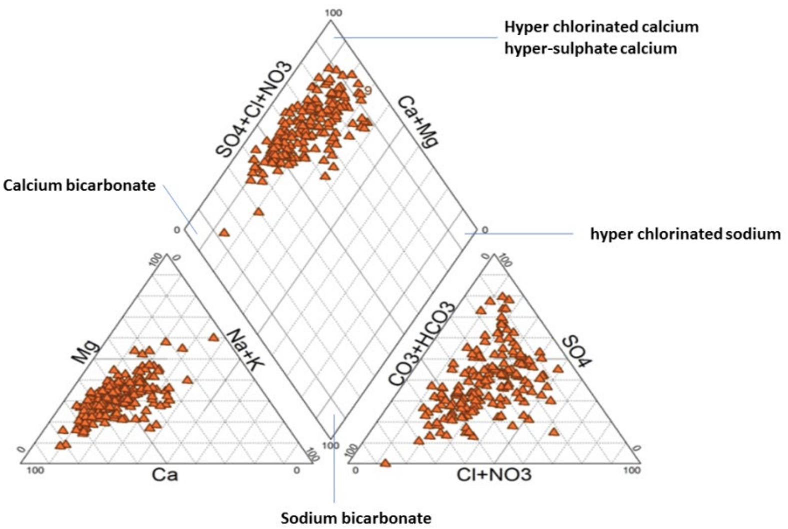


Fig. 10. Graphical representation of synclinal water analyses of Aflou using the Piper diagram.

$$\text{IS} = \log\left(\frac{\text{IAP}}{K}\right) \tag{1}$$

where IAP is the product of ionic activity; $K$ is the equilibrium constant.

A simulation was performed by Phreeq-C software, to calculate a saturation index [24,25]. For evaporates, gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) were chosen to illustrate this evolution, Fig. 15 showing that the water sample is under-saturated with gypsum and anhydrite. As a result, the waters are enriched by sulfates and calcium (for gypsum and anhydrite).

For the carbonates, calcite, dolomite, and aragonite were chosen. Fig. 16 shows water samples oversaturation with respect a dolomite, calcite, and by more degree respect to the aragonite. Fig. 17 shows that a very significant correlation between saturation index (IS) of gypsum and anhydrite ($Ca + SO_4$), confirms the dissolution hypothesis of evaporates. However, the saturation index of calcite and aragonite

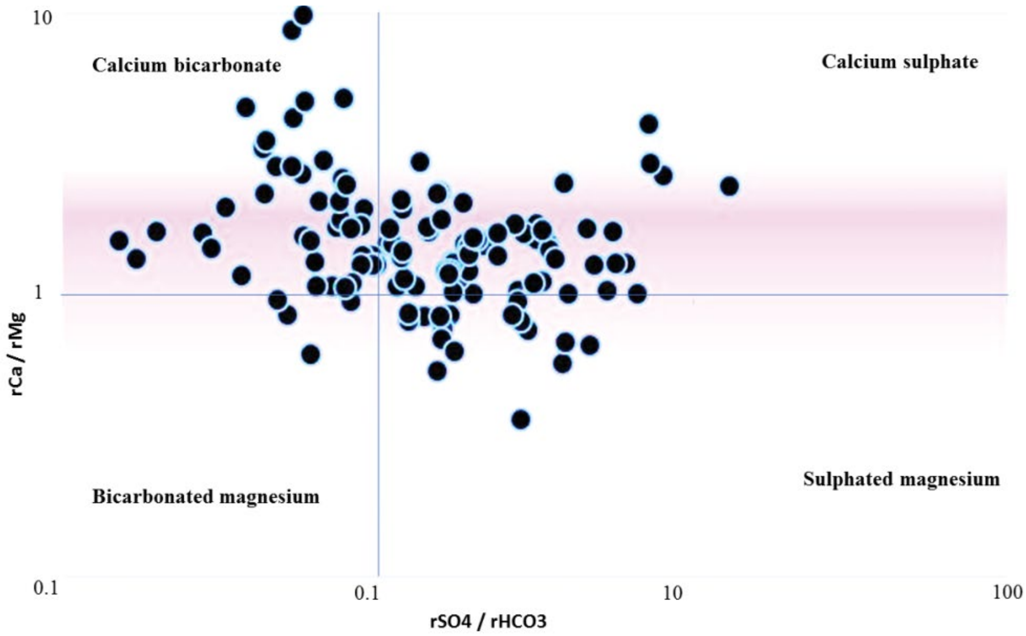


Fig. 11. Ca/Mg and $SO_4/HCO_3^-$ relationship.

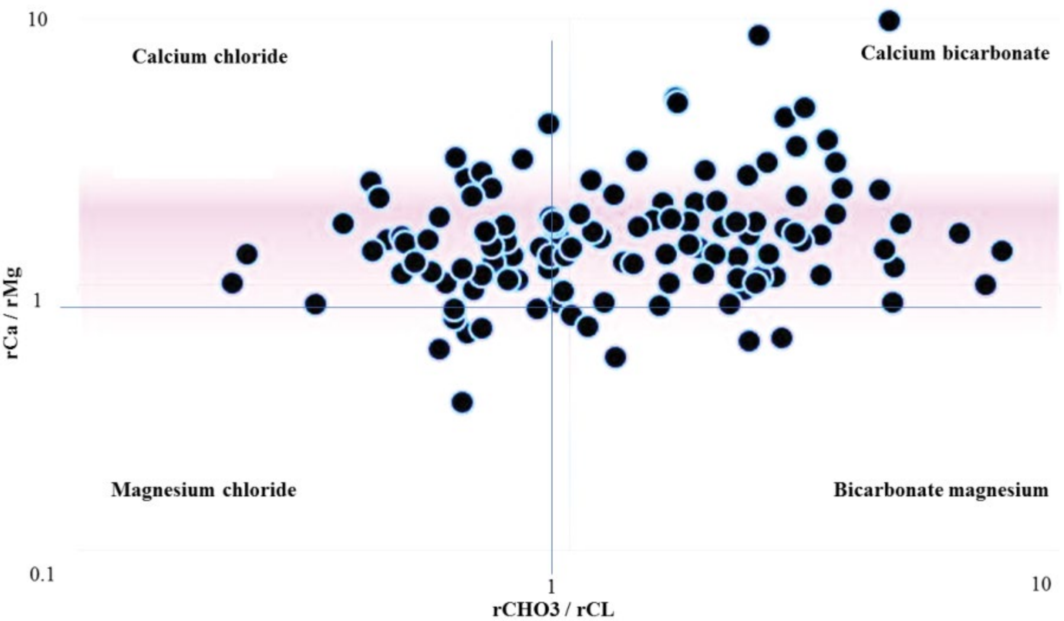


Fig. 12. Ca/Mg and $HCO_3^-$/Cl relationship.

($Ca + HCO_3$) and dolomite ($Ca + Mg + HCO_3$) given lower correlation than the others, which invalidates precipitation of carbonate minerals.

In summary, the interpretation of the figures has shown the influence of evaporated minerals on the chemistry of water. In conclusion, the interpretation of figures has shown the evaporate minerals influence on water chemistry. Both continuity in dissolution and enrichment of water caused by sub-saturation in gypsum and anhydrite. Moreover, the carbonate minerals are sometimes close to the equilibrium, often in oversaturation, and tend towards precipitation in the calcite and dolomite form.

### *4.6. Multidimensional analysis*

The following elements: $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$, $HCO_3^{2-}$, and $NO_3^{2-}$, electrical conductivity and pH were used in this treatment. 51.58% and 11.67% are two axes limit data processing, in this case the variation 63.25% was considered. In variables space, the I axis is defined by electrical

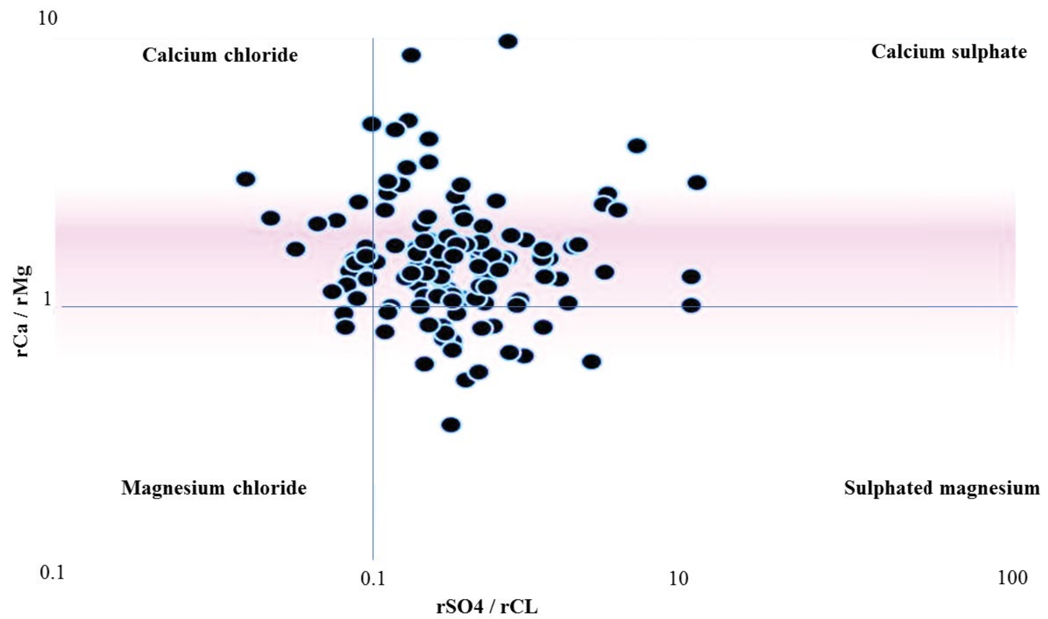


Fig. 13. Ca/Mg and $SO_4$/Cl relationship.

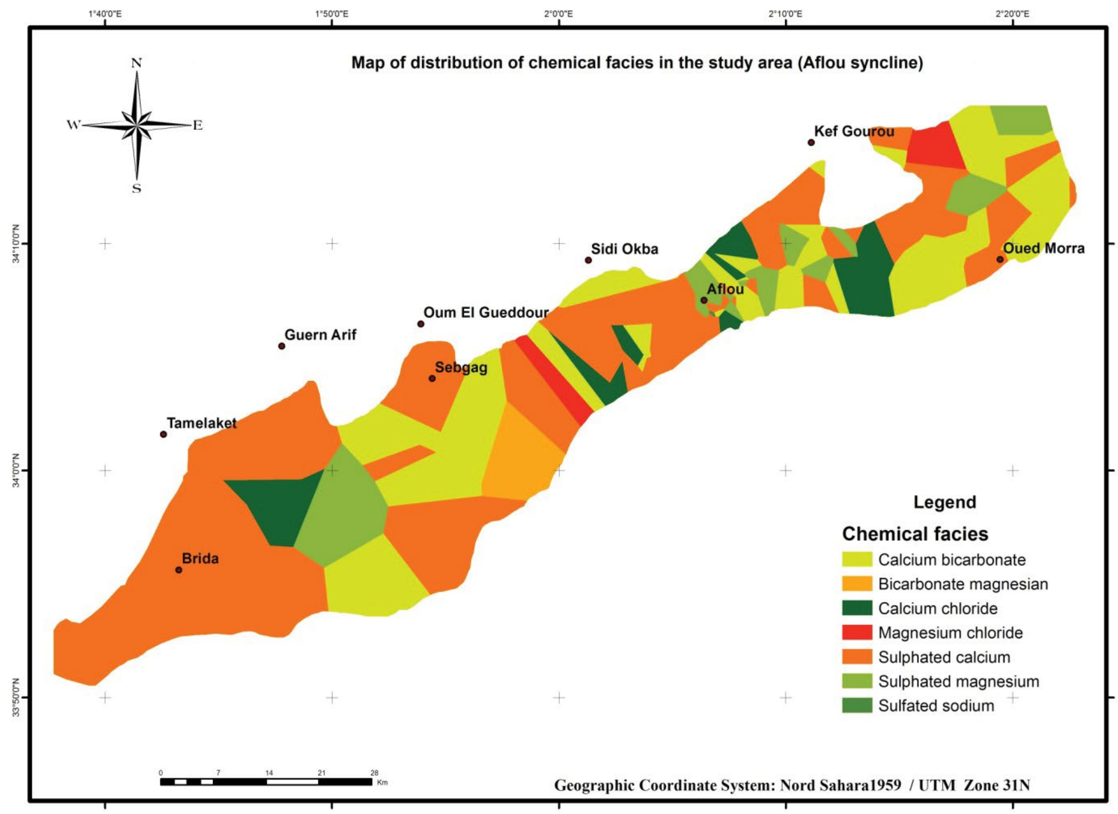


Fig. 14. Map of distribution of chemical facies in the study area (Aflou syncline).

conductivity, $Mg^{2+}$, $Cl^-$, $Na^+$, $Ca^{2+}$, and $SO_4^{2-}$ which characterizes reservoir rock mineralization. While $NO_3^{2-}$ appears clearly opposite to *K*, there is an opposition of anthropogenic pollution ($NO^3$) and natural pollution-related by formations geology especially salt formations rich in potassium such as Sylvite (KCl) and translates salinization processes and fixation phenomena by clay minerals (e.g., case of potassium $K^+$). So, the F2 is determined by pollution

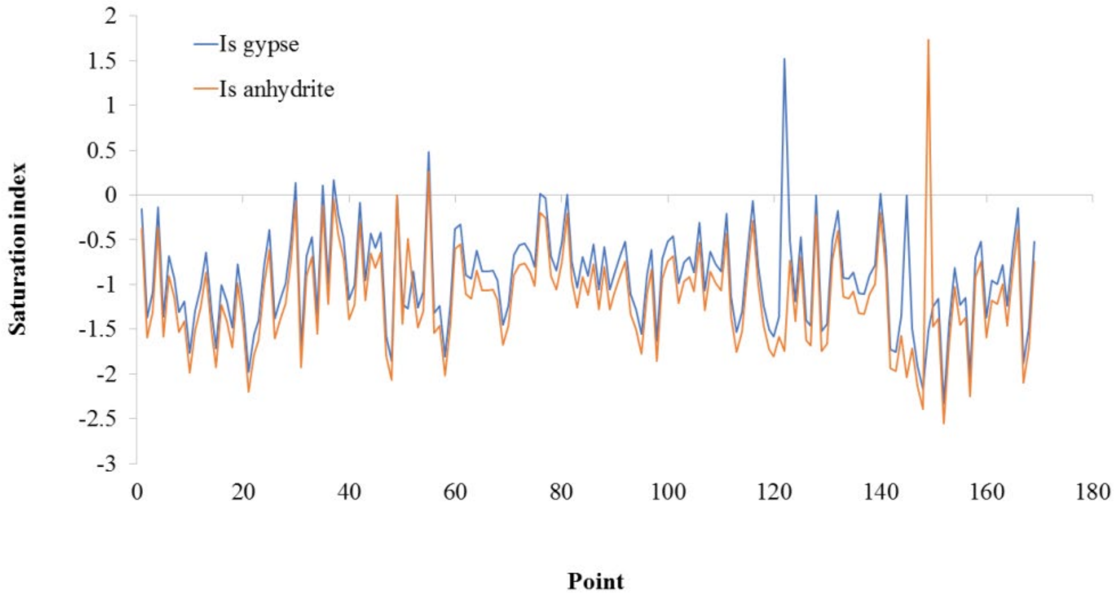


Fig. 15. Evolution of saturation indices (gypsum and anhydrite).

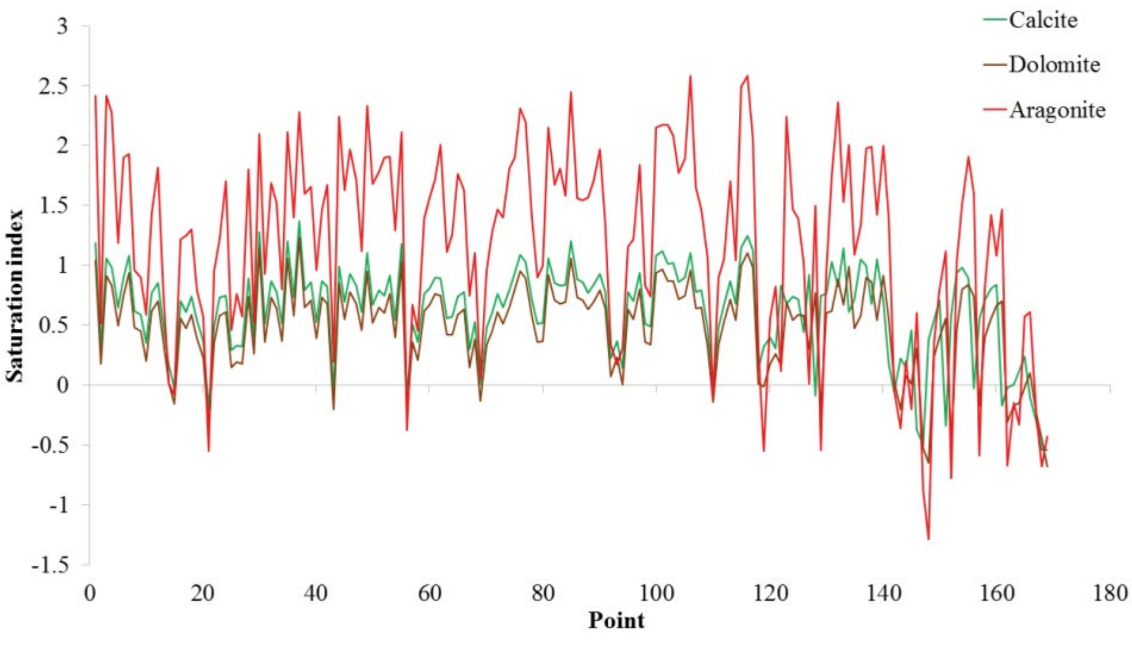


Fig. 16. Evolution of saturation indices (calcite, dolomite, and aragonite).

factors. In diagram, high-grade samples are positioned on the negative side of main axis represent evaporates influence in water. With medium mineralization, water can be positioned in the positive side and present Continental Intercalary water. Some points can be distinguished: surface waters (30 and 37) with medium mineralization. In rivers, low flow resources are influenced by marn-gypsiferous formations of nearby Portlandian, high levels of $SO_4^{2-}$ and $Na^+$ and averages for 121 and 123 points. Point 77 is characterized by a high content of nitrates greater or equal than 50 mg/L but up to 120 mg/L for point 123. Grades are related by points situation in spraying areas or in areas in the case the irrigation is mainly carried out from wastewater discharges in the northeast of Aflou city. At points 4, 47, 60, 80, and 86, limestones and gypsiferous marls influence is important. The points catching Jurassic limestones are 4, 47, and 60. Points capturing Cenomano-Turonian marl-limestones are 80–86 (Figs. 18 and 19).

## 5. Conclusion

Groundwater hydrochemical study was conducted in the alluvial region of Aflou syncline aquifer. In conclusion, the lithological nature of the aquifer directly affects

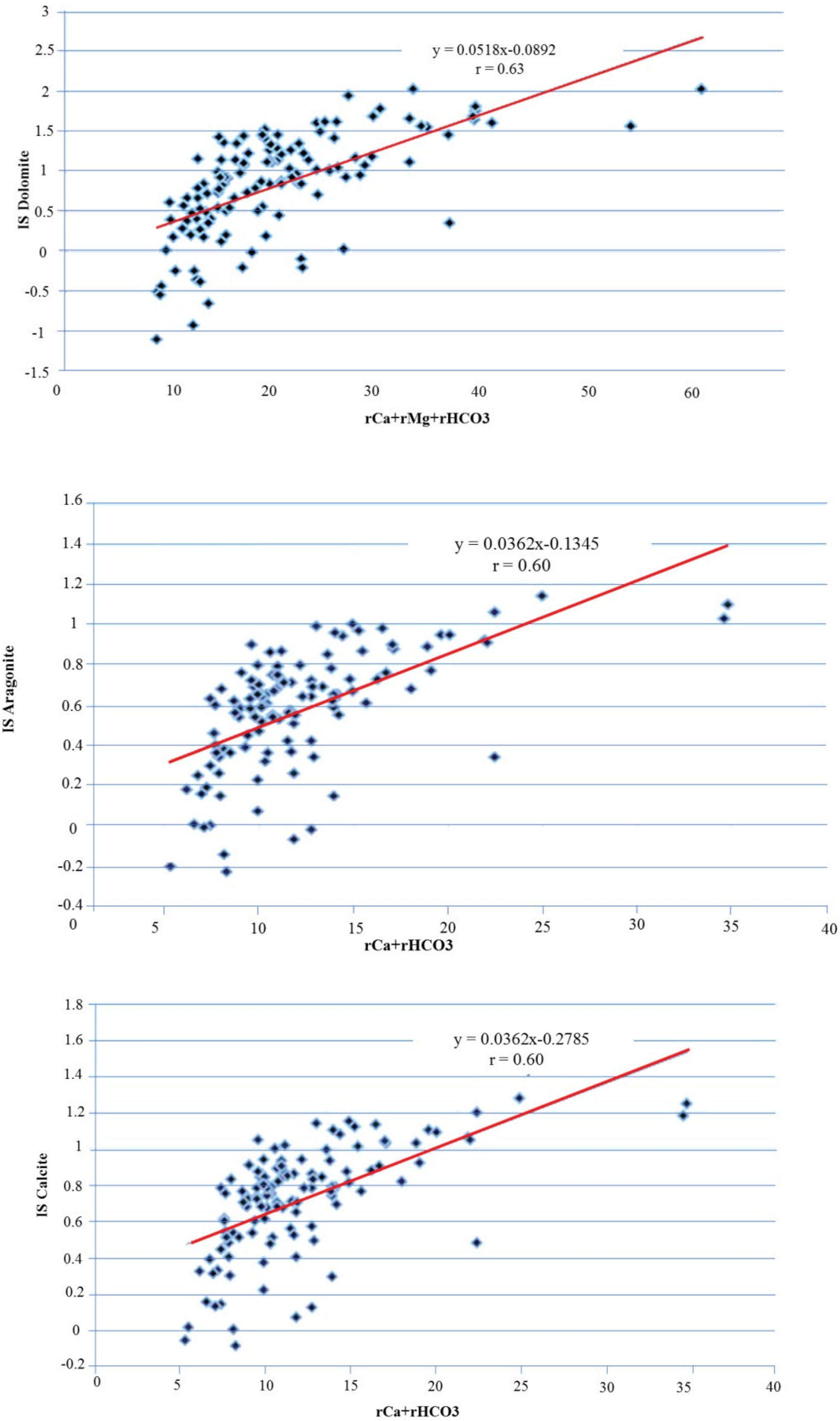


Fig. 17. Correlations between minerals and saturation indices.

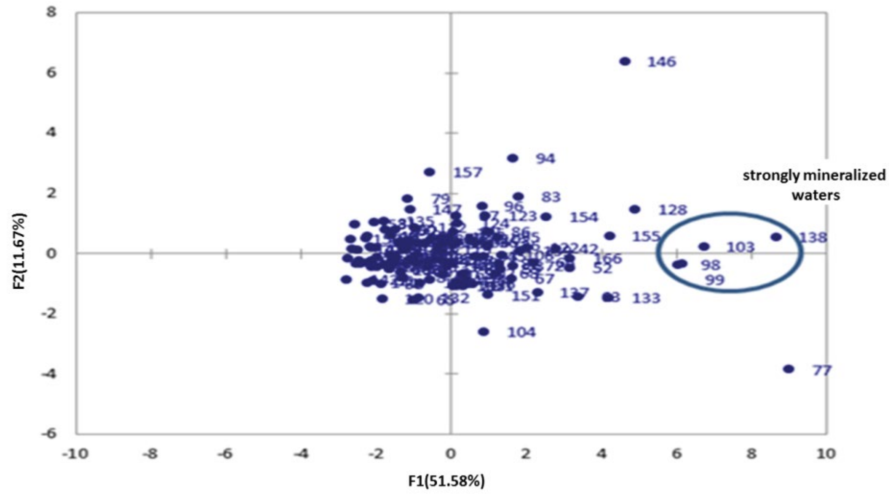


Fig. 18. Projection of variables.

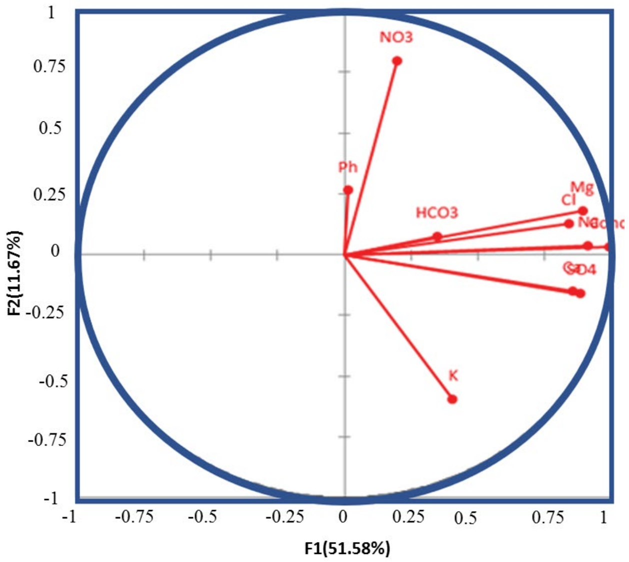


Fig. 19. Projection of individuals according to plan F1–F2.

the chemistry of water: $Ca^{2+}$, $Na^{+}$, $Cl^{-}$, and $SO_4^{2-}$: all of these characterize essentially the aquifer mineralization, sometimes $Ca^{2+}$ and $SO_4^{2-}$ which may originate from Portland or the Triassic formations. $HCO_3^{-}$ comes from the Barremian, Aptian, and Albian sandstones leaching after calcareous matrix solution. At the level of aquifer axis which coincides with the basin, the waters include sulfated, calcium, and bicarbonate calcium facies with the exception of the points located in wastewater discharge zones. In addition to the influence of the evaporated minerals that are widely cited at different levels especially Triassic ascents materials that we have observed in several points in Amour mountains. By approaching the Lower Cretaceous (Portlandian) and Upper Jurassic (limestone) formations, the sulfated calcium facies, has very high contents of $SO_4^{2-}$, $Cl^{-}$, $Ca^{2+}$, and $Na^{+}$. The examinations of iso-contents maps and ACP have proved that waters composition was very closely related by lithological nature of the different formations.

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