JJEES

JJEES (2025) 16 (1): 50-60
ISSN 1995-6681

Jordan Journal of Earth and Environmental Sciences

# Assessment of Groundwater Quality for Irrigation and Drinking Using Water Quality Indexes in the Upper Sebaou Valley (Tizi Ouzou-eastern Algeria)

Agrouche Sabrina[1], Mansouri Zineb[2*], Reghais Azzeddine[3], Kardache Ramdane[1], Dinar Haythem[4], Abdelkader Laafer[5]

[1]UMMTO University, Department of Geology, Algeria.
[2]MGRE Laboratory, Department of Geology, Batna2 University, Algeria.
[3]University Mohamed Seddik Benyahia of JijelGeological Engineering Laboratory (LGG)
[4]Centre de Recherche en Aménagement du Territoire (CRAT), Campus Zouaghi Slimane, Route de Ain el Bey, 25000 Constantine, Algérie.
[5](LSTM Laboratory, Department of Mechanic, Faculty of Technology, University of Blida 1, Soumâa Street No. 270, 09130 Blida, Algeria)

Received on 21 October 2023, Accepted on 29 November 2024

**Abstract**

This study assesses the suitability of groundwater for irrigation and drinking purposes in the Upper Sebaou Valley, using various methods. Eight water samples were collected during the high-water period in 2019 and were analyzed for major ions and physical parameters. The results revealed that the analyzed physical-chemical parameters were generally below the permissible limits of the World Health Organization (WHO), indicating good drinking water quality in 99% of the samples. The groundwater exhibited low alkaline characteristics, with pH values ranging from 7.5 to 7.8. The conductivity ranged between 843 and 1180 s/cm, and the total dissolved solids (TDS) levels ranged from 762 to 1009 in the research area. Hydrochemical facies analysis identified calcium and magnesium bicarbonate as the dominant types, with significant ions including Ca2+, Mg2+, Na+, HCO3-, Cl, and SO4-2. Multivariate statistical analysis, such as principal component analysis (PCA), provided insights into groundwater quality characterization. The analysis also highlighted the presence of high sodium levels, impacting soil permeability and causing water infiltration issues, which are crucial considerations for irrigation purposes. Overall, the results suggest that groundwater in the Upper Sebaou Valley is suitable for both drinking and irrigation purposes, with a few exceptions related to geogenic factors and excessive fertilizer use.



**Keywords:** *Drinking Water, Eastern Algeria, Hydrogeochemical Facies, Irrigation, Groundwater Quality, Upper Sebaou Valley, Water Quality Index.*

## 1. Introduction

One of the world's most valuable water sources is groundwater, which is located around three-fourths of the earth's surface. It provides a steady supply of freshwater, sustains ecosystems, and is a vital source of drinking water for numerous communities. Because of its subterranean location and filtration capabilities, groundwater is a valuable resource for the environment and humans (Soleimani et al., 2018; Muhammad and Ullah, 2022). It is a necessity for every person, including farmers, households, and manufacturers. Compared to other sources, it is regarded as pure (Jamshidzadeh et al., 2018; Boufekane et al., 2022). When rainfall hits the surface, it causes water to go through various processes that affect its chemical composition. These include the interactions between rocks and minerals as they move through the subsurface. This interaction helps shape the unique features of groundwater (Yousefi, Dehghani, et al., 2018; Muhammad and Usman, 2022). The water cycle affects the quality of groundwater. It is affected by various natural processes, such as ion exchange and mineral dissolution (Muhammad, 2023). Human activities, such as urbanization, overexploitation, and population growth can also have a significant impact on groundwater quality (Goyal et al., 2010; Kawo et al., 2018; Jasrotia et al., 2019; Asadi et al., 2019; Balamurugan et al., 2020; Adimalla et al., 2020; Haque et al., 2020; Panneerselvam et al., 2020; Aravinthasamy et al., 2021). However, the use of agrochemicals such as pesticides and fertilizers, as well as untreated industrial wastewater causes metals to infiltrate into water bodies (Khedidja et al., 2023).

In addition, industrial waste residues can leak into the groundwater, which can cause severe pollution (Muhammad, 2023). Although the Sebaou Valley has a lot of water, it is also heavily contaminated by agricultural, industrial, and urban sources (Din et al., 2023). The high stratum is the source of drinking water, while the rest is used for irrigation. It's important to monitor the water quality in a particular area (Muhammad and Ullah, 2022).

The evaluation of water quality involves assessing the various characteristics of groundwater, such as its pH level, color, temperature, turbidity, and dissolved oxygen. Hydrobiological features, including major anions and cations, are used as indicators for improving the classification process (Vadiati et al., 2016; Yousefi, Ghoochani, et al., 2018). The weighted and chosen parameters represent the end-uses of

* Corresponding author e-mail: z.mansouri@univ-batna2.dz

water, such as irrigation and drinking water (Sharma et al., 2006; Yousefi, Ghoochani, et al., 2018).

Various methodologies have been used to evaluate water quality to assess it more correctly, comparably, and realistically. The quality index (WQI) has been developed and invented since the 1960s. In 1848, the first investigations of the evolution of pollution levels and water quality were conducted in Germany. The Oregon Water Quality Index (OWQI) was developed by the Oregon Department of Environmental Quality (DEQ) in 1967 based on the transformation of water quality parameters without unity using sub-index equations, then, combining these sub-indices with mathematical expression to obtain a water quality index value. Following that, many indexes were devised in the 1970s, including Horton's index and Brown's index, used in 2010.

The Water Quality Index (WQI) serves as a convenient and standardized measure to evaluate water quality on a scale of 0 to 100. Higher WQI values indicate better water quality, while lower values signify poorer quality (Horton, 1965; Brown et al., 1970; Yousefi et al., 2017; Amin et al., 2021). WQI has been widely utilized by researchers to assess groundwater quality, examine regional variations in groundwater metrics, and evaluate the appropriateness of water for irrigation purposes (Stigter et al., 2006; Yousefi et al., 2017; Al-Hadithi et al., 2019; Hyarat et al., 2021; Hussien et al., 2022; Khaled et al., 2024).

Many studies, such as Djemai's hydrogeological study of the Sebaou Valley in 1985 (Djemai et al., 2017), conducted a study on physico-chemical water characteristics in the Upper Sebaou Valley (Great Kabylia), analyzing the variation of physico-chemical variables (pH) and electrical conductivity (EC), T°, $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $HCO_3^{-}$, $SO_4^{-2}$, Cl-, and $NO_3^{-}$) and changes in water quality over time (2005–2007). This study's conclusions are geologically classic and broad in scope. The study analyzed the chemistry of groundwater and studied various hydrogeochemical processes. It also evaluated the Upper Sebaou groundwater's quality for irrigation and drinking water. Different indices, including the WQI, were used to analyze the region's water quality.

## 2. Materials and Methods

### *2.1. Study area:*

The Sebaou plain is located 80 kilometres, east of northeast Algeria in the Tizi-Ouzou region. The area drained by the Sébaou River, and its watershed is confined by latitudes 36°27' and 36°55' North and longitudes 3°55' and 4°53' East. It has an estimated area of 1432 Km², extends from Boubhir upstream to the Belloua Pass downstream, and has a length of 30 km with a width ranging from 0.8 to 3 km (Figure 1).

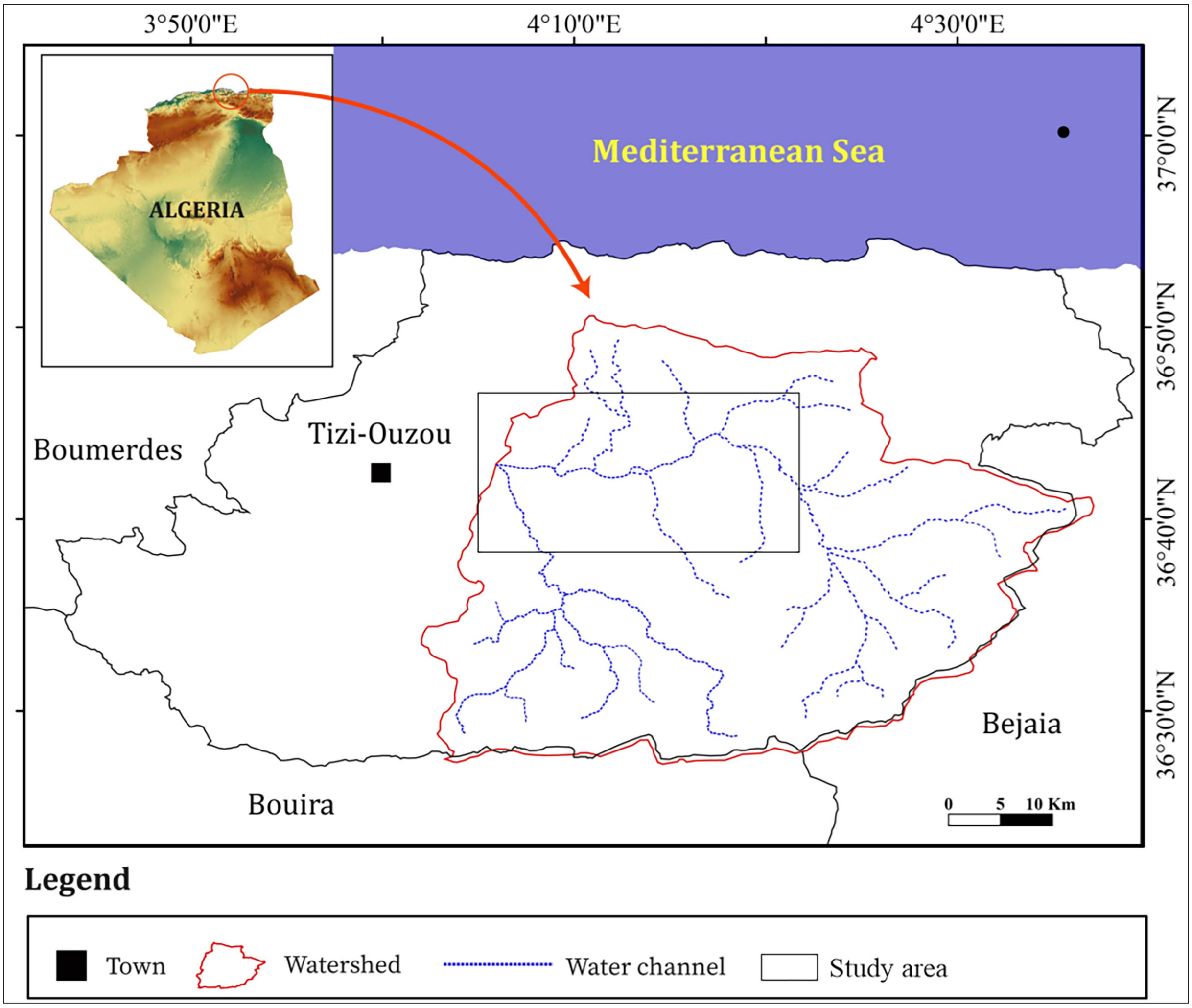


**Figure 1.** Geographical situation of the study area.

### *2.2. Agriculture and climate context:*

Sebaou Valley, covering 50,000 hectares, is encompassed by densely inhabited areas, such as Oued Aisi, Freha, and Tizi Rached. The valley supports a population of 1,127,166 , with an EPA system connection rate of approximately 150 liters per capita per day as of 2020. The agricultural system in this region is predominantly multicultural, with mixed crop-livestock systems being the most prevalent.

The climate in the region is temperate, characterized by rainy winters and cool summers (Smail et al., 2013). The valley of Sebaou has a subhumid and mild climate with an average annual precipitation of around 824 mm per year. Between 2012 and 2019, the mean annual temperature was around 18.6 °C, and the Thornthwaite moisture index revealed a value of 944.05 mm. An average relative humidity of 70.5% is indicative of a humid season.

### *2.3. Geological and Hydrodynamical Setting:*

The Upper Sebaou Valley has a free alluvial water table that runs east-west (Figure 2). It is surrounded by the Djurdjura mountains to the south and the Aftir coast to the north. This synclinal depression, filled with detrital materials derived from the crystalline rocks of the Kabyle socle, has resulted in the formation of stepped terraces. The underlying substrate comprises Miocene marls, which host a distinct hydraulic unit within the water table (Smail et al., 2013).

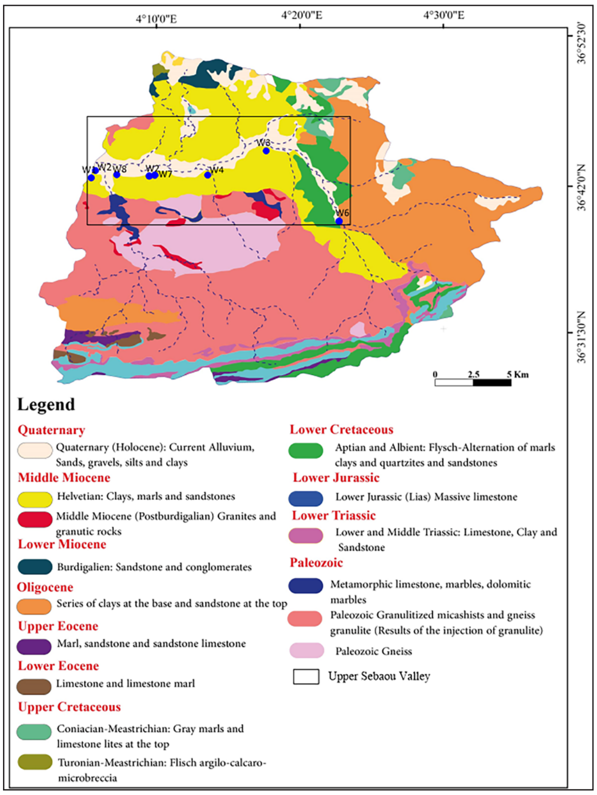


**Figure 2.** Geological formations of the Sébaou Valley.

23 water samples distributed throughout the plain of Sebaou were measured during the high-water and low-water periods of 2019. The piezometric maps revealed lateral flows from the east to west of the valley, which constitute an NE-SW-oriented drainage axis in the direction of the wadi flow (Figures 3 and 4).

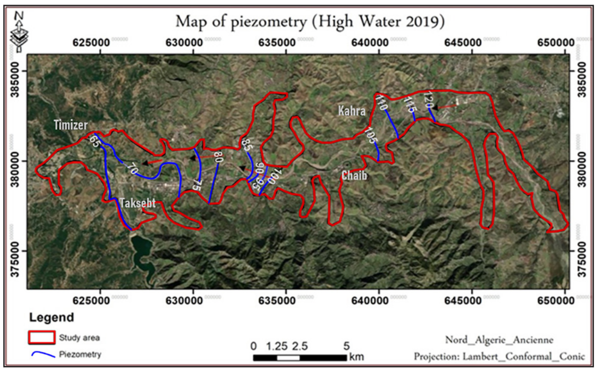


**Figure 3.** Map of piezometry (High Water 2019) ANRH 2019.

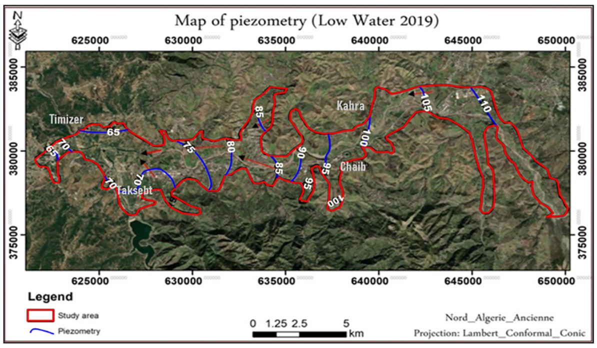


**Figure 4.** Map of piezometry (Low Water 2019) ANRH 2019.

### *2.4. Sampling and analysis:*

The study aimed to assess the water quality of both irrigation and drinking water on the alluvial plain of the Sebaou Valley. By employing analytical techniques such as conductivity and pH measurements, it was feasible to acquire a more profound comprehension of the water's behavior. A total of eight boreholes was employed for the purpose of sample collection. The analysis was carried out at ANRH's laboratory in Tizi Ouzou, and the samples were gathered, using high-density polyethylene bottles. Subsequently, these bottles were securely closed in order to avoid any air contact . A filter was employed to exclude contaminants and particle matter from the samples. To mitigate the deposition of metal ions on the surfaces of the bottles, a solution of hydrochloric acid that has been acidified was employed. The study collected and prepared the samples in a way that ensured their reliability and accuracy. This was done to ensure that the results of the analysis were reliable. The concentration of Ca and Mg ions was estimated, using the EDTA sodic titration method, which is a complexometric approach. The concentration of Cl ions was measured using the Mohr method. On the other hand, the concentration of $SO_4^{-2}$ ions was examined using the conductimetric titration method. The concentrations of potassium ions ($K^+$) and sodium ions (Na+) were determined using a flame photometer. The data obtained in milligrams per liter (mg/L) were converted to milliequivalents per liter (meq/L).

### *2.5. Multivariate statistical analysis :*

Multivariate statistical analysis is a quantitative and independent method used to classify groundwater samples. Furthermore, a connection can be established between metals and groundwater samples, as demonstrated by Cloutier et al. in 2008. Furthermore, the present study employed principal component analysis (PCA) and cluster analysis (CA), utilizing R Language version 4.1.1. (2021). Key statistical measures are the mean, range, and standard deviation (Khanoranga et al., 2019). K-means clustering was performed to group the sites into groups. The process of splitting a dataset into discrete groups or clusters based on a pattern optimizes certain clustering criteria.

***2.6. Assessment for Drinking:***

The index water quality was one of the most successful methods for measuring drinking water quality for policymakers (Reghais et al., 2023; Bezai et al., 2024). WQI is a rating that indicates the combined impact of many physico-chemical parameters on water quality (Belkhiri et al., 2018).

The relative weight (Wi) of each parameter was estimated as follows (Fehdi et al., 2009):

$$WQI = \sum Qi * Wi \text{ and } Qi = \sum Vn/Sn*100$$

Wi is the weight and number of each parameter, for each parameter, the consistency rating scale (Qi) is assigned by dividing its concentration by its respective norm in each water sample (Al-Mashhadany, 2021).

***2.7. Assessment Irrigation water quality indexes:***

The following equations express the index: the concentration units were transformed from [mg/L] to [meq/L] according to the conversion factors given by (Lesch et al., 2009).

SAR (eq. 1) Laboratory of the USDA (Wilcox et al., 1995):

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{+2} + Mg^{+2}/2}} \quad (1)$$

PI This parameter was estimated as follows (eq. 2), according to (Dinka, 2016):

$$PI = \frac{Na^{+} + \sqrt{HCO_3^{-}}}{Ca^{+2} + Mg^{+3} + Na^{+}} x100 \quad (2)$$

RSC (Residual Sodium Carbonate) index (eq. 3) (Richards, 1954);

$$RSC = [HCO_3^{-} + CO3^{-2}] - [Ca^{+2} + Mg^{+2}] \quad (3)$$

The sodium content percent (percent Na) was calculated using the following equation 4 (Todd, 1980):

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{+2} + Mg^{+2} + Na^{+} + K^{+}} x100 \quad (4)$$

Kelly's Ratio (KR) was calculated using the following equation 5 (Kelley, 1963):

$$KR = \frac{Ca^{+2}}{Ca^{+2} + Mg^{+2}} \quad (5)$$

Total Hardness (TH) was calculated using the following equation 6 (Crittenden et al., 2012):

$$TH\left(\frac{mg}{L}\right) = 2.497Ca^{+2} + 4.1152Mg^{+2} \quad (6)$$

## 3. Results and Discussion

***3.1. Groundwater Chemistry:***

Table 1 summarizes the results of the hydrogeochemical analysis hydrogeochemical of the collected data.

**Table 1.** Hydrogeochemical analysis of the Groundwater outputs.

| Wells name | year | $Ca^{+2}$ (meq/L) | $Mg^{+2}$ | $Na^{+}$ | $K^{+}$ | $HCO_3^{-}$ | $Cl^{-}$ | $SO_4^{-2}$ | $NO_3^{-}$ | TH | TA | TDS | pH | CE μ/cm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W1 | June 2018 | 6,943 | 3,006 | 1,435 | 0,051 | 5,998 | 1,517 | 1,416 | 0 | 49,743 | 0 | 779 | 7.6 | 1063 |
| W2 | June 2018 | 6,075 | 3,006 | 2,088 | 0,102 | 5,998 | 2,022 | 2,249 | 0,403 | 45,404 | 0 | 781 | 7.6 | 1060 |
| W3 | June 2018 | 7,377 | 1,288 | 2,262 | 0,026 | 7,747 | 1,657 | 1,874 | 0,065 | 43,324 | 0 | 842 | 7.5 | 987 |
| W4 | June 2018 | 6,509 | 2,147 | 1,348 | 0,051 | 6,748 | 1,32 | 1,624 | 0 | 43,279 | 0 | 726 | 7.8 | 846 |
| W5 | June 2018 | 6,292 | 1,718 | 2,088 | 0,026 | 6,248 | 1,798 | 1,145 | 0 | 40,047 | 0 | 696 | 8.2 | 843 |
| W6 | June 2018 | 8,244 | 3,865 | 1,957 | 0,077 | 7,747 | 1,742 | 3,31 | 0,887 | 60,546 | 0 | 1009 | 7.6 | 1290 |
| W7 | June 2018 | 7,377 | 2,147 | 1,522 | 0,077 | 7,248 | 1,404 | 1,166 | 0,339 | 47,618 | 0 | 781 | 7.6 | 905 |
| W8 | June 2018 | 7,81 | 4,079 | 2,262 | 0,051 | 8,747 | 1,742 | 2,561 | 0 | 59,5 | 0 | 979 | 7.7 | 1180 |
| 752 | October 2018 | 6,719 | 3,716 | 1,174 | 0,072 | 6,498 | 1,882 | 2,457 | 0,032 | 52,176 | 0 | 806 | 7,6 | 1010 |
| 753 | October 2018 | 7,905 | 2,347 | 2,392 | 0,038 | 7,498 | 2,247 | 1,999 | 0,29 | 51,259 | 0 | 895 | 7,37 | 1193 |
| 754 | October 2018 | 5,929 | 2,738 | 2,218 | 0,026 | 5,998 | 2,36 | 1,416 | 0,29 | 43,334 | 0 | 737 | 7,6 | 963 |
| 755 | October 2018 | 8,695 | 4,694 | 2,088 | 0,128 | 7,498 | 2,5 | 3,748 | 0,758 | 66,946 | 0 | 1025 | 7,43 | 1386 |
| 756 | October 2018 | 5,533 | 2,738 | 1,653 | 0,026 | 5,498 | 2,303 | 1,353 | 0,032 | 41,358 | 0 | 681 | 7,6 | 847 |
| 757 | October 2018 | 6,719 | 2,542 | 1,348 | 0,23 | 6,498 | 2,022 | 1,416 | 0,508 | 46,309 | 0 | 569 | 7,27 | 950 |
| 758 | October 2018 | 2,569 | 2,347 | 0,913 | 0,486 | 4,499 | 1,77 | 0,208 | 0,161 | 24,58 | 0 | 448 | 7,3 | 604 |
| W01 | May 2013 | 5,3 | 3,15 | 1,78 | 0,06 | 3,99 | 2,022 | 3,331 | 0,08 | 43 | 20 | 727 | 7,4 | 1 101 |
| W02 | May 2013 | 2,65 | 3,67 | 0,91 | 0,05 | 5,49 | 0,562 | 1,062 | 0,08 | 32 | 28 | 468 | 7,4 | 750 |
| W03 | May 2013 | 1,59 | 6,61 | 0,95 | 0,05 | 7,99 | 0,534 | 1,499 | 0,24 | 41 | 40 | 560 | 7,4 | 1 000 |
| W04 | May 2013 | 3,18 | 7,35 | 1,95 | 0,12 | 6,99 | 0,674 | 5,663 | 0,59 | 53 | 35 | 847 | 7,2 | 1 284 |
| W05 | May 2013 | 3,39 | 5,04 | 1,87 | 0,04 | 6,99 | 0,758 | 1,457 | 0,35 | 43 | 35 | 532 | 7,3 | 919 |
| W06 | May 2013 | 3,61 | 4,83 | 1,26 | 0,05 | 6,49 | 0,646 | 1,707 | 0,43 | 43 | 33 | 562 | 7,5 | 903 |
| W07 | May 2013 | 2,65 | 3,67 | 1,6 | 0,03 | 4,99 | 0,787 | 1,499 | 0,29 | 32 | 25 | 590 | 7,3 | 900 |
| W08 | May 2013 | 3,71 | 3,67 | 1,13 | 0,06 | 5,99 | 0,646 | 1,145 | 0,22 | 37 | 30 | 527 | 7,4 | 800 |

Table 1 presents the descriptive data for groundwater, indicating that the conductivity levels range from 800 to 1386 µS/cm. Some of these samples exhibit unsuitable water quality, which can be attributed to excessive salinity in the Basale section of Great Kabylia. This salinity issue arises from contamination by wastewater and agricultural practices involving the extensive use of chemical fertilizers.

The pH of groundwater varied from 7,2 to 8,2, indicating a low alkaline kind. HCO3 can increase the pH and affect corrosion rates due to importing alkalinity into the water (Fijani et al., 2023). TDS levels ranged from 527 to 1025 in the research area. The dissipation of the dolomitic limestone terrains of Chellata-Djurdjura is also responsible for the high TDS levels detected in the dissolved matter. TDS levels are lower due to dilution from rainfall and the influent nature of surface water. Chloride and sodium concentrations in groundwater range from 0,53 to 1,88 meq/L and 0,91 to 2,26 meq/L. respectively, calcium ion concentrations are moderately greater than other cations, ranging from 1,5 to 8,6 meq/L, and magnesium concentrations range from 1,2 to 7,3 meq/L.

The concentrations of HCO3 and $SO_4^{-2}$ vary from 3,9 to 8,7 and from 0,2 to 3,7 meq/L. During the rainy season, the dissolution of limestone-dolomite rocks in the sedimentary rocks of the Kabila basement frequently results in high magnesium, calcium, bicarbonate, and sulfate concentrations. However, potassium K concentrations in sample water ranged from 0.02 to 0.4 meq/L, with the greater value of $K^+$ possibly related to the excessive usage of lime in agricultural zones.

### *3.2. Groundwater classification:*

The physical-chemical data are provided in Figure 5 to determine the chemical facies of Upper Sebaou Valley groundwater. Hydrochemical facies characterize calcium and magnesium bicarbonate and chloride and sulfate calcium and magnesium types, with Ca2+> Mg > Na and HCO3>Cl> SO4> NO3 as significant ions. The first group consists of samples (W1, W5, and W7), dominated by bicarbonate and chloride. The second group comprises wells (W2, W3, W4, W6, and W8), with HCO3 > SO4>Cl > NO3 as significant ion abundance, sulfate as the dominant element, and bicarbonate and calcium being the most prevalent in this group.

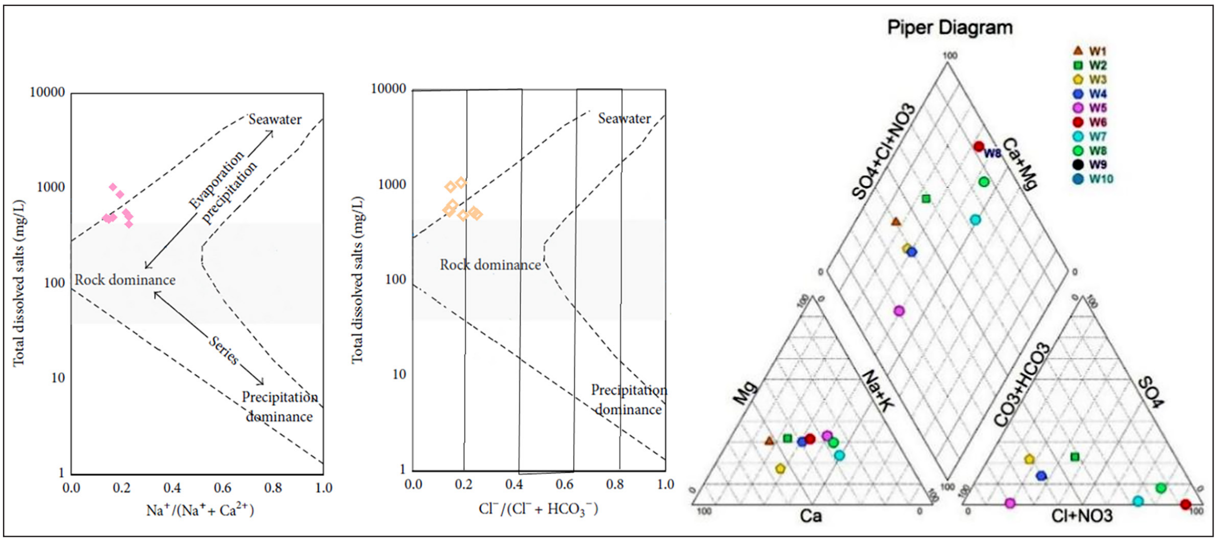


**Figure 5.** Piper diagram for water samples, and the ratio of Na+K/(Na+K+Ca) and Cl/(Cl+HCO3) as a function of TDS (High waters, Low waters).

### *3.3. Chemical weathering:*

The ratio-I for cations [(Na+K)/(Na+K+Ca)] and ratio-II for anions [Cl/(Cl+HCO3)] as a function of TDS is commonly used to analyze the functional sources of dissolved chemical constituents, as shown in Figure 6 (Polemio et al., 2005). The location of the samples obtained in TDS > 500 mg/L segments. However, the majority of water samples in Sebaou Valley had high TDS concentrations and low I/I ratios and were found on the left side, indicating the preponderance of rock weathering. The phreatic water is controlled by the water rock.

### *3.4. Multivariate statistical analysis:*

It is critical to do a statistical analysis of the given results. The basic statistics and correlation analysis provided insights into groundwater quality characterization. However, principal component analysis (PCA) uses 8 groundwater samples for 13 variables, including chemical-physical parameters (EC at 25°C, TH, TAC, TD, and pH) and major ions ($Na^+$, $K^+$, $Ca^{2+}$, $Mg^{+2}$, $Cl^-$, $NO_3^-$, $SO4^{-2}$, and $HCO_3^-$). Table 2 illustrates the physico-chemical element correlation matrix, with the latter indicating the correlateable elements by a high correlation coefficient ratio. A strong 0.82 connection exists between Ca, HCO3, and an average 0.77 correlation exists between (Mg, SO4). The chemical facies calcium-magnesium bicarbonate contains related components of the same origin. Ca (0.863), SO4 (0.7), and TDS are all substantially associated with electrical conductivity (0.962). It's also worth noting that chlorides have a relationship with Na and other elements, probably the result of the invasion by the sea.

**Table 2.** Correlation coefficient matrix of hydrochemical parameters (June 2018).

| Variables | Ca2+ | Mg2+ | Na+ | K+ | Cl- | SO42- | HCO3- | NO3- | pH | EC | Rsc | TH | TAC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ca2+ | 1 | 0,4739 | 0,1839 | -0,009 | -0,149 | 0,4906 | 0,8224 | 0,4428 | -0,462 | 0,6843 | 0,8144 | 0,8122 | 0,8224 |
| Mg2+ | 0,4739 | 1 | 0,1099 | 0,5111 | 0,2937 | 0,7720 | 0,3431 | 0,4266 | -0,250 | 0,8437 | 0,7877 | 0,8986 | 0,3431 |
| Na+ | 0,1839 | 0,1099 | 1 | -0,159 | 0,7910 | 0,0779 | 0,4383 | 0,0861 | 0,0450 | 0,3704 | 0,4506 | 0,1644 | 0,4383 |
| K+ | -0,009 | 0,5111 | -0,159 | 1 | 0,2635 | 0,2861 | -0,157 | 0,6693 | -0,438 | 0,3823 | 0,1922 | 0,3337 | -0,157 |
| Cl- | -0,149 | 0,2937 | 0,7910 | 0,2635 | 1 | 0,2450 | -0,060 | 0,2916 | 0,0878 | 0,4235 | 0,3312 | 0,1201 | -0,060 |
| SO42- | 0,4906 | 0,7720 | 0,0779 | 0,2861 | 0,2450 | 1 | 0,1765 | 0,4142 | -0,489 | 0,8897 | 0,7953 | 0,7559 | 0,1765 |
| HCO3- | 0,8224 | 0,3431 | 0,4383 | -0,157 | -0,060 | 0,1765 | 1 | 0,1313 | -0,295 | 0,4726 | 0,6834 | 0,6371 | 1,0000 |
| NO3- | 0,4428 | 0,4266 | 0,0861 | 0,6693 | 0,2916 | 0,4142 | 0,1313 | 1 | -0,357 | 0,5955 | 0,4813 | 0,5032 | 0,1313 |
| pH | -0,462 | -0,250 | 0,045 | -0,438 | 0,0878 | -0,489 | -0,295 | -0,357 | 1 | -0,500 | -0,454 | -0,396 | -0,295 |
| EC | 0,6843 | 0,8437 | 0,3704 | 0,3823 | 0,4235 | 0,8897 | 0,4726 | 0,5955 | -0,500 | 1 | 0,9604 | 0,8999 | 0,4726 |
| Rsc | 0,8144 | 0,7877 | 0,4506 | 0,1922 | 0,3312 | 0,7953 | 0,6834 | 0,4813 | -0,454 | 0,9604 | 1 | 0,9276 | 0,6834 |
| TH | 0,8122 | 0,8986 | 0,1644 | 0,3337 | 0,1201 | 0,7559 | 0,6371 | 0,5032 | -0,396 | 0,8999 | 0,9276 | 1 | 0,6371 |
| TAC | 0,8224 | 0,3431 | 0,4383 | -0,157 | -0,060 | 0,1765 | 1,0000 | 0,1313 | -0,295 | 0,4726 | 0,6834 | 0,6371 | 1 |

The link between the variables is explained in the graph Variable-PCA in Figure 6. NO3, Mg, SO4, Cl, Na, Ca, CE, TDS, and HCO3 dominated component 1 on this axis, accounting for 50,9% of the total variations. Component 2 accounts for approximately 18,4 percent of unlimited variations; the pH is highly represented on this axis, opposite the first factor.

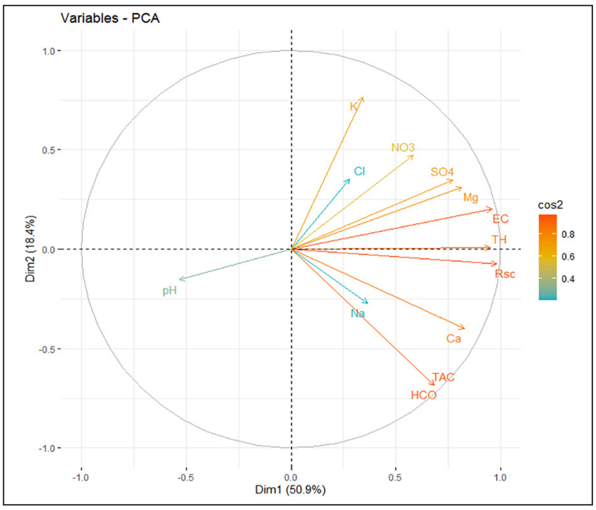


**Figure 6.** PCA of physical-chemical parameters of wells.

Figure 7's Boxplot results revealed the maximum and minimum values for Ca (121.73 mg/L and 165.21 mg/L, respectively) and Mg (15.65 mg/L and 49.56 mg/L, respectively), which fall within the permissible limits set by WHO in 2017. However, significant variations were observed in the values of Na (ranging from 21 mg/L to 57 mg/L), surpassing the prescribed permissible limit of 200 mg/L by WHO in 2017. The potassium concentration in groundwater exhibited variability, ranging from 1 mg/L to 4 mg/L, which is below the permissible limit according to WHO guidelines.

In all regions, chloride concentrations ranged from 47 to 72 mg/L, and Cl values in water samples did not surpass the WHO-recommended limit of 250 mg/L for drinkable water. The sulfate concentration fluctuates from a minimum of 55 mg/L to a maximum of 159 mg/L; current readings were below the WHO limit of 250 mg/L, and the concentration was at a level that did not pose a health risk. The concentrations of nitrates have not exceeded the allowed level of 50 mg/L (WHO 2017).

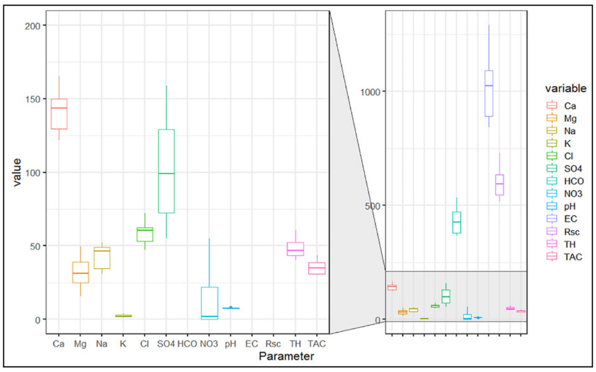


**Figure 7.** Boxplot of geochimical parameters.

***3.5 Drinking water quality assessment:***

Table 3 shows the water samples used to calculate the Water Quality Index (WQI). According to WHO 2017 (Table 4) based on the World Health Organization's 2017 report (Table 6), the drinking water quality index indicates a high standard of drinking water quality, with 90% of the samples meeting the criteria for good quality. Additionally, we found exceptional water quality in one specific well (W3).

**Table 3.** Water quality index.

| | W1 | W2 | W3 | W4 | W5 | W6 | W7 | W8 |
|---|---|---|---|---|---|---|---|---|
| *WQI* | 30.208 | 37.635 | 23.795 | 33.413 | 40.952 | 41.834 | 34.164 | 35.998 |

**Table 4.** WQI range according to WHO,2017.

| WQI range | Water quality |
|---|---|
| 0-25 | Excellent |
| 26-50 | Good |
| 51-75 | Poor |
| 76-100 | Very Poor |
| Above 100 | Unsuitable |

### *3.6. Irrigation water quality assessment:*

We demonstrate in this part indexes of irrigation water quality, data is presented in Table 5.

**Table 5.** Irrigation water quality evaluation

| SAR | RSC | Na% | PI | MH | TH | KR |
|---|---|---|---|---|---|---|
| 0,643591 | -3,951 | 12,99995 | 34,12257 | 30,21453 | 49,7427 | 0,144 |
| 0,979845 | -3,083 | 19,43208 | 40,62248 | 33,10208 | 45,40356 | 0,230 |
| 1,086676 | -0,917 | 20,88551 | 46,17407 | 14,86757 | 43,32398 | 0,261 |
| 0,648163 | -1,908 | 13,91858 | 39,44403 | 24,80505 | 43,27898 | 0,156 |
| 1,043318 | -1,761 | 20,87788 | 45,43254 | 21,44548 | 40,04712 | 0,261 |
| 0,795486 | -4,362 | 14,38216 | 33,70279 | 31,91591 | 60,54558 | 0,162 |
| 0,697659 | -2,276 | 14,37708 | 38,15437 | 22,54472 | 47,61813 | 0,160 |
| 0,927663 | -3,143 | 16,28542 | 36,88169 | 34,31012 | 59,44954 | 0,190 |

**Table 6.** Classification of irrigation water based on SAR, KR, Na%, TH RSC, and PI values (Eaton, 1950; Richards, 1954; Kelley, 1963; Doneen, 1964).

| | | Class |
|---|---|---|
| **SAR** | <10 | Excellent |
| | 10-18 | Good |
| | 18-26 | Fair |
| **Total hardness (TH) mg/L** | <75 | Soft |
| | 75-150 | moderately |
| | 150-300 | hard |
| **KR** | KR> 1<br>KR<1 | Unsuitable<br>Safe |
| **Na%** | <20 | Excellent |
| | 20-40 | Good |
| | 40-60 | Permissible |
| | 60-80 | Doubtful |
| | >80 | Unsuitable |
| **PI** | >75 | Good |
| | 25-75% | Doubeful |
| | <25 | unsuitable |
| **RSC** | <1.25 | Good |
| | 1.25-2.5 | Doubeful |
| | >25 | unsuitable |

Figure 8 and Table 6 highlight the common use of EC (Electrical Conductivity) and SAR (Sodium Adsorption Ratio) in conjunction. High sodium levels in water pose a challenge as they affect soil permeability and lead to issues with water infiltration. Sodium displaces calcium and magnesium that are absorbed by clay particles, resulting in soil compaction. This compaction reduces the rate of water infiltration during irrigation cycles, leading to insufficient soil saturation for crop roots before the next watering. All groundwater samples analyzed in this study exhibited SAR values within the excellent class, indicating satisfactory irrigation water quality. SAR values ranged from 0.60 to 1.08.

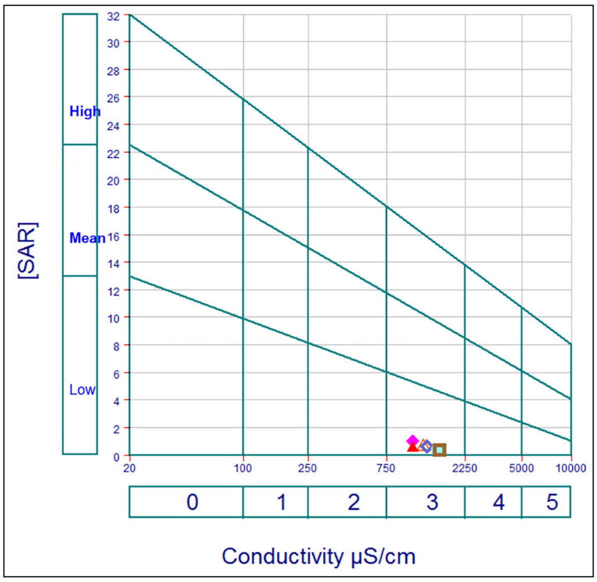


**Figure 8.** Classification of irrigation water quality according to Richards (1954).

The carbonate and bicarbonate ratios of residual sodium carbonate (RSC) are used to assess the groundwater for irrigation suitability (Selvakumar et al., 2017). The negative value of RSC indicate that the concentration of $Ca^{+2}$ and $Mg^{+2}$ is in excess (Rawat et al., 2018). The high value of RSC points to a high concentration of calcium and magnesium related to the reaction of HCO3-, generating calcium bicarbonate and magnesium bicarbonate (Chitsazan et al., 2019). High alkalinity of water could increase the pH value of the soil or plant development environment to the point of damaging their growth (Khedidja et al., 2014). The RSC values are -0,917 to -4,362 indicate a considerable risk of sodization degrading the soil's physical qualities (Feraga et al., 2021).

The Permeability Index (PI) is a useful tool to assess irrigation water suitability. It outlines the effect of sodium, calcium, magnesium, and bicarbonate ions concentrations on soil permeability (Doneen, 1964; Singh et al., 2020). It suggests water classification criteria according to the PI, which is related to water quality and displays the rate of water penetration (irrigation) into and through the soil (Mandal et al., 2019). A criterion for assessing the suitability of water for irrigation is based on PI water and can be classified into classes I, II, and III. Class I and II water were categorized as good for irrigation with more than 75% of permeability (Khedidja et al., 2021). However, class III water was unsuitable with 25% of maximum permeability (Figure 9). All samples fall into class I, thus reflecting a good suitability for irrigation (Wu et al., 2014).

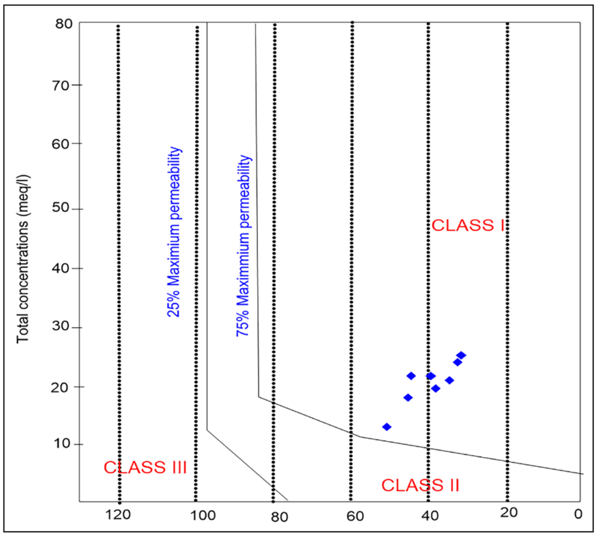


**Figure 9.** Classification of irrigation water based on the permeability index (June 2018).

The sodium percentage (Na%) in water is one of the criteria used to define the appropriateness of irrigation water (Tiwari et al., 1985). Sodium could indirectly harm vegetation by weakening the soil's physical quality (Richards, 1954). Moreover, the soil develops compact. The ability of plants to receive water or nutrients from their growth environment is hampered by high osmotic pressure in the soil-plant interface (Naseem et al., 2012). The percentage of Na in the examined sites varied from 12 to 22% (Figure 10). Sebaou Valley irrigation waters are grouped into class 2 (good).

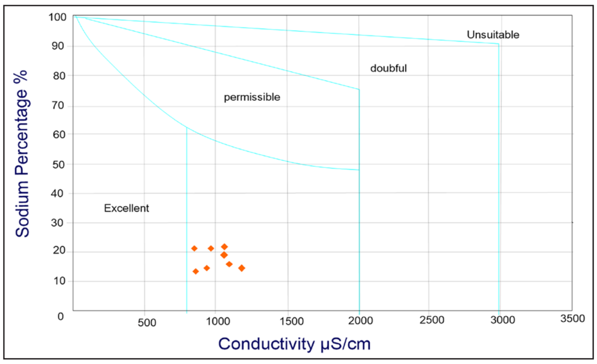


**Figure 10.** Suitability of Groundwater for irrigation in Wilcox diagram (June 2018).

The ratio between the concentration of sodium $Na^{+}$ and the total of $Ca^{+2}$ and $Mg^{+2}$ is known as Kelly's Ratio (KR).

Groundwater with a Kelly ratio of less than one is generally considered suitable for irrigation (Paliwal et al., 1967). RK readings in this study are in the safe category, indicating that it is adequate for irrigation (Table 6).

### *3.7. Distribution of Spatial and Temporal Irrigations Index*

The water quality for irrigation purposes via irrigation index spatiotemporal was calculated for a time period from 2013 to2018 (Docheshmeh Gorgij et al., 2023) . The results, depicted in Figure 12, exhibit notable variations in SAR values over a span of four years. Specifically, the SAR values observed in 2018 were considerably higher compared to those in 2013. Intensive cultivation practices and the expansion of agricultural lands, which result in higher concentrations of sodium in the soil, are likely responsible for this increase in SAR values. The excessive presence of sodium ions in the soil has a detrimental effect on the behavior of the colloidal fraction and leads to the dispersion of soil aggregates, subsequently reducing soil permeability and causing soil hardening (Tijani, 1994; Herrero et al., 2005).

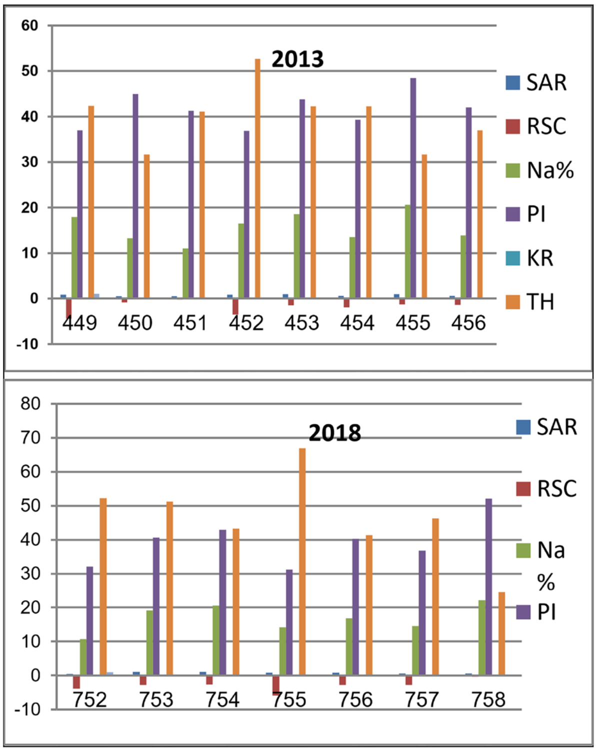


**Figure 11.** Evolution temporal of SAR, RSC, Na%, PI, KR and TH in 2013 and 2018.

## 4. Conclusions

This research employed multiple approaches to enhance the understanding of water quality in Sebaou, Tizi Ouzou. These approaches included Principal Component Analysis (PCA), Cluster Analysis (CA), and Correlation Matrix to examine the origin of mineralization and assess suitability for drinking water. The multivariate statistical techniques utilized evaluated the Sebaou Valley plain in Northeastern Algeria.

The research findings indicated that the groundwater quality in the study area was acceptable for irrigation purposes. Although the anatomical results showed satisfactory groundwater quality, thunderstorm effects led to changes in quality, including reduced rainfall, runoff, seepage, and alterations in the composition of precious water stones.

The identified significant chemical facies were primarily Ca-HCO3 (with variations of Mg, Cl, SO4, and Na), reflecting the mineralization patterns of the geological facies in the Sebaou Basin.Djemai et al. (2017) attributed the presence of HCO3 to limestone deposits in the Djurdjura mountains to the south of the Sebaou River Valley (SRV) and attributed the origin of SO4 to agricultural and domestic effluents in the upstream agglomerations of the Sebaou valley. However, the samples fell within the medium to high salinity range (843–1290 µS/cm) based on electrical conductivity (EC) values, making them suitable for horticultural crops.

Nearly 99% of the water samples exhibited water quality above the allowed standards for irrigation, while the remaining samples exceeded the acceptable limits due to the influence of sulphate stones in the evaporator. The waters of the Sebaou Valley were categorised into category three, namely C3S1, based on their sodium adsorption ratio and electrical conductivity. This classification indicates their appropriateness for irrigation purposes. In addition, the water was categorized into four irrigation appropriateness categories based on its sodium percentage, with the majority falling into the "excellent" category. According to the Water Quality Index (WQI), groundwater from three districts was also safe for drinking, indicating that it was of good quality.

**Acknowledgment**

This work was supervised by the MGRE Laboratory, Department of Geology, Batna2 University, Algeria. And the ANRH Tizi Ouzou. Acknowledgments to the DGRsDT-mesRs for the technical support.

**References**

Adimalla, N. Taloor., Ajay, K. (2020), Hydrogeochemical Investigation of Groundwater Quality in the Hard Rock Terrain of South India Using Geographic Information System (GIS) and Groundwater Quality Index (GWQI) Techniques. Groundwater for Sustainable Development, 10: 100288. available at https://www.sciencedirect.com/science/article/pii/S2352801X19302231

Al-Hadithi, M., Hasan, K., Algburi, A. and Al-Paruany, K. (2019), Groundwater Quality Assessment Using Irrigation Water Quality Index and GIS in Baghdad, Iraq. Jordan Journal of Earth and Environmental Sciences, 10(1): 15–20.

Al-Mashhadany, M.H. S. (2021), Application of the CCME Water Quality Index to Evaluate the Groundwater Quality of Shouira Village for Drinking and Domestic Purposes in Nineveh Governorate. IOP Conference Series: Earth and Environmental Science, 722(1): 012029. available at

Amin, Sehrish, Muhammad, Said and Fatima, Hina (2021), Evaluation and Risks Assessment of Potentially Toxic Elements in Water and Sediment of the Dor River and Its Tributaries, Northern Pakistan. Environmental Technology & Innovation, 21: 101333.

Aravinthasamy, P., Karunanidhi, D., Subramani, T. and Roy, Priyadarsi D. (2021), Correction to: Demarcation of Groundwater Quality Domains Using GIS for Best Agricultural Practices in the Drought-Prone Shanmuganadhi River Basin of South India. Environmental science and pollution research international, 28(15): 18436. available at http://dx.doi.org/10.1007/s11356-020-09225-x

Asadi, Esmaeil, Isazadeh, Mohammad, Samadianfard, Saeed, Ramli, Mohammad Firuz, Mosavi, Amir, Nabipour, Narjes, Shamshirband, Shahaboddin, Hajnal, Eva and Chau, Kwok-Wing (2019), Groundwater Quality Assessment for Sustainable Drinking and Irrigation. Sustainability: Science Practice and Policy, 12(1): 177. available at https://www.mdpi.com/2071-1050/12/1/177 [8 July 2023].

Balamurugan, P., Kumar, P. S. and Shankar, K. (2020), Dataset on the Suitability of Groundwater for Drinking and Irrigation Purposes in the Sarabanga River Region, Tamil Nadu, India. Data in brief, 29: 105255. available at http://dx.doi.org/10.1016/j.dib.2020.105255

Belkhiri, Lazhar, Mouni, Lotfi, Tiri, Ammar, Narany, Tahoora Sheikhy and Nouibet, Razki (2018), Spatial Analysis of Groundwater Quality Using Self-Organizing Maps. Groundwater for Sustainable Development, 7: 121–132. available at https://www.sciencedirect.com/science/article/pii/S2352801X1730070X

Bezai, Abderrahim, Brinis, Nafaa, Reghais, Azzeddine, Djenba, Samir and Bouzid, Khadidja (2024), Hydrochemical Analysis and Groundwater Quality Assessment for Irrigation in the Remila Plain, Khenchela, Northeast Algeria. Geomatics Landmanagement and Landscape, (3): 35–57. available at http://gll.ur.krakow.pl/

Boufekane, Abdelmadjid, Belloula, Moufida, Busico, Gianluigi, Drias, Tarek, Reghais, Azzeddine and Maizi, Djamel (2022), Hybridization of DRASTIC Method to Assess Future GroundWater Vulnerability Scenarios: Case of the Tebessa-Morsott Alluvial Aquifer (Northeastern Algeria). NATO Advanced Science Institutes series E: Applied sciences, 12(18): 9205.

Brown, R. M., McClelland, N. I. and Deininger, R. A. (1970), A Water Quality Index-Do We Dare. Water and sewage.

Chitsazan, M., Aghazadeh, N., Mirzaee, Y. and Golestan, Y. (2019), Hydrochemical Characteristics and the Impact of Anthropogenic Activity on Groundwater Quality in Suburban Area of Urmia City, Iran. Environment, Development and Sustainability, 21(1): 331–351. available at https://doi.org/10.1007/s10668-017-0039-1

Crittenden, John C., Rhodes Trussell, R., Hand, David W., Howe, Kerry J. and Tchobanoglous, George (2012), MWH's Water Treatment: Principles and Design. John Wiley & Sons.

Din, Imran Ud, Muhammad, Said and Rehman, Inayat ur (2023), Groundwater Quality Assessment for Drinking and Irrigation Purposes in the Hangu District, Pakistan. Journal of food composition and analysis: an official publication of the United Nations University, International Network of Food Data Systems, 115: 104919.

Dinka, Megersa Olumana (2016), Quality Composition and Irrigation Suitability of Various Surface Water and Groundwater Sources at Matahara Plain. Water Resources, 43(4): 677–689. https://doi.org/10.1134/S0097807816040114

Djemai, Mohammed, Saibi, Hakim, Mesbah, Mohamed and Robertson, Andrew (2017), Spatio-Temporal Evolution of the Physico-Chemical Water Characteristics of the Sebaou River Valley (Great Kabylia, Algeria). Journal of Hydrology: Regional Studies, 12: 33–49.

Docheshmeh Gorgij, A., Askari, Gh, Taghipour, A. A., Jami, M. and Mirfardi, M. (2023), Spatiotemporal Forecasting of the Groundwater Quality for Irrigation Purposes, Using Deep Learning Method: Long Short-Term Memory (LSTM). Agricultural water management, 277: 108088.

Doneen, Lloyd David (1964), Notes on Water Quality in Agriculture. Department of Water Science and Engineering, University of California, Davis.

Eaton, Frank M. (1950), SIGNIFICANCE OF CARBONATES IN IRRIGATION WATERS. Soil science, 69(2): 123.

Fehdi, Ch, Rouabhia, Aek, Baali, F. and Boudoukha, A. (2009), The Hydrogeochemical Characterization of Morsott-El Aouinet Aquifer, Northeastern Algeria. Environmental geology, 58(7): 1611–1620. https://doi.org/10.1007/s00254-008-1667-4

Feraga, Touhami and Pistre, Séverin (2021), Qualitative and Comparative Study of Different Methods of Interpolation for the Mapping of Groundwater Salinity: Case Study of Thermal Waters Used for Irrigation in Northeastern Algeria. Journal of geoscience and environment protection, 09(07): 115–132.

Fijani, Elham and Meysami, Sahar (2023), Assessment of Hydrochemical Characteristics and Groundwater Suitability for Drinking and Irrigation Purposes in Garmsar Plain, Iran. Geopersia, 13(1): 83–102.

Goyal, Sanjay Kumar, Chaudhary, B. S., Singh, Omvir, Sethi, G. K. and Thakur, Praveen K. (2010), GIS Based Spatial Distribution Mapping and Suitability Evaluation of Groundwater Quality for Domestic and Agricultural Purpose in Kaithal District, Haryana State, India. Environmental Earth Sciences, 61(8): 1587–1597. available at https://doi.org/10.1007/s12665-010-0472-z

Haque, Skmafizul, Kannaujiya, Suresh, Taloor, Ajay Kumar, Keshri, Dipika, Bhunia, Rakesh Kumar, Champati Ray, Prashant Kumar and Chauhan, Prakash (2020), Identification of Groundwater Resource Zone in the Active Tectonic Region of Himalaya through Earth Observatory Techniques. Groundwater for Sustainable Development, 10: 100337.

Herrero, J. and Pérez-Coveta, O. (2005), Soil Salinity Changes over 24 Years in a Mediterranean Irrigated District. Geoderma, 125(3): 287–308. available at https://www.sciencedirect.com/science/article/pii/S0016706104002204

Horton, Robert K. (1965), An Index Number System for Rating Water Quality. Journal - Water Pollution Control Federation, 37(3): 300–306.

Hussien, H., Samuel, Z. A. and Bokke, A. S. (2022), Assessment of Surface Water Resources Based on Different Growth Scenarios, for Borkena River Sub-Basin, Awash River Basin, Ethiopia. , (JJEES 13 (3): 199-214).

Hyarat, T. and Al, Kuisi M. (2021), Comparison between Weighted Arithmetic and Canadian Council of Ministers of the Environment Water Quality Indices Performance in Amman-Zarqa Area, Jordan. Earth Environ. Sci, 12(4): 295–305.

Jamshidzadeh, Zahra and Barzi, Majid Tavangari (2018), Groundwater Quality Assessment Using the Potability Water Quality Index (PWQI): A Case in the Kashan Plain, Central Iran. Environmental Earth Sciences, 77(3): 59. available at https://doi.org/10.1007/s12665-018-7237-5

Jasrotia, Avtar Singh, Kumar, Rajesh, Taloor, Ajay Kumar and Saraf, Arun Kumar (2019), Artificial Recharge to Groundwater Using Geospatial and Groundwater Modelling Techniques in North Western Himalaya, India. Arabian Journal of Geosciences, 12(24): 774. available at https://doi.org/10.1007/s12517-019-4855-5

Kawo, Nafyad Serre and Karuppannan, Shankar (2018), Groundwater Quality Assessment Using Water Quality Index and GIS Technique in Modjo River Basin, Central Ethiopia. Journal of African Earth Sciences, 147: 300–311.

Kelley, W. P. (1963), USE OF SALINE IRRIGATION WATER. Soil science, 95(6): 385.

Khaled, Eman Bani, Obeidat, Mutawakil, Al-Ajlouni, Ahmad, Awawdeh, Muheeb and Dalo, Muna Abu (2024), Demarcation of Groundwater Quality Using Drinking Water Quality Index (DWQI), Nitrate Pollution Index (NPI), and Irrigation Indices: A Case Study from Jerash Region. Jordan Journal of Earth and Environmental Sciences (JJEES), 15 (1): 37-52.

Khanoranga and Khalid, Sofia (2019), An Assessment of Groundwater Quality for Irrigation and Drinking Purposes around Brick Kilns in Three Districts of Balochistan Province, Pakistan, through Water Quality Index and Multivariate Statistical Approaches. Journal of Geochemical Exploration, 197: 14–26.

Khedidja, Abdelhamid and Boudoukha, Abderrahmane (2014), Risk Assessment of Agricultural Pollution on Groundwater Quality in the High Valley of Tadjenanet-Chelghoum Laid (Eastern Algeria). Desalination and water treatment, 52(22–24): 4174–4182.

Khedidja, Abdelhamid and Boudoukha, Abderrahmane (2021), Quality Assessment of Shallow Groundwater for Irrigation Purposes in Tadjenanet – Chelghoum Laid Area (Eastern Algeria). International Journal of River Basin Management, 19(2): 141–148. available at https://doi.org/10.1080/15715124.2019.1628031

Khedidja, Abdelhamid, Drias, Tarek and Reghais, Azzeddine (2023), Assessment of Groundwater Vulnerability to Pollution Using DRASTIC and the SI Methods: Case of the Alluvial Aquifer in Tadjenanet-Chelghoum Laid (East Algeria). Acque Sotterranee-Italian Journal of Groundwater, 12(2): 37–47. available at https://acquesotterranee.net/acque/article/view/644

Lesch, S. M. and Suarez, D. L. (2009), A Short Note on Calculating the Adjusted SAR Index. available at https://pubag.nal.usda.gov/catalog/30435

Mandal, S. K., Dutta, S. Kole, Pramanik, S. and Kole, R. K. (2019), Assessment of River Water Quality for Agricultural Irrigation. International Journal of Environmental Science and Technology, 16(1): 451–462. available at https://doi.org/10.1007/s13762-018-1657-3

Muhammad, Said (2023), Evaluation of Heavy Metals in Water and Sediments, Pollution, and Risk Indices of Naltar Lakes, Pakistan. Environmental science and pollution research international, 30(10): 28217–28226. available at http://dx.doi.org/10.1007/s11356-022-24160-9

Muhammad, Said and Ullah, Insha (2022), Spatial and Seasonal Variation of Water Quality Indices in Gomal Zam Dam and Its Tributaries of South Waziristan District, Pakistan. Environmental science and pollution research international, 29(19): 29141–29151. available at http://dx.doi.org/10.1007/s11356-022-18524-4

Muhammad, Said and Usman, Qazi Ahmed (2022), Heavy Metal Contamination in Water of Indus River and Its Tributaries, Northern Pakistan: Evaluation for Potential Risk and Source Apportionment. Toxin reviews, 41(2): 380–388. available at https://doi.org/10.1080/15569543.2021.1882499

Naseem, Shahid, Hamza, Salma and Bashir, Erum (2012), Assessment of Geochemistry of Soils for Agriculture at Winder, Balochistan, Pakistan. Water quality, soil and managing irrigation of crops, InTech-Open Access Publisher, Croatia: 73–94.

Paliwal, K. V. and Singh, S. (1967), Effect of Gypsum Application on the Quality of Irrigation Waters. Madras Agric J.

Panneerselvam, Balamurugan, Paramasivam, Suresh Kumar, Karuppannan, Shankar, Ravichandran, Nagavinothini and Selvaraj, Pauline (2020), A GIS-Based Evaluation of Hydrochemical Characterisation of Groundwater in Hard Rock Region, South Tamil Nadu, India. Arabian Journal of Geosciences, 13(17): 837. available at https://doi.org/10.1007/s12517-020-05813-w

Polemio, M., Limoni, P. P., Mitolo, D. and Santaloia, F. (2005), Nitrate Pollution and Quality Degradation of Ionian Coastal Groundwater (Southern Italy).

Rawat, K. S. and Singh, Sudhir Kumar (2018), Water Quality Indices and GIS-Based Evaluation of a Decadal Groundwater Quality. Geology, Ecology, and Landscapes, 2(4): 240–255. https://doi.org/10.1080/24749508.2018.1452462

Reghais, Azzeddine, Drouiche, Abdelmalek, Zahi, Faouzi and Debieche, Taha-Hocine (2023), Hydrogeochemical Evaluation of the Terminal Complex Aquifer System in an Arid Area: A Case Study from the Biskra Region, North-East Algeria. Environmental Earth Sciences, 82(7): 182. https://doi.org/10.1007/s12665-023-10786-6

Richards, L. A. (1954), Diagnosis and Improvement Of. Saline and Alkali Soils. Handbook.

Selvakumar, S., Chandrasekar, N. and Kumar, G. (2017), Hydrogeochemical Characteristics and Groundwater Contamination in the Rapid Urban Development Areas of Coimbatore, India. Water Resources and Industry, 17: 26–33.

Sharma, M. P., Sharma, S., Gael, V. and Sharma, P. (2006), Water Quality Assessment of Behta River Using Benthic Macroinvertebrates. Life sciences.

Singh, Kshitindra Kr, Tewari, Geeta and Kumar, Suresh (2020), Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand. Journal of chemistry and chemical engineering, 2020.

Smail, Ali Si, Bouheraoua, Ali and Abdesselam, Malek (2013), Caractérisation Hydrodynamique Des Sols de La Haute Vallée de l'oued Sébaou (Algérie) : Étude Expérimentale, Numérique et Analytique. Physio-Géo, (Volume 7): 261–283.

Soleimani, Hamed, Abbasnia, Abbas, Yousefi, Mahmood, Mohammadi, Ali Akbar and Khorasgani, Fazlollah Changani (2018), Data on Assessment of Groundwater Quality for Drinking and Irrigation in Rural Area Sarpol-e Zahab City, Kermanshah Province, Iran. Data in brief, 17: 148–156. http://dx.doi.org/10.1016/j.dib.2017.12.061

Stigter, T. Y., Ribeiro, L. and Carvalho Dill, A. M. M. (2006), Application of a Groundwater Quality Index as an Assessment and Communication Tool in Agro-Environmental Policies – Two Portuguese Case Studies. Journal of Hydrology , 327(3–4): 578–591.

Tijani, M. 'N (1994), Hydrogeochemical Assessment of Groundwater in Moro Area, Kwara State, Nigeria. Environmental geology, 24(3): 194–202. http://dx.doi.org/10.1007/bf00766889

Tiwari, T. N. and Mishra, M. A. (1985), A Preliminary Assignment of Water Quality Index of Major Indian Rivers. Indian Journal of Environmental Protection.

Todd, David Keith (1980), Groundwater Hydrology. Brisbane, QLD, Australia: John Wiley and Sons (WIE).

Vadiati, M., Asghari-Moghaddam, A., Nakhaei, M., Adamowski, J. and Akbarzadeh, A. H. (2016), A Fuzzy-Logic Based Decision-Making Approach for Identification of Groundwater Quality Based on Groundwater Quality Indices. Journal of environmental management, 184(Pt 2): 255–270. http://dx.doi.org/10.1016/j.jenvman.2016.09.082

WHO (World Health Organization) (2017), Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum. World Health Organization, Geneva, Switzerland.

Wilcox, B. J., Applegate, M. D., Portera-Cailliau, C. and Koliatsos, V. E. (1995), Nerve Growth Factor Prevents Apoptotic Cell Death in Injured Central Cholinergic Neurons. The Journal of comparative neurology, 359(4): 573–585. http://dx.doi.org/10.1002/cne.903590405

Wu, Jianhua, Li, Peiyue, Qian, Hui, Duan, Zhao and Zhang, Xuedi (2014), Using Correlation and Multivariate Statistical Analysis to Identify Hydrogeochemical Processes Affecting the Major Ion Chemistry of Waters: A Case Study in Laoheba Phosphorite Mine in Sichuan, China. Arabian Journal of Geosciences, 7(10): 3973–3982. https://doi.org/10.1007/s12517-013-1057-4

Yousefi, Mahmood, Dehghani, Mohammad Hadi, Nasab, Saba Maghsoudi, Taghavimanesh, Vahid, Nazmara, Shahrokh and Mohammadi, Ali Akbar (2018), Data on Trend Changes of Drinking Groundwater Resources Quality: A Case Study in Abhar. Data in brief, 17: 424–430. http://dx.doi.org/10.1016/j.dib.2018.01.032

Yousefi, Mahmood, Ghoochani, Mahboobeh and Hossein Mahvi, Amir (2018), Health Risk Assessment to Fluoride in Drinking Water of Rural Residents Living in the Poldasht City, Northwest of Iran. Ecotoxicology and environmental safety, 148: 426–430. http://dx.doi.org/10.1016/j.ecoenv.2017.10.057

Yousefi, Mahmood, Saleh, Hossein Najafi, Mohammadi, Ali Akbar, Mahvi, Amir Hossein, Ghadrpoori, Mansour and Suleimani, Hamed (2017), Data on Water Quality Index for the Groundwater in Rural Area Neyshabur County, Razavi Province, Iran. Data in brief, 15: 901–907. http://dx.doi.org/10.1016/j.dib.2017.10.052