Assessment of the hygienic quality of well and spring water: A case study of the Oued Leben watershed (Central Prerif, Morocco)

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Abstract. This study aimed to determine the physical, chemical, and bacteriological quality of groundwater in the Oued Leben basin and to identify the pollutants present and their origins. The research included a spatial study of 37 groundwater stations over a period of nine months (September 2024 to June 2025). The results showed spatial differentiation influenced by natural and human factors. The groundwater analyzed shows a deterioration in its physical-chemical and bacteriological quality, expressed by a high load of pathogenic bacteria and high salinity downstream of the Oued Leben, reaching 8.60 g/L in P1 and P10. This leads to a considerable deterioration in groundwater quality, calculated at approximately 86.5% of points with poor to very poor quality, thus rendering it unfit for human consumption. This deterioration depends mainly on various natural and anthropogenic factors.

Key words. Oued Leben, Salinity, Groundwater, Water quality.

1. Introduction

Groundwater accounts for nearly 97% of liquid freshwater resources on land [1]. Approximately 80% of the world's population depends on groundwater for their drinking water needs [2]. Several recent studies indicate that groundwater pollution stems from geological and anthropogenic sources [3], including wastewater infiltration and the intensive use of chemical fertilizers in agriculture [4, 5]. Furthermore, this pollution is exacerbated by poorly managed septic tanks, a lack of treatment infrastructure, inadequate sanitation networks, and failure to comply with public health regulations [6].

Indeed, the combination of several factors promotes the spread of fecal-oral diseases. These include the use of water from open public wells or unprotected individual wells, inadequate sanitation infrastructure, and a lack of knowledge of basic hygiene rules. These serious conditions include gastroenteritis, hepatitis, and typhoid fever [7].

The problem of salinity makes the water resource situation critical in the Taounate region. Water management must take into account all components of the hydrological cycle. The depletion and degradation of water quality are not easily perceived. Generally, groundwater sources complement easily accessible surface water sources. In addition, drought is one of the most significant phenomena resulting from climate variability and change. Groundwater pollution is one of the most worrying aspects, and the use of this water for food purposes poses a health hazard [8].

This study focuses on determining the physicochemical and bacteriological quality of groundwater in the Oued Leben watershed using multivariate statistical methods and diagram analysis. The physicochemical and bacteriological parameters of water from 37 representative groundwater points in the Oued Leben basin are monitored in order to determine the extent of pollution and identify its source.

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2. Materials and methods

2.1. Study area

The Oued Leben watershed is considered one of the most important sub-basins of the Oued Sebou, covering an area of 1,387 km². Our study area is geographically located in the transition zone between the southern Rif mountains and the low hills of the central and eastern Prérif. Administratively, it covers the provinces of Taounate and Taza, which are part of the Fez-Meknes region (Figure 1). Oued Leben, a right-bank tributary of the Oued Inaouene, crosses the urban commune of Tissa, which is located on the RR 508, 3 km from the RN 8 and 35 km from the provincial capital, at the crossroads of major transport routes, namely the RR 508 (connecting RN 8-Tissa Had Jbarna and R505 Taza-Aknoul), RN No. 8 (connecting Fez to Taounate), RP No. 5329 (connecting Tissa to RP 5335) and RN 6 Fez-Taza (Figure 1).

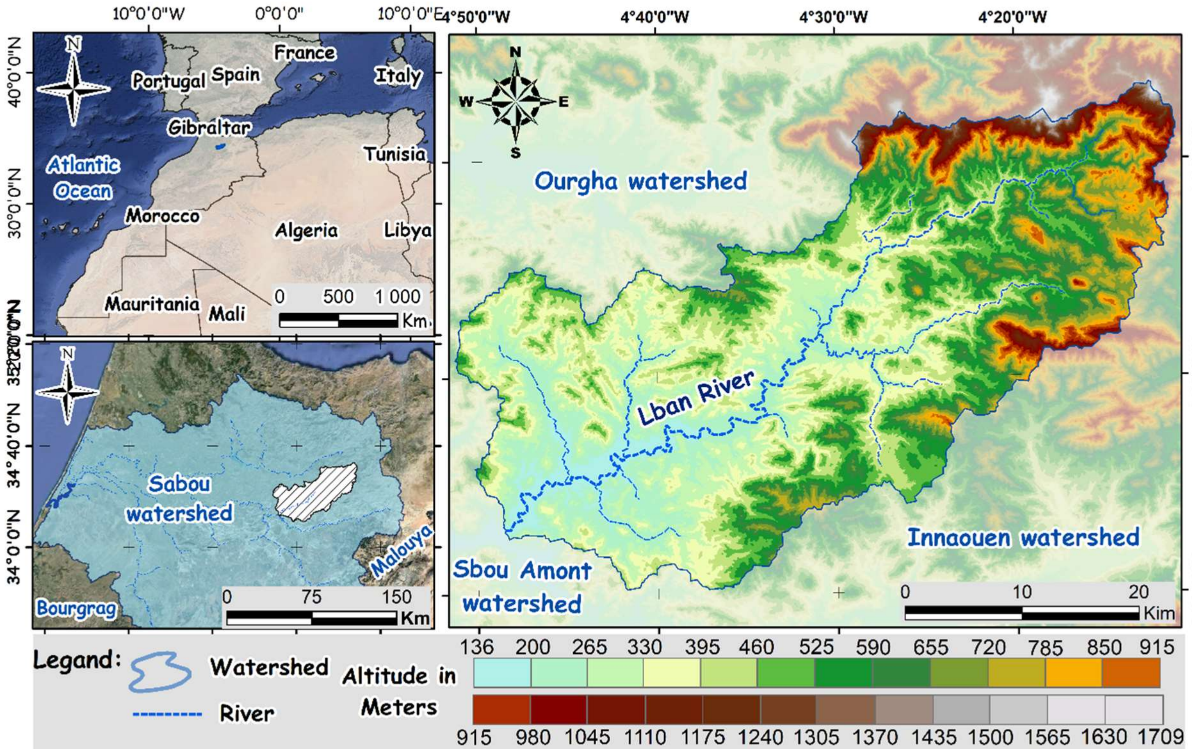
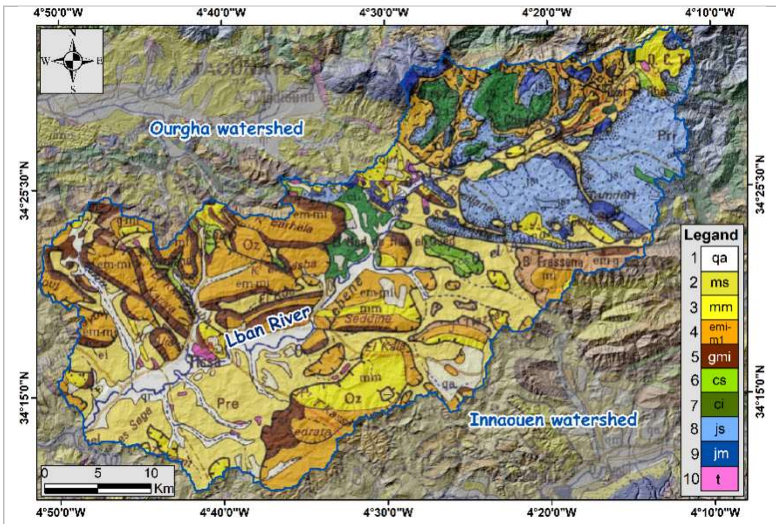


Fig. 1. Geographical location of the Leben watershed.



1- Quaternary: Symbol, (qa) Alluviums (gravel, sand, clay, clay, silt), 2- Upper Miocene: Symbol, (ms) marls, grey and brown, with interbedded limestones. 3- Middle Miocene: Symbol, (mm) marls and marly limestones, turbiditic sequences. 4- Middle to Lower Eocene: Symbol, (emi-m1) hard marls and micritic limestones, alternating beds. 5- Eocene: Symbol, (gmi) marls and gray marls. 6- Upper Cretaceous: Symbol, (cs) massive limestones, occasionally dolomitized. 7- Middle Cretaceous: Symbol, (ci) Fine-grained grey limestones with fossils. 8- Upper Jurassic: Symbol, (js) massive white to grey limestones, recrystallized. Carbonate platform. 9- Middle Jurassic: Symbol, (jm) Alternating dolomites and micritic limestones. Shelf facies. 10- Upper Triassic: Symbol, (t) gypsum, anhydrite, chlorite.

Fig. 2. Geological map of the Oued Leben watershed (excerpt from the 1/1000.000 geological map of Morocco).

The Oued Leben basin lies in the transition zone between the southern Rif Mountains (800-1,700 m) and the low hills (300-600 m) of the central and eastern Prérif (Figure 1). The course of the river carves its path upstream (456 m) through resistant rocks (limestone, dolomite, sandstone, and flysch) and flows through fragile terrain (marl-limestone, white marl with flint, marl with intercalated sandstone banks (Figure 2), and soft marl from the Triassic complex) until it joins the Inaouène wadi at an altitude of 149 m. Along its 110 km length, the valley alternates between narrow sections and wide valleys [9].

2.2. Experimental protocol

Field trips organized by a certified expert from the National Office of Electricity and Drinking Water - Water Branch-, are conducted to collect and analyze water samples. The sampling, transportation, and preservation of the water samples are carried out in accordance with the laboratory protocol for water quality control [10]. The sampling frequency adopted over a nine-month period (from September 2024 to June 2025).

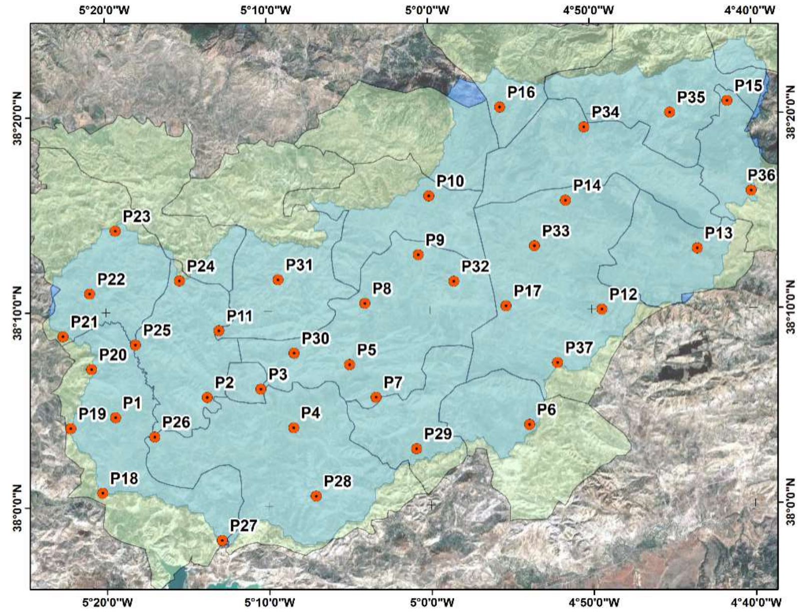


Fig. 3. Sampling points of groundwater.

The hydrochemical analysis considered twenty parameters, of which five were measured in the field right after the device's calibration, utilizing four essential tools. We have used a volumetric device to identify multiple chemical parameters such as bicarbonates, chlorides, calcium, and magnesium. Other instruments like molecular absorption spectrophotometry and flame spectrophotometry allowed us to determine sulfates, nitrates, nitrites, ammonium ions, orthophosphates, sodium, and potassium.

The study of bacterial parameters was mostly about finding out how many fecal coliforms (FC), total coliforms (TC), and fecal streptococci (FS) there were. We collected samples monthly, following the National Office for Drinking Water and Sanitation [11] sampling and analysis procedure. The enumeration of FC, TC, and FS was carried out using the indirect multiple tube fermentation method in lactose broth; the count was then statistically deduced using the most probable number method[12].

3. Results and discussion

The results of this study are presented by discussing the parameters measured, including measurements taken on site and in the laboratory. For each parameter, we have chosen to provide a cartographic representation using GIS from September 2024 to June 2025.Physicochemical analysis.

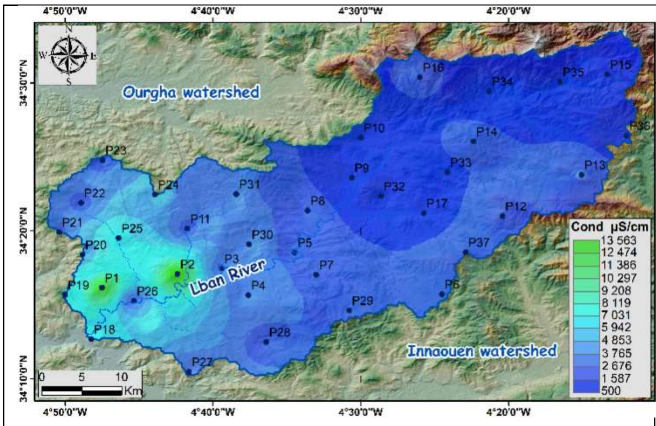


Fig. 4. Spatial evolution of groundwater conductivity (µs/cm) in the Oued Leben watershed.

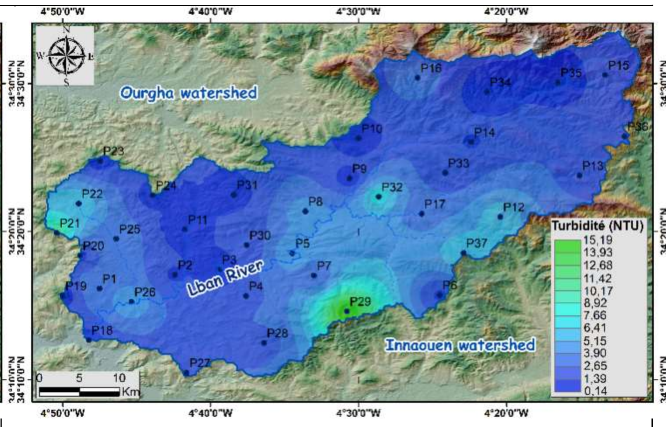


Fig. 5. Spatial evolution of turbidity (NTU) in groundwater in the Oued Leben watershed.

The evolution of conductivity shows increasing enrichment along the Oued Leben 13,590 µs/cm, while in the wells of the municipality of Ain Maatouf, conductivity is low at 499 µs/cm (Figure 4). This high conductivity may be due to a natural origin through the leaching of carbonate lithological formations (gypsum, red salt-bearing marl, dolomite, limestone, etc.), resulting in the release of carbonate ions ($CO3$-), bicarbonate ions ($HCO3$-), magnesium ($Mg2$+), calcium ($Ca2$+), etc., particularly in wells close to the Oued Leben.

Turbidity varies from one station to another but remains below the 5 NTU standard at 80% of the points, with the exception of stations P8 and P19, where it is 15.20 and 10.60 NTU respectively. This could be due to poor protection of the wells. In general, turbidity varies between stations depending on the nature of the substrate through which the water flows and rainfall. Since high turbidity can allow microorganisms to attach themselves to suspended particles, the bacteriological quality of this water may be suspect. This can affect the potability of the water and is an important parameter for its treatment (Figure 5).

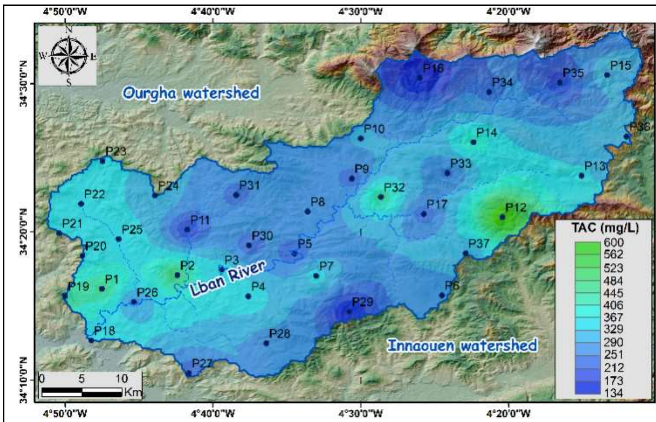


Fig. 6. Spatial evolution of HCO3- ions (mg/L) in groundwater in the Oued Leben watershed.

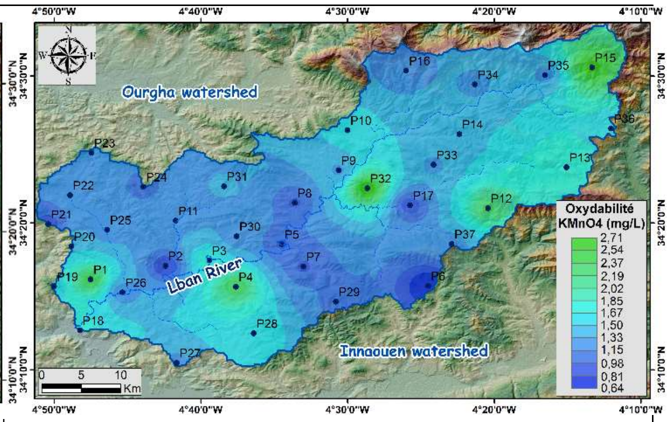


Fig. 7. Spatial evolution of the oxidizability (mg O_2/L) of groundwater in the Oued Leben watershed.

The presence of bicarbonates in water is due to the dissolution of carbonate formations and is the result of the physical-chemical equilibrium between rock, water, and carbon dioxide, according to the following reaction:

$$CaCO_3\ (Roche) + H_2O + CO_2 \rightleftharpoons 2HCO_3^- + Ca^{2+}$$

The concentration of bicarbonates in water depends on the water temperature, the tension of the dissolved CO_2, the concentration of salts in the water, and the lithological nature of the terrain traversed.

Significant concentrations appear in well P10, with levels reaching 475 mg/L. In well P34, the concentration is relatively low at 134.20 mg/L (Figure 6).

The water at most of the points analyzed has low oxidizability, except at a few points (P1, P4, P12, P15, and P32) (Figure 7). This indicates good groundwater recharge and low contamination by organic matter, and the water load of oxidizable organic or mineral matter is very low. This suggests that these waters are slightly polluted.

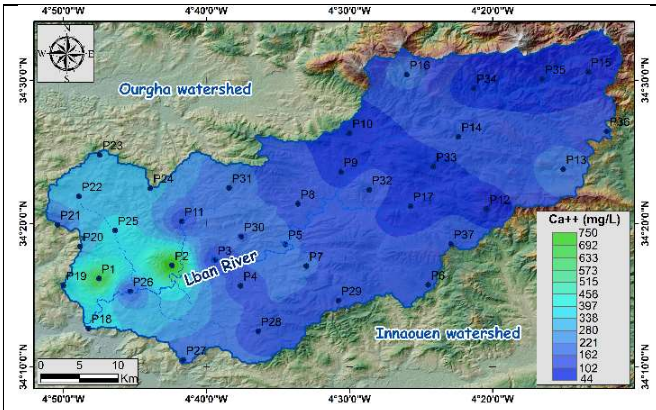


Fig. 8. Spatial evolution of Ca^{2+} ions (mg/L) in groundwater in the Oued Leben watershed.

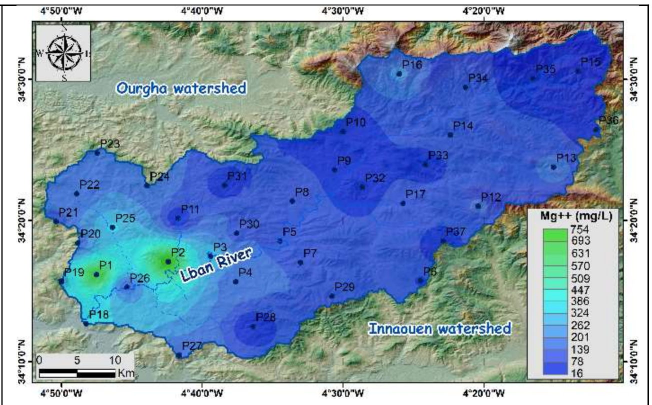


Fig. 9. Spatial evolution of Mg^{2+} ions (mg/L) in groundwater in the Oued Leben watershed.

The characteristic of Ca^{2+} is that it is easily exchangeable with Mg^{2+}, K^{+}, and $Na+$ ions. Water is composed of many mineral and organic elements. Its mineral content varies depending on the composition of the soil it passes through. Limestone soils will produce water rich in calcium.

Calcium is one of the parameters that contribute to water mineralization. It appears that the groundwater in the Tissa circle has quite remarkable calcium contents. These vary between 752 mg/L in well P10 and 44 mg/L in well P23 (Figures 8 & 9). This is thought to be due to the dissolution of Miocene carbonate formations ($CaCO3$) and Quaternary gypsum alluvial formations ($CaSO_4$).

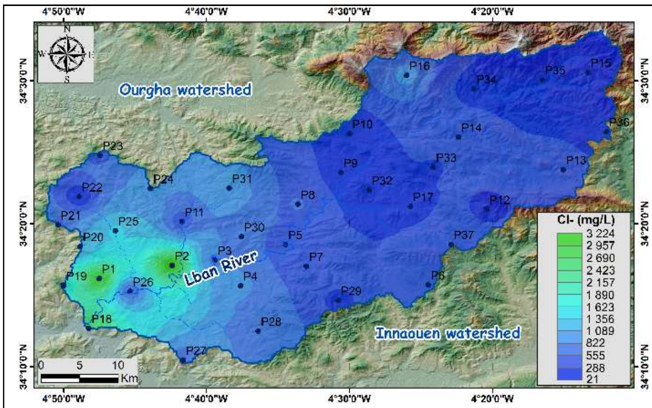


Fig. 10. Spatial evolution of Cl^{-} ions (mg/L) in groundwater in the Oued Leben watershed.

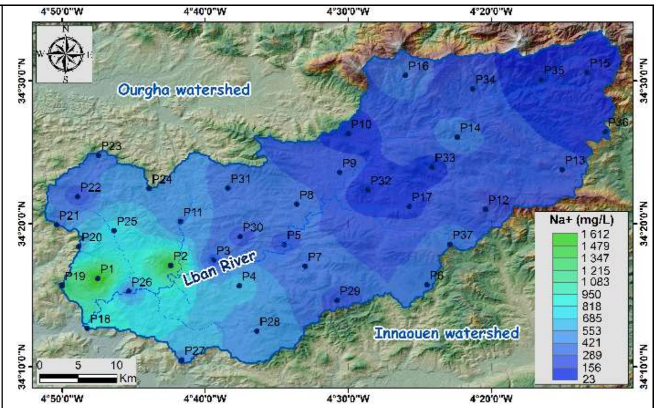


Fig. 11. Spatial evolution of Na^{2+} ions (mg/L) in groundwater in the Oued Leben watershed.

Chloride concentrations are high, reaching very high values, especially downstream of the Oued Leben. They reach 3250.5 mg/L, especially during low water periods, whereas in the well far from the Oued Leben these concentrations do not exceed 21.30 mg/L (Figures 10 & 11).

These high values are due to the leaching of marl and dolomitic limestone at the edge of the area on the one hand, and the leaching of Quaternary sediments covering the area on the other. The presence of alluvium and evaporitic sediments on the soil surface facilitates leaching. During low water periods, intense evaporation influences the concentrations, especially when the piezometric level is close to the soil surface, while the low mineralization is due to dilution by aquifer water or the absence of gypsum levels [13, 14].

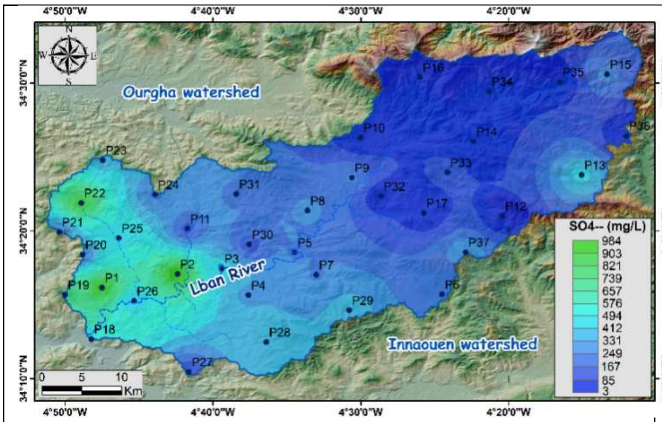


Fig. 12. Spatial evolution of SO_4^{2-} ions (mg/L) in groundwater in the Oued Leben watershed.

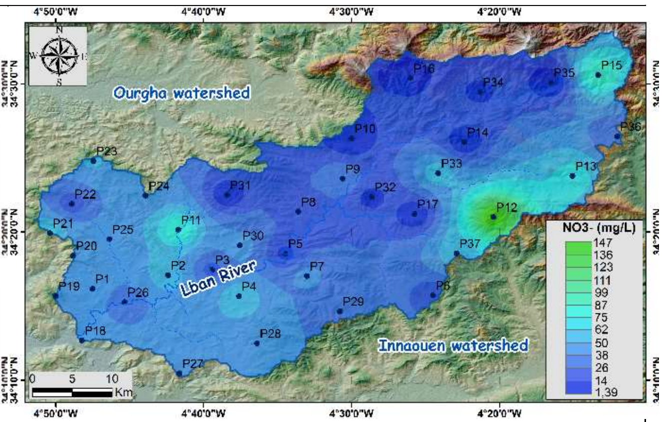


Fig. 13. Spatial evolution of NO_3^- ions (mg/L) in groundwater in the Oued Leben watershed.

The variability in sulfate content observed in groundwater is of great hydrogeological interest. Their origin is linked to precipitation, which can contain significant amounts of $SO42$-, to the leaching of evaporitic rocks (gypsum, anhydrite), or to the oxidation of sulfur in pyrite contained in rocks according to the following reaction:

$$CaSO_4 + 2H_2O \rightleftharpoons Ca^{2+} + SO_4^{2-} + 2H_2O$$

The highest value was recorded in well P6 at 986 mg/L. The lowest was 3.55 mg/L in well P25 (Figure 12).

The nitrogen load is high in some wells far from Oued Leben, mainly due to nitrates that greatly exceed the standard for drinking water set at 50 mg/L due to heavy agricultural activity in these areas. This pollution poses health risks, particularly for infants, and contributes to the eutrophication of aquatic ecosystems.

3.1. Bacteriological analysis

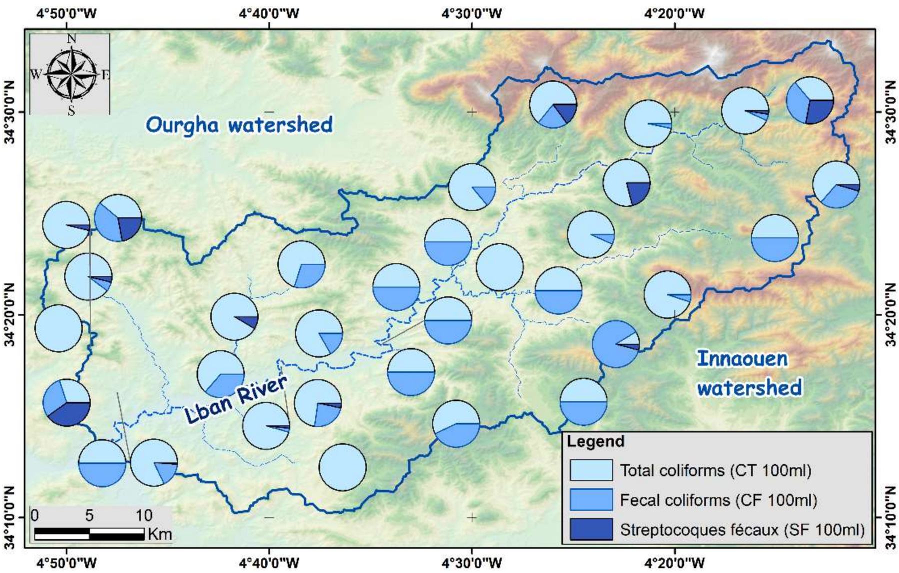


Fig. 14. Spatial evolution of CF, CT, and SF in the groundwater of the Oued Leben watershed.

Bacteriological results show that several wells have high levels of total coliforms, fecal coliforms, and fecal streptococci. The highest values are observed in wells located downstream of the Lben wadi, particularly P1, P3, P22, P35, and P4 (Figure 14). This high level of contamination reflects fecal pollution, probably linked to untreated domestic wastewater discharges, septic tank leaks, or surface runoff. The simultaneous presence of all three types of bacteria indicates a high health risk, making this water unfit for consumption without prior treatment [15].

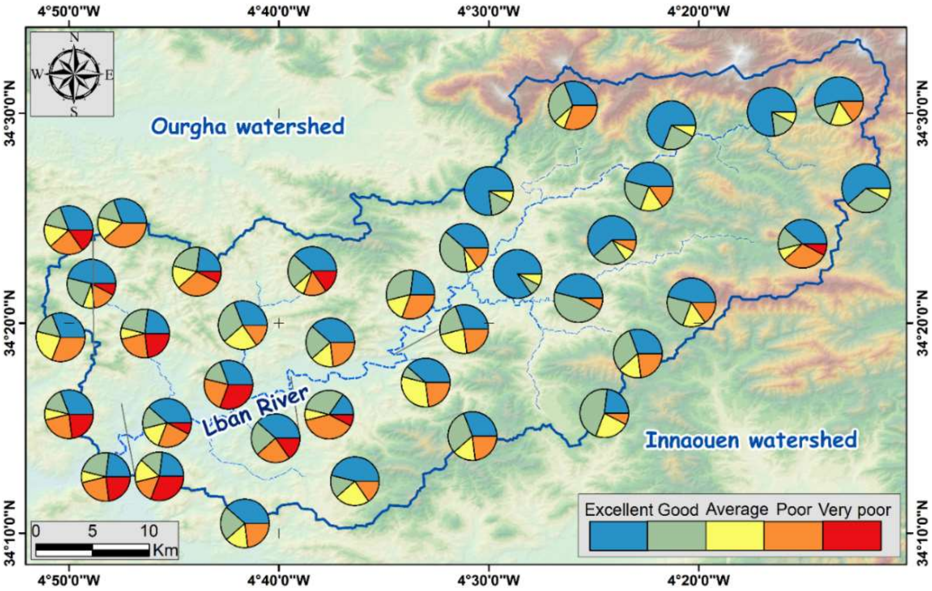


Fig. 15. Summary map of groundwater quality in the Oued Leben watershed.

Hydrogeochemical and pedological interpretation of the results showed high salinity in the nearby groundwater and in the downstream area of the Oued Leben. The main elements measured in the groundwater at the 37 stations (P1 to P37) (Figure 15) indicate differences in the concentrations of the various chemical compounds. The majority of maximum concentrations were recorded in the wells adjacent to the Oued Leben. A comparison of the geological context of the region with the spatial distribution of chemical elements shows that the origin of this mineralization is mainly linked to the dissolution of three types of formations: evaporitic, carbonate, and Quaternary alluvial. The variation in the concentration of chemical elements in the study area is linked to the effect of climatic conditions and the nature of the geological terrain of the Tissa circle. Indeed, precipitation and, above all, evaporation and the geological nature of the terrain traversed modify the physical and chemical properties of the water.
Following an assessment of groundwater quality in the Tissa district, a total of 37 wells, for individual or collective use, were identified. The majority of these wells contain brackish water, requiring costly treatment, particularly for desalination. In addition, there are significant technical constraints, such as the maintenance of treatment equipment and the continuous monitoring of treated water quality.

4. Conclusion

The potential of GIS tools provides significant support for the visualisation and modelling of geospatial data and enables effective analysis of environmental parameters. Water resource pollution is a major problem in the management of these resources, especially when they are used by the population as drinking water. In this study, we attempt to present a geostatistical model using GIS tools to determine the quality status and develop summary maps of groundwater in this region, based primarily on the study of the physical, chemical and bacteriological parameters of groundwater. The analyses were carried out on 37 sampling points evenly distributed across the Oued Lebene watershed using standardised methods. This study led us to conclude that contamination (bacteriological and chemical) of well and spring water in the Oued Leben watershed is almost universal, with 86.5% of the water analyzed being of poor to very poor quality, either due to high concentrations of chloride ions and nitrate ions or due to the presence of pathogenic bacteria, varying from one well to another. The main cause of this pollution is the nature of the geological terrain and anthropogenic activities, which continue to pose a major risk to humans and their environment, particularly to underground water resources. This study also demonstrated the importance and usefulness of GIS mapping to obtain spatial information on water quality and thus prevent all types of pollution originating from domestic, agricultural, and/or industrial human activities. The results of this study will be of great interest to health and hygiene services, which will be responsible for implementing preventive and corrective measures to avoid potential serious health risks. They will also enable decision-makers to establish policies and programs for information, education, communication, and awareness-raising aimed at rationalizing, preserving, and enhancing our water resources, while aligning with sustainable development recommendations.

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