Assessment of Groundwater Quality in the Alluvial Aquifer Using GIS and Water Quality Indices in the Feija Plain, South-East Morocco

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***Abstract*—This study examines groundwater quality in the Feija alluvial plain, southeastern Morocco, shedding light on the impacts of agricultural overexploitation and climate change. Employing the Water Quality Index (WQI) and Geospatial Analysis (GIS), it evaluates the suitability of water for domestic and agricultural uses through seasonal analysis of samples. The data reveal a wide variation in water quality, with some regions having average to poor M'nasra aquifer and the Tinzouline aquifer (Draa, Morocco). Some research is being carried out Tinzouline and M'nasera aquifers.**

The Feija aquifer boasts a heterogeneous composition, comprising Plio-Quaternary terrains of varying thickness. The analysis identifies diverse chemical facies of groundwater, encompassing calcium bicarbonate, sodium chloride, and chloride sulfate, calcium, and magnesium. These characteristics mirror the influence of both human activities and natural conditions on water quality. The spatial distribution of the WQI predominantly indicates good water quality, albeit with variations attributed to agricultural practices and the unique geology of the region, particularly noticeable at sites P5 and P6 where quality is diminished.

In terms of agricultural use, quality indices suggest marginal water suitability, with concerns revolving around salinity and sodium, necessitating vigilant management to uphold agricultural sustainability. Lastly, the study unveils an absence of significant nitrate pollution, with groundwater maintaining cleanliness. These findings underscore the significance of monitoring and managing water resources to tackle current and future challenges posed by agriculture and climate change in the region.

***Keywords*—groundwater quality, WQI, irrigation uses, GIS, Feija plain**

I. Introduction

The critical importance of water resources has become a crucial issue for both the human population and living beings on Earth. The rarity of precipitation in Morocco, accentuated by climate change, is creating major challenges for the country, particularly desertification, which endangers agricultural land, irrigation infrastructures, and urban areas [1]. The overuse of groundwater, intensified by demographic growth and agricultural activities, is contributing to the fall in piezometric levels at water points [2, 3]. Morocco has emerged as one of the country's most vulnerable to the adverse impacts of climate change and water scarcity [4]. Irrigation accounts for 70–90% of water usage, including storage and other forms [5]. Consequently, there is a growing demand for groundwater, driven by factors such as expanded land irrigation through groundwater pumping [6]. Urbanization, pollution, and climate change collectively contribute to a notable increase in evaporation. Therefore, effective water resource management stands as a pivotal aspect of Morocco's present and future in the context of climate change [7].

The south-eastern regions of Morocco, in particular the Feija plain, face a potential risk of groundwater overexploitation due to climate change and intensive agricultural pumping [8]. Observations of the piezometric level reveal a significant drop in the water table, especially noticeable after the severe drought of previous years, with a decrease of 10 m's between 2013 and 2015 [9]. As a result, groundwater salinization in the Draa oases has emerged as a limiting factor for agricultural development and its long-term sustainability [10].

The degradation of water quality due to natural contamination, anthropogenic pollution, and quantitative imbalance poses a significant risk for the region [11, 12]. However, the available data, which is mainly limited to rural areas, makes it challenging to predict water quality issues accurately. Numerous studies have been conducted to investigate the hydrogeological and hydrogeochemical characteristics of arid and semi-arid regions [13–16], providing decision-makers with valuable insights to develop sustainable water use policies.

This study aims to examine the quality of groundwater in the Feija plain. The specific objectives include investigating the hydrochemical characteristics and assessing the spatial and temporal status of groundwater quality in the aquifer using both the water quality index and geographic information system. The ultimate goal is to evaluate its suitability for both domestic and agricultural purposes.

In the AntiAtlas basin, the Tinzouline study area is part of the hydrological system where extensive research has been carried out as part of the Moroccan-German project [17]. During this project, research was carried out on the Oued Draa, the main river in the Anti-Atlas basin. The Oued Draa is a major river flowing south from the Atlas Mountains.

The M'nasra water table, the region's main water resource, is extremely vulnerable, with a volume estimated at

80×106 rn^3 for an area of 500 km^2. The highly filtering sandy texture, the fact that the water table is fed by surface water (rain, Oued Sebou, irrigation return water) and the excessive use of nitrogen fertilizers are responsible for this vulnerability. The average level of leachable nitrogen in the M'nasra area is approximately 189 kg 1.1/ha per year. One of the most worrying aspects is groundwater pollution, and using this water for food is a health risk.

Groundwater plays an essential role in Morocco's hydraulic heritage. Often protected geologically, groundwater is vulnerable to pollution from agriculture, industry, or urban planning. The M'nasra water table, which is the region's main water resource, is extremely vulnerable, with a volume estimated at 80×10m for an area of 500 km.

The highly filtering sandy texture, the nourishment of the groundwater by surface water (rain, Oued Sebou, return of irrigation water), and the excessive use of nitrogen fertilizers are responsible for this vulnerability. The average level of leached nitrogen in the M'nasra zone is approximately 189 Kg N/ha per year. One of the most worrying aspects is the pollution of groundwater, and the exploitation of this water for food purposes constitutes a health risk.

In the Tinzouline oasis, the aquifer, like all the five others, is fed by a drainage system by pipes, released by dams. Seven times a year, these are carried out to measure the level of the water tables throughout the Draa wadi and to provide irrigation water to the 6 palm groves. The objective has been achieved, but with a demographic increase and rapid socio-economic development, the region is facing a crisis due to the excessive exploitation of water resources. This is reinforced by the great climatic diversity that prevails in the region, leading to increasing water scarcity.

II. Materials and Methods

A. Study Area

The Feija plain spans nearly 1,000 km² to the south of Zagora along the Draa wadi. It comprises a synclinal depression encircled by east-west mountainous ranges stretching approximately 80 km (Fig. 1). Plio-Quaternary fluvial deposits, stemming from erosion of the central Anti-Atlas, have caused the plain's axis to shift towards its southern edge. The Feija wadi runs through the plain, primarily fed by tributaries originating from the Anti-Atlas.

The Feija plain is situated on the southern flank of the BouAzzermetallogenic province, known for its significant deposits of Co, Ni, and As [18, 19] formed during the Cryogenian-Ediacaran evolution of the Pan-African-Cadomian orogeny [20–22]. This region is primarily composed of Paleozoic formations, spanning from the Cambrian to the Silurian period [23]. The nappe is bordered to the north by Cambrian formations such as Jbel Bou Khachba and Jbel Boujniba (Fig. 1). In this area, the water table is influenced laterally by runoff from temporary valleys (wadis) originating from the relief of the Bou Azzerinlier. To the south, the boundary is defined by Jbel Bani, where Ordovician shale formations, carved by erosion, act as a barrier to water flow. In the west, the highest elevations of the Feija and Foum Zguid basins, composed of schistose terrain from the external Feija (Ordovician), mark the limits of the water table. Finally, to the east, Draa wadi and its extension towards the Fezouata and Foum Takkat aquifers serve as an outlet for the Feija aquifer through the Plio-Quaternary alluvial deposits [24].

B. Climate

The climate of the Feija region is characterized as dry, ranging from semi-arid to arid, with a consistent deficit. Conversely, the climate of the palm forests is dry, categorized as sub-humid, with a slight surplus of precipitation in winter. Climate conditions vary based on latitude and proximity to the Anti-Atlas Mountains. The area's climate is significantly influenced by the Anti-Atlas, renowned for its arid climate. Furthermore, the presence of anticyclones contributes to the rarity of rainfall [25].

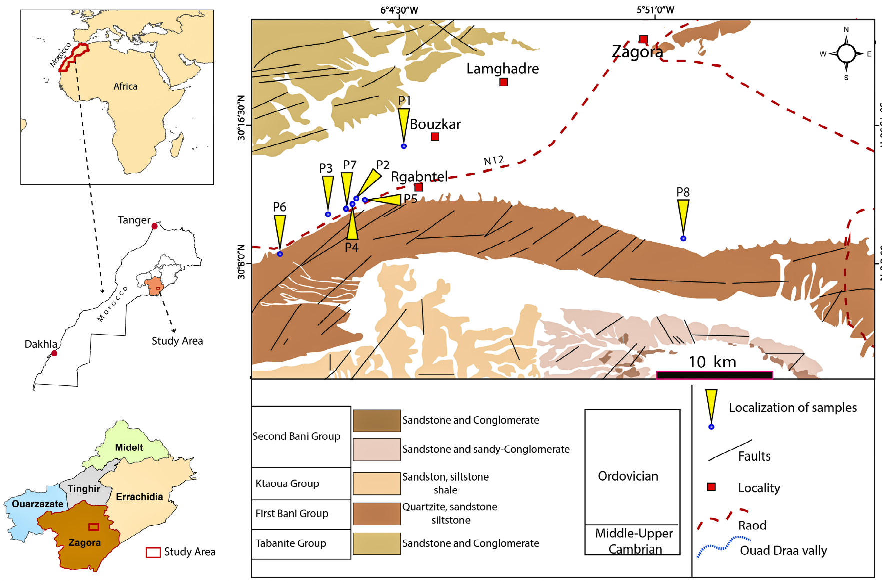

Fig. 1. Situation and geological map and of the study area. The geological map is redrawer after [26].

The rainy season spans from September to May (Fig. 2), with an average annual rainfall of approximately 78.70 mm. Regarding temperatures, certain areas of the basin undergo hot, dry summers and cold winters. Alongside the prevailing aridity in the studied basin and low precipitation, temperatures can drop to 0 °C in winter and exceed 45 °C in summer, leading to substantial evapotranspiration rates.

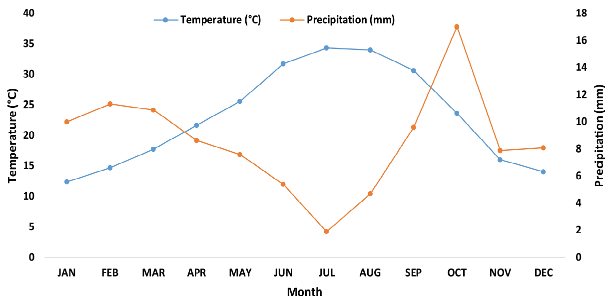

Fig. 2. Homoeothermic diagram for related meteorological station.

C. Geology and Hydrogeology

The aquifer is situated within the alluvial plain of the Feija valley and consists of permeable Quaternary deposits with gentle slopes. Its shallow structural bedrock allows for the drainage of water throughout the basin. The Feija water table is replenished by the valley alluvium as well as weathered formations of Ordovician quartzite, sandstone, and shale [27].

The Feija depression is filled with Quaternary deposits originating from the Feija wadi and Pliocene deposits unconformably overlaying Palaeozoicschists. These sediments accumulate water flowing from the southern flank of the Anti-Atlas towards the Feija depression [28, 29]. The Feija aquifer exhibits a heterogeneous composition, characterized by Plio-quaternary sediments of varying thickness, often containing silty or clayey components, including alluvial fill, alluvial fans, and eolian sand deposits. A synthetic cross-section reveals an alluvial fill with conglomerate layers at the center of the Feija depression, succeeded by continental marly sands reaching depths of 10 to 15 m, resting atop a schist bedrock [30].

D. Piezometry

Underground flow primarily occurs within Plio-quaternary alluvial deposits, which are deposited in angular unconformity on Ordovician shales. The piezometry of the area, as assessed using the piezometric map, offers an initial insight into the flow patterns (Fig. 3). The piezometric curves on these maps predominantly indicate west-to-east flow, albeit with local variations and a tendency to bend northwards in the northern part of the area (Fig. 3). An important observation is the discharge of the Feija water table into the Fezouata alluvial water table, displaying a variable hydraulic gradient. Additionally, the map illustrates that the Feija aquifer receives significant input from south-dipping Cambrian Formations of the southern flank of the Bou-Azzer inlier. In addition, the saturated thickness of the alluvial aquifer has markedly reduced at Bouzkar, and some areas have completely dried up [31].

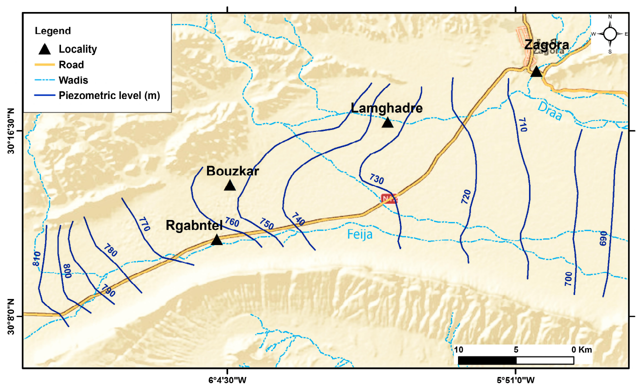

Fig. 3. Piezometric map of the aquifer in the Feija plain.

E. Groundwater Sampling and Analysis

In this work, in-depth field analysis plays a key role and is a key milestone in the scientific approach to the problem. Sampling of pit water was carried out in two distinct campaigns: after the heavy rainfall of spring 2022 (wet period) and during April 2023, during a dry period. The samples were taken in the open air. The samples were taken in pre-cleaned glass jars and stored at 4°C until they were analyzed in the laboratory. Parameters such as temperature, pH, dissolved oxygen, and conductivity were measured in situ using a portable multi-parameter meter. Analyses included the determination of suspended solids by filtration, chemical oxygen demand by oxidation with potassium dichromate, phosphates and nitrates by spectrophotometry, and sulfates, chlorides, calcium, and magnesium by gravimetric method. The elements sodium and potassium were analyzed by flame photometry, while lead, copper, zinc, chromium, cadmium, and cobalt were analyzed by atomic adsorption.

The ion balance (IB) was employed to validate the analysis results within an acceptable error range, typically around 5% [31, 32]. The total of the cation concentrations should equate to the sum of the anion concentrations. The hydrochemical findings of the water samples analyzed are consolidated in Table 1. The ion balance was computed as follows:

$$IB = \frac{(\sum Cations)-(\sum Anions)}{(\sum Cations)+(\sum Anions)} \times 100 \quad (1)$$

Table 1. Statistics on the major chemical characteristics of water in the Feija aquifer

Statistic	pH	T	EC	DO	Na^+	Ca^{2+}	Mg^{2+}	K^+	NH_4^+	NO_3^-	NO_2^-	Cl^-	HCO_3^-	SO_4^{2-}	Fe^{2+}	Zn^{2+}	Mn^{2+}	Cu^+
2022 Campaign																		
Minimum	7 .33	23.12	790.00	2.10	292.00	85.00	18.14	11.35	0.00	8.08	0.00	86.15	237.90	55.29	0.01	0.01	0.01	0.02
Maximum	7 .88	28.10	4995.00	2.70	480.00	380.27	34.15	12.52	0.09	45.29	0.09	1402.12	359.29	310.52	0.07	0.04	0.04	0.05
Median	7 .50	26.24	1426.00	2.35	367.50	94.34	24.94	11.47	0.01	24.73	0.07	117.84	258.03	121.15	0.04	0.02	0.02	0.04
Mean	7 .55	26.06	1992.5	2.38	359.13	155.71	25.26	11.82	0.03	24.96	0.06	372.33	281.67	141.97	0.04	0.02	0.02	0.04
Standard deviation	0 .17	1.58	1286.50	0.19	59.42	111.02	4.16	0.50	0.03	12.20	0.03	430.65	45.77	80.01	0.02	0.01	0.01	0.01
2023 Campaign																		
Statistic	pH	T	EC	DO	Na^+	Ca^{2+}	Mg^{2+}	K^+	NH_4^+	NO_3^-	NO_2^-	Cl^-	HCO_3^-	SO_4^{2-}	Fe^{2+}	Zn^{2+}	Mn^{2+}	Cu^+

Minimum	7.19	26.12	850.00	2.10	280.00	80.00	19.25	11.02	0.00	8.07	0.00	71.25	195.20	50.33	0.01	0.01	0.01	0.02
Maximum	8.01	30.40	4979.00	3.10	417.00	457.22	32.77	12.50	0.10	22.10	0.06	1391.60	305.00	82.33	0.08	0.05	0.03	0.06
Median	7.51	29.35	1257.00	2.20	340.00	92.47	22.52	11.43	0.01	17.58	0.03	99.63	216.55	54.69	0.05	0.02	0.02	0.04
Mean	7.52	29.08	1875.63	2.31	339.50	150.74	23.31	11.69	0.02	15.96	0.03	355.41	230.28	58.92	0.04	0.03	0.02	0.04
Standard deviation	0.28	1.23	1273.58	0.31	45.07	122.27	3.86	0.56	0.03	5.50	0.02	429.57	32.96	10.13	0.02	0.01	0.01	0.01

F. Data Analysis

Piper diagrams, Gibbs diagrams, hierarchical cluster analysis, and principal component analysis (PCA) were conducted using XLSTAT software. Subjective maps were generated using the relevant geographic information system (GIS) to analyze the spatial variation of the parameters in Fig. 4.

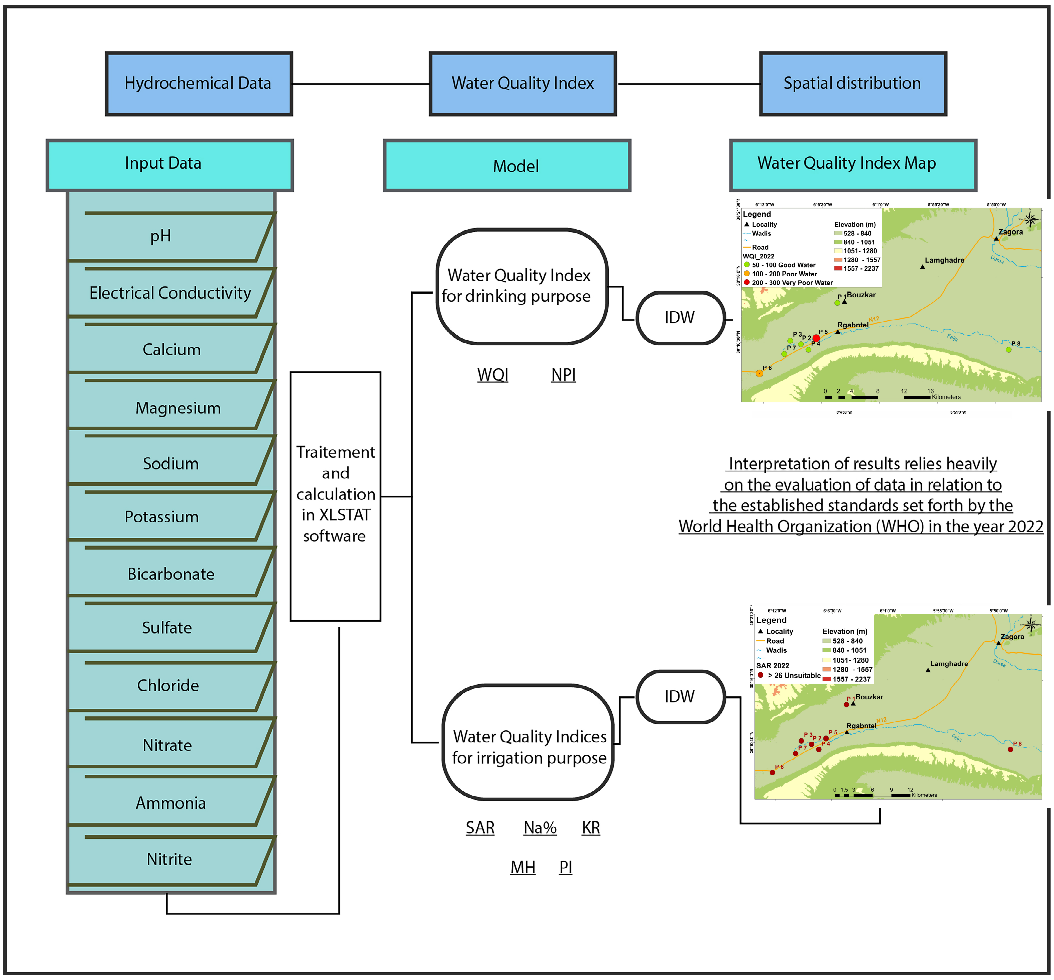

Fig. 4. Flowchart of the methodology.

Major ions and Dissolved oxygen are given in mg/L, Temperature in °C, and Electrical Conductivity (EC) in µS/cm.

III. Water Quality Indices Calculations

A. Water Quality Index (WQI)

The Water Quality Index (WQI) was utilized to evaluate the suitability of water resources in the Feija region for domestic use. This study identified twelve water quality parameters as priority parameters for monitoring [32], which include pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), chloride (Cl^{-}), nitrate (NO_3^{-}), ammonia (NH_4^{+}), nitrite (NO_2^{-}), and electrical conductivity (EC). The WQI was computed using these parameters as follows:

$$Wi = \frac{wi}{\sum_1^n wi} \tag{2}$$

$$Qi = \frac{Ci}{Si} \times 100 \tag{3}$$

$$WQI = \sum_1^n Wi \times Qi \tag{4}$$

In the context of the analysis, "*Wi*" represents the weight assigned to each parameter, with "*n*" indicating the total number of parameters considered. The term "*wi*" refers to the relative weight assigned to each specific parameter, as outlined in Table 2. Additionally, "*Qi*" is utilized to evaluate the overall water quality, while "*Ci*" represents the concentration of a single physicochemical parameter in each water sample. "*Si*" corresponds to the standard established by the World Health Organization (WHO, 2022) for each physicochemical parameter.

Table 2. Guideline values, Weight (wi) and estimated relative weight (Wi) for the different parameters

Parameter	WHO, 2022standards	Weight (Wi)	Relative Wight (Wi)
EC	2500	5	0.156
PH	6.5-8	3	0.094
Na^+	200	3	0.094
K^+	12	1	0.031
Ca^{2+}	150	3	0.094
Mg^{2+}	70	2	0.063
Cl^-	250	5	0.156
NO_3^-	50	3	0.094
HCO_3^-	120	2	0.063
SO_4^{2-}	250	3	0.094
NH_4^+	0.50	1	0.031
NO_2^-	3.00	1	0.031
		∑ = 32	∑ = 1

Table 3. Water quality classification

Water Quality Index range	Classification of groundwater
< 50	Excellent water
50 – 100	Good water
100- 200	Poor water
200 – 300	Very poor water
> 300	Unsuitable for drinking

1) Irrigation water quality indices

Water resources in the aquifer significantly impact agricultural development in the region. The presence of excessive salinity in irrigation water can lead to soil salinization, while high sodium concentrations can cause soil alkalinization, compaction, and reduced soil permeability [33]. Consequently, several key parameters, namely Sodium Absorption Ratio (SAR), Percent Sodium (%Na), Kelly Ratio (KR), Magnesium Hazard (MH), and Permeability Index (PI), were utilized to conduct a comprehensive assessment of water suitability for agricultural purposes. The calculation for each of these indicators is as follows:

$$SAR = \frac{Na^+}{\left(\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}\right)} \quad (5)$$

[33]

$$Na\% = \frac{Na^+ + K^+}{Ca^{2+}+Mg^{2+}+Na^++K^+} \times 100 \quad (6)$$

[34]

$$KR = \frac{Na^+}{(Ca^{2+}+Mg^{2+})} \quad (7)$$

[35]

$$MH = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100 \quad (8)$$

[36]

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{(Ca^{2+}+Mg^{2+}+Na^+)} \times 100 \quad (9)$$

[37]

2) Nitrate Pollution Index (NPI)

A valuable tool for assessing nitrate pollution in groundwater is the Nitrate Pollution Index (NPI), which offers a numerical representation of the contamination level [38]. The NPI is calculated using the following formula:

$$NPI = \frac{Cs - HAV}{HAV} \quad (10)$$

In the equation, Cs represents the measured concentration of nitrate in a specific sample, while HAV designates the acceptable nitrate value for humans, generally set at 50 mg/L according to World Health Organization (WHO) guidelines from 2022. The application of this index makes it possible to quantify and assess the degree of nitrate contamination in water. This, in turn, promotes effective management and mitigation of potential undesirable effects on groundwater quality and, consequently, on human health.

IV. Results and Discussion

A. Physicochemical Parameters

The mineralization of the water is characterized by its Electrical Conductivity (EC), which shows significant variations in the study area. Mean EC values changed slightly, from 1992.75 µS/cm in 2022 to 1875.625 µS/cm in 2023, reflecting a decrease of around 117.12 µS/cm. It should be noted that the highest EC readings were recorded at P5 in 2022 (Fig. 5a), while in 2023 P5 reached a maximum value of 4979 µS/cm (Fig. 5b). On the other hand, the lowest EC values were observed at sampling site P8 (a control sample far from the farms), with a value of 970 µS/cm in 2022, decreasing to 850 µS/cm in 2023.

It is worth noting that the EC measurements obtained at sites P5 and P6 systematically exceed the requirements for human consumption and agricultural use. The high values found in the water at P5 and P6 are due to dissolved salts, on the one hand, and the leaching of fertilizers by irrigation water on the other. It could be stated that this area is considered to be an irrigated perimeter with intense agricultural activity.

Water temperature is a crucial factor in the aquatic environment, influencing physico-chemical and biological reactions, and also playing a significant role in water evaporation. The analyzed water temperature values range from 23.12 °C to 28.1 °C, with an average of 26.06 °C for the winter period in 2022. During the second campaign, the temperature of the water analyzed ranged from 26.12 °C to 30.4°C, with an average of 29.08 °C. It's noteworthy that these temperatures fall within the quality standards for water intended for irrigation (35 °C), and they are close to the ambient temperature, indicating a shallow origin for the water studied.

Measurements of pH in 2022 ranged from 7.33 to 7.88 (Fig. 5c), and in 2023 it ranged from 7.19 to 8.01 (Fig. 5d). Spatial mapping of the pH distribution indicates that the groundwater in the study area is characterized by an almost neutral ph. Interestingly, the highest pH values are mainly concentrated in the northern and eastern parts of the study area.

Dissolved oxygen refers to the quantity of oxygen present in solution in water at a given temperature. The concentration of dissolved oxygen in water results from physical factors (such as temperature, salinity, and mixing of the water mass), chemical processes, and biological parameters, including exchanges at the land-sea interface (gain or loss), diffusion and mixing within the water mass, photo-oxidation (loss), respiration of aquatic organisms (loss), nitrification (loss), and photosynthesis (gain). The water in the sampled pits has dissolved oxygen concentrations ranging from 2.1 to 3.1 mg/L, with a maximum value of 3.1 mg/L in P5 and an average of around 2.34 mg/L.

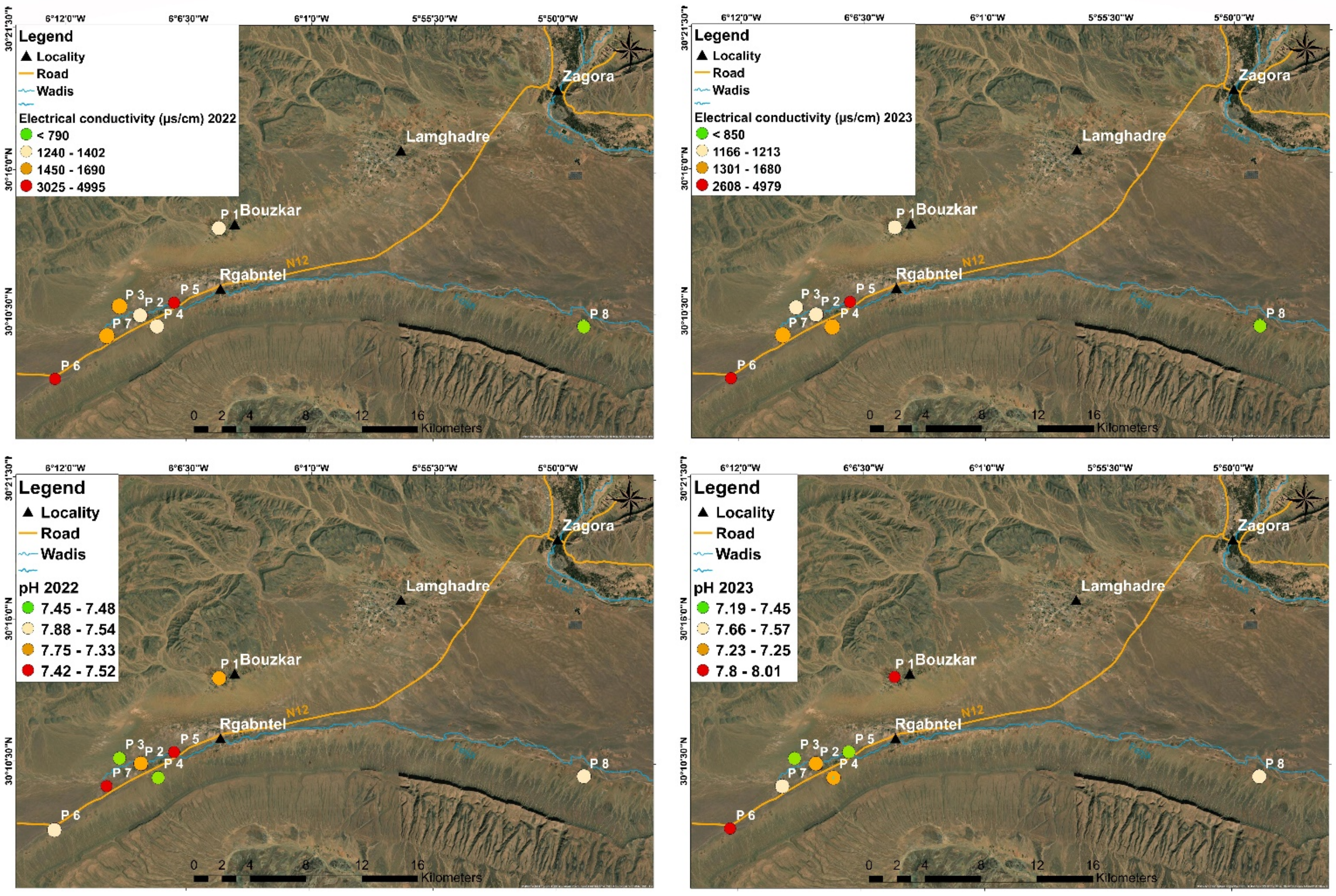

Fig. 5. Spatial distribution of groundwater quality parameters in 2022 campaign, a) EC, b) pH, and 2023 campaign c) EC, d) ph.

Calcium is a crucial element for the human body and is of particular importance, as an adequate quantity of this mineral is required to maintain optimal health[39]. Average calcium concentrations varied from 155.71 mg/l in 2022 to 150.74 mg/l in 2023, indicating a decrease of approximately 4.97 mg/l (Fig. 6a and Fig. 7a). It should be noted that samples from P5 and P6 recorded concentrations exceeding the guidelines for human consumption as indicated by the WHO.

Chloride-containing water originates from various sources, including domestic and public waste, as well as chloride leakage from the erosion of sedimentary rocks [35]. The recommended chloride concentration for drinking water, according to prescribed standards, is 250 mg/l. However, upon analyzing the collected samples, it becomes evident that chloride levels are significantly elevated. The average chloride content exhibited notable variations, decreasing from 372.33 mg/l in 2022 (Fig. 6b) to a slightly higher value of 355.40 mg/l in 2023, indicating a decrease of approximately 16.93 mg/L over the 6-month period. Except for certain specific locations, the concentration of chloride in this water remains within the standards authorized for domestic use (Fig. 7b).

The bicarbonate present in water originates from the dissolution of carbon dioxide (CO_2) in natural sources (Wu, 2021). The results of the current study reveal that HCO_3^- concentrations in groundwater samples collected in 2022 ranged from 237.9 to 359.29 mg/l, with an average value of 261.67 mg/l (Fig. 6c). Similarly, in 2023, HCO_3^- concentrations ranged from 195.2 to 305 mg/l, with an average value of 230.27 mg/l (Fig. 7c), with the maximum value recorded at P5. The bicarbonate values for all the wells do not exceed the quality standards for water intended for irrigation (518 mg/L).

Potassium is a naturally occurring element in water, but it can also be introduced through human activities such as salt mines, the glass industry, and the use of fertilizers. Like magnesium, it plays a crucial role in ensuring the proper functioning of the nervous system [40]. Analysis of the results presented in Fig. 5d and Fig. 6d indicates that potassium concentrations vary between 11.02 mg/l and 12.52 mg/l overall, with the highest value recorded at P5. Approximately 37.5% of these potassium values exceed the drinking water standard set by the WHO at 12 mg/l. The presence of potassium may result from the dissolution or leaching of potassium fertilizers.

Magnesium, a vital mineral, naturally occurs in water sources [41], and its deficiency can lead to various health problems such as hypomagnesemia, hypertension, osteoporosis, and headaches, as noted by [41]. Magnesium levels are relatively stable; mean magnesium concentrations have varied from 25.26 mg/l in 2022 (Fig. 6e) to 23.31 mg/l in 2023, indicating a decrease of approximately 1.95 mg/l. It's worth noting that the lowest magnesium value was recorded at P8 (Fig. 7e), with variations from 18.14 mg/l in 2022 to 19.25 mg/l in 2023.

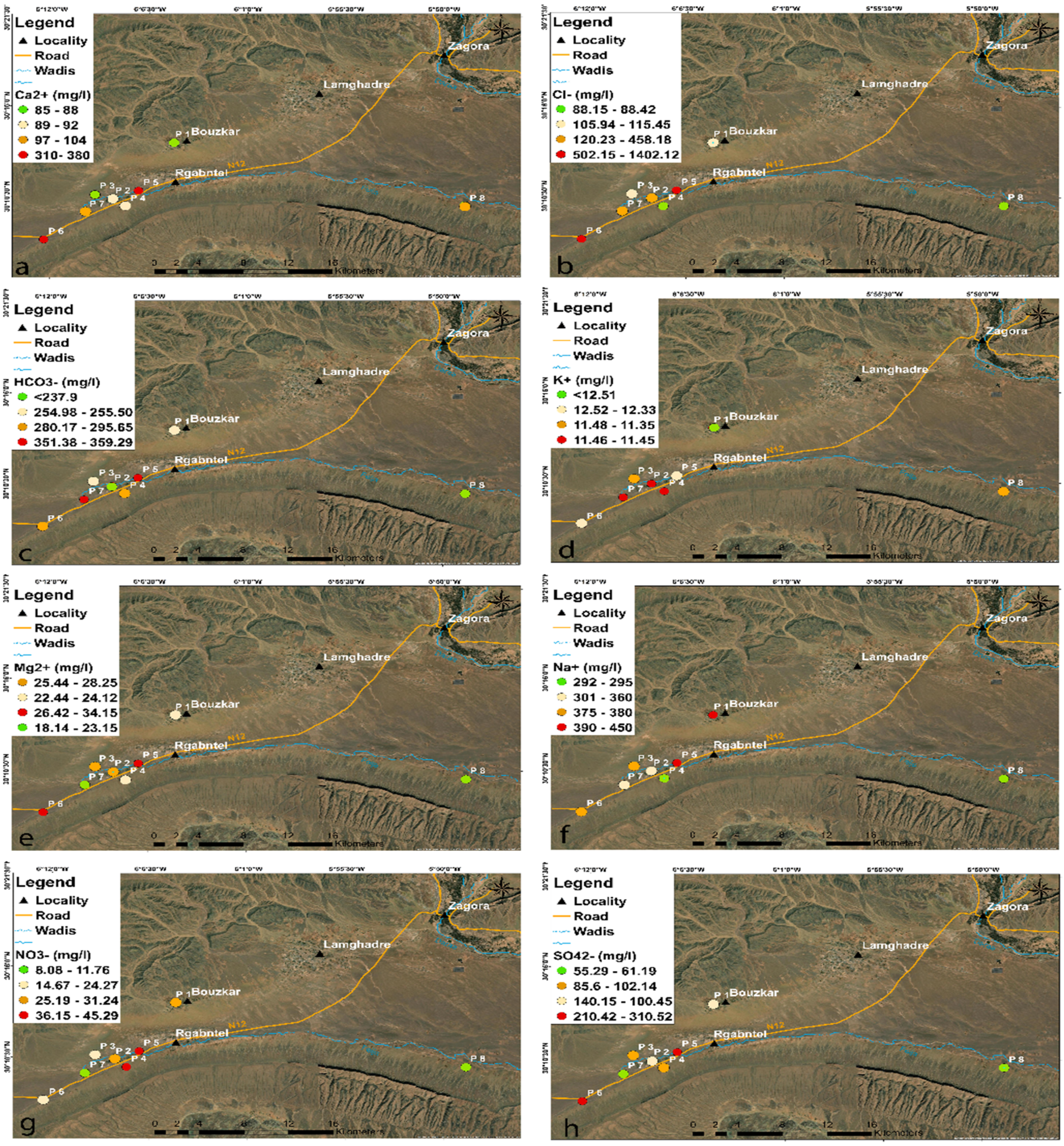

Fig. 6. Spatial variation map of groundwater quality parameters in 2022 campaign, a) Ca^{2+}, b) Cl-, c) HCO^{3-}, d) K+, e) Mg^{2+}, f) Na+, g) NO^{3-}, and h) $SO4^{2-}$.

Mean sodium (Na^+) measurements varied considerably, from 359.12 mg/l in the 2022 campaign (as shown in Fig. 6f) to 339.50 mg/l in the 2023 campaign. The lowest sodium concentrations were found in the two samples from P8 and P4, where values were 280 mg/l in 2022 and rose significantly to 292 mg/l in 2023 (Fig. 7f). In contrast, when potassium levels in the samples were assessed, it became evident that the concentrations are within the acceptable range for drinking water.

The analysis of nitrate levels in groundwater intended for human consumption is crucial for assessing water quality, primarily due to the significant consequences that high nitrate concentrations in drinking water can pose [42]. In this study, the results obtained from different samples showed a wide range of nitrate values, ranging from 8.08 to 45.29 mg/l, with an average value of 24.95 mg/l in 2022 (Fig. 6g). For the year 2023, the nitrate concentrations ranged from 8.07 to 22.10 mg/l, with an average value of 15.96 mg/l (Fig. 7g). Higher nitrate concentrations were recorded at specific locations, namely P4 (36.15 mg/l) and P5 (45.29 mg/l), which are likely attributed to anthropogenic sources, such as agricultural water [43]. It is essential to stress that, in accordance with the guidelines issued by the WHO (2022), the NO_3^- concentration in all the groundwater samples analyzed did not exceed the permitted value of 50 mg/l.

Sulfate, naturally present in water through the process of gypsum leaching and influenced by human activities [44], is introduced into these groundwaters from both natural and anthropogenic sources [45]. Upon examination of the analyzed samples, it was observable that SO_4^{2-} levels ranged from 55.29 to 310.52 mg/l, with an average concentration of 141.97 mg/l in 2022. Additionally, the observed concentrations of SO_4^{2-} in the samples ranged from 50.33 to 82.33 mg/l, with an average concentration of 58.92 mg/l in 2023. These results undeniably indicate that all the groundwater analyzed in the area did not exceed the permitted limit of 250 mg/l, with the exception of a single sample, P6, located toward the eastern end of the zone (Fig. 6h and Fig. 7h).

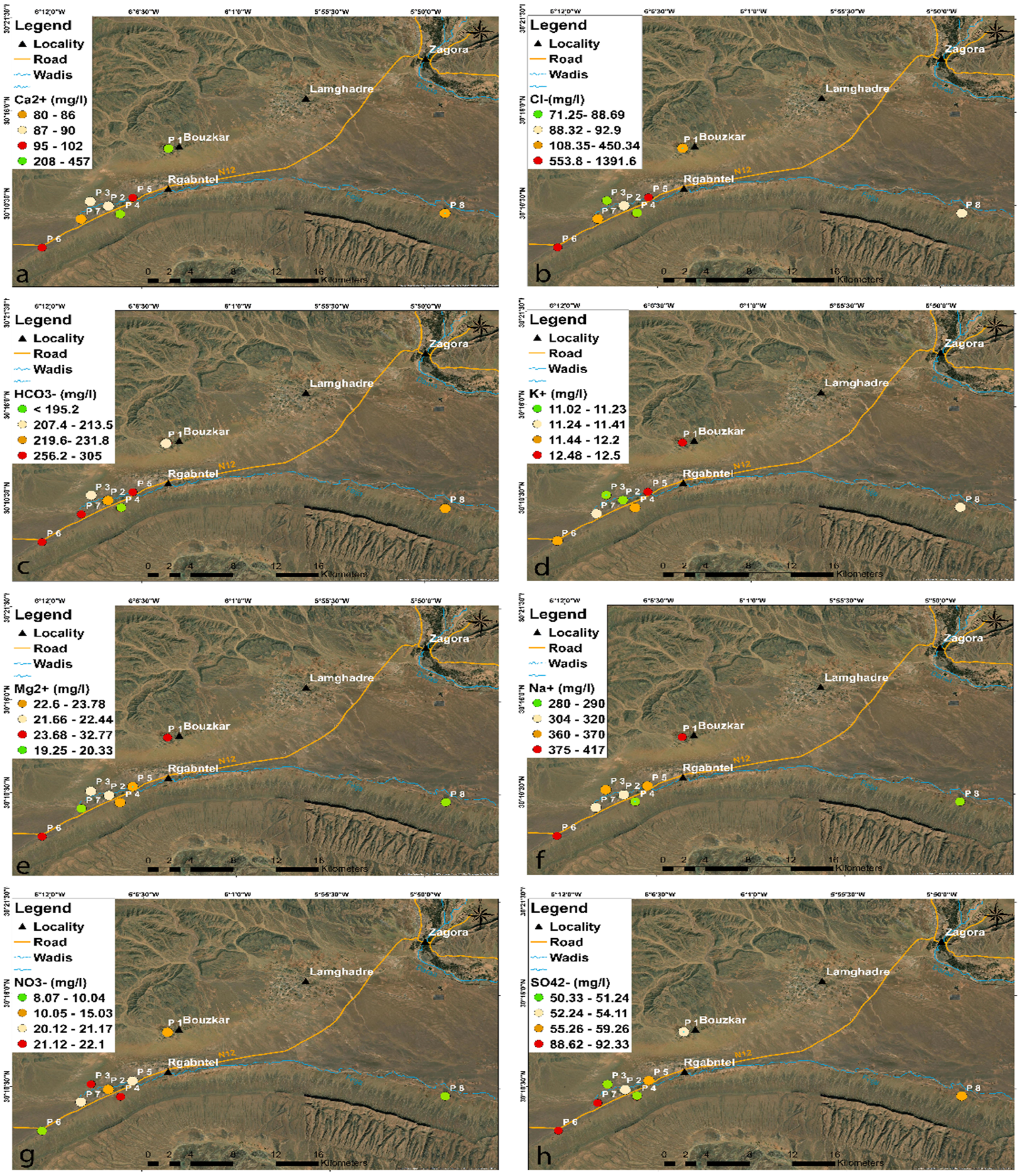

Fig. 7. Spatial variation map of groundwater quality parameters in 2023 campaign, a) Ca^{2+}, b) Cl^-, c) HCO_3^-, d) K^+, e) Mg^{2+}, f) Na^+, g) NO_3^-, and h) SO_4^{2-}.

B. Natural Factors Influencing Water Quality

1) Principal Component Analysis (PCA)

The Principal Component Analysis (PCA) approach reduces the dimensionality of data analysis with many correlated parameters while retaining as much variation as possible in the original data [46–48]. According to the analysis carried out, PCA reveals a positive correlation between certain variables along the F1 axis. Specifically, the variables NH_4^+, NO_2^-, and Fe^{2+} form a negatively correlated cluster, while electrical conductivity, Cl^-, Ca^2+, and HCO^{3-} represent another cluster showing a similar negative correlation. The third cluster is composed of NO_3^-, pH, K^+, SO_4^{2-}, and Mg^{2+}, but this time in a positive manner (Fig. 8a and 8c). However, these three clusters of variables show a negative correlation along the F1 axis. When the observations and variables are projected onto the factorial plane (F1 & F2), a strong correlation of the first cluster is observed with samples P2, P3, and P4, particularly in month P1, while the second and third clusters are more correlated with samples P5 and P6 (Fig. 8b and 8d). The remaining samples show a negative correlation along the F2 axis. This indicates that wells P5 and P6, whose quality is more degraded, are threatened by the same sources of pollution.

The findings show that the two primary variables (F1 & F2) encompass the majority of the desired information and considerably contribute to the categorization of water samples, accounting for about 71.99% to 72.46% of the total explained variation. This fraction can be considered enough for assessing factors and individuals approaches to identifying the principal causes of hydrochemical variance.

The graphs do not indicate any significant variations between 2022 and 2023, suggesting that no new external interventions or factors have disrupted this relationship during this period. This implies that the characteristics and correlations between the variables remain stable, which could be of significant utility for water quality management and decision-making in this particular region.

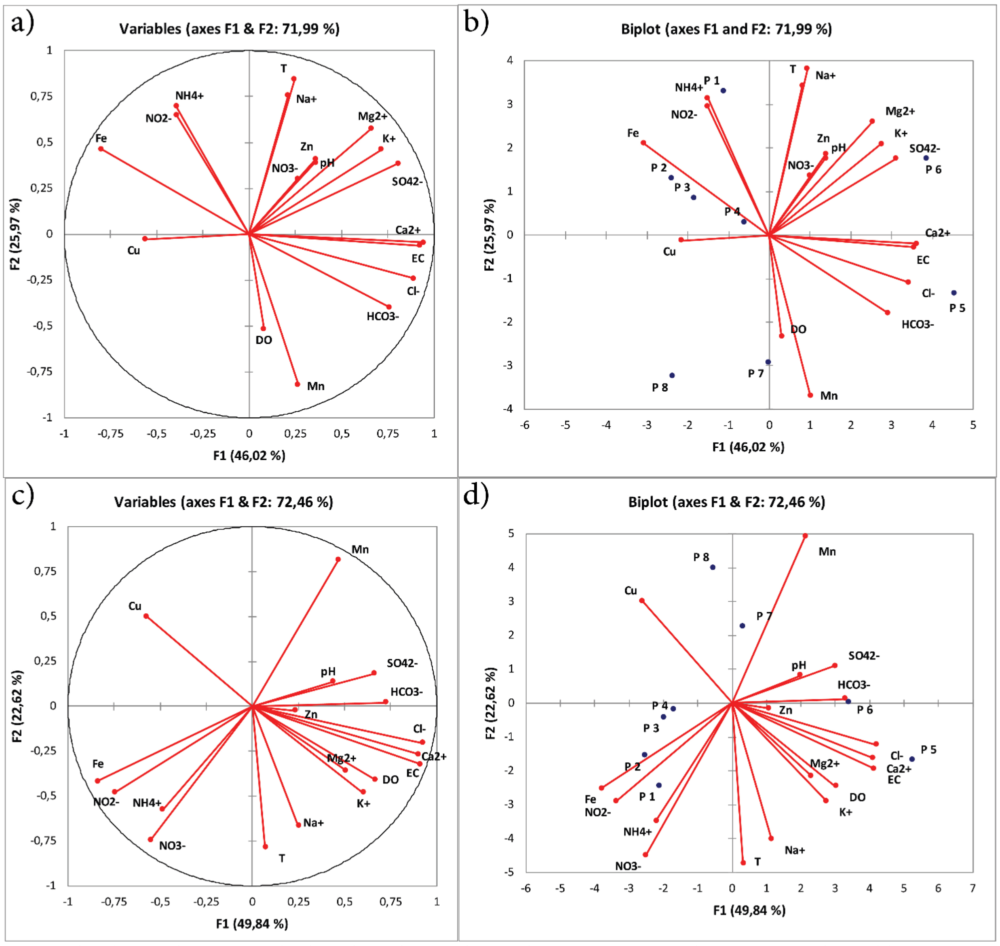

Fig. 8. Correlation circle of groundwater samples based on physicochemical parameters a, c), observations and variables projection onto the factorial plane b and d).

2) Piper diagram and hydrochemical facies

The diagram introduced by Piper in 1944 provides a valuable tool for estimating the proportion of different chemical elements and their categorization. By plotting the results of water analysis on the diagram (Fig.9), we can observe the predominance of two distinct phases. Firstly, we note the prevalence of the mixed HCO_3-Na-K phase in most of the wells. This suggests the presence of salt-rich layers, which could be linked to the geological composition of the aquifer and regional climatic conditions. In the study area, the water is characterized by three main facies: the calcic bicarbonate, with an electrical conductivity generally below 820 µS/cm; the sodium chloride, with an electrical conductivity of around 2000 µS/cm and high concentrations of Cl, SO_4, HCO_3, K, and Na; finally, the chloride, sulfate, calcic, and magnesian facies, with electrical conductivity between 1000 µS/cm and 1800 µS/cm, predominant in the region, particularly at Bouzkar and between Oum Laachar and Anagame.

3) Gibbs diagram

The Gibbs diagram is a widely recognized tool for analyzing the main factors leading to the hydrochemical composition and evolution of water sources. It assesses these factors in terms of the equivalent concentration ratios of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ to total dissolved solids (TDS)[42]. These diagrams are invaluable for identifying hydrogeochemical variations, including the processes of precipitation, rock weathering, and evaporation-crystallization. In the Gibbs diagram, water samples are positioned in specific quadrants, each representing distinct hydrochemical influences. The lower right quadrant, characterized by low TDS values with high ratios of $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$, suggests that the chemical compositions of these samples have been affected by precipitation. Samples clustered in the central region mean that the main dominant process is weathering. Alternatively, samples with high TDS values and high $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ values are located in the upper right quadrant, indicating the influence of evaporation.

Most of the groundwater samples in the study area are situated in the transition zone, positioned between domains influenced by the processes of rock alteration and evaporation. This suggests that the primary hydrochemical process observed in the water sources is the interaction between water and rocks, especially in an evaporitic environment. Nevertheless, the hydrochemical process remained relatively stable between 2022 and 2023 (Fig. 10), with only slight variations. This suggests the hydrochemical stability of the water, likely influenced by the surrounding rocks of the Anti-Atlas, the intense use of fertilizers and phytosanitary products, as well as the low rainfall and high temperatures characteristic of the study area. This highlights the relationship between quality and quantity in the existing Quaternary aquifers in the southeastern regions of Morocco.

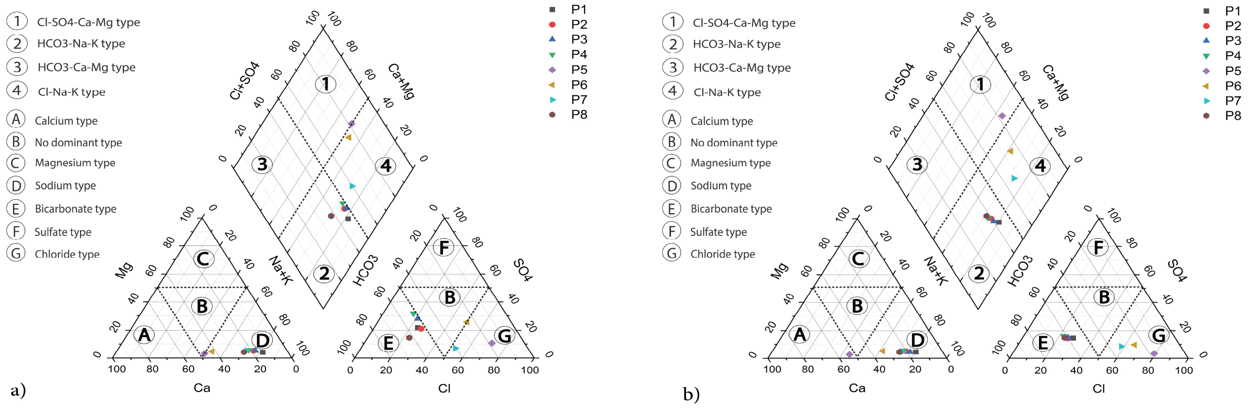

Fig. 9. Hydro chemical facies (Piper) in the study area, a) 2022, and b) 2023 campaigns.

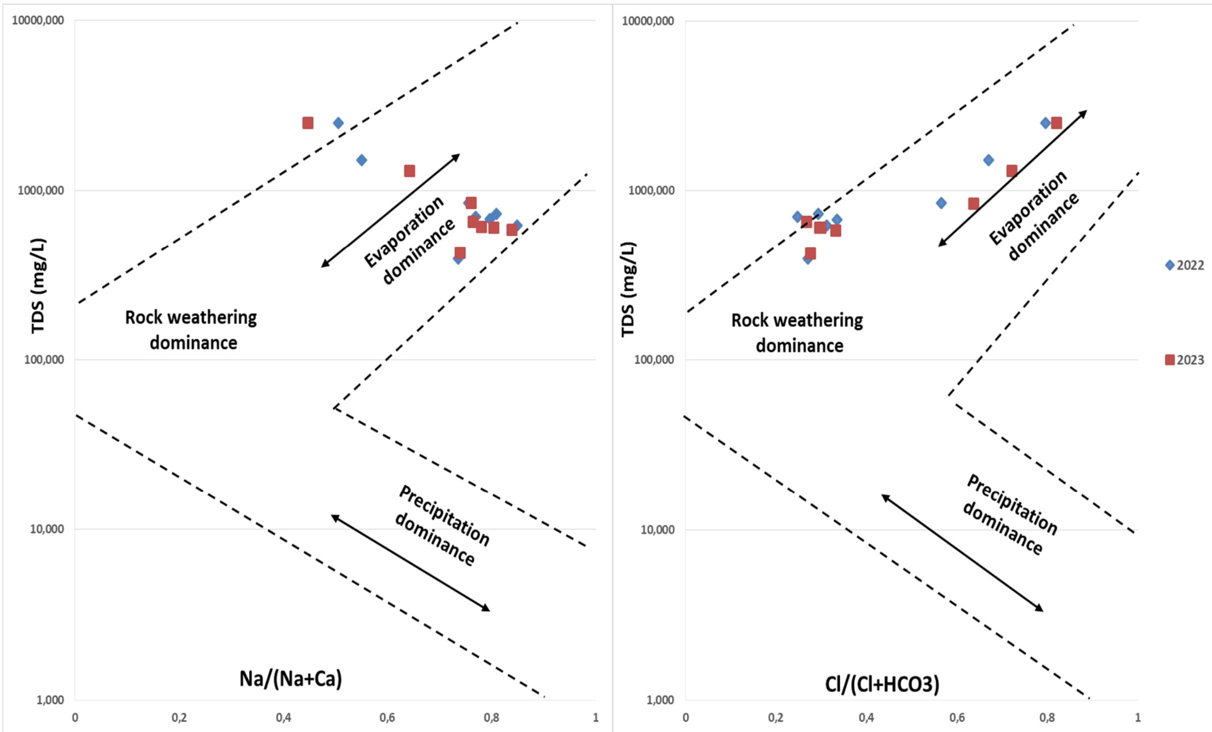

Fig. 10. Gibbs diagrams for the concentration composition of major ions in the study area.

V. Assessment of Groundwater Quality

A. Water Quality Index for Drinking Water (WQI)

Assessing water quality involves considering various critical aspects and indicators, ultimately leading to the calculation of the Water Quality Index (WQI). This index serves as an overall measure, aiding in assessing the suitability of water for specific purposes and identifying potential risks associated with its consumption [49]. The methodology employed in the present study is widely recognized and adopted by scientists worldwide, highlighting the similarity in study approaches [50–53]. It is important to note that the factors and weightings used in the calculation of the water quality index may vary from region to region, allowing the specific requirements of local water quality monitoring and assessment to be taken into account. This approach, categorized into five classes, ensures that the Water Quality Index (WQI) reflects the unique characteristics and concerns of the specific region under investigation. The five WQI categories are detailed in Table 3.

The results indicate stability in groundwater quality in the Feija region between 2022 and 2023. The water quality index calculated for 2022 shows that 75% of the samples are of good quality, with one sample each categorized as average and poor quality, representing 12.5% of all the sites examined (Fig. 11a). For the 2023 campaign, 75% and 25% of samples respectively fall into the good and average water quality categories for drinking water (Fig. 11b). Overall, the WQI maps for all the water points indicate that the majority of the study region has a WQI <100, indicating good water quality.

On the other hand, sites P5 and P6 exhibit average to poor water quality and are situated at the eastern end and in the center of the study area, associated with the Paleozoic formations of the Anti-Atlas and the intensive agricultural activity in this region. This disparity in distribution can be attributed to the heterogeneity of the geological formations surrounding each study site, as well as to the dilution of the aquifer and the extraction of water for irrigation purposes [54].

This variation in water quality is likely influenced by the region's scant rainfall, a consequence of the ongoing impact of climate change. The downward trend in piezometric levels from year to year corresponds to an upward trend in electrical conductivity and, consequently, a deterioration in water quality. This underscores the significance of comprehending the intricate relationship between geological formations, hydrological processes, and climatic factors in understanding the spatial distribution of groundwater quality in the study area.

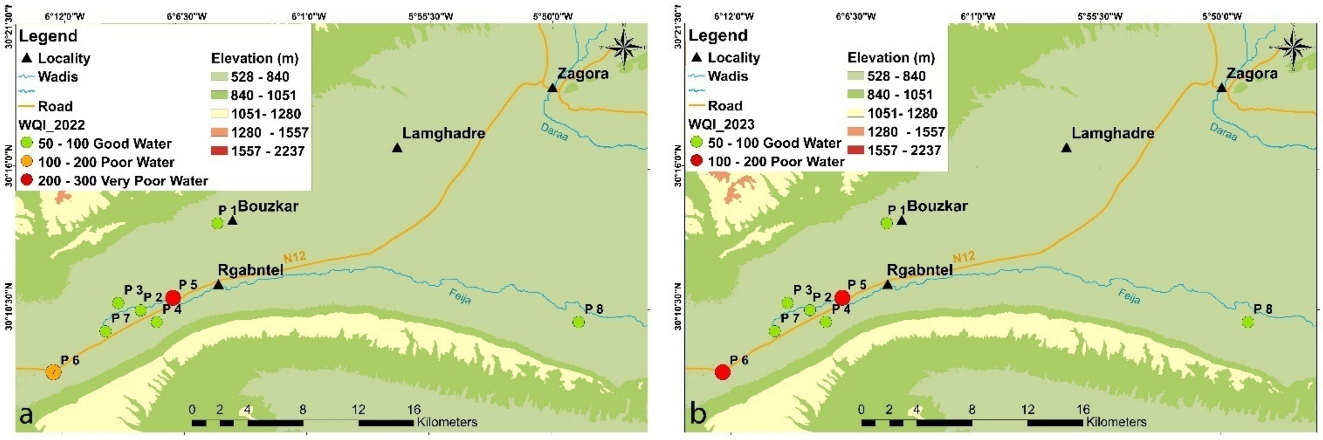

Fig. 11. Spatial variation of water quality index in the study area, a) 2022 and b) 2023 campaigns.

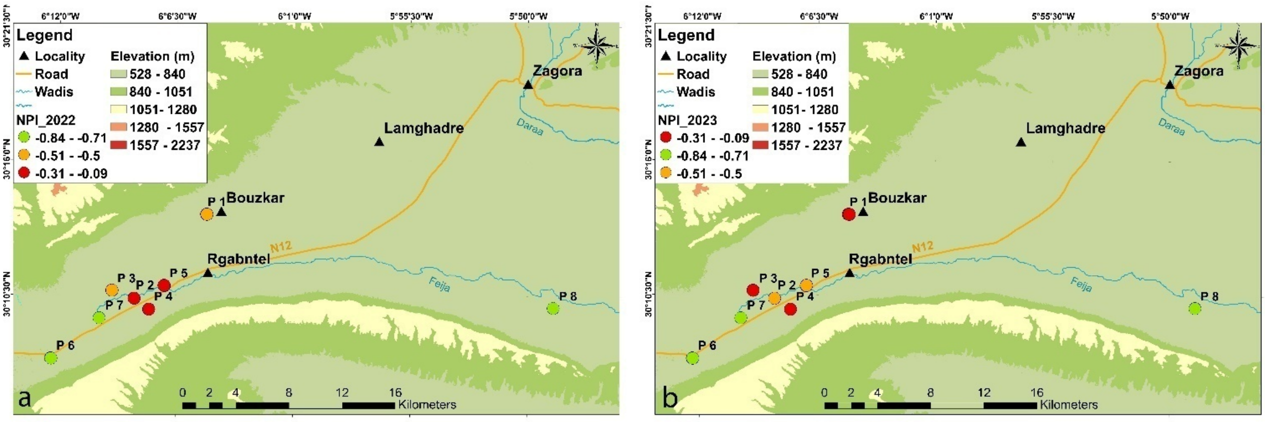

Fig. 12. Spatial distribution of Nitrate pollution index in the study area, a) 2022 and b) 2023 campaigns.

1) Nitrate Pollution Index (NPI)

Excessive nitrate concentration in groundwater is attributed to various factors, including uncovered septic tanks, sewage leakage, agricultural activities, and leachate from uncontrolled landfills [50, 51].

Table 4. Classification of groundwater based on NPI index

NPI value	Type of pollution	2022%	2023%
< 0	Clean	100	100
0 – 1	Light	0	0
1 – 2	Moderate	0	0
2 – 3	Significant	0	0
> 3	Very significant	0	0

The nitrate pollution index (NPI) is a valuable tool for assessing the extent of groundwater pollution resulting from high nitrate concentrations [52]. In the research area, NPI values ranged from -0.84 to -0.09, with an average of -0.5 for the 2022 survey (Fig. 12a). In the 2023 survey, the index varied from -0.84 to -0.56, with an average of -0.68. Based on the groundwater classification provided in Table 4, all sampling locations were classified as clean, indicating an absence of nitrate pollution in the study area. In 2023, the distribution shows no significant changes, indicating stability in terms of index class, although nitrate concentrations showed minimal variations (Fig. 12b).

2) Assessment of irrigation water quality

The expansion areas outside the palm groves on the Feija plain are irrigated areas that cover an area exceeding 300 hectares, according to field surveys conducted in 2014 and 2019 [53]. These extension areas comprise several distinct sectors. The Lamghadre sector accommodates a large number of farms over the largest area of the plain, resulting in competition for water with the drinking water abstraction by the Office National de l'Eau Potable for Zagora [54]. Similarly, the Foum Laachar sector is home to large farms practicing modern, high-value-added agriculture, mainly focused on watermelon and date palms.

Throughout the Feija plain, approximately 700 agricultural users are listed as owners or tenants of 700 farms covering a total area of around 6,600 hectares, half of which is irrigated, totaling approximately 3,300 hectares [60]. Various crops are grown, with watermelon dominating, followed by henna, alfalfa, and date palms. Drip irrigation is widespread, covering more than 94% of the irrigated area, while the remainder is irrigated by gravity, with watermelon being entirely irrigated by this water-efficient method. The number of wells in the Draa basin was estimated at just 205 in 1965, rose to 4,200 in 1977 with the use of motor pumps, and increased to 10,000 wells in 2011 [55].

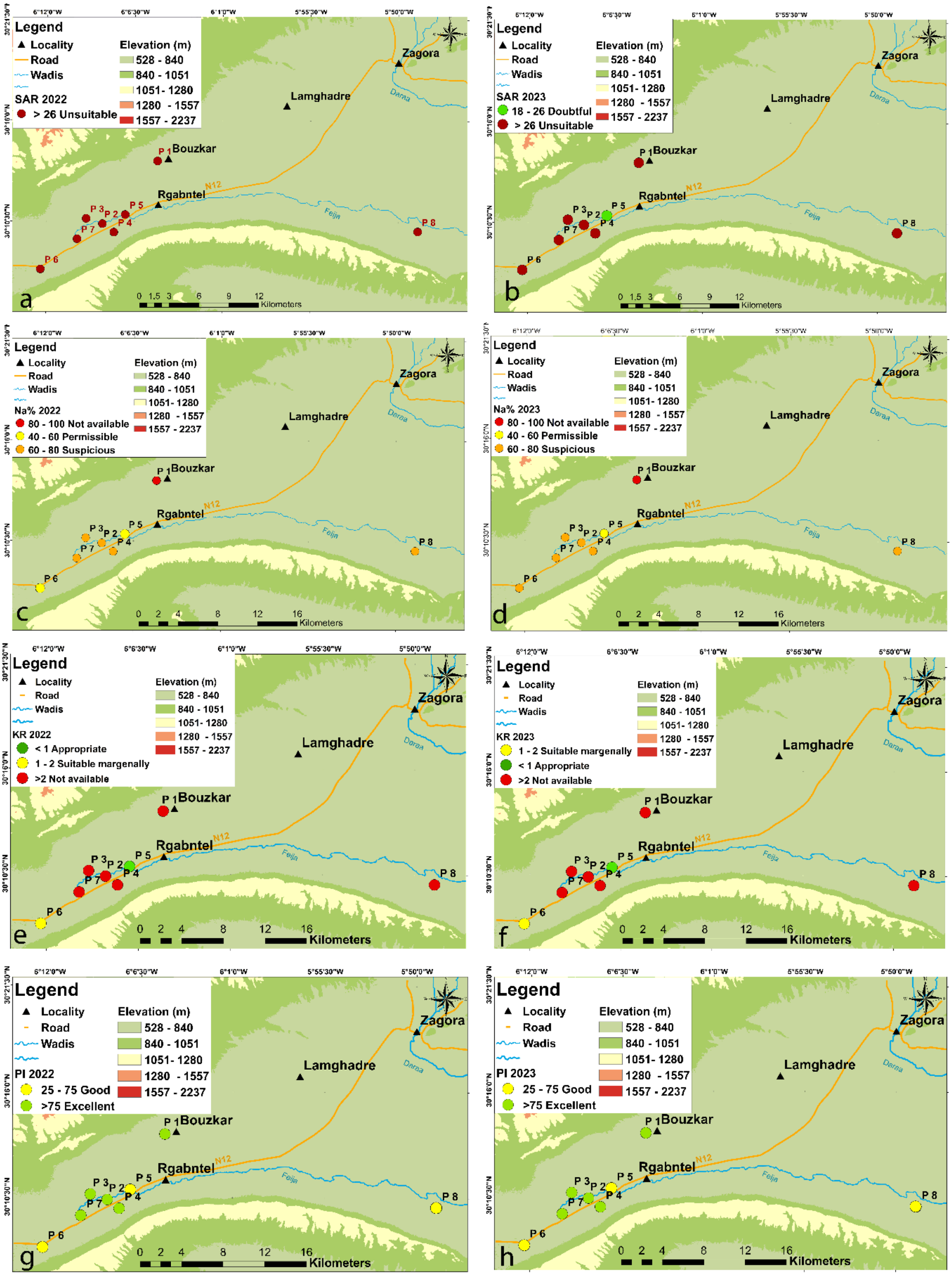

Fig. 13. Groundwater quality variation for irrigation purposes based on SAR a, c), and %Na b, d).

Indicators frequently used to assess the adequacy of irrigation in terms of water significance include Sodium Absorption Rate (SAR), Sodium Percentage (Na%), Kelly Ratio (KR), Magnesium Hazard (MH), and Permeability Index (PI), all calculated using the formulas presented previously.

a) Sodium Absorption Ratio (SAR)

The Sodium Absorption Rate (SAR) provides a snapshot of the relative degree of sodium compared to the presence of calcium and magnesium in a given water sample. An increase in sodium concentration raises the sodium adsorption rate. Systematic management and monitoring of sodium concentrations in irrigation water are necessary, because the residual sodium released in the soil after adsorption has the potential to impair soil permeability and damage soil structure, emphasizing the relevance of the SAR value [56]. According to the classification by Richard in 1954 (Table 5), the majority of samples analyzed in the two sampling campaigns exhibit undesirable quality for irrigation purposes (Fig. 13a and 13b). Except for P5, located in the central part of the study area, which falls into the mediocre class according to the SAR classification.

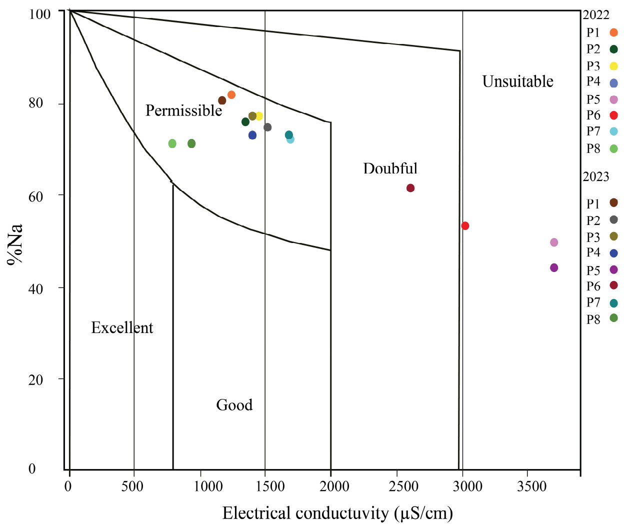

Fig. 14. Wilcox diagram for the studied wells [57].

b) *Sodium content (%Na)*

Assessing the percentage of sodium in irrigation water is a vital aspect of evaluating its suitability for agricultural purposes. In this study, we observed a notable range of Na% values in water samples, ranging from 49.74 to 81.82 in 2022 and from 40.33 to 88.55 in 2023. These values play a crucial role in determining the water's ability to irrigate crops. In the spring season of 2022, the classification revealed that the overwhelming majority of samples, 75%, fell into the category of poor-quality irrigation water (Fig. 13c).

In addition, a notable 12.5% of samples were classified as permissible quality, indicating their suitability for agricultural purposes. These results indicated relatively unfavorable conditions for irrigation in the region during this period. However, in the 2023 campaign, there was a change in classification with one sample, representing 25% of the total points analyzed, being classified as permissible quality, and possibly raising concerns about its suitability for irrigation (Fig. 13d). On the other hand, one sample, representing 12.5% of the total, was classified as of very poor quality, indicating that certain areas continued to offer strictly unfavorable conditions for agricultural irrigation. The majority of this year's samples, approximately 62.5%, showed poor quality, emphasizing the overall suitability of the water for irrigation, provided that special treatments are applied to remedy the problem of high sodium levels in these areas (Fig. 14).

These results highlight the dynamic nature of water quality, particularly concerning its sodium content, which can significantly impact agricultural practices. Monitoring sodium levels in irrigation water is crucial to ensure optimal conditions for crop growth and to make informed decisions about water use in agriculture.

c) *Kelly Ratio (KR)*

The Kelly ratio (KR) is a parameter used to assess the excess of sodium over calcium and magnesium in water, and according to Kelley's 1963 guidelines, the KR should ideally not exceed 1 for irrigation water. The results show that KR values range from 0.96 to 4.39, with an average KR of 2.54 in 2022. Whereas in the 2023 campaign, KR values range from 0.77 to 4.02, with an average KR of 2.51 (Fig. 13e and 13f).

What is notable is that there is no significant seasonal variation in this index between the two years. In 2022 and 2023, the percentages are the same, with six samples (75%) deemed unsuitable for agricultural use, while the remaining 25% were deemed suitable and suitable to a limited extent (Table 5). This consistent pattern in KR values suggests that there was no substantial change in the levels of excess sodium relative to calcium and magnesium between the two years. Although a significant proportion of the samples cannot be used for agriculture, it is important to treat and manage groundwater with higher KR values to ensure its suitability for irrigation and to avoid potential problems associated with excess sodium.

d) *Permeability Index (PI)*

The permeability index (PI) is generally classified into three classes: class I, class II, and class III. According to Doneen's 1964 classification, class I and class II indicate excellent and good water quality, respectively, for irrigation (with permeability above 75% and permeability between 25% and 75%), while class III, with permeability below 25%, is considered unsuitable for agriculture. In the current study, PI values in the study area ranged from 52.08 to 84.47 in 2022, with an average of 72.50. In 2023, these values ranged from 46.32 to 83.29, with an average of 72.50. Based on this classification, the majority of the eight samples, i.e., 62.5%, were classified as class III, while 37.5% were classified as class II (Fig. 13g and 13h). These results confirm that the groundwater samples from the Feija aquifer are indeed suitable for irrigation purposes, highlighting the region's dependence on these water resources for agriculture. This is a positive sign for the sustainability of agricultural practices in the region.

e) *Magnesium Hazard (MH)*

The suitability of water for irrigation can be determined by assessing magnesium hazard (MH) values [58], which ideally should be below 50%. A high MH content, exceeding 50%, can potentially increase soil pH and negatively affect plant growth [59]. In this study, the water samples analyzed showed a range of MH values, with a maximum value of 22.92 and a minimum value of 6.50, resulting in an average MH value of 17.36 in 2022. In 2023, values ranged from 4.94 to 22.84, with an average MH value of around 16.94. It is important to note that all samples fell below the 50% threshold (Table 5), indicating that the water is more suitable for irrigation [61]. These results demonstrate a shift towards better water quality for irrigation purposes, particularly in terms of magnesium risk, in the region between 2022 and 2023. This information is essential for farmers and agricultural practitioners, as it provides insights into the suitability of water sources for growing crops and their potential impact on soil pH and plant behavior.

Table 5. Assessment quality using irrigation indices for different campaigns

Indices	Classifications	2022%	2023%
	Excellent 0-10	0	0
SAR (Richards 1954)	Good 10-18	0	0
	Doubtful 18-26	0	12.5
	Unsuitable>26	100	87.5
	Excellent <20	0	0
	Good 20-40	0	0
Na% (Wilcox 1955)	Permissible 40-60	25	12.5
	Suspicious 60-80	62.5	75
	Not available >80	12.5	12.5
KR (Kelley 1963)	Appropriate<1	12.5	12.5
	Suitable marginally 1-2	12.5	12.5
	Not available >2	75	75
MH (Paliwal 1972)	Appropriate<50	100	100
	Not available >50	0	0
PI (Doneen 1964)	Not suitable 0-25	0	0
	Good 25-75	37.5	37.5
	Excellent 75-80	62.5	62.5

VI. Spatial Evolution of Concentrations in the Tinzouline Aquifer

The iso-content maps illustrate the fluctuation of chemical elements in the aquifer. According to the following illustrations, almost equivalent to the electrical conductivity, the presence of extreme values at the level of the ovens is caused by the geomorphology of the environment

and the piezometry of the aquifer. The tightening of the furnaces and the flow of water towards.

The central zone reduces the capacity of the reservoir. There is a significant decrease in the volume of groundwater in the periphery of the study area, which explains the problems encountered. A high concentration of dissolved chemicals.

These high levels of chlorides and sulfates have harmful consequences on the biological diversity of the region. A decrease in vegetation is observed upon arrival of the ovens, which is due to the presence of salinity. High level of groundwater use for irrigation [60]. Regarding the opposite effect between the central and lateral part of the buyer, it can be explained in the following way. by the accumulation of water, taking to the Cl- content distribution map, it was possible to determine areas where concentrations are high, up to 1125 mg/l at the limits of the aquifer, and areas where The origin of chlorides is quite complex. According to Ouysee [62]., they can originate from the most distant regions of the watershed (High Atlas, Haut M'gouna), from the geological terrains crossed, or from the leaching of alluvium which constitutes the seat of the alluvial layer of the oasis of Tinzouline, or by recycling irrigation water from plots under palm groves. Concentrations are low, up to 107 mg/l in the center of the aquifer.

A. *Causes of the Mineralization of the Tinzouline Aquifer*

To understand the mechanisms that govern the mineralization of the waters studied, various correlations were carried out between the total number of dissolved ions (TDS) and certain chemical elements K^+, Na^+, Ca^{2+}, Mg^{2+}, Cl^-, $SO4^{2-}$ (Fig 15B). Potassium and bicarbonates make a very small contribution compared to the other components of the mineralization.

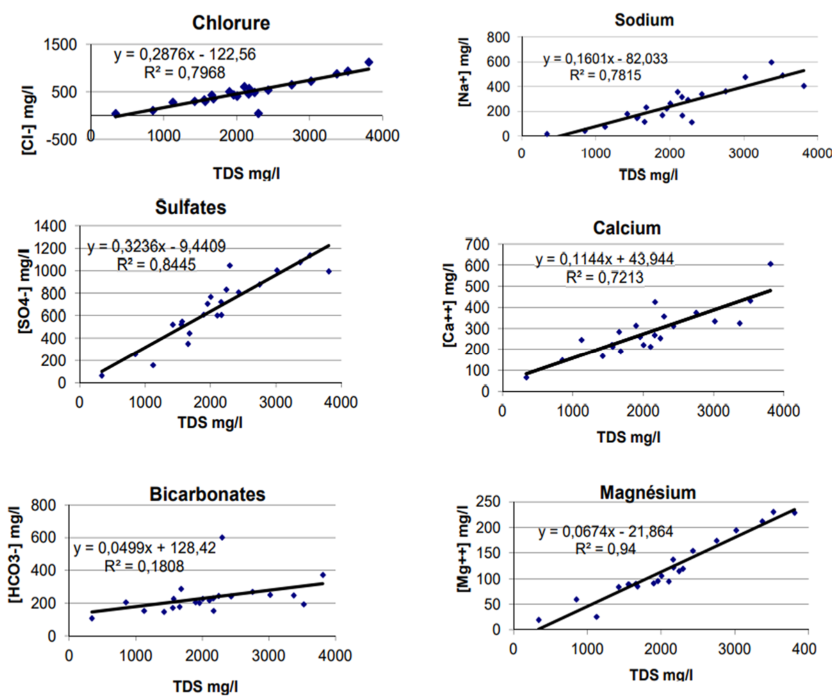

Fig. 15. Relationships between the total mineralization (TDS) of groundwater and some chemical elements of the Tinzouline aquifer [63].

Table 6. Physical chemical parameters depending on the wells

Puits	P_1	P_2	P_3	P_4	P_5	P_6	P_7	M
T°C	21 .5	21.5	21.5	21.5	25.0	21.5	21.5	21.5
PH	7.5	7.5	7.4	7.3	7.4	7.2	7.3	7.3
NO_2^-(mg/L)	0.007	0.017	0.003	0.004	0.001	0.06	0.002	0.014
NH_4^+ (mg/L)	0	0	0	0.028	0	0	0	0.004
SO_4^-(mg/L)	63.87	81.3	18.62	6.73	34.58	12.13	51.99	38.46
Mg^+ (mg/L)	17.74	13.61	5.59	13.37	4.86	5.59	16.53	11.04
MO (mg/L)	0.85	1.1	0.35	0.4	0.25	0.45	0.4	0.54
Na^+ (mg/L)	166.25	34.74	34.75	79.25	20	30.25	81.25	63.78
K^+ (mg/L)	3.5	10.5	4	10	0.5	0.5	3	4.57
Cs (µg/cm)	1493	1114	688	1015	722	562	1204	971
Cl^- (mg/L)	236.07	11.82	44.37	101.17	86.97	46.15	138.45	95
HCO_3^- (mg/L)	298.9	161.65	176.9	192.15	146.6	140.3	161.65	182.59
TH (méq /L)	5.2	6.76	4.68	7.2	4.56	4.16	8.2	5.82
TAC (°F)	24	13	14	15.25	11.5	11	12.75	14.5
TA (°F)	0	0	0	0	0	0	0	0
Ca^+ (mg/L)	74.95	113.02	84.56	122.23	83.36	74.14	137.06	98.47
NO_3^- (mg/L)	26.16	217.16	107.76	114.47	85.83	84.42	198.46	119.17

From Fig. 15, the highest degrees of correlation are observed in $SO4^{2-}$, Cl^-, $Ca^{2+,}$ and Mg^{2+} ions, suggesting a common origin of the dissolved elements. Magnesium 2+ displays the highest correlation coefficient with TDS (R=0.94).

The abundance of carbonate rocks in the Upper Draa region can explain the high concentrations of calcium and magnesium ions [64].

The lowest correlation coefficient is observed for the HCO_3 elements, and their evolution presents no significant correlation with total salinity. This weak correlation (R=0.36) for bicarbonates (HCO_3^-) is since these ions are volatile and are influenced by the contact between water and the atmosphere, as well as by the partial pressures of dissolved CO_2, which are generally high.

This weak correlation (R=0.36) can be explained by the fact that these ions are volatile and likely to be influenced by contact between water and the atmosphere, as well as by the partial pressures of dissolved CO_2, which are generally higher in groundwater, which explains the constant relative concentrations.

B. Analysis of the Results Obtained from the M'nasra Region

Based on the results obtained, we note that the temperature, pH, nitrites, ammoniacal nitrogen, sulfates, magnesium and oxidizable materials are respectively lower than the recommended standards (25°C, 6.5 and 8 .5, 0.1 mg/L, 0.05 mg/L, 200 mg/L, 100 mg/L and 0.5 mg/L). The average values of electrical conductivity, chlorides and bicarbonates (HCO) are 971 S/cm, 95 mg/L and 182.59 mg/L, respectively. It is observed that these parameters present high values in well P, with values of 1493 HS/cm, 236.07 mg/L and 298.9 g/L. average concentration of sodium and potassium is 67.78 and 4.57 mg/L respectively.

The total hardness of the waters of the M'nasra aquifer is also high, particularly at the P., P. and P wells, with respectively 6.76; 7.2 and 8.2 Mg/however, the M'nasra tablecloth presents strong nitrate pollution, with an average concentration of 119.17 mg/L, thus exceeding the standard that was established by the World Health Organization [65].

The conclusions of the physicochemical study exposed in the Menasha aquifer demonstrated that the pH, temperature, organic matter, and sulfates can be considered acceptable and do not modify the quality of the aquifer. Water supply standards are therefore respected for average values of pH (7.3), temperature (22°C), organic matter (0.54 mg/L), and sulfates (38 mg/L). Physico-chemical tests also showed high hardness at wells P., P. and P, with 6.76; 7.2 and 8.2 mg/L respectively. High salinity was observed in well P, with a value of 1493 US/cm. The presence of well P near Wadi Sebou explains the strong presence of chlorides [66].

VII. Conclusion

The physicochemical quality of the Feija aquifer is generally good overall. However, a few points located to the north of the plain, near areas of intense agricultural activity, exhibit average quality due to high salinity. While groundwater resources are generally of good quality, there's a noticeable deterioration in quality observed in the north and west parts of the plain. This decline is believed to be associated with agricultural activities, primarily due to the water's salinity and moderately high chloride content.

Groundwater samples from the Feija aquifer in the study area were found to be marginally suitable for domestic and agricultural use. The study underscores the significance of managing and preserving these water sources to ensure ongoing agricultural productivity in the region. Chloride contamination and salinization are the primary groundwater quality concerns, and various indices have been employed to assess and quantify the extent of contamination. The degradation of water quality in the region is attributed to natural contamination as well as various sources of pollution such as fertilizers, untreated wastewater discharges, and uncontrolled solid waste landfills.

The study does not delve into the socio-economic aspects of groundwater management and decision-making, which could offer valuable insights into the challenges and opportunities for sustainable water resource management in the region. A more comprehensive and detailed examination of groundwater quality in the study area, incorporating a larger number of sampling sites and an extended monitoring period, is necessary to yield a more precise assessment of groundwater quality and its temporal variations.

Given that water pollution in the study area is closely linked to agricultural activities, policymakers must address this issue with urgency. It should be noted that these activities have the potential to introduce various other types of pollutants that can adversely affect human health if their levels exceed national standards, such as the use of pesticides and plant protection products. In the unfortunate event that all of these pollutants find their way into groundwater consumed by humans, the associated health risks would be exceedingly high, particularly for residents directly affected by this concern.

The following are some crucial suggestions that such research may provide to enhance groundwater resource conditions and groundwater quality management in the Feija plain:

1. Adopt sustainable agriculture methods to reduce influence on water quality.
2. To guarantee drinking water supply, make infrastructure investments in water purification.
3. Put in place a mechanism for continuously monitoring water quality.
4. Make the local population aware of the value of sustainable water management.

The presence of sulfates and calcium in the surface waters of Tinzouline explains why their chemical composition is of the sulfate-calcium type. This can be explained by the dissolution of the formations and by the dissolution of carbonate outcrops (limestone and dolomite). In the case of surface water, chemical elements tend to move from upstream to downstream. The

mineralization of groundwater is greater than that of surface water. The chemical composition of the waters in the area reveals:

The water quality of Oued Drâa is poor for human consumption, with sulfate concentrations exceeding 250 mg/l, making it unsuitable for agriculture and livestock. Most of Tinzouline's groundwater is of average quality in terms of potability.

The M'nasra aquifer is heavily polluted with bacteria, with a total concentration of aerobic mesophilic flora of around 11.55 log10/100 ml. Additionally, the presence of high levels of total coliforms, fecal coliforms and fecal streptococci is confirmed by the presence of 5.10 log10/100 ml, 2.43 log10/100 ml and 5.31 log/100 ml. The level of fecal pollution increases after the rainy season. In the future, the use of groundwater could represent a major health risk

for the inhabitants of the M'nasra region. These practical steps will safeguard local populations' health and well-being while promoting the sustainable use of water resources.

The presence of sulfates and calcium in Tinzouline's surface waters explains why their chemical composition is of the sulfate-calcium type. This can be explained by the dissolution of formations and by the dissolution of carbonate outcrops (limestone and dolomite). In the case of surface water, chemical elements show a tendency to rise from upstream to downstream. The mineralization of groundwater is higher than that of surface water. The chemical composition of the area's water reveals:

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The M'nasra aquifer is highly polluted by bacteria, with a total concentration of aerobic mesophilic flora of around 11.55 $\log_{10}$ /1 00 ml. In addition, the presence of high levels of total coliforms, fecal coliforms and fecal streptococci is confirmed by the presence of 5.10 $\log_{10}$/100 ml, 2.43 $\log_{10}$/100 ml and 5.31 log/100 ml. The level of fecal pollution increases after the rainy season. In the future, use of the water table could represent a major health hazard for residents of the M'nasra region.

Conflict of Interest

The authors declare no conflict of interest.

Data availability statement

The datasets used to evaluate water quality during the current are available from the corresponding author upon reasonable request.

Author Contributions

Hamid Nadi write review and edited; Zakaria Zher write, make an original draft and make a methodology; Nabila Auajjar write review and edited; Naima Dohou made the software and Resources; Khalid Yamni visualize and validation Moulay Laarbi Ouahidi write and make the original draft.

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