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# Impact of agriculture on soil and water quality in the north-east of Algeria: Boumaiza Plain

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**Summary**

The Boumaiza Plain is situated in the northeast of Algeria and encompasses a vast area of the El-Kebir West watershed, which has a significant water potential. The intensification of agricultural activities in this region has led to a notable increase in the use of phytosanitary products, which may impact the physico-chemical quality of groundwater and soil. A sampling campaign was conducted in 2022 to assess the impact of agriculture. To achieve this aim, we analysed 12 points, comprising 7 wells and 5 boreholes, as well as the grain size and physicochemical characteristics of 12 soil samples. The methodology employed for processing the analysis results is based on multivariate statistical methods. The results of the analyses revealed pollution of agricultural origin. This is substantiated by the observation of relatively high levels of nutrients, including $NO_2$, $NO_3$, as well as potassium which exceed 5 mg/l in water and 40.76 mg/l for soil analyses. Principal component analysis (PCA) was also applied, while the opposition of physicochemical elements to nitrites, nitrites, chlorides, sulfates, ammonium, and potassium variables highlights another mechanism involved in water mineralization, which is governed by the inputs of surface water fromagricultural areas and the intrusion of rich in organic matter waste from domesticated animals.

**Keywords**

agricultural activities • Boumaiza Plain groundwater • intrusion pollution • principal component analysis (PCA) • nutriment • soil

## 1. Introduction

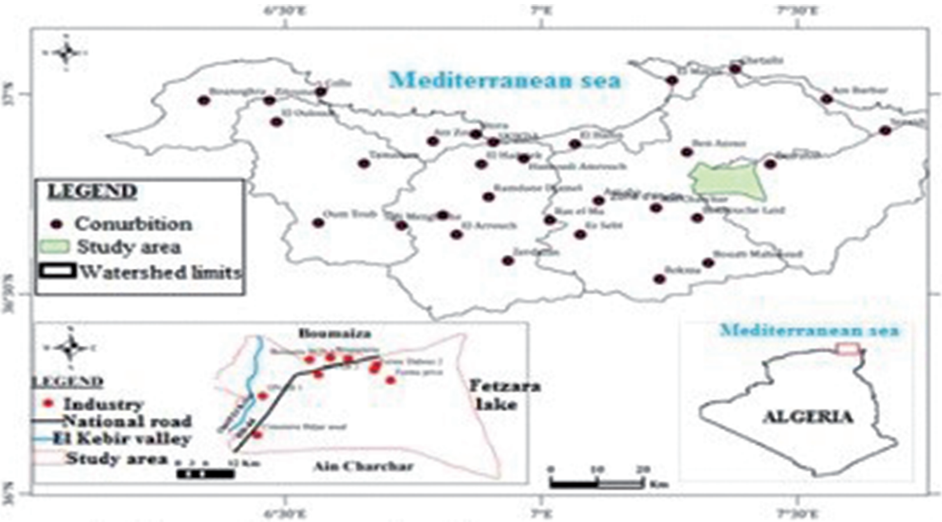
The agricultural practices affect other environmental services like a nutrient cycle, soil erosion, carbon sequestration, and many other ecological patterns [Kumar et al. 2021]. Most of the farming activities are responsible for water pollution and soil contamination due to excessive use of pesticides and chemical fertilizers, which ultimately leach to groundwater and soil [Lawani et al. 2017]. The application of nitrogen fertilizers meets the productivity demands of farmers by improving the quality and yield of crops. However, towards the end of the 1960 [Mebarki 2005], the harmful effects of these fertilizers on water and soil were gradually discovered due to nitrate leaching and denitrification [Guechi 2004, Khammar 1981].

Several studies have highlighted the significance of employing various methods not just for measuring groundwater quality but also for evaluating pollution sources and identifying susceptible distribution patterns [Boumaiza 2022]. The alluvial plain of Boumaiza, located in northeastern Algeria, is characterized by an alluvial aquifer containing a very significant water potential [Aouadi 1989]. The socio-economic development of the Boumaiza region in recent years has led to a constantly increasing demand for water, consequently creating a diversity of pollution sources. Agriculture and livestock farming are the primary occupations of the population in the Boumaiza region, alongside the industrial sector, which shows remarkable growth. Indeed, agriculture is the most promising sector in the region, with agricultural land covering 80% of the study area [Hadj-Said 2007]. The region produces over two million quintals of industrial tomatoes, accounting for one-third of the national production. Due to the government's focus on developing the livestock sector, several newly built farms in the region house hundreds of dairy cows producing nearly 4000 liters per day, along with two complexes for poultry farming [ASD Skikda 2021]. The region has also experienced remarkable industrial development through the establishment of new industrial units such as SIFCO (Industrial Company for Corrugated Cardboard Manufacturing), Ben Azzouz Brickworks (brick manufacturing unit), and an industrial tomato processing unit with a capacity of 2500 to 5000 tons per day [Bourbia 2018].This study will be extremely important and useful to make a general diagnosis of the quality of soil and groundwater in order to minimize the risk of contamination resulting from irrigation practices on the environment that may limit the durability of the agricultural production and cause an irreversible damage.

## 2. Methods

### Study area

Boumaiza region is a part of the watershed of the Oued Kébir West, located in northeastern Algeria between the wilayas of Annaba and Skikda. It is bounded at longitudes 7°10'E and 7°27'E, and latitudes 36°42'N and 36°50'N. It belongs to the coastal watersheds of the central Constantine region and covers an area of 88.8 km² (Fig. 1).




Source: Authors' own study

**Fig. 1.** Geographic location of study area

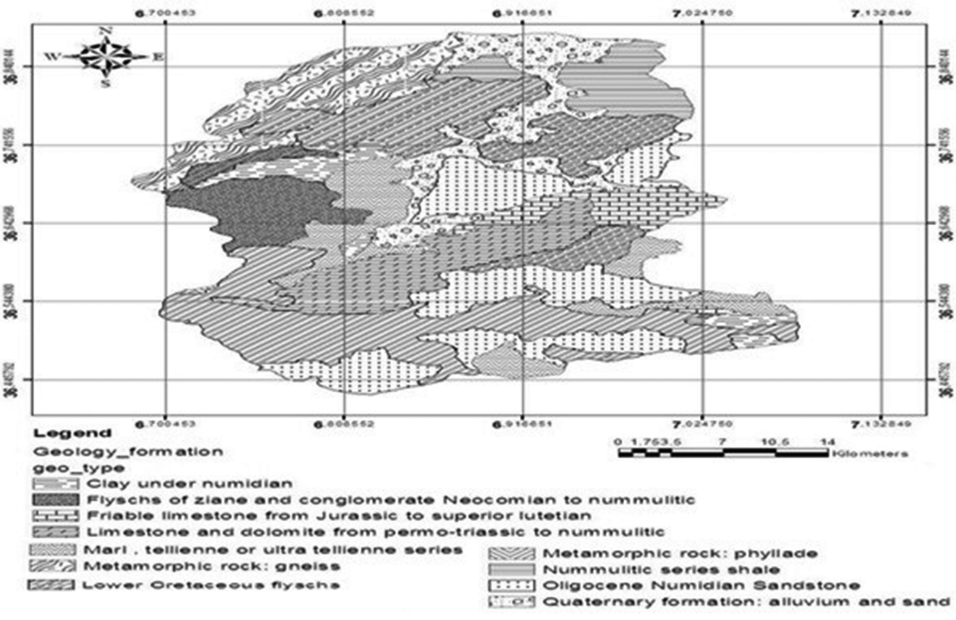



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**Fig. 2.** Geology map

The temperate climate of this region promotes the development of typical vegetation with a predominance of vegetable crops and a few rare olive trees. Eucalyptus plantations are also found near settlements connected to stagnant water areas [Hilly 1962]. The average temperature in the area varies from 7°C in January to 40.5°C in May and June, and the annual average rainfall is about 592 mm. The study area falls within a temperate climate, with mild and humid winters, hot and dry summers (Fig. 2). The depth of groundwater levels fluctuates in the range of less than 2–18 m below ground level (BGL) during the high water period and 4–24 m BGL during the low water period [Attoui 2020].

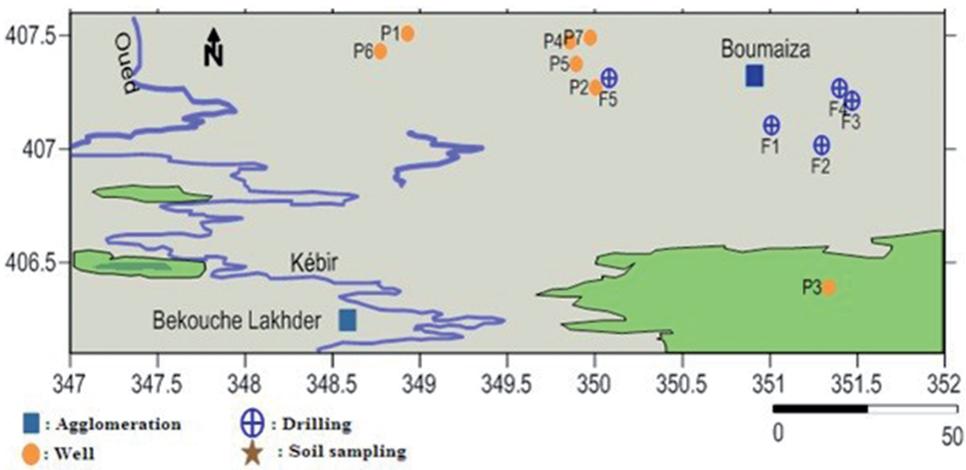


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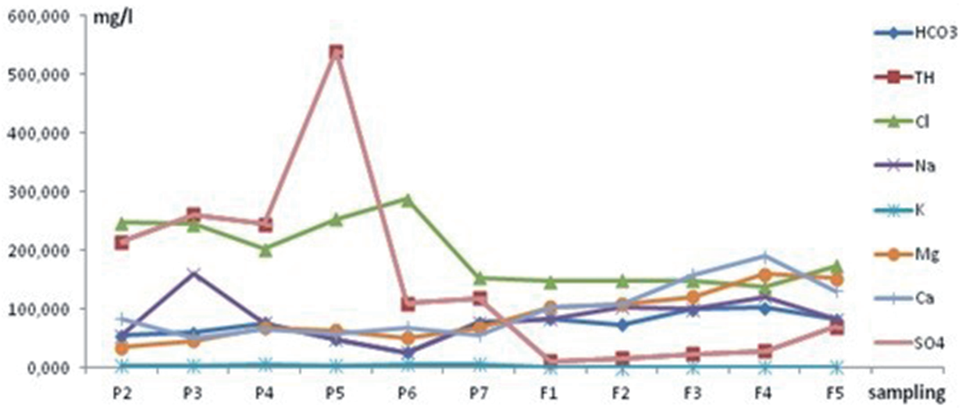
**Fig. 3.** Location map of the study area with groundwater and soil sample positions

The Boumaiza region belongs to the Atlas mountain chain, a folded zone in northern Algeria that demonstrates complex ductile and brittle tectonics [Durand et al. 1967]. The main fold being (Fig. 3) the Cretaceous and Jurassic anticline of Djebel Safia. It is longitudinally fractured by a fault, which has made the flanks very steep [WHO 1993]. The lithological sections of the drilling in the Boumaiza region show that the Boumaiza alluvial aquifer is found on the Quaternary gravels: a mixture of gravel, sand, pebbles [Hannouche 2007] and characterized by alluvial deposits with a maximum thickness of 110 meters spread over the entire plain. Silt, clay, and sandy clay separate the clayey soils on the surface from the gravel deposits that characterize the deep aquifer. With resistivities ranging from 20 to 30 Ωm; yielded transmissivity values ranging from 0.2 to 0.48 × $10^{-3}$ $m^2/s$ [APHA 2012].The values of the storage coefficient are in the order of 0.04%. The substrate is represented by the clayey-sandy sediments of the Numidian and Cretaceous flysch [Carter 2006]. The main watercourse of the study area is represented by the Oued Kébir West and Oued Magroune occupying the northwestern part, and a series of intermittent streams (in winter) flowing directly into Lake Fetzara [Khelfaoui and Zouini 2010]. The aquifer system under study exhibits significant heterogeneities in deposits. Impermeable limestones and marls correspond to the substratum. Coarse alluvial deposits and localized sandy layers in the south and southeast of the Boumaiza alluvial plain have significant water potential. The general trend of the isopiestic lines (Fig. 4) shows a convergence of groundwater flow towards the southeast part of the Boumaiza Plain and towards Lake Fetzara (the system's outlet) [Mebarki 2005].




Source: Authors' own study

**Fig. 4.** Variation of chemical elements in well water and drilling

## An essentially agricultural economy

Agriculture is the most promising sector in the Skikda province. The dominant crops are tomatoes, truck farming and cereals: durum wheat, and common wheat. The Boumaiza region (commune of Ben Azzouz) ranks first nationwide in the industrial tomatoes production, yielding over two million quintals of crop, which accounts for one-third of the national production. The agricultural area represents 80% of this plain [Cesonien et al. 2023]. Since the independence, the people of Boumaiza have been distinguished by their passion for livestock farming, including cattle, poultry, and bovines. In recent years, due to the focus of the state on developing this sector, several farms have been built, such as Dahoui Farms 1 and 2 , housing hundreds of dairy cows that produce nearly 4000 liters per day [Bouleknafet and Derradji 2017], as well as two complexes for poultry farming affiliated with the National Office of Livestock Feed (ONLF).

Excessive use of chemical products (intensive use of pesticides, herbicides, and chemical fertilizers), soil erosion, discharge of agricultural waste (crop residues, manure, and wash water), excessive irrigation, and intensive livestock practices (resulting in soil water saturation and leaching of nutrients and chemicals deep into the soil) are the main sources of groundwater contamination in the Boumaiza Plain.

**Collection of samples and analytical techniques**

The sampling campaign was carried out in April, 2022: 12 water sampling points (7 wells and 5 boreholes) were chosen according to the intensity of agriculture, livestock and urbanization. Chemical analyses focused on the major elements calcium, magnesium, sodium, potassium, bicarbonates, chlorides, and sulphates ($Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $HCO_3^-$ $Cl^-$, $SO_4^{2-}$) as well as on the nutrients ($NO_2^-$, $NO_3^-$, and $NH_4^+$. The physical parameters (electrical conductivity, temperature and pH), associated with dissolved oxygen, were measured in situ. Soil sampling was carried out in parallel with water sampling. Chemical elements of water and soil were examined at the Fertial Agronomic Laboratory in Annaba.

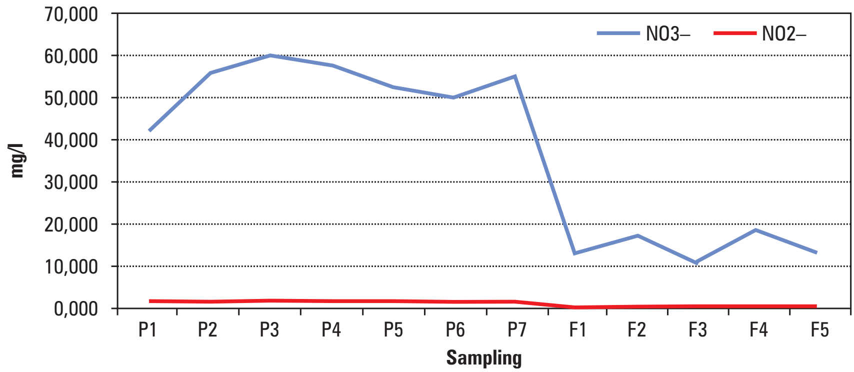
**Groundwater**

Samples were collected from 12 locations via tube wells and hand pumps exclusively used for drinking purposes during April 2022. The precise locations of the tube wells and hand pumps in the study area were obtained using a portable GPS device (Fig. 5). Groundwater samples were collected using pre-cleaned 1-L high-density polyethylene bottles rinsed with the groundwater samples three to four times. The standard procedures outlined by the World Health Organization [1994] were strictly followed for the collection, storage, transportation, and analysis of groundwater samples. The pH, EC, and TDS were measured at each sampling site using a portable digital pH/EC/TDS meter. The concentrations of TH, $HCO_3$, Ca, Mg, $HCO_3$, and Cl were estimated using the titration method [Howard Amster 1986]. The concentrations of Na and K were calculated using a flame photometer. The concentrations of $SO_4$ and $NO_3$ were estimated using a spectrophotometer.

Samples were collected using an agricultural auger from the 0–25 cm horizons. A total of 12 soil samples were collected. The samples were air-dried at room temperature in the laboratory at 40°C before separating coarse elements from fine soil using a round-mesh sieve with a 2 mm mesh size. The fine soil samples were packed into numbered plastic bottles. Chemical element analysis of both water and soil was conducted at the Fertial Agronomic Laboratory in Annaba. The procedure for physicochemical analysis of water and soil included granulometric analysis of the latter. The analysed physicochemical and granulometric parameters underwent multivariate treatment using computer software tools (Statistica, Excel, Diagramme, and ArcGIS).

To check the reliability of the groundwater quality dataset, an ion balance error (IBE) test was also carried out using the equation (1) as given below: all the cation and anion concentrations are in mg/L, and all groundwater samples fall within the acceptable limit of +10%.

$$\mathrm{IBE} = \sum \frac{(\mathrm{Cations} - \mathrm{Anions})}{(\mathrm{Cations} + \mathrm{Anions})} \cdot 100 \tag{1}$$




Source: Authors' own study

**Fig. 5.** Variation of nitrate and nitrite concentrations in well water and drilling

### Soil

The methodological approach adopted for this work consisted of characterizing the soils through profiles aimed at providing an accurate representation of the soils and superficial formations (0–20 cm) for 17 soil samples in total that were taken in April of 2022, The soil element analysis was conducted at the Fertial Agronomic Laboratory in Annaba following criteria [APHA 2012] adopted in Algeria.

### Statistical analysis

The analytical data were processed using the Principal Component Analysis (PCA). Indeed, this multidimensional descriptive statistical method serves as an aid in interpreting data. The PCA is widely employed for interpreting hydrochemical data. The primary objective of this analysis is to synthesize and classify a dataset to extract the main factors underlying the simultaneous evolution of variables and their reciprocal relationships. It also highlights similarities between two or more chemical variables during their evolution.

The physicochemical data matrices consist of 'm' analyses (or measured elements). This method, by seeking the preferential elongation directions of a multidimensional point cloud (eigenvalues), summarizes information by projecting the point cloud onto its preferential directions (factorial axes). Factors are linear combinations of the original variables. Each variable contributing to the factor is associated with a coefficient called an eigenvector. For the analysis of chemical contents, where the ranges of variation may be disparate, it is appropriate to standardize these variables by centring and scaling them. To do this, the contents are centred around a mean of zero and divided by the standard deviation. The variance contributed by each variable is then equal to 1, and thus the total inertia (variance) of the point cloud is equal to $1 \times n$ if 'n' variables are processed on 'm' individuals. The first factorial axis is the one that explains the largest percentage of this total variance, while the second explains the largest percentage of residual variance.

## 3. Results and discussion

### Statistical data analysis

Sampling that was not carried out under optimal collection and storage conditions, analytical results should be interpreted with caution. However, for pollution analysis, one can rely on exceeding the maximum permissible concentrations (MPC) set by the WHO for drinking water, and on criteria for the quality of soil set by [APHA 2012].

As to chemical facies, the cations and anions based on their average values are in the following order: Mg, Ca, Na, K, and Cl, $SO_4$, $HCO_3$, $NO_3$. Moreover, this water (Fig. 6) is highly mineralized (electric conductivity > 1000 µS/cm) because of the intensive use of artificial fertilizers and to the poor quality of water irrigation.

The analysis of nitrate results (Table 1) shows that they vary from 11.66 mg/l to 61.66 mg/l in the wells. Among all the water points analysed from the wells, 5 of them exhibit high nitrate levels (P2, P3, P4, P5, and P7). The nitrite levels in the analysed water points fluctuate between a maximum concentration of $NO_2$ = 2.003 mg/l recorded in well 3 and a minimum of 0.12 mg/l in borehole 3, with an average of 1.12 mg/l. Consequently, the histogram of nitrite and nitrates variations illustrated in Figure 5 show that the water samples taken from all wells do not meet the WHO drinking water guidelines. However, the levels recorded in the borehole waters comply with drinking water standards. These relatively high levels are related to the spread of fertilizers and animal excrement (livestock points).

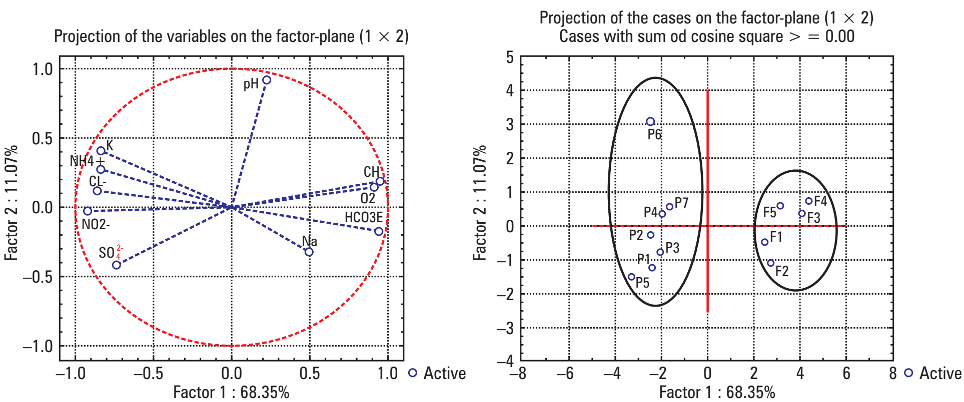
**Table 1.** Statistical parameters of the physicochemical elements of groundwater

| Variables (mg/l) | Mean | Min | Max |
|---|---|---|---|
| Ca | 94.92 | 51.50 | 189.31 |
| Mg | 84.26 | 34.07 | 160.12 |
| Na | 82.93 | 26.33 | 159.59 |
| K | 2.82 | 0.13 | 5.99 |
| Cl | 197.54 | 137.00 | 287.00 |
| $SO_4$ | 155.30 | 11.46 | 539.51 |
| $HCO_3$ | 70.70 | 26.33 | 102.56 |
| $NH_4$ | 0.31 | 0.10 | 0.60 |
| TH | 179.19 | 97.50 | 349.43 |
| $NO_2$ | 1.11 | 0.12 | 2.00 |
| $NO_3$ | 38.26 | 11.66 | 61.60 |
| EC (µS/cm) | 1756.29 | 1237.00 | 2196.00 |

The correlation matrix (Table 2) provides an initial approximation of the associations and the degree of linkage between the various parameters considered.

**Table 2.** Correlation matrix

| Variables | pH | CE | $HCO_3$ | TH | $NO_3^-$ | $NO_2^-$ | $Cl^-$ | Na | K | Mg | Ca | $SO_2^-$ | $NH_4^+$ | $O_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1.00 | | | | | | | | | | | | | |
| CE | 0.05 | 1.00 | | | | | | | | | | | | |
| $HCO_3$ | 0.05 | 0.85 | 1.00 | | | | | | | | | | | |
| TH | 0.39 | 0.80 | 0.77 | 1.00 | | | | | | | | | | |
| $NO_3^-$ | −0.15 | −0.87 | −0.67 | −0.86 | 1.00 | | | | | | | | | |
| $NO_2^-$ | −0.21 | −0.85 | −0.63 | −0.88 | 0.95 | 1.00 | | | | | | | | |
| $Cl^-$ | −0.03 | −0.89 | −0.91 | −0.73 | 0.73 | 0.69 | 1.00 | | | | | | | |
| Na | −0.04 | 0.58 | 0.55 | 0.35 | −0.24 | −0.24 | −0.45 | 1.00 | | | | | | |
| K | 0.21 | −0.82 | −0.60 | −0.72 | 0.87 | 0.88 | 0.60 | −0.40 | 1.00 | | | | | |
| Mg | 0.38 | 0.81 | 0.75 | 0.97 | −0.85 | −0.86 | −0.76 | 0.36 | −0.67 | 1.00 | | | | |
| Ca | 0.37 | 0.74 | 0.74 | 0.97 | −0.82 | −0.85 | −0.66 | 0.32 | −0.71 | 0.88 | 1.00 | | | |
| $SO_4^-$ | −0.46 | −0.70 | −0.54 | −0.63 | 0.71 | 0.66 | 0.67 | −0.26 | 0.44 | −0.59 | −0.63 | 1.00 | | |
| $NH_4^+$ | 0.01 | −0.78 | −0.70 | −0.82 | 0.80 | 0.88 | 0.64 | −0.38 | 0.88 | −0.81 | −0.77 | 0.34 | 1.00 | |
| $O_2$ | 0.32 | 0.85 | 0.71 | 0.73 | −0.78 | −0.72 | −0.74 | 0.60 | −0.61 | 0.71 | 0.70 | −0.83 | −0.59 | 1.00 |



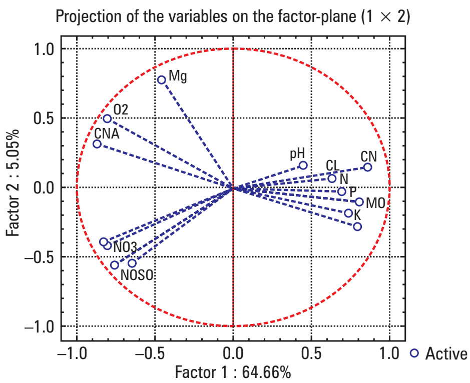

Source: Authors' own study

**Fig. 6.** The PCA for the entire groundwater data and distribution of individuals along the F1–F2 axis

## Modelling

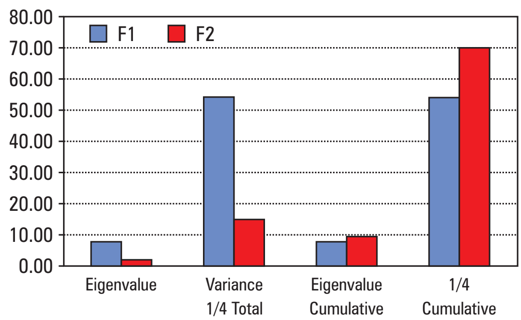
The ACP has positive loadings of TDS, EC, TH, $Mg^2$, Ca, K, O2, $Cl^-$, Na and suggests that groundwater chemistry primarily replicates the influence of natural sources, rock and mineral weathering, and anthropological activities. The positive loadings of $NO_3$, $NO_2$, $NH_4$ and pH, indicating ions, are primarily associated with human inputs, domestic sewage infiltration, unexpected irrigation practices, animal waste.

The graphical representation in the factorial space of the statistical units (Fig. 7) shows the distribution of water points according to the different factors (F1–F2). The overall analysis of these graphs highlights two clusters of water points.




Source: Authors' own study

**Fig. 7.** Correlation circle of the PCA for the entire soil data




Source: Authors' own study

**Fig. 8.** Graphical representation in the factorial space of statistical units

The class 1 comprises highly mineralized waters whose ionic acquisition is under the control of mineralization-residence time. These waters are essentially characterized by the highest values of electrical conductivity and total hardness (TH). These water points correspond to deep groundwater from wells rich mainly in minerals borrowed from the reservoir rock.

The class 2 groups water from well water points, with relatively low conductivity and TH values compared to water from boreholes. However, the nutrient levels are significant. It should be noted that the intersection of these different parameters may originate from contamination processes by various anthropogenic activities, particularly urban and rural agricultural activities. Numerous studies have identified different levels of groundwater and surface water pollution in the region [Benrabah et al. 2013, Hadjel et al. 2017, Daifallah 2017, Hadjel 2019]. They highlighted significant pollution by organic matter (nitrates, nitrites, phosphates).

### Granulometric and physico-chemical characteristics of the studied soils

Table 3 and the granulometric test according to [APHA 2012] shows that 41.67% of the soil samples have a sandy texture, 25% have a sandy-loamy texture, 16.67% have a clay-loamy texture, and 8.33% have a clayey texture. The characteristics of sandy texture are: well-aerated, easy to work with, low in water retention, low in nutrients, low anionic and cationic exchange capacity. Consequently, it does not promote the adsorption of nutrient or toxic chemical elements [Khouli 2023].

**Table 3.** Statistical values of the analysed soil parameters

| Variables (mg/l) | Mean | Min | Max |
|---|---|---|---|
| Ca | 0.67 | 0.20 | 1.30 |
| Mg | 15.30 | 4.60 | 29.89 |
| Na | 1.04 | 0.15 | 5.50 |
| K | 40.76 | 5.86 | 215.04 |
| $P_2O_5$ ppm | 37.01 | 83.01 | 7.80 |
| N % | 3.73 | 0.60 | 7.03 |
| Ct % | 1.91 | 0.00 | 2.73 |
| MO % | 1.96 | 0.40 | 4.20 |
| EC [mS/cm] | 0.23 | 0.06 | 0.74 |
| pH | 7.62 | 7.01 | 8.14 |

### Influence of agricultural practices

The results of studies conducted over several years by [Bouleknafet and Derradji 2017, Khelfaoui and Zouini 2010] studies on nitrogen, phosphorus, and TSS losses from the Kebir West watershed have highlighted the correlation between land use and water quality. Forested areas and extensive grasslands do not experience the same issues of nutrient increase in water as intensive agriculture and livestock areas.

**Table 4.** The PCA results for the entire dataset of sample soil data

| | F1 | F2 |
|---|---|---|
| Eigenvalue | 8.20 | 2.25 |
| Variance [%] | 54.66 | 15.03 |
| Cumulative variance [%] | 54.66 | 69.69 |
| Ca | 0.86 | 0.14 |
| Mg | –0.46 | 0.78 |
| Na | –0.80 | 0.33 |
| K | 0.79 | –0.28 |
| P | 0.74 | –0.11 |
| $SO_4$ | –0.65 | –0.55 |
| Ct | 0.63 | 0.08 |
| $NH_4$ | –0.81 | –0.41 |
| MO | 0.75 | –0.18 |
| $NO_2$ | –0.77 | –0.57 |
| $NO_3$ | –0.84 | –0.46 |
| $O_2$ | –0.81 | 0.50 |
| N | 0.70 | –0.01 |
| pH | 0.45 | 0.17 |
| EC | –0.87 | 0.32 |

Table 4 and the graphical representation in the factorial space of statistical units (Fig. 8) shows the distribution of water points and analysed soils according to different factors (F1–F2). The overall analysis of these graphs synthesizes the observations made on the variable distribution diagram and highlights 3 clusters of sampled points (boreholes, wells, and soil):

**Class 1** comprises all soil samples rich in fertilization substances (organic matter, potassium, carbon, nitrogen, phosphorus, and calcium).

**Class 2** comprises water samples taken from highly mineralized boreholes, where the ionic acquisition is controlled by mineralization-residence time. These waters are characterized primarily by their highest values of electrical conductivity.

**Class 3** comprises water samples from well points with relatively low conductivity values compared to borehole waters. However, the nutrient contents are significant. It should be noted that the intersection between these different parameters likely originates from contamination processes due to various anthropogenic activities, particularly urban and rural agricultural activities.

For all fertilizers, there is a risk of transfer to water, especially during the first days following their application, if precipitation occurs [Singh and Craswell 2021]. The input of nitrates into water and soil is not only linked to the use of chemical fertilizers but also to the use of animal and human waste in agriculture. Domesticated animal cultures use 70% of all rural land and 30% of the planet's land surface, being heavily responsible for such ecological issues, as the corruption of water quality, at each scale from local to worldwide [Bouderka et al. 2016].

## 4. Conclusion

The soil is very rich in nitrogen, phosphorus, and potassium due to the intensive use of fertilizers. Also, there is an enrichment of the surface horizon (0–20 cm) with OM, and decreases in salinity are the most important changes that we have noticed in the perimeter. As the quality of groundwater is concerned, the nitrate pollution is very alarming, with 45% of water samples (boreholes, wells, and springs) having nitrate concentrations above the limits admitted by the WHO (50 mg/l).

In this study, we measured the concentration of nutrient parameters in groundwater and soil. We then conducted the Principal Component Analysis (PCA) to identify contamination zones and potential sources of pollution related to agricultural activities. Groundwater generally exhibits a neutral to slightly alkaline nature. The cations and anions based on their average values are in the following order: Mg, Ca, Na, K, and Cl, $SO_4$, $HCO_3$, $NO_3$. The dominance of these chemical facies is to be found in the dissolution and solubilization of the constituent elements of the reservoir formation of the aquifer and environmental conditions, primarily linked to agriculture and pasturing, as well as soil leaching. The soil is very rich in nitrogen, phosphorus, and potassium due to the intensive use of fertilizers. Also, there is an enrichment of the surface horizon (0–20 cm) with organic matter. The spatial maps demonstrate that a higher contamination is observed in the most of the study area. The PCA has positive loadings of TDS, TH, Mg, Ca, and EC, and suggests that groundwater chemistry and soil quality are manifesting the influence of sol and human inputs, domestic sewage infiltration, unexpected irrigation practices, animal waste.

On the whole, this study has confirmed the pollution of groundwater and soil contamination in the alluvial plain of Boumaiza due to the agricultural intensification experienced in the region. In light of this alarming situation, unfortunately persisting over a longer period now, it is important to monitor the quality of water and soil using appropriate tools in order to correct and preserve the alluvial aquifer, which remains an important source for drinking water supply in this region.

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