

Groundwater Quality Assessment And Vulnerability To Mineral Pollution, And Implications For Sustainable Water Use In The Arid Region (Ouargla Basin) Southeastern Algeria

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Abstract

This study aims to assess the vulnerability of groundwater to mineral pollution in the arid region of Ouargla, Southeastern Algeria. Eighteen groundwater samples were collected from boreholes tapping into various aquifers, particularly the Terminal Complex (TC), which is a key source of drinking water. A set of physicochemical parameters was analyzed in the laboratory, including pH, electrical conductivity, turbidity, calcium, magnesium, sulfates, chlorides, and bicarbonates. The results showed a wide variability in water quality, with elevated salinity and mineral content in several locations. To quantify the extent of contamination, a Mineral Pollution Index (MPI) was introduced and applied using spatial analysis software (Surfer 22), allowing for the development of vulnerability maps. The findings highlight the spatial distribution of pollution levels, from low to very strong, and underscore the impact of both natural geology and anthropogenic pressures on groundwater quality. The proposed MPI-based mapping approach provides a valuable decision-support tool for sustainable water resource management in arid environments.

Keywords: Groundwater, Mineral pollution, Vulnerability mapping, Ouargla, Arid zones, MPI.

1. INTRODUCTION

Water resources are an essential component of sustainable development, as they must meet the needs of current generations without compromising the ability of future generations to meet theirs. Groundwater, in particular, plays a critical role in arid and semi-arid regions, where surface water is scarce or absent. While natural processes such as sedimentation and dilution can attenuate pollutants over time, these mechanisms become insufficient in the presence of elevated pollution loads. Increasing urbanization, agricultural intensification, and industrial activities have led to the discharge of harmful substances into aquifers, significantly degrading water quality [1,2].

Groundwater pollution occurs when foreign substances exceed the natural capacity of the aquifer to neutralize or remove them. These pollutants may originate from natural geological sources—such as saline or mineral-rich formations—or from anthropogenic sources, such as fertilizers, industrial effluents, and household waste [3,4]. In Algeria, groundwater resources represent a strategic reserve, especially in the Saharan regions, where they are extensively exploited for drinking, irrigation, and industrial use. However, the quality of these waters is increasingly threatened, particularly in the Ouargla basin in Southeastern Algeria.

The Ouargla region is located in a large structural depression characterized by arid climatic conditions, limited rainfall, high evaporation, and a growing demand for water. Its main aquifer systems include the Continental Intercalary and the Terminal Complex, which are heavily used for human consumption and irrigation [5,6]. These aquifers are highly vulnerable to mineral pollution, especially due to the dissolution of evaporitic formations, agricultural return flows, and poor sanitation infrastructure [7,8].

This study focuses on evaluating the mineral pollution of the Terminal Complex aquifer in the Ouargla basin. It aims to (i) assess the physicochemical quality of groundwater through field sampling and laboratory analysis, (ii) propose and apply a Mineral Pollution Index (MPI) to classify and quantify

contamination levels, and (iii) generate vulnerability maps using Surfer 22 software. The resulting analysis provides critical insights into spatial variability in groundwater quality and offers a decision-making tool for environmental planning and sustainable resource management.

2. MATERIALS AND METHODS

2.1. Study Area

The Wilaya of Ouargla is located in southeastern Algeria, covering a surface area of approximately 163,230 km². It is one of the largest administrative divisions in the country, with a population estimated at 640,368 in 2015 and 653,358 in 2022 [5]. It is bounded to the north by the wilayas of Djelfa, El Oued, and Biskra, to the east by Tunisia, to the west by Ghardaïa, and to the south by Tamanrasset and Illizi.

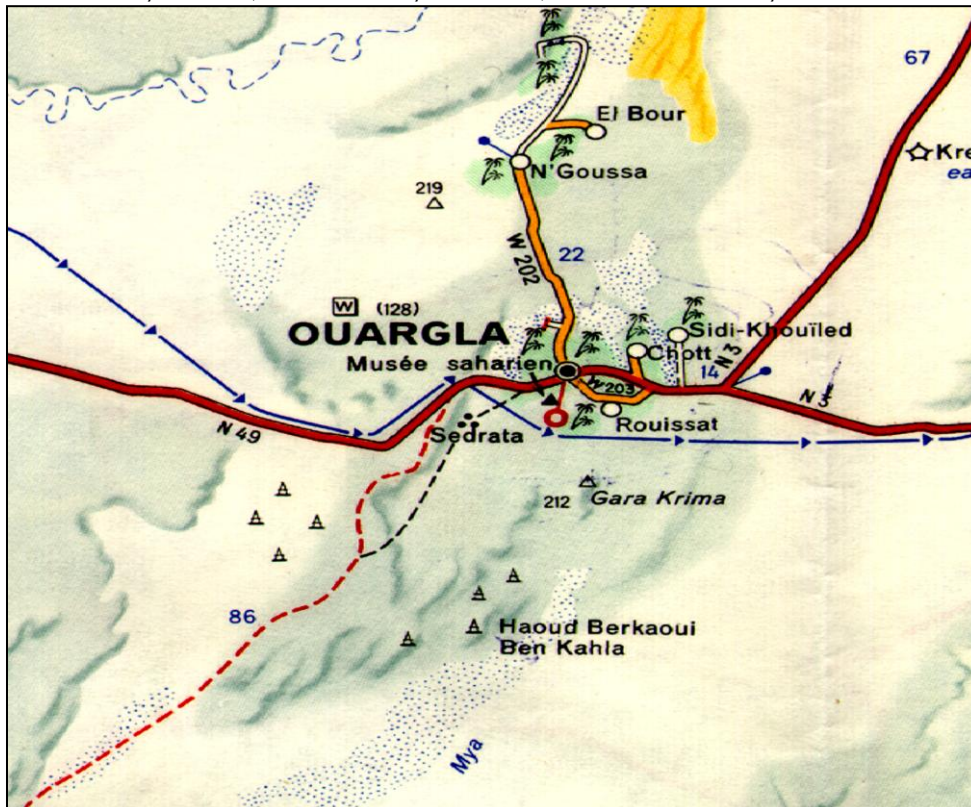


Fig. 01. Geographical location of the study area.

The urban area of Ouargla lies within a geological depression or "bowl" that comprises several settlements, including Ouargla, N'Goussa, Rouissat, Aïn El Beïda, and Sidi Khouiled, extending over 750 km² [6]. The basin is bordered by Sebkhia Safioune to the north, the ergs of Touil and Arifdji to the east, the dunes of Sedrata to the south, and the M'Zab ridge to the west.

Table 01. Communes and districts of Ouargla region

Districts	Communes
Ouargla	Ouargla, Rouissat.
N'goussa	N'goussa.
Sidi Khouiled	Sidi Khouiled, Aïn Beïda, Hassi Ben Abdellah
H. Messaoud	Hassi Messao.
El Borma	El Borma.
El-Hadjira	El-Hadjira, El-Alia.
Temacine	Temacine, Blidet-Amor.
Touggourt	Touggourt, Nezla, Tebesbest,

Megarine	Megarine, Sidi Slimane.
Taïbet	Taïbet, Bennaceur M'Nagueur.

2.2. Climate Conditions

Ouargla is characterized by a hot arid desert climate (BWh, Köppen classification), with extreme summer temperatures, low annual precipitation, and very high evaporation rates due to low relative humidity. These conditions exacerbate water scarcity and increase the reliance on deep groundwater resources [8].

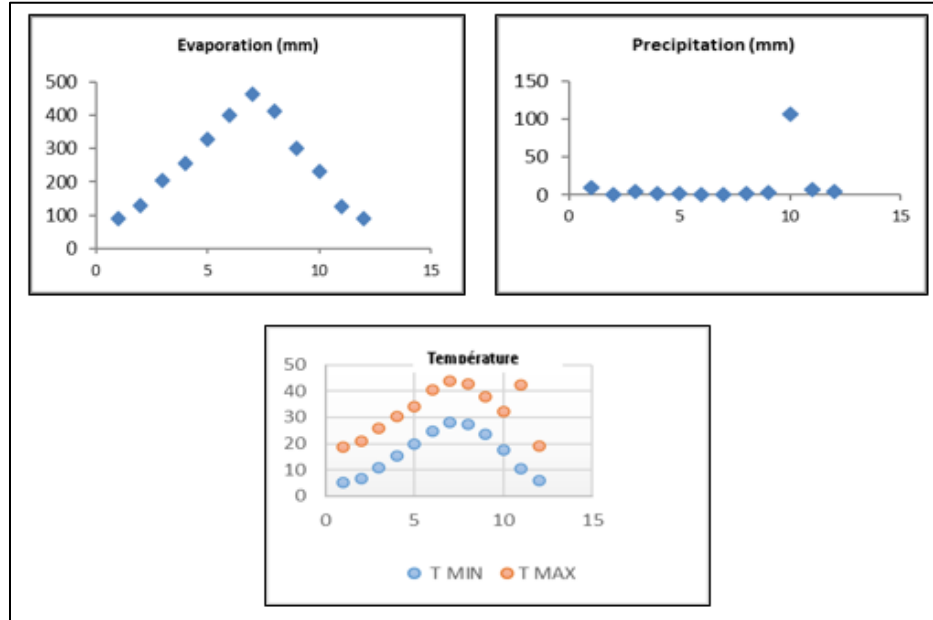


Fig 02. Evolution of meteorological parameters

2.3. Hydrogeological Setting

The main aquifer system in the region is the Terminal Complex (TC), which provides water for domestic and agricultural use. The aquifer comprises sandy and calcareous formations and is particularly sensitive to contamination due to its shallow depth in certain areas and the presence of evaporitic layers [6,7].

2.4. Sampling and Analysis

A total of 18 groundwater samples were collected from boreholes distributed across the Ouargla basin (Fig. 3). The sampling sites were selected based on their spatial distribution and relevance to human consumption. Field parameters such as pH, electrical conductivity (EC), and turbidity were measured in situ using portable equipment. Laboratory analysis was conducted for major ions, including calcium (Ca^{2+}), magnesium (Mg^{2+}), chlorides (Cl^-), sulfates (SO_4^{2-}), and bicarbonates (HCO_3^-) [1,2].

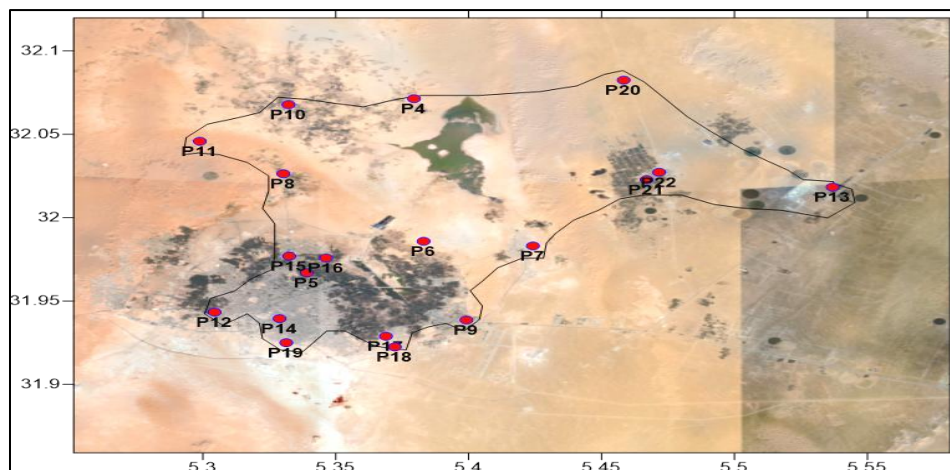


Fig 03. Inventory map of water points.

3. RESULTS

3.1. Physico-Chemical Parameters of Groundwater

The physicochemical characterization of the 18 groundwater samples from the Ouargla basin reveals significant spatial variability in water quality. Three key physical parameters were analyzed: pH, electrical conductivity (EC), and turbidity.

3.1.1. Physical parameters

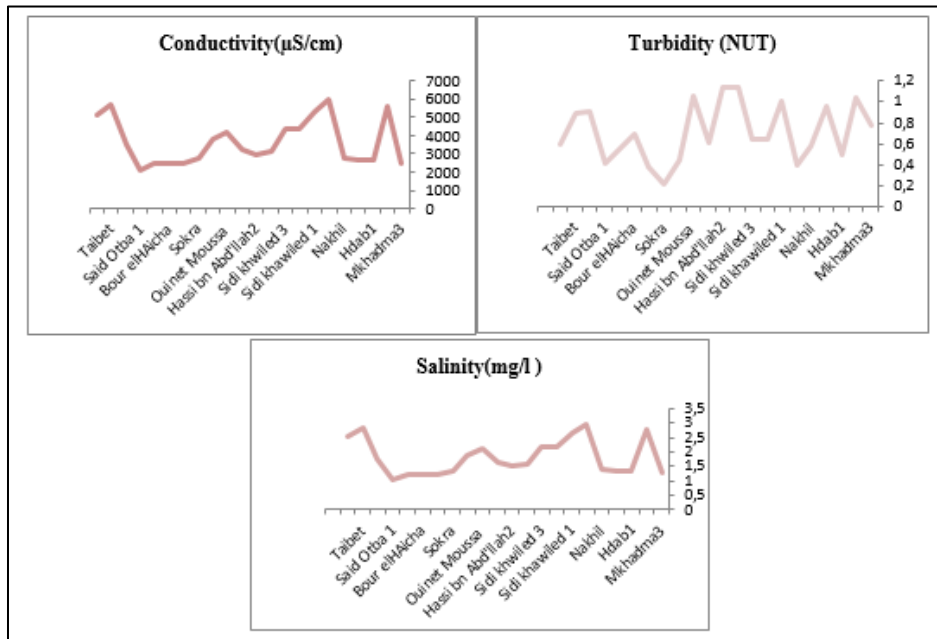


Fig 04. Evolution of physical parameters

- Electrical conductivity (EC) values varied significantly between 2080 $\mu\text{S}/\text{cm}$ (Said Otba 1) and 5710 $\mu\text{S}/\text{cm}$ (Taibat), reflecting elevated salinity in many sites.

- Turbidity levels ranged from 0.215 NTU (Sokra) to 1.13 NTU (Hassi Ben Abdallah 1, suggesting the presence of suspended or colloidal particles of mineral or organic origin.

- In general, the waters of the Ouargla basin show a salinity ranging from 1.04 mg / l (Said otba1) to 2.97 mg l (Ain baida).

3. 1. 2. Chemical parameters

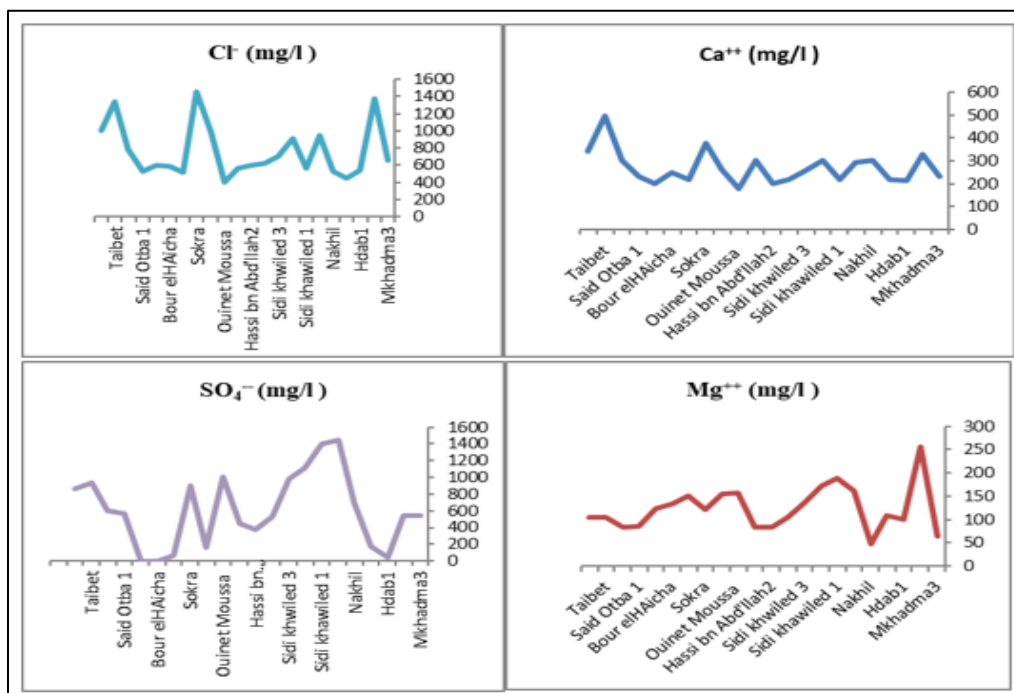


Fig 05. Evolution of chemical parameters

Chemical analysis highlighted the dominance of several major ions:

- Calcium (Ca^{2+}) concentrations ranged from 180.36 mg/L (Ouinet Moussa) to 496.99 mg/L (Taïbat), contributing significantly to water hardness.
- Magnesium (Mg^{2+}) levels varied between 48.25 mg/L (Nakhil) and 255.15 mg/L (Zyayna), with higher concentrations affecting taste and potential health for sensitive individuals [3].
- Chloride (Cl^-) concentrations ranged from 400.68 mg/L to 1458.34 mg/L (Sokra), indicating the presence of saline water and evaporite dissolution [4].
- Sulfates (SO_4^{2-}) reached up to 1448 mg/L at Ain Baida, far exceeding WHO standards, and are likely derived from gypsum dissolution and agricultural inputs [3].
- Bicarbonates (HCO_3^-) were also present in varying quantities, reflecting carbonate mineral weathering.

3. 2. Spatial Distribution of Mineral Pollution

Geostatistical analysis using Surfer 22 software enabled the spatial interpolation of mineral pollution across the basin. The maps indicate localized zones of high contamination, particularly in the southeastern and central parts of the basin, where anthropogenic pressure and geological conditions converge.

- Areas near Taibat, Sokra, and Ain Baida exhibit particularly elevated values of SO_4^{2-} and Cl^- .
- In contrast, zones such as Hassi Miloud and Said Otba 1 showed relatively lower mineral loads, with lower MPI values.

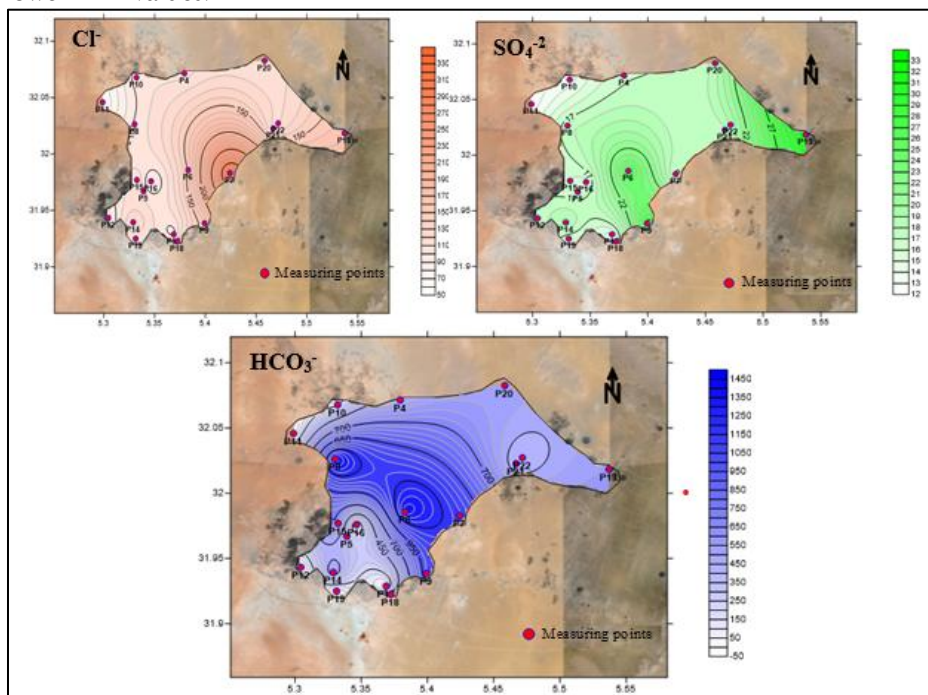


Fig 06. Chemical parameter mapping.

3. 3. Study of the vulnerability of the aquifer (CT) to mineral pollution

From the results obtained (calculation of the MPI mineral pollution index), a map was drawn (Fig 06), which represents the evolution of the MPI. The latter is of great importance in order to combat this mineral pollution.

3.3.1. Classification of drinking water

The method of data processing is based on the value of the MPI mineral pollution index. The classification of the mineral parameters is carried out according to three quality classes corresponding to the calculated IPM values (Table 02). Follow-up of the results of the analysis in the various points has been the subject of data processing by the establishment of a map of mineral pollution of the natural waters of the region of Ouargla which informs us about the quality of the waters by means of a mineral pollution index, in order to assess the contamination of the waters of the aquifer with mineral contamination. Each of the chemical elements (Ca^{2+} , Mg^{2+} , HCO_3^- , SO_4^{2-}) is adopted which is determined for each sampling point. The sum of these classes gives the index representing the mineral contamination. [10]

Table. 2. Classification of the Mineral pollution index (MPI).

Elements mg/l	Ca ⁺²	Mg ²⁺	HCO ₃ ⁻	SO ₄ ⁻²	MPI	Mineral pollution
	Levels					
Level 1	0-100	0-50	0-50	0-100	<10	Low
Level 2	100-200	50-100	50-100	100-500	10-12	Average
Level 3	200-300	100-150	100-150	500-1000	12-14.5	Strong
Level 4	>300	>150	>150	>1000	14.5-16	Very strong

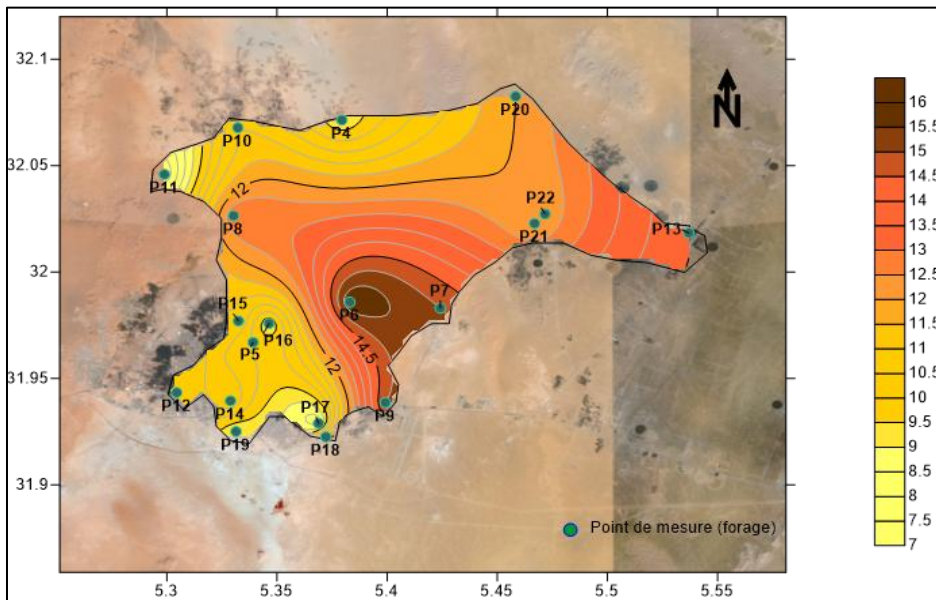


Fig. 07. Evolution of the Mineral pollution index (MPI).

From Fig 07, it can be noted that our study region is represented by an MPI_{min} which corresponds to Hassi Miloud and MPI_{max} which corresponds to Sidi Khouiled.

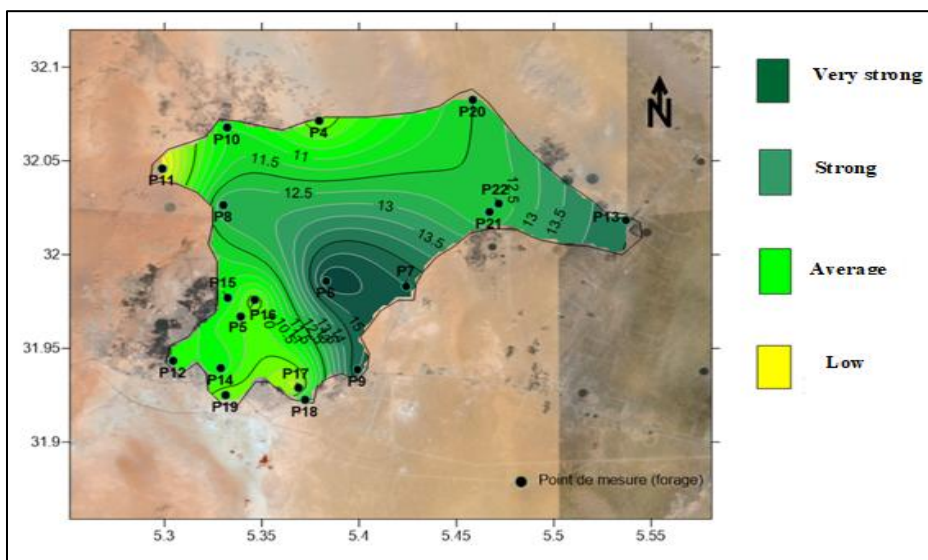


Fig. 08. Spatial evolution of degrees of vulnerability to mineral pollution.

4. DISCUSSION

The analysis of groundwater quality in the Ouargla basin reveals considerable spatial variation in mineral pollution levels, primarily influenced by both natural and anthropogenic factors. The high concentrations of calcium, magnesium, sulfates, and chlorides observed in several boreholes indicate a degradation of water quality that poses risks to human health and agricultural practices.

4.1. Natural and Anthropogenic Origins of Mineral Pollution

A substantial portion of the observed mineral load is likely of geogenic origin, due to the dissolution of evaporitic formations, such as gypsum and halite, that are common in the sedimentary sequences of the Saharan basins [4,6]. These geological structures naturally release ions such as Cl^- and SO_4^{2-} into groundwater as water circulates through the formations.

In addition to natural sources, human activities significantly contribute to the deterioration of groundwater quality:

- The use of chemical fertilizers and pesticides in agriculture, especially in peri-urban zones, leads to the infiltration of sulfates and nitrates into the aquifer [9].
- Uncontrolled wastewater discharge and the absence of modern sanitation infrastructure, particularly in semi-urban communities like Sidi Khouiled and Ain Baida, promote contamination by both organic and mineral substances [4,8].
- Overexploitation of the aquifer for irrigation and drinking purposes lowers the water table and increases the risk of salinization and intrusion of mineral-rich water from deeper layers.

4.2. Implications for Portability and Public Health

The concentrations of several chemical constituents especially chlorides and sulfates exceed WHO drinking water standards, rendering many groundwater sources unsuitable for human consumption without prior treatment [1]. Elevated magnesium and calcium levels also contribute to water hardness, which can lead to scaling in pipes and reduce the efficiency of household appliances.

From a public health perspective, high sulfate concentrations are associated with gastrointestinal disturbances, especially in children and the elderly. Excess chloride may not pose a direct health hazard but can influence the taste and corrosiveness of water, affecting user acceptability and infrastructure durability [3,7].

4.3. Environmental and Agricultural Concerns

Mineral pollution affects not only domestic water use but also irrigation suitability. Saline and hard water can:

- Reduce crop productivity by causing osmotic stress and nutrient imbalances.
- Degrade soil structure through sodium accumulation and alkalinity.
- Promote the formation of secondary salinization, which is difficult and expensive to reverse in arid environments [9].

4.4. Toward a Sustainable Management Strategy

The spatial analysis conducted via the Mineral Pollution Index (MPI) and Surfer 22 software provides a robust decision-support framework for regional water management. Based on the current findings, several recommendations can be made:

- Establish regular monitoring programs for groundwater quality across the Ouargla basin.
- Promote eco-friendly agricultural practices, including organic fertilization and drip irrigation, to reduce leaching.
- Upgrade wastewater treatment infrastructure in vulnerable communities to limit contaminant infiltration.
- Designate protected recharge zones and regulate borehole drilling to prevent overexploitation and further degradation.
- Raise public awareness regarding the value and fragility of groundwater resources, encouraging conservation-oriented behaviors.

A combination of regulatory measures, technological investments, and public engagement is essential to ensure the long-term sustainability of groundwater in the Ouargla region.

5. CONCLUSION

This study provides a comprehensive evaluation of the vulnerability of groundwater to mineral pollution in the Ouargla basin, an arid region of Southeastern Algeria. Through the analysis of 18 groundwater samples, significant spatial heterogeneity was identified in physicochemical parameters, particularly in

terms of salinity, sulfate, and chloride concentrations. The use of a Mineral Pollution Index (MPI) allowed for the classification of water quality and the generation of vulnerability maps that reveal zones of high pollution risk, especially in the central and southeastern parts of the basin.

The findings indicate that both natural factors such as evaporite dissolution and anthropogenic activities such as agricultural intensification and lack of wastewater treatment contribute to groundwater degradation. The quality of several samples does not meet WHO drinking water standards, raising concerns over potability and long-term human and environmental health.

To ensure the sustainable use of groundwater in the region, this study recommends the implementation of a coordinated management approach that includes quality monitoring, improved agricultural practices, wastewater infrastructure development, and public awareness. The MPI based mapping methodology presented here offers a valuable tool for policymakers and stakeholders to prioritize intervention zones and develop strategies for groundwater protection in arid and semi-arid environments.

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