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Qualitative evaluation of groundwater in terms of its suitability for drinking and irrigation. The case study of Sidi-Bel-Abbes alluvial aquifer (NW Algeria)

Valutazione qualitativa delle acque sotterranee in termini di idoneità alla potabilità e all'irrigazione. Il caso di studio dell'acquifero alluvionale di Sidi-Bel-Abbes (NO Algeria)

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Riassunto

La provincia di Sidi-Bel-Abbes è una regione semi-arida situata nell'Algeria nord-occidentale, principalmente utilizzata per attività agricole. Le sue risorse idriche sotterranee sono caratterizzate da un'elevata salinità che varia da una zona all'altra. Questo lavoro mira a migliorare la conoscenza di queste acque, attraverso la classificazione idrochimica, per definire le facies chimiche e per monitorare la loro evoluzione spaziale. Inoltre, la qualità di queste acque sotterranee è valutata per quanto riguarda la loro idoneità alla potabilità e all'irrigazione. I risultati ottenuti hanno mostrato che le acque sotterranee di Sidi-Bel-Abbes sono dominate dai cloruri, in particolare le facies cloruro calcica e sodica. Infatti, la distribuzione spaziale delle diverse facies chimiche conferma il contributo delle unità idrogeologiche adiacenti e l'interazione delle acque sotterranee con l'uadi Mekerra.

In termini di di idoneità alla potabilità, la concentrazione degli elementi chimici nella maggior parte dei campioni supera la concentrazione massima consentita dalla legislazione algerina, in particolare per i nitrati, i cloruri, il sodio ed il calcio.

L'interpretazione del diagramma di Riverside e Wilcox ha rivelato che le acque alluvionali di Sidi-Bel-Abbes sono generalmente caratterizzate da un'elevata salinità con un rischio per l'alcalinità medio-basso. Quindi, la qualità di quest'acqua è medio-bassa, sfruttabile per l'irrigazione, ma sotto determinate condizioni. Inoltre, le acque sotterranee non sono utilizzabili per alcune piante sensibili a causa del loro alto contenuto di ione cloruro (Cl). Inoltre, i risultati ottenuti indicano che l'uso di queste acque in irrigazione presenta bassi rischi per quanto concerne il sodio, il cui contenuto quindi non è in grado di modificare la struttura dei suoli nella piana di Sidi-Bel-Abbes o di ridurne la permeabilità.

Abstract

Sidi-Bel-Abbes province is a semi-arid area mainly used for agricultural activity in northwestern Algeria. Its groundwater resources are characterized by high salinity varying from one area to another. This work aims at improving our understanding of these waters, through hydrochemical classification, to define their chemical facies and monitor their spatial evolution. In addition, this groundwater's quality is assessed regarding their suitability for drinking and irrigation.

The obtained results showed that the groundwater of the Sidi-Bel-Abbes area is dominated by chlorides, particularly the chloride calcium and sodium facies. Indeed, the spatial distribution of the different chemical facies confirmed the contribution of adjacent hydrogeological units and the interaction between the groundwater and the Mekerra Wadi.

In terms of suitability for drinking, the maximum chemical element concentration accepted by the Algerian legislation is exceeded in most samples, especially for nitrates, chlorides, sodium and calcium.

The interpretation of Riverside and Wilcox diagram revealed that the alluvial groundwater of Sidi-Bel-Abbes is generally characterized by a high salinity with a low to medium alkalinity danger. Therefore, the quality of this water is medium to poor, suitable for irrigation, but under certain conditions. Also, the groundwater is unsuitable for sensitive plants because of its high chloride (Cl) ion content. Moreover, the results obtained indicate that the use of these waters in irrigation presents low sodium risks, and therefore are not likely to modify the structure of the soils in the Sidi-Bel-Abbes plain or reduce their permeability.

Introduction

The increasing global demand for water combined with unsustainable development in some regions of the world have significantly heightened the anthropogenic risk on water resources and placed almost one-third of the world's population at risk of water shortage (Gain & Giupponi, 2015; Vörösmarty et al., 2010). Indeed, according to future projections, at least 40% of the world's population will face serious challenges in securing clean water for drinking and agriculture (Gleick, 2003).

In semi-arid regions, the main factor constraining the exploitation of groundwater resources is their chemical quality as opposed to the available volume. The groundwater quality is deteriorating due to the intensive use of chemical fertilizers in agriculture, and particularly the uncontrolled exploitation of these resources (Gouaidia, 2008).

This quality degradation can cause the resource to be unsuitable for human consumption, industrial use, and affect agriculture if the mineralization levels exceed the crop plants salt tolerance (Kloppmann et al., 2011). According to Doneen (1962), the suitability of a water for irrigation does not depend on total salinity but on the salinity of highly soluble salts. Indeed, some plants developed adaptive and resilient mechanisms to some extent, yet salinity is reported to be one of the most controlling factors in crop productivity (Ashraf, 2004; Hedin, 1961; Shannon 1997).

According to Ghassemi et al. (1995) and Savoye (1998), water salinity is referred to as the concentration of salts and minerals. Furthermore, aquifer salinization can be defined as the process by which groundwater salinity increases resulting in the deterioration of its quality (Custodio, 2017; Velázquez, 2019).

Thus, salinization can result from: overexploitation of aquifers by pumping (saline intrusions into coastal aquifers or vertical exchanges, upwelling of deep saline waters), intensive agriculture, soil characteristics, and particularly the water quality used in irrigation (Kloppmann et al., 2011). Indeed, salinity is highly dependent on the host aquifer material of the water used in irrigation (Eriksson, 1977).

According to Gassemi et al. (1995), the estimated loss due to salinization is about US$12 billion per year; a figure that is likely to increase in the coming years as salinization steadily gains ground.

In Algeria, more than 20% of irrigated soils are affected by salinity (Bekkoussa et al., 2013; Bouhlassa et al., 2008; Douaoui & Hartani, 2007; Gouaidia et al., 2013; Megherfi, 2014; Rouabhia & Djabri, 2010). The plain of Sidi-Bel-Abbes is no exception to this type of risk, particularly with drought periods persisting for more than three decades, forcing farmers to use groundwater for irrigation (Bouanani et al., 2013; El Mahi et al., 2004; Ghenim & Megnounif, 2013; Meddi et al., 2009; Nouaceur et al., 2013; Otmane et al., 2018; 2021; Radia et al., 2021)

This study focuses on identifying the quality of groundwater in the Sidi-Bel-Abbes plain to supply potable and irrigation water. In addition, the main objective is to determine the origin and spatial evolution of this salinity to develop sustainable strategies against the risk of expanding the agricultural land degradation due to salinization.

Materials and methods

Presentation of the study area

Sidi-Bel-Abbes province hosts one of the most fertile plains in Algeria. It is characterized by an average altitude varying from 400 to 700m. It includes: Sidi-Bel-Abbes plain in the center; Belarbi plain in the East; Boukhanefis-Tabia plain in the South; Hassi-Zahana plain with undulating topography in the South West.

Sidi-Bel-Abbes plain, is an elongated depression, oriented WSW-ENE with an area of 1180.5 km², located between northern latitudes 34°86' and 35°22' and western longitudes 0°94' and 0°32'. It is part of the downstream Mekerra sub-watershed (Otmane et al., 2019; 2021). Geographically, the study area is limited by Tessala Mountains to the north, the Tabular Massif of Tlemcen and Saida to the south, Oued Isser basin to the west and Beni Chougrane and Bouhanifia Mountains to the east (Fig. 1). The Mekerra Wadi runs through the plain of Sidi-Bel-Abbes from the south to the north for about 50 km.

The study area includes a set of plains with heterogeneous topography. It features gently undulating landforms in the central and southwestern parts of the plain, where a few hills occur with an average altitude ranging between 500 and 800 m. The high altitudes are located to the south of the plain, exceeding 1000 m on the summits of the Tlemcen-Saida Mountains (Fig. 1b). The hydrographic network is relatively new, poorly developed, and currently being formed (Fig. 1a).

Geologically, the plain of Sidi-Bel-Abbes is a vast basin with an impermeable clayey-marl bedrock of Miocene or lower Pliocene age, covered by detrital quaternary formations, essentially conglomerate, sand and sandstone deposits alternating with silts, originating from the disaggregation of the surrounding reliefs (Sourisseau, 1972). Hydrogeologically, the area is defined by four different entities: the Jurassic-Cretaceous limestones in the South; the Plio-Quaternary alluvial in the center; the Pliocene sandstones of the Ténira forest in the East; the Eocene limestones of Sidi-Ali-Boussidi in the North (Fig. 1a).

In terms of climate, the study area is characterized by a semi-arid climate, with an annual rainfall not exceeding 500mm. Hence, two different areas can be identified: a rainy, cold and relatively low amplitude mountain climate and a dry, relatively hot and high temperature range lowland climate (Khaldi, 2005).

The pedological map is based on 138 pedological profiles and physico-chemical analyses that are reasonably representative (Fig. 2). The profiles selected are based on homogeneous zones determined by an information overlay (slope, geology, altitude) (Faraoun & Benabdeli, 2010). The most common soil type in the plain is brown limestone.

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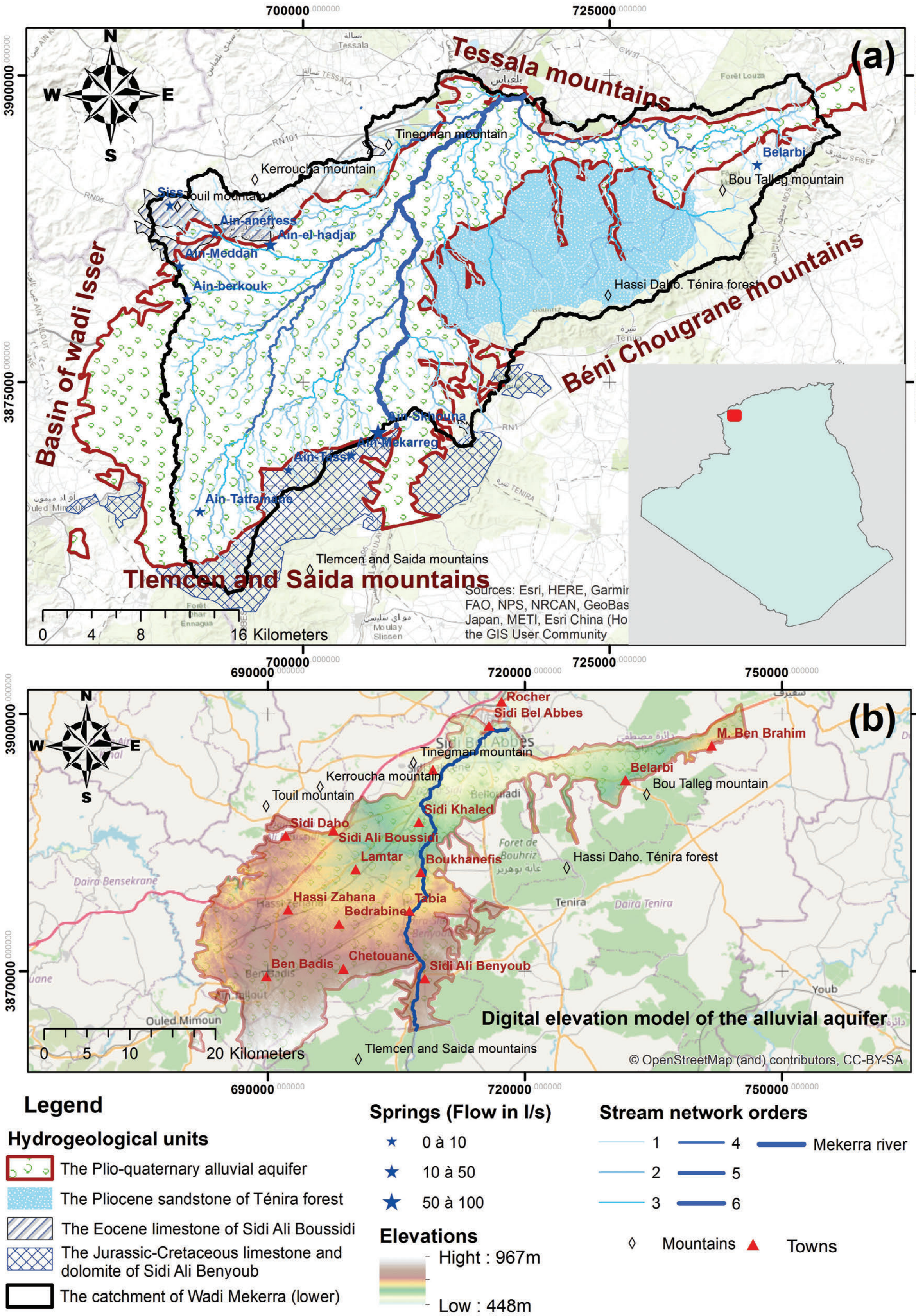

Fig. 1 - Geographical location of Sidi-Bel-Abbes plain (a). Digital elevation model (b).

Fig. 1 - Posizione geografica della piana di Sidi-Bel-Abbes (a). Modello di elevazione digitale del terreno (b).

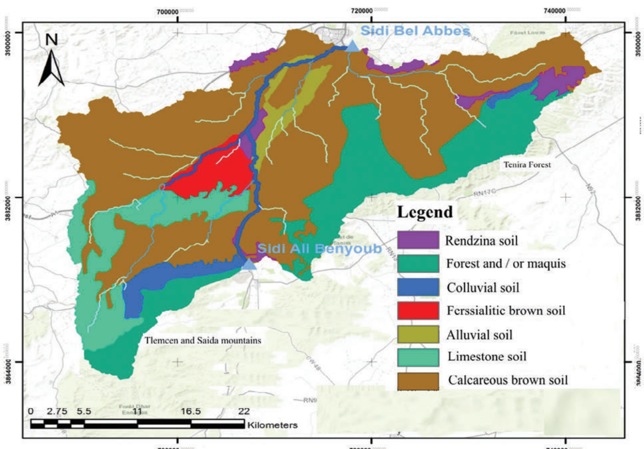

Fig. 2 - Soil types of Sidi-Bel-Abbes Plain.

Fig. 2 - Tipi di suolo della Piana di Sidi-Bel-Abbes.

Methodology

The methodology adopted in this study consists in firstly to determine the physico-chemical characteristics of the water, and to identify the various chemical facies. Then, using a GIS, we proceeded with geostatistical interpolation technique known as ordinary kriging to map the spatial evolution of each chemical element, and consequently to highlight the chemical interactions that may exist between the groundwater and its environment.

Indeed, the interpolation method adopted is considered to be a useful technique for the monitoring, evaluation and management of groundwater resources (Arslan, 2012).

To illustrate the intensity of agricultural activity, it is very useful to draw up a land use map. This was produced, from Landsat 8 spatial data collected on March 14, 2022, in ENVI 5 software. Based on the requirements of this study, two visible channels were used: band 2 (blue) and band 3 (green) with spectral ranges of 0.452-0.512 µm and 0.525-0.600 µm, respectively, as well as infrared band 5 (0.851-0.879 µm) (Bannari et al., 2004).

The thematic maps were produced in a GIS environment after positioning the sampling points. The corresponding data was reclassified and processed to create iso-contour maps.

The Base Exchange Index (b.e.i) or Chloro-Alkaline Imbalance Index, established by Schoeller (1934), describes the interactions between groundwater and the rock formation. It is expressed by the following formula:

$$b.e.i = \frac{rCl^{-} - r\left(Na^{+} + K^{+}\right)}{rCl^{-}}$$

Where Cl^-, Na^+, K^+ are given in meq/L.

According to Schoeler:

- If b.e.i > 0 the Na^+ and K^+ ions from the water are replaced by Ca^{2+} and Mg^{2+} from the rock formation;
- If b.e.i < 0 the Ca^{2+} and Mg^{2+} ions are replaced by the Na+ and K^+ from the formation;
- If b.e.i = 0 there is no ionic exchange between the rock and the groundwater (equilibrium state).

The risk of permeability decrease is one of the main irrigation parameters and is determined by the Sodium Absorption Ratio (S.A.R.). This is defined by the following formula (Oster & Sposito, 1980):

$$SAR = \frac{rNa^{+}}{\sqrt{\frac{rCa^{2+} + rMg^{2+}}{2}}}$$

The concentrations are given in meq/L

- SAR<10: the used water presents a minor risk of soil alkalization;
- 10<SAR<18: the used water presents a moderate risk of alkalinization;
- 18<SAR<26: the used water can cause alkalinization;
- SAR>26: the used water presents a very high risk of alkalinization.

Finally, to properly understand the groundwater salinity phenomenon in the studied area, it is interesting to determine the spatial evolution of the aquifer's thickness. Therefore, the geo-electric profiles from the CGG campaign of 1970 (Compagnie Générale de Géophysique) were used to extract the bedrock's depth. Subsequently, the aquifer thickness map was produced using a Digital Elevation Model ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) in a GIS environment.

Sampling technique and method of analysis

The samples were taken after a long sufficient pumping for the water contained in the casing to exchange. Next, in order to reduce the risks associated with sample contamination, we followed the ISO 5667 standard with regard to sampling techniques, sample storage and the different types of recipients used.

In addition, we have taken into account the conservation of the samples when they are sent to the lab (keep the samples in a cool box at a temperature of 4 to 10 degrees Celsius).

The analytical methods used to determine the major chemical elements are summarized in Table 1.

Tab. 1 - Methods and instruments used in the lab.

Tab. 1 - Metodologie e strumentazioni utilizzate in laboratorio.

	Elements	Methods	Standard
Anions	Calcium	EDTA titrimetric method	ISO 6058:1984
	Magnesium	EDTA titrimetric method	ISO 6059:1984
	Sodium	Emission spectrometric method	ISO 9964-3:1993
	Potassium	Emission spectrometric method	ISO 9964-3:1993
Cations	Sulfate	Method by continuous flow analysis (CFA)	ISO 22743:2006
	Bicarbonate	Total soluble alkalinity-Titrimetric method	ISO 740:1976
	Chloride	Mohr's method	ISO 9297:1989(fr)
	Nitrate	Spectrometry with sulfosalicylic acid	ISO 7890-3:1988

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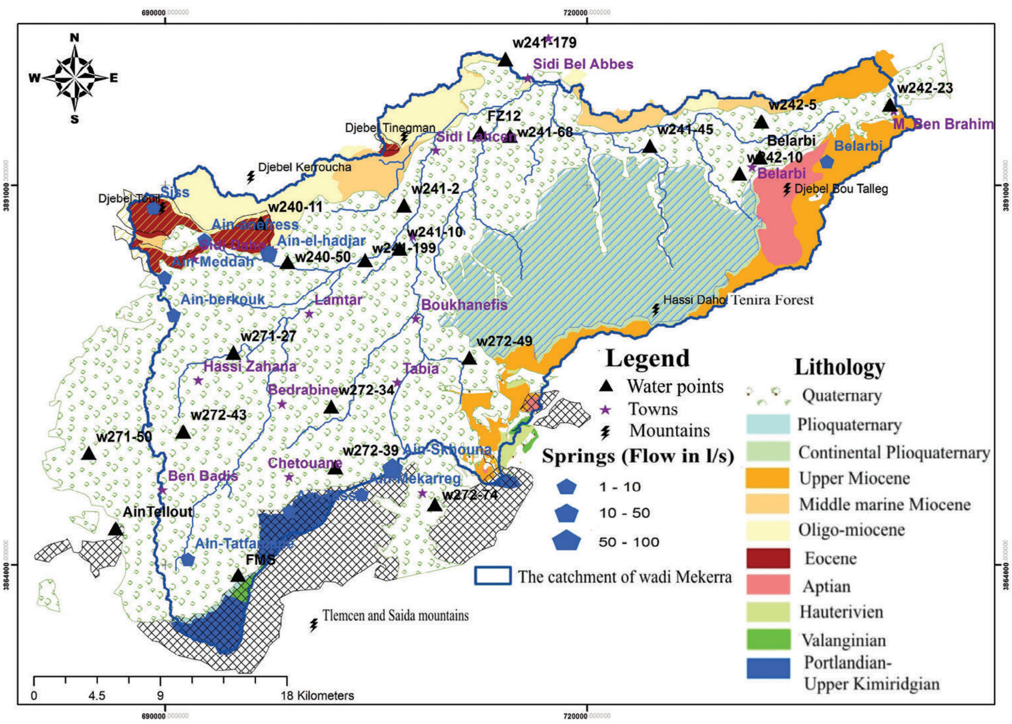

Fig. 3 - Location of water points (June 2018).

Fig. 3 - Posizione dei punti di prelievo delle acque (Giugno 2018).

Moreover, the temperature, pH and electrical conductivity were measured in situ, using a thermometer, pH-meter and conductivity-meter respectively. On the other hand, alkalinity was measured by titration in a bucket placed at the pump discharge.

This study is based on data collected during a sampling campaign carried out in June 2018 at 22 well-distributed water points in the plain (Fig. 3 and Appendix 1).

Results and discussion

The physical parameters analysis revealed that pH values vary little, and is close to neutrality for most samples (between 7.05 and 7.8). The alkalinity of the water in the plain is low, where the Alkalimetric Title (A.T) equals 0 and the Complete Alkalimetric Title (C.A.T) varies between 42.2°F at borehole w241-10 and 14.85°F at borehole w240-11 (Appendix 2).

Water mineralization

According to the limits set by the Algerian legislation on the water Quality (Official Journal, 2011) , the dry residue analysis results revealed that only two samples (FMS and Ain-Tellout) present a good taste character (Appendix 2). The spatial distribution of the dry residue and electrical conductivity are very well correlated. In fact, the areas of high iso-conductivity values coincide with those of high dry residue values.

Thus, the dry residue indicates low concentrations in the southeastern region of Ben-Badis and at the center of the aquifer (Boukhanefis) (Fig. 4). Moderate and high concentrations are recorded in the north of the study area and in the Bedrabine, Lamtar and Sidi-Ali-Boussidi sector. This difference in mineralization is associated with:

- The dissolution of the evaporite Mio-Oligocene formations in the north.
- Geological facies change from alluvium with good permeability, to a finer sedimentation, especially between Sidi-Khaled and Sidi-Lahcen, leading to a slower circulation and longer water/rock contact time.
- The depth of water table (piezometric level) is shallow (significant drop in relief from Boukhanefis to the outlet of the Rock) which leads to a significant increase in evapotranspiration.
- Interaction between the aquifer and the Wadi, particularly in the Tabia-Boukhanefis sector.
- Water contributions from adjacent hydrogeological units.

In addition to the natural factors mentioned above, the intensive overpumping of groundwater for irrigation is returned to the aquifer, through infiltration, but highly concentrated with salts. Indeed, fertilizers and pesticides used in agriculture, and domestic discharges contribute significantly to the salinity of the water.

Electrical conductivity values range from 778 to 7870 µS/cm (Appendix 2). The iso-conductivity map displays a highly significant variation from south to north and from the center to plain boundaries (Fig. 4). Low to medium values are concentrated in the south and center (500-1500 µS/cm), following channels with good transmissivity. While, the highest values (above 1500 µS/cm) are found in the North, at the contact of the Eocene limestone between Sidi-Ali-Boussidi and Sidi-Kaled, the Aptian limestone and the Pliocene sandstones at the bottom of the Caid-Belarb valley. This gradual increase in conductivity indicates that this groundwater is in permanent contact with the enclosing rock formation, allowing its enrichment in dissolved salts and confirms the contribution of limestone and sandstone of other aquifers.

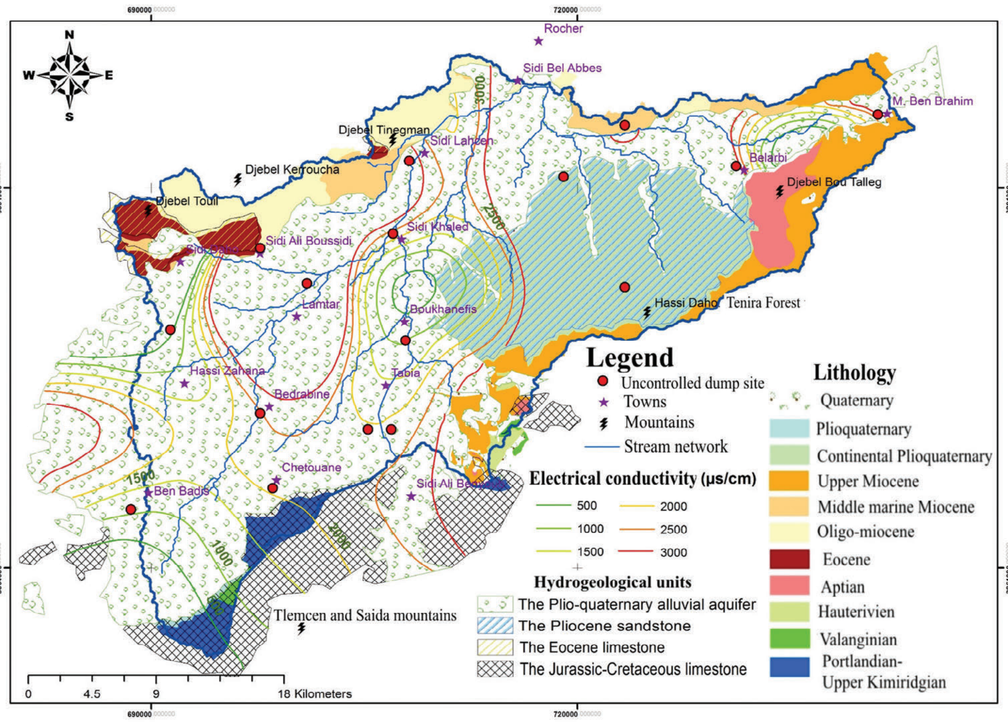

Fig. 4 - Spatial evolution of the electrical conductivity.

Fig. 4 - Andamento spaziale della conducibilità elettrica.

Cation and anion contents

The chemical element analysis is acceptable for all samples as the error on the ionic balance < 5%.

The calcium iso-values map (Fig. 5a) indicates an upstream to downstream increase, ranging from 62 mg/L at Ain-Tellout to 1267 mg/L at F240-50. High contents are mainly found at the limit of karstic areas, associated with carbonates dissolution, particularly, those of the Eocene formations located northwest of Sidi-Ali-Boussidi. On the other hand, the low calcium contents are located near the rivers (less than 300 mg/L) indicating a contribution of the river to the aquifer's recharge.

Magnesium contents are low compared to calcium, and are concentrated near the marl and clay soils of the Mio-Oligocene (Fig. 5b). Na^+ + K^+ concentrations range from 37mg/L (Ain-Tellout) to 630mg/L (w240-50), and vary in the same way as chlorides (Fig. 5c).

The high chloride concentrations at the northern limit of the plain, causing the high groundwater salinity, are thought to have an evaporitic origin linked to the Mio-Oligocene bedrock. Thus, the high chloride contents (varying between 2876 mg/L and 80 mg/L) are recorded upstream of the plain, where the depth of the water table is shallow (Fig. 5d).

The sulfate variation pattern can be explained by the leaching of the Mio-Oligocene clayey-gypsum formations to the north, resulting in their concentration increase from the south to the north of the plain, and/or anthropogenic pollution by fertilizers used in agriculture, especially in the Sidi-Lahcen and Belarbi areas (Fig. 5e).

The bicarbonate contents oscillate between 24 mg/L (w271-27) upstream of oued Tissaf and 515 mg/L (w241-10) downstream, following the main flow axis. Indeed, the highest values are concentrated in the South and near the Mekerra and Tissaf Wadis. It is probably related to the contributions of the Jurassic-Cretaceous limestone springs in the South and to a reduction of sulfates in the East of the plain. These values are less pronounced towards the center of the plain (Fig. 5f).

The analysis of the land use map shows that our study area is dominated by agriculture, particularly in the downstream zone (Fig. 5h), which explains the high level of nitrates (exceeds the quality norms) and consequently the excessive use of fertilizers (Fig. 5g).

In terms of water potability, the maximum chemical element concentration allowed by the Algerian legislation is exceeded for chlorides, sodium and calcium for most samples. On the other hand, the Hydrometric Title (HT) shows us that the most water points (15 samples) have fresh water with HT lower than 75 mg/L, while six are moderately hard (75 < HT in mg/L < 150) and only one sample is hard (HT = 182.55mg/L) (Appendix 2). Therefore, the water quality is acceptable in places, but mostly poor to bad for the majority of the samples.

Chemical facies of water

The classification of Sidi-Bel-Abbes groundwater plain according to the Piper and Stabler diagrams (Fig. 6) reveals the abundance of the chloride facies (68.18% of samples), with 36.36% of the chloride-calcic waters and 31.82% of sodium chloride waters. On the other hand, the bicarbonate facies appear to be relatively infrequent with a percentage of 27.18%, including 22.73% of calcium bicarbonate waters and only 4.54% of sodium bicarbonate waters. However, the most rare facies in our study area is that of sodium sulphate, with only one water point (4.54%).

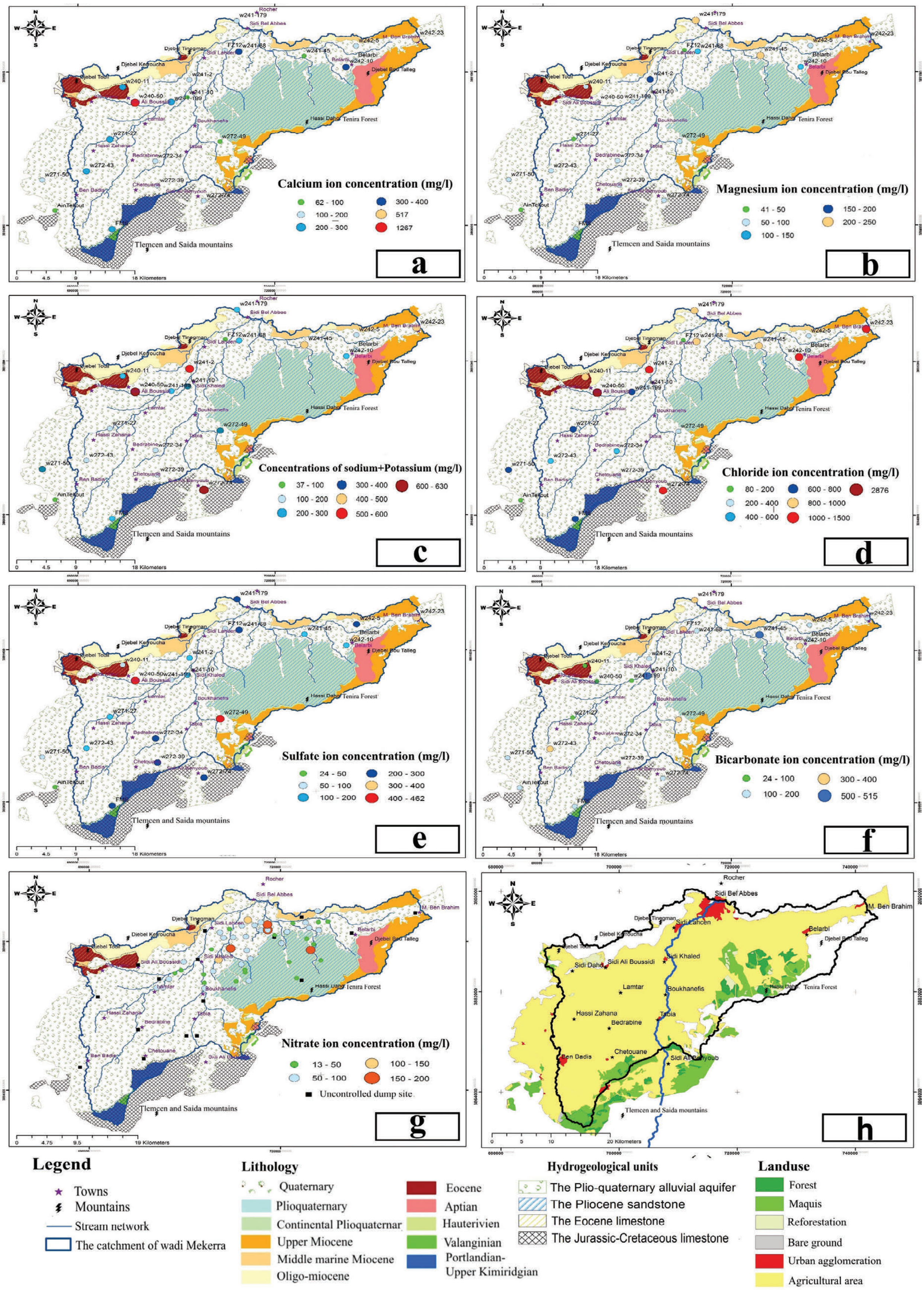

Fig. 5 - Spatial evolution of cation and anion contents (a: Calcium; b: Magnesium; c: Sodium and Potassium; d: Chloride; e: Sulfate; f: Bicarbonate; g: Nitrate; h: Landuse).

Fig. 5 - Andamento spaziale del contenuto di cationi e anioni (a: Calcio; b: Magnesio; c: Sodio e Potassio; d: Cloruro; e: Solfato; f: Bicarbonato; g: Nitrato; h: Uso del suolo).

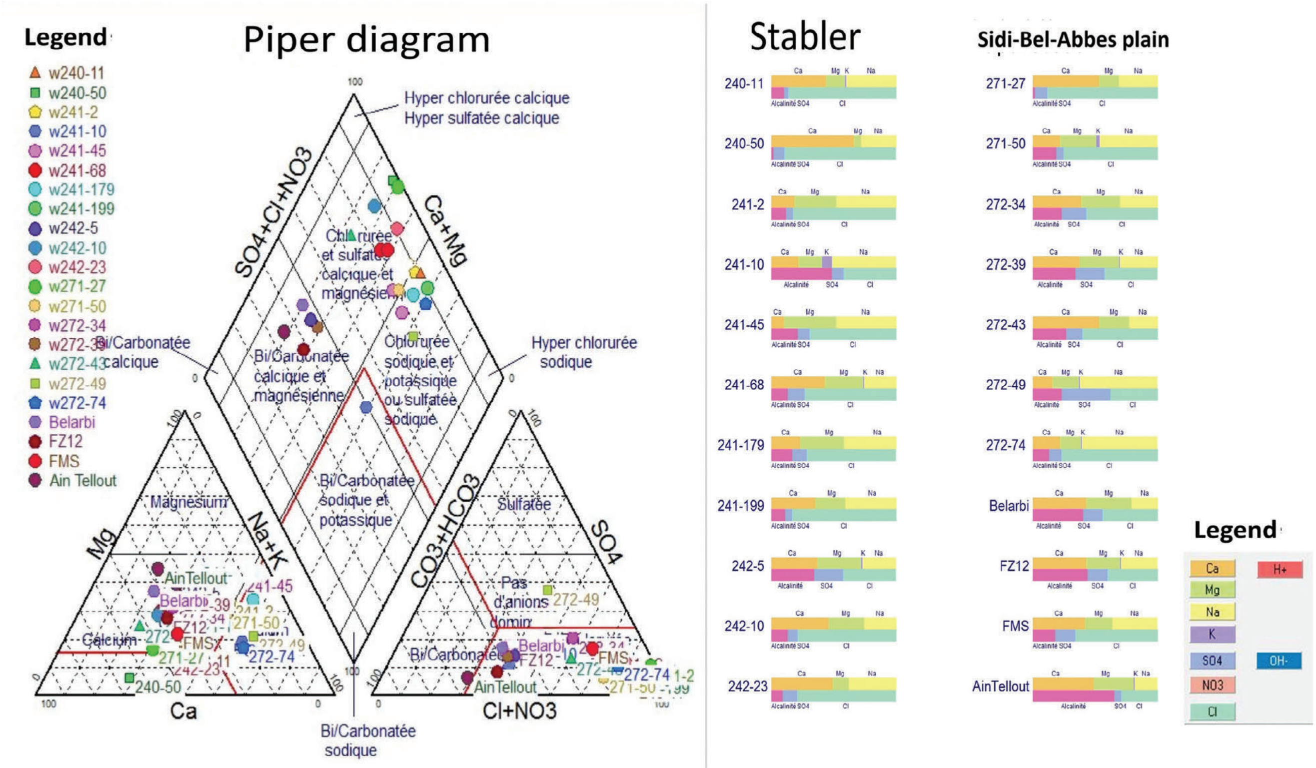

Fig. 6 - Sidi-Bel-Abbes Groundwater classification with Piper and Stabler diagrams.

Fig. 6 - Classificazione delle acque sotterranee di Sidi-Bel-Abbes tramite i grafici di Piper e Stabler.

The spatial representation of the chemical facies of the samples shows (Fig. 7):

- **Calcium bicarbonate waters**: generally found upstream at the southern limit (in contact with the Jurassic-Cretaceous limestone "open limit") and eastern limit (in contact with the Aptian limestone). Five Water samples (22.73%) are in these facies and reflect the circulation of groundwater in coarse alluvium (gravels, pebbles). In addition, it confirms the contribution of adjacent aquifers to the recharge of the alluvial aquifer, especially during low water periods when overexploitation is intense, causing an overflow condition (Otmane et al., 2021).
- **Sodium bicarbonate waters**: represented by only one sample (4.54%) located south of Sidi-Lahcen (center of the plain). Its occurrence may result from the leaching of the existing rocks and probably from the infiltration of surface water.
- **Chloride-calcic waters**: This is the most common facies and includes to the majority of the samples (36.36%) spread over the entire plain.
- **Sodium chloride waters**: usually located on the limits of the plain near the Miocene and the Pliocene sandstones of the post-nappe formations, these facies are also found in the Jurassic-Cretaceous karstic terrains (272-74). It constitutes 31.82% of the total samples analyzed.
- **Sodium sulphate waters**: represented by a single water sample located northeast of the Tabia city, just at the limit of the Pliocene sandstone.

According to the Base Exchange Index established by Schoeller (1934), most of the calculated values are positive (Appendix 2). Therefore, K^+ and Na^+ from the groundwater are exchanged for Ca^{2+} and Mg^{2+} from the host rock. On the other hand, the water-points w272-49 and w241-10 have negative values indicating that Ca^{2+} and Mg^{2+} from the groundwater are exchanged for Na^+ and K^+ from the host rock.

Thus, the aquifer formation in the study area releases much more calcium than sodium and potassium, and is marked by an exchange of alkalis, resulting in the relationship $rCl^- - r(Na^+ + K^+) > 0$. This implies that groundwater is charged with chlorine more quickly than with sodium and potassium.

Alkalinity hazards

For agriculture, the assessment of the alluvial groundwater quality used for irrigation is based on salinity and the risk of soil alkalinization (Dosso, 1980). Indeed, the salts contained in irrigation water can migrate and infiltrate primarily by fluid. Therefore, the content of soluble salts in the soil is detrimental to agricultural production. The main irrigation criteria include conductivity, toxic elements and the permeability drop evaluated by the Sodium Absorption Ratio (SAR). The SAR results oscillate between 0.82 and 9.07 (Appendix 2). The projection of the different values obtained with those of the conductivity on the diagram of Riverside yielded the following results (Fig. 8):

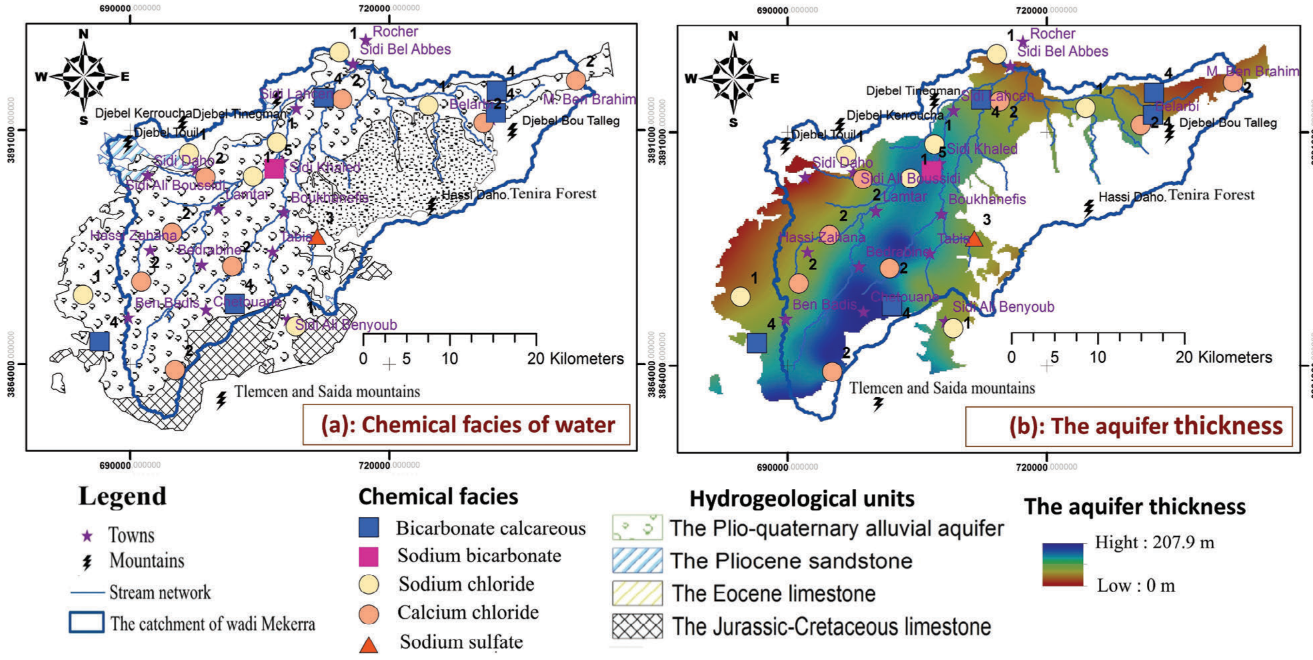

Fig. 7 - The spatial representation of chemical facies according to the various hydrogeological units (a) and the thickness of the alluvial aquifer (b).

Fig. 7 - Rappresentazione spaziale delle facies chimiche a seconda delle diverse unità idrogeologiche (a) e spessore dell'acquifero alluvionale (b).

– Most of the analyses belong to the classes (C4, S1), (C4, S2) with a high salinity and exhibit a low to medium alkalinity hazard. On the other hand, sample 272-74 shows a strong alkalinity hazard (C4, S3). According to the Wilcox diagram, this water category is of poor to bad quality (Fig. 8), suitable for irrigation of certain species with good salt tolerance and on well-drained and leached soils.
– Very high salinity waters with a low alkalinity hazard (C5S2) characterize some samples. This water of very poor quality is generally not suitable for irrigation, but can be used under certain conditions (very permeable soil, good leaching, and plants tolerating salt very well).
– The water samples from Belarbi, Ain-Tellout and FMS are ranked as of medium salinity with a low danger of alkalinity (C3, S1), which explains their good qualities (Wilcox diagram). Sample 241-10, on the other hand, belongs to the C3S2 class, characterized by a medium alkalinity hazard and acceptable quality.

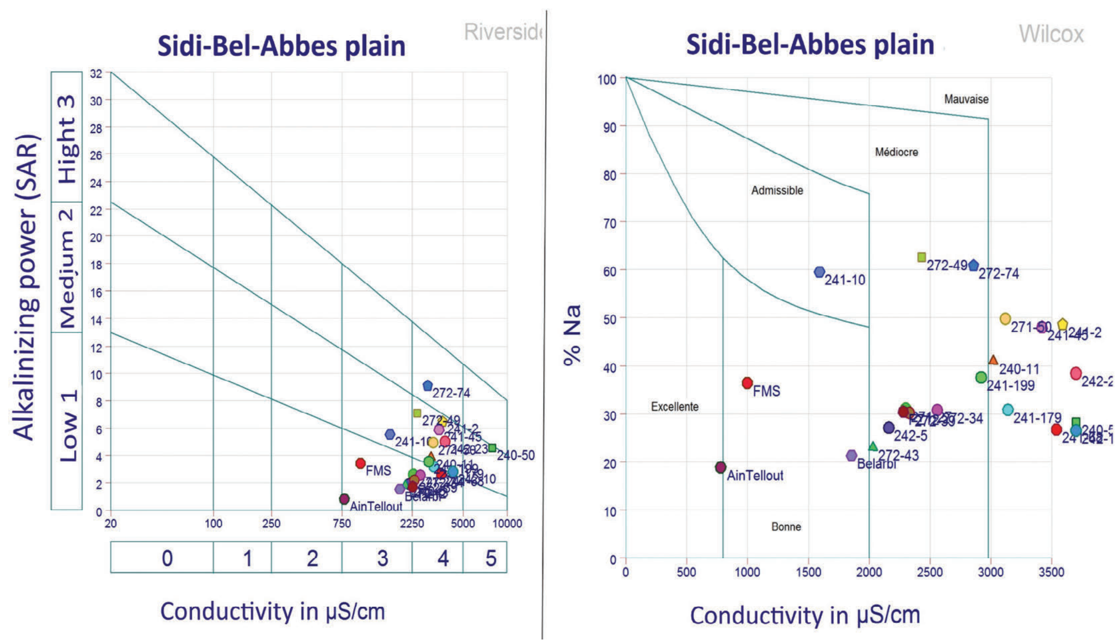

Fig. 8 - Water classification of the Sidi-Bel-Abbes alluvial aquifer according to the Riverside and Wilcox diagram (June 2018).

Fig. 8 - Classificazione delle acque dell'acquifero alluvionale di Sidi-Bel-Abbes secondo il diagramma do Riverside e Wilcox (Giugno 2018).

The use of water with high electrical conductivity (EC) leads to a decrease in crop productivity due to the inability of plants to compete with ions in the soil for water (physiological drought). Indeed, the salinity at the root zone increases the osmotic pressure of the soil solution and leads to a reduction in the rate of water uptake by the plants. Thus, the higher the EC, the less water there will be for the plants; this can result in continuous water deficiency, even if the soil is constantly irrigated (Saleh et al., 1999).

Conclusion

The Hydrochemical study of groundwater in Sidi-Bel-Abbes alluvial aquifer reveals the importance of water salinity in contact with the evaporite formations, particularly in the north and northeast of the plain. As opposed to the other parts of the plain where it would be low to moderate under the predominance of waters coming from carbonate environments (Jurassic-Cretaceous limestone in the south) and aquifer-river interaction (the Tabia-Boukhanefis sector).

Moreover, the analysis of the electrical conductivity values reveals a risk of salinity, regarding their use in irrigation. Indeed, almost half of the analyzed samples (nine samples) have EC values above 3000 (µS/cm). Therefore, their uses in irrigation must be followed either by extensive leaching or by drainage of agricultural land.

The interpretation of the Riverside diagram showed that most of the samples are characterized by high salinity with low to medium alkalinity hazard. According to the Wilcox diagram, this category of water is of poor to bad quality, On the other hand, the water points of Belarbi, Ain-Tellout and FMS are classified as medium salinity water, with a low danger of alkalinity, which explains their good qualities.

So, the adaptability of the alluvial groundwater to irrigation requires, depending on the case, either extensive leaching or drainage. However, this work has shown that these waters are inappropriate for sensitive plants because of their high toxicity in chloride ions ($Cl>350$ mg/L). Also, the results found show that the use of water from the plio-quaternary aquifer in irrigation presents low risks in sodium ($SAR<10$), so they are not likely to modify the structure of the soils in the plain of Sidi-Bel-Abbes or to reduce their permeability.

On the other hand, the result of the base exchange index shows that the aquifer formation releases much more calcium than sodium and potassium, and the groundwater is loaded with chlorine faster than sodium and potassium. This explains the abundance of chlorinated calcium/sodium facies, corresponding to the majority of the samples collected (more than 68%) and covering practically the entire plain.

According to the limits set by Algerian legislation on the potability of groundwater, the quality of the water is acceptable in places, but mostly poor to bad for the majority of samples, due to high levels of nitrates, chlorides, sodium and calcium.

From these results, we can conclude that the salinity of the water is principally derived from the dissolution of the evaporite Mio-Oligocene formations. Nevertheless, anthropogenic factors such as intensive overexploitation of the groundwater and agricultural activities (fertilizers, pesticides and the return phenomenon of irrigation water charged with salts) will contribute to the severity of this phenomenon.

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Competing interest

All authors states that there is no conflict of interest.

Author contributions

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Additional information

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