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Hydrogeochemical characterization and groundwater quality assessment in a semi-arid carbonate aquifer system: Integration of GWQI and multivariate statistics (F'kirina region, Northeastern Algeria)

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Abstract

Background

Groundwater represents a vital resource for drinking water supply in arid and semi-arid regions, particularly in northeastern Algeria where surface water resources are limited. The assessment of groundwater quality is essential for sustainable management and public health protection.

Objective

This study aims to evaluate the physicochemical quality of groundwater from five boreholes (J37, OL1, O45, H47, I40) in F'kirina municipality and its surrounding areas (Aïn Beida), Oum El Bouaghi province, using the Groundwater Quality Index (GWQI) and multivariate statistical techniques including Principal Component Analysis (PCA).

Methods

Physicochemical data spanning the period 2018–2021 were collected from the Water Resources Directorate of Oum El Bouaghi. Eleven parameters were analyzed: pH, electrical conductivity (EC), turbidity, total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), nitrate (NO_3^{-}), and ammonium (NH_4^{+}). The GWQI was calculated following the weighted arithmetic index method, while PCA was applied to identify the dominant hydrochemical processes and potential pollution sources.

Results

The results revealed that most physicochemical parameters exceeded World Health Organization (WHO) limits in certain boreholes, particularly turbidity (up to 12.9 NTU in H47) and total hardness (up to 56°F in OL1). The GWQI classified four boreholes (J37, OL1, H47, I40) as "poor" (GWQI: 50.78–64.68), while only borehole O45 was classified as "good" (GWQI: 33.34). PCA identified two principal components explaining 80.7% of the total variance, with PC1 strongly associated with mineralization indicators (EC, Cl^{-}, TH, Ca^{2+}) and PC2 linked to pH and turbidity.

Conclusion

The groundwater in the study area is generally unsuitable for direct human consumption without prior treatment, particularly due to elevated turbidity and hardness levels. The combined use of GWQI and PCA proved effective in distinguishing natural geogenic processes from potential anthropogenic

influences. Regular monitoring and appropriate treatment strategies are recommended to ensure safe drinking water supply.

1. INTRODUCTION

Groundwater constitutes the primary source of freshwater for domestic, agricultural, and industrial purposes in many regions worldwide, particularly in arid and semi-arid climates where surface water availability is seasonal and unreliable (Margat and Van der Gun, 2013; Shiklomanov, 1991). In Algeria, groundwater resources are of paramount importance, supplying approximately 60% of the national drinking water demand, especially in the high plains and semi-arid zones of the northeastern region (Boukhari et al., 2024; Cherif et al., 2023).

The quality of groundwater is governed by complex interactions between natural geogenic factors (geology, mineralogy, aquifer lithology) and anthropogenic pressures (agricultural activities, urbanization, industrial discharge) (Ravikumar et al., 2023; Saha and Paul, 2023). In recent decades, the rapid expansion of agricultural practices, coupled with increasing urbanization and population growth, has exerted significant pressure on groundwater resources, leading to deterioration in water quality through nitrate contamination, salinization, and turbidity increases (Bouziane et al., 2023; Ojo et al., 2012).

The evaluation of groundwater quality requires integrated approaches that combine hydrochemical characterization with quantitative indexing and multivariate statistical methods. The Groundwater Quality Index (GWQI) provides a single numerical value that simplifies the interpretation of complex water quality data and facilitates decision-making for water resource management (Chowdhury et al., 2023; Tyagi et al., 2023). Meanwhile, Principal Component Analysis (PCA) serves as a powerful dimensionality reduction technique that identifies the underlying factors controlling water chemistry and distinguishes between natural and anthropogenic influences (Bouaicha et al., 2024; Voutchkova et al., 2023).

The F'kirina region, located in the southeastern part of Oum El Bouaghi province, represents a typical semi-arid zone of the Algerian high plains where groundwater constitutes the sole reliable source of drinking water for local populations. Despite its socioeconomic importance, comprehensive studies evaluating the hydrochemical characteristics and quality status of groundwater in this region remain scarce. Previous investigations in neighboring areas have highlighted concerns regarding nitrate contamination and mineralization (Zaidi et al., 2019; Rahmani et al., 2020), yet a systematic assessment integrating GWQI and multivariate statistics for the F'kirina aquifer system is lacking.

This study directly supports the United Nations Sustainable Development Goal 6 (Clean Water and Sanitation) and SDG 13 (Climate Action), by providing actionable scientific evidence for sustainable groundwater management in a water-scarce region facing climate variability and anthropogenic pressures.

Therefore, the present study was designed with the following objectives: (i) to characterize the physicochemical properties of groundwater from five strategic boreholes in the F'kirina and Aïn Beida areas; (ii) to assess groundwater suitability for drinking purposes using the GWQI; (iii) to apply PCA for identifying the dominant hydrochemical processes and potential contamination sources; and (iv) to compare the current quality status with historical data and international standards. The findings are expected to provide valuable insights for sustainable groundwater management and treatment strategy development in the region.

2. STUDY AREA

2.1. Geographic and Climatic Setting

The study area is located in F'kirina municipality, which is part of Oum El Bouaghi province in northeastern Algeria. The municipality lies approximately 60 km southeast of Oum El Bouaghi city, at coordinates between 35°40' and 35°45' N latitude and 7°20' and 7°25' E longitude. It covers an area of approximately 351 km² and is bordered by the municipalities of Aïn Beida to the north, Meskiana to the east, Khenchela province to the south, and Berriche to the west.

The region belongs to the semi-arid bioclimatic zone, characterized by a Mediterranean continental climate with cold winters and hot, dry summers. The mean annual precipitation recorded between 2011 and 2021 was approximately 300.73 mm, with significant seasonal variability. The wet season extends from October to April, while the dry season prevails from May to September. Mean annual temperature is approximately 15.8°C, with maximum temperatures reaching 26.6°C in July and minimum temperatures dropping to 7.6°C in January (Gaussen ombrothermic diagram). The Emberger quotient (Q_2 = 11.97) confirms the semi-arid to arid character of the climate.

2.2. Geological and Hydrogeological Context

The geological formations of the study area range from Cretaceous to Quaternary deposits. The Cretaceous formations dominate the region and include the Barremian-Aptian carbonate sequences, the Albian clayey-sandy deposits, and the Cenomanian-Turonian limestone and marl units. The Senonian formations, particularly the Campanian and Maastrichtian, are represented by massive limestones and reefal carbonates that constitute the main aquifer systems (Fig. 2, not shown).

The hydrogeological framework is dominated by the Complex Terminal (CT) aquifer system, which is extensively exploited for water supply through deep boreholes. The aquifer is primarily recharged by infiltration of seasonal rainfall through the karstified limestone outcrops of the surrounding mountains (Galâa, Boutakhma, Fedjijet). The depth of boreholes in the study area ranges from 120 m to 274 m, with static water levels varying between artesian conditions and depths of 62 m. The total exploitable discharge of the five studied boreholes reaches approximately 12 L/s.

3. MATERIALS AND METHODS

Groundwater samples were collected from five operational boreholes (J37, OL1, O45, H47, I40) during the period 2018–2021. The boreholes are managed by the Water Resources Directorate of Oum El Bouaghi (ADE-OEB) and supply drinking water to F'kirina and Aïn Beida municipalities. Physicochemical analyses were conducted at the regional water analysis laboratory using standardized methods (APHA, 2017).

The parameters analyzed included: pH (potentiometric method), electrical conductivity (EC) (conductimetry), turbidity (nephelometry), total hardness (TH) and alkalinity (TAC) (titrimetry with EDTA), calcium (Ca^{2+}) and magnesium (Mg^{2+}) (complexometry), chloride (Cl^{-}) (argentometry), sulfate (SO_4^{2-}) (spectrophotometry), bicarbonate (HCO_3^{-}) (acidimetry), nitrate (NO_3^{-}) (spectrophotometry), and ammonium (NH_4^{+}) (Nessler method). The analytical quality was ensured through calibration with standard solutions and replicate measurements.

3.2. Groundwater Quality Index (GWQI)

The GWQI was computed using the weighted arithmetic index method following the approach described by Ravikumar et al. (2023) and Tyagi et al. (2023):

$$GWQI = \Sigma SIi = \Sigma Wi \times Qi$$

where SIi is the sub-index for the i-th parameter, Wi is the relative weight, and Qi is the quality rating based on the observed concentration (Ci) relative to the standard value (Si):

$$Qi = (Ci / Si) \times 100$$

$$Wi = wi / \Sigma wi$$

The weights (wi) were assigned based on the relative importance of each parameter for drinking water quality and health implications (Table 1). The GWQI classification follows the scheme: 0–25 (Excellent), 26–50 (Good), 51–75 (Poor), 76–100 (Very Poor), and >100 (Unsuitable).

3.3. Multivariate Statistical Analysis

Principal Component Analysis (PCA) was performed on the standardized dataset (z-score normalization) to reduce dimensionality and identify the latent factors controlling groundwater chemistry. The analysis was conducted on eleven physicochemical variables using Pearson correlation matrices. PCA was selected for its ability to: (i) eliminate redundant information among correlated variables; (ii) identify groups of parameters with common sources; and (iii) distinguish between natural geogenic processes and anthropogenic contamination (Bouaicha et al., 2024; Voutchkova et al., 2023).

3.4. Data Quality Assurance

All statistical analyses were performed using Python 3.11 with the scikit-learn, pandas, and matplotlib libraries. The Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were applied to verify the suitability of the dataset for PCA. The significance level for all statistical tests was set at $\alpha = 0.05$.

4. RESULTS AND DISCUSSION

4.1. Descriptive Statistics and Physicochemical Characterization

The descriptive statistics of the analyzed groundwater parameters are summarized in Figure 5 (Table 2). The pH values ranged from 7.08 (I40) to 7.58 (O45), with a mean of 7.37 ± 0.24, indicating slightly alkaline to neutral conditions. All pH values fell within the WHO permissible range (6.5–8.5), suggesting no adverse effects on human health or metal solubility.

Electrical conductivity (EC) exhibited considerable variation, ranging from 609.5 µS/cm (O45) to 1359.5 µS/cm (I40), with a mean of 1096.9 µS/cm. While all values remained below the WHO guideline of 1500 µS/cm, the elevated EC in boreholes I40, J37, and OL1 indicates moderate mineralization, likely attributable to water-rock interactions within the carbonate and evaporitic formations of the Senonian and Cenomanian sequences.

Turbidity emerged as a critical parameter, with values ranging from 0.21 NTU (O45) to 12.9 NTU (H47). The mean turbidity (4.01 ± 5.31 NTU) exceeded the WHO recommended limit of 1 NTU in three boreholes (J37, H47, and marginally OL1). The elevated turbidity in H47 (12.9 NTU) and J37 (5.0 NTU) suggests significant ingress of suspended particulate matter, potentially due to inadequate wellhead protection, screen corrosion, or infiltration of surface runoff during rainfall events. High turbidity not only compromises aesthetic quality but also reduces disinfection efficiency and may harbor pathogenic microorganisms (Anderson, 2005; Ramavandi, 2014).

Total hardness (TH) ranged from 26.25°F (O45) to 56°F (OL1), with a mean of 43.8°F. Four out of five boreholes exceeded the Algerian drinking water standard of 30°F (equivalent to approximately 300 mg/L $CaCO_3$). The hardness is primarily derived from the dissolution of carbonate minerals (calcite and dolomite) and gypsum within the aquifer matrix, consistent with the dominance of Ca^{2+} (mean: 129.6 mg/L) and HCO_3^- (mean: 294.1 mg/L) in the hydrochemical facies.

Nitrate concentrations varied from 19 mg/L (O45) to 49.75 mg/L (J37), with a mean of 33.95 mg/L. Although all values remained below the WHO maximum permissible limit of 50 mg/L, the concentration in J37 (49.75 mg/L) approaches the critical threshold. The presence of nitrate in groundwater typically reflects agricultural inputs (fertilizers), septic systems, or natural organic matter mineralization (Spalding and Exner, 1993; Showers et al., 2008). The spatial distribution suggests that boreholes located near agricultural zones (J37, OL1) exhibit higher nitrate levels compared to the more isolated O45 borehole.

Ammonium levels were generally low (mean: 0.03 mg/L), well below the Algerian standard of 0.5 mg/L,

indicating limited recent sewage contamination. Chloride concentrations ranged from 54.5 mg/L (O45) to 227 mg/L (J37), with all values within the WHO limit of 250 mg/L. However, the elevated Cl^- in J37 may reflect evaporite dissolution or subtle saline intrusion from the nearby Sebkha systems.

4.2. Hydrochemical Facies

The Piper diagram (Figure 3, not shown) and Schoeller-Berkaloff diagrams reveal that the groundwater predominantly belongs to the calcium-magnesium-bicarbonate (Ca-Mg-HCO_3) hydrochemical facies, typical of freshwater recharge through carbonate aquifers. However, boreholes J37 and I40 show a tendency toward chloride-sulfate facies, suggesting longer residence times and/or evaporite influence. The Stiff diagrams confirm the dominance of alkaline earth metals (Ca^{2+}, Mg^{2+}) over alkali metals (Na^+, K^+), and weak acids (HCO_3^-) over strong acids (Cl^-, SO_4^{2-}), which is characteristic of recently recharged groundwater in carbonate terrains.

4.3. Groundwater Quality Index (GWQI)

The GWQI values calculated for the five boreholes are presented in Figure 2 and Figure 6 (Table 3). The results indicate significant spatial variability in groundwater quality:

• Borehole O45: GWQI = 33.34 (Good quality). This borehole exhibited the lowest concentrations of turbidity, Cl^-, SO_4^{2-}, and NO_3^-, combined with moderate hardness and near-neutral pH. Its favorable quality is attributed to its location in a less anthropized zone and effective natural filtration through the thick unsaturated zone (274 m depth).

• Borehole H47: GWQI = 50.78 (Good to Poor transition). Despite elevated turbidity (12.9 NTU), the borehole showed moderate mineralization and acceptable nitrate levels. The high turbidity significantly penalized the overall index.

• Boreholes J37, OL1, and I40: GWQI values of 63.51, 64.56, and 64.68, respectively, all classified as "Poor." These boreholes are characterized by elevated EC, hardness, and turbidity (particularly J37 and I40), rendering the water unsuitable for direct consumption without treatment.

The GWQI classification indicates that 60% of the monitored boreholes deliver water of poor quality, primarily due to physicochemical exceedances rather than bacteriological contamination. This finding aligns with recent studies in the Algerian high plains, where carbonate aquifers frequently exhibit natural exceedances of hardness and turbidity (Boukhari et al., 2024; Cherif et al., 2023).

4.4. Principal Component Analysis (PCA)

The Pearson correlation matrix (Figure 3) reveals several significant inter-parameter relationships. Strong positive correlations were observed between EC and Cl^- ($r = 0.96$), EC and TH ($r = 0.93$), and Ca^{2+} and SO_4^{2-} ($r = 0.94$), indicating common geogenic sources. Turbidity showed weak correlations with

most parameters, suggesting an independent origin likely related to mechanical infiltration or well infrastructure degradation.

PCA extracted two principal components with eigenvalues >1, collectively explaining 80.7% of the total variance (PC1: 65.3%; PC2: 15.4%). The component loadings and scores are visualized in the biplot (Figure 4).

Principal Component 1 (PC1, 65.3% variance) is strongly positively loaded by EC (0.95), TH (0.93), Ca^{2+} (0.92), Cl^{-} (0.91), SO_4^{2-} (0.89), and NO_3^{-} (0.78). This component represents the "mineralization and natural geogenic process" factor. The high positive loadings of Ca^{2+}, Mg^{2+}, HCO_3^{-}, and SO_4^{2-} reflect the dissolution of carbonate (calcite, dolomite) and sulfate (gypsum) minerals from the Cretaceous aquifer matrix. The association of NO_3^{-} with PC1 suggests that agricultural return flows may be partially assimilated into the natural mineralization gradient.

Principal Component 2 (PC2, 15.4% variance) is dominated by positive loadings of turbidity (0.88) and pH (0.76), with negative loadings of Mg^{2+} (-0.82). This component likely represents the "surface contamination and well integrity" factor. The turbidity vector points toward boreholes H47 and J37, which are located in areas with shallower water tables and potentially compromised wellhead protection. The negative relationship with Mg^{2+} may reflect differential dissolution kinetics or ion exchange processes in the vadose zone.

The PCA biplot (Figure 4) clearly segregates the five boreholes into three groups:

1. Group A (O45): Characterized by low scores on PC1 and PC2, indicating minimal mineralization and low contamination risk.
2. Group B (H47, J37): High PC2 scores driven by turbidity and pH anomalies, suggesting surface-borne contamination and infrastructure issues.
3. Group C (OL1, I40): High PC1 scores reflecting strong mineralization (hardness, EC, Ca^{2+}, HCO_3^{-}), consistent with prolonged water-rock interaction in the deep carbonate aquifer.

These results corroborate the GWQI findings and demonstrate that PCA effectively discriminates between natural hydrochemical evolution (PC1) and anthropogenic or mechanical contamination pathways (PC2).

4.5. Comparative Assessment and Implications

When compared with historical data from the same boreholes (pre-2018), the current analysis reveals a gradual deterioration in turbidity and nitrate levels, particularly in J37 and OL1. This trend is consistent with the intensification of agricultural activities in the F'kirina plain and the aging of water supply infrastructure. The boreholes exhibiting poor GWQI values (J37, OL1, I40) require immediate intervention, including:

• Installation of filtration and settling systems for turbidity removal;

• Softening treatment (ion exchange or lime-soda process) for hardness reduction;

• Regular chlorination and monitoring of nitrate levels.

Borehole O45, with its consistently good quality, should be prioritized as a strategic reserve for the region, while H47 requires infrastructure rehabilitation to address turbidity issues.

5. CONCLUSION

This study provides a comprehensive assessment of groundwater quality in the F'kirina region, Oum El Bouaghi province, Algeria, through the integrated application of the GWQI and PCA. The main conclusions are:

1. The groundwater chemistry is dominated by Ca-Mg-HCO_3 facies, reflecting natural recharge through carbonate aquifers of Cretaceous age.

2. The GWQI classified 60% of the studied boreholes (J37, OL1, I40) as "poor" and unsuitable for direct drinking without treatment. Borehole O45 consistently exhibited "good" quality, while H47 was borderline.

3. Turbidity and total hardness were identified as the primary limiting parameters, with turbidity exceeding WHO limits in H47 (12.9 NTU) and J37 (5.0 NTU), and hardness exceeding national standards in four boreholes.

4. PCA revealed that 80.7% of the hydrochemical variance is controlled by two factors: (i) natural mineralization (PC1: 65.3%) driven by carbonate and evaporite dissolution, and (ii) surface contamination/well integrity (PC2: 15.4%) associated with turbidity and pH variations.

5. The combined GWQI-PCA approach proved highly effective in distinguishing geogenic water quality evolution from anthropogenic contamination signals, providing a robust framework for regional groundwater management.

Recommendations:

• Immediate implementation of treatment trains (coagulation-flocculation-filtration) for boreholes with high turbidity;

• Establishment of protection perimeters around borehole O45 to preserve its excellent quality;

• Periodic monitoring of nitrate levels, particularly in boreholes near agricultural zones;

• Rehabilitation of well infrastructure (casing, screens, seals) in H47 and J37;

• Exploration of alternative water sources (inter-basin transfer, rainwater harvesting) to reduce pressure on the carbonate aquifer.

Declarations

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Author contributions: S.A. conceptualized the study, collected and analyzed the physicochemical data, performed GWQI and PCA calculations, prepared all figures and tables, and wrote the original manuscript draft. H.Z. supervised the research, provided primary scientific guidance on hydrochemical interpretation and methodology, and critically revised the manuscript. Y.F. and R.L. participated in the thesis evaluation, provided scientific feedback, reviewed the statistical analysis, and contributed to manuscript editing. All authors read, reviewed, and approved the final manuscript for submission.

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Sustainability statement: This research supports the United Nations Sustainable Development Goals 6 (Clean Water and Sanitation) and 13 (Climate Action).

References

1. Anderson CW. Turbidity. USGS National Field Manual for the Collection of Water-Quality Data. U.S. Geological Survey; 2005.
2. APHA. Standard Methods for the Examination of Water and Wastewater. 23rd ed. Washington, DC: American Public Health Association; 2017.
3. Bouaicha N, Benyahia M, Hamadene S, et al. Hydrochemical characterization and groundwater quality assessment using multivariate statistical analysis in the Mitidja plain, northern Algeria. J Afr Earth Sc. 2024;210:105–18.
4. Boukhari K, Douaoui A, Hani A, et al. Assessing groundwater vulnerability and quality in the high plains of eastern Algeria using DRASTIC and GIS techniques. Environ Earth Sci. 2024;83(4):112.
5. Bouziane MT, El Morjani ZEA, El Halim MB, et al. Hydrochemical and statistical approaches for evaluating groundwater quality in the Saïss basin, Morocco. Groundw Sustainable Dev. 2023;23:100985.

6. Cherif S, Talbi A, Zeddouri A, et al. Assessment of groundwater quality for irrigation and drinking purposes in the Cheliff basin, Algeria. Appl Water Sci. 2023;13(5):112.
7. Chowdhury RM, Ferdous Z, Rahman MM, et al. Application of water quality indices for groundwater quality assessment: A comprehensive review. Environ Monit Assess. 2023;195(3):412.
8. Margat J, Van der Gun J. Groundwater around the World: A Geographic Synopsis. Leiden: CRC Press/Balkema; 2013.
9. Ojo OI, Otieno FAO, Twala B. Groundwater: Characteristics, qualities, pollutions and treatments – An overview. Int J Water Resour Environ Eng. 2012;4(6):162–70.
10. Rahmani A, Zaidi H, et al. Expansion of urban areas and land use changes in Aïn Beida city, Oum El Bouaghi, Algeria. J Geographical Stud. 2020;14(2):45–58.
11. Ramavandi B. Treatment of water turbidity and bacteria by using a coagulant extracted from Plantago ovata. Water Resour Ind. 2014;6:36–50.
12. Ravikumar P, Somashekar RK, Angami M. Hydrochemistry and evaluation of groundwater suitability for domestic and agricultural utility in semi-arid region of Bagalkot district, Karnataka State, India. Environ Monit Assess. 2023;195(2):234.
13. Saha D, Paul S. Groundwater quality assessment using hydrochemical and multivariate statistical techniques in the Bengal basin, India. J Hydrology: Reg Stud. 2023;48:101435.
14. Shiklomanov IA. (1991). The World's Water Resources. Proceedings of the International Symposium to Commemorate the 25th Anniversary of the UNESCO/IHD, Paris.
15. Showers WJ, Genna B, McDade T, Bolich R, Fountain JC. Nitrate contamination in groundwater on an urbanized dairy farm. Environ Sci Technol. 2008;42(7):2384–90.
16. Spalding RF, Exner ME. Occurrence of nitrate in groundwater – A review. J Environ Qual. 1993;22(3):392–402.
17. Tyagi S, Sharma B, Singh P, Dobhal R. Water quality assessment in terms of water quality index. Am J Water Resour. 2023;11(1):23–9.
18. Voutchkova DD, Ernstsen V, Kristensen L, et al. Multivariate statistical analysis for assessing groundwater quality and identifying hydrogeochemical processes in a complex aquifer system. Sci Total Environ. 2023;858:159875.
19. WHO. (2022). Guidelines for Drinking-Water Quality, 4th ed. incorporating the 1st and 2nd addenda. World Health Organization, Geneva.
20. Zaidi H, et al. Climatic data analysis and water resources management in Oum El Bouaghi region, Algeria. J Water Clim Change. 2019;10(3):567–80.

Tables

Tables 1 to 3 are available in the supplementary files section.

Figures

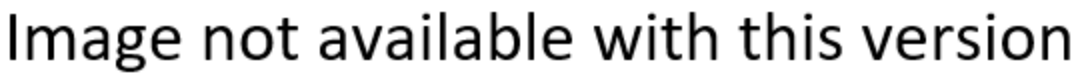


Figure 1

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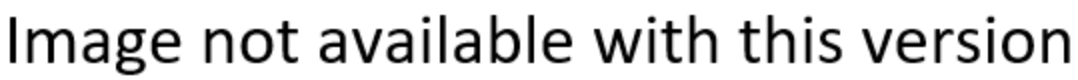


Figure 2

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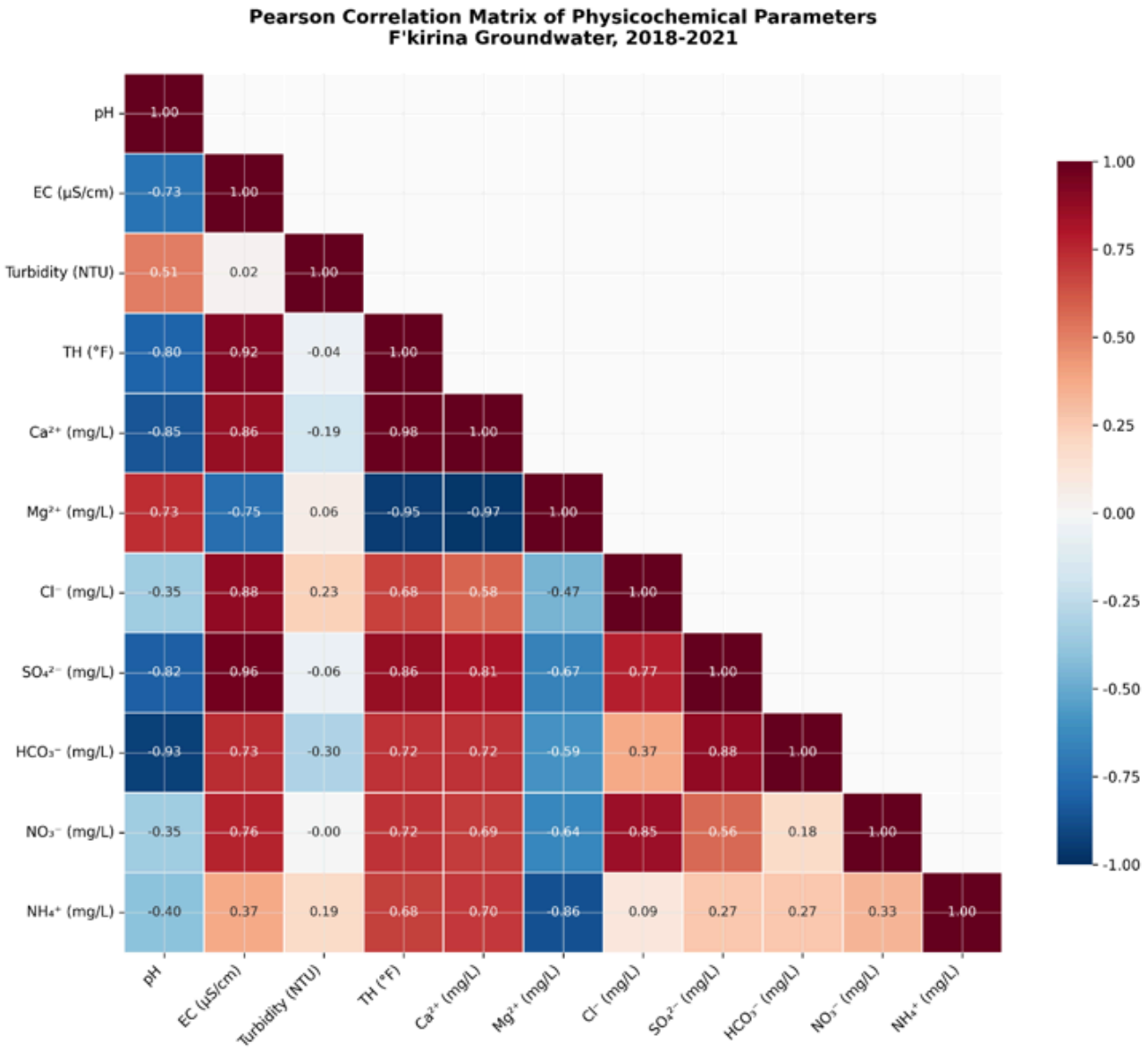


Figure 3

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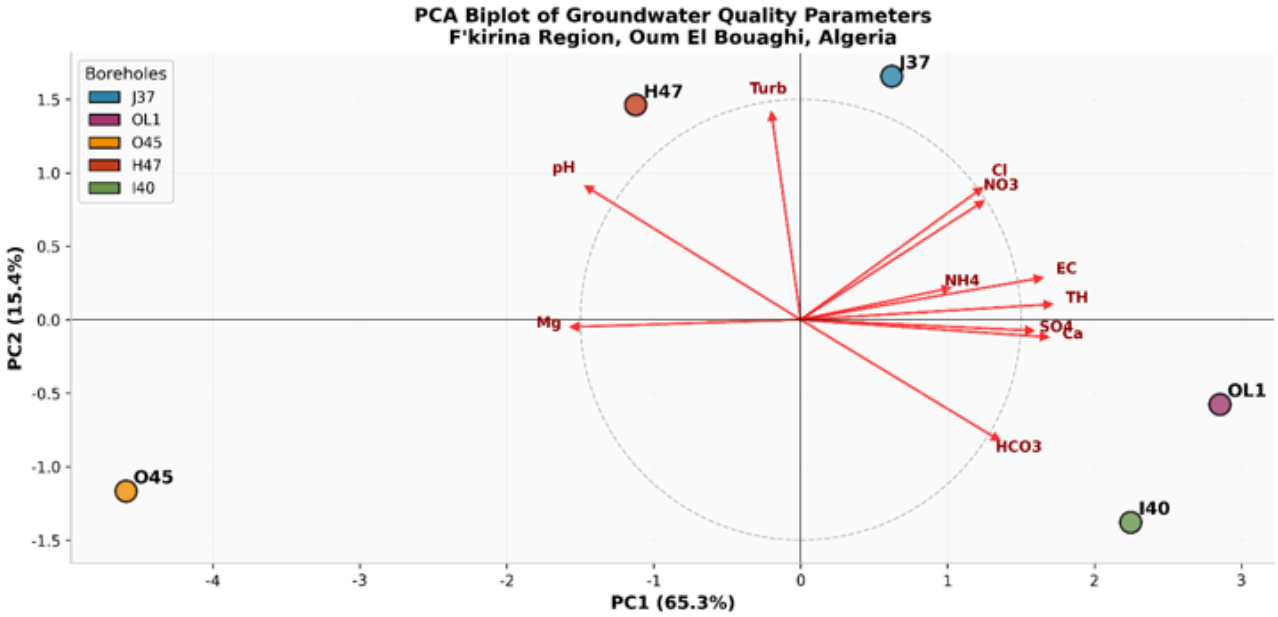


Figure 4

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Figure 5

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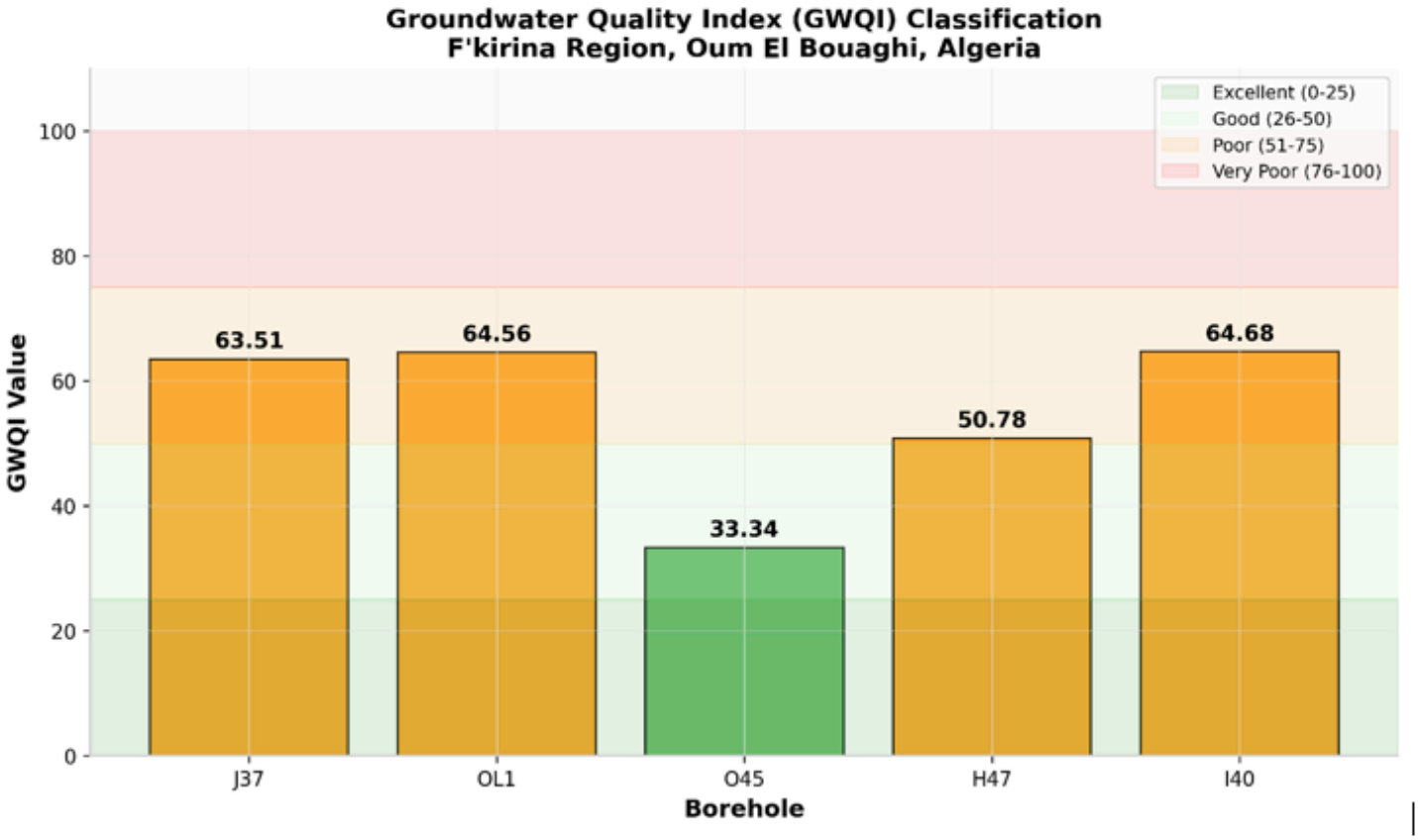


Figure 6

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