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# Evaluation of the physico-chemical quality of groundwater in arid areas: case study (watershed of the Oued Bechar) in Bechar- Kenadsa Region

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**ABSTRACT**

This work is based on the characterization of the physico-chemical parameters in the groundwater of the Bechar-Kenadsa region in southwest Algeria. To achieve this goal, we have collected a database of a water sampling survey that has been done by the National Hydric Resources Agency (ANRH) of the different water points located in the study area according to recognized standards for the collection and analysis protocols of water samples. We extracted the pH, EC, TDS, $Ca^{+2}$, $Mg^{+2}$, $Na^{+}$, $K^{+}$, $Cl^{-}$, $HCO_3^{-}$, $SO_4$ and $NO_3^{-}$ parameters, we used these physical and hydro chemical characteristics to evaluate the parameters of the sodium content (Na %), Kelly's rate and permeability index. The results showed that just small portion of the groundwater was drinkable. We also used diagrams like Piper's to distinguish that the main water quality is of the Mg-Cl-$SO_4$ class. The Durov's diagram helped us to know that most of this water is concentrated in the area, of magnesium-dominance, characterized by two main classes of water (Mg-Cl-$SO_4$ and Mg-Ca-Cl-$SO_4$). The Gibbs diagram was used to assess the mechanisms controlling the chemistry of water. We noticed that the quality of the water was influenced by the precipitation process in the first row. According to the Wilcox diagram, it was noted that most of groundwater in the study area is characterized by high salinity under three main classes (C4-S1, C4-S2 and C4-S3). We can than conclude that the groundwater in the study area is of poor quality for drinking and irrigation and requires serious treatment to be exploited.

*Keywords:* Hydro-chemical; Gibbs; Cluster analysis; Quality; Irrigation

## 1. Introduction

The control and management of water is a major challenge for the development of human societies, and the rational management of water is nowadays a primary concern for all users. Indeed, water resources are becoming increasingly limited for obvious reasons of increasing and competitive demand from different uses (drinking, irrigation and industry). Water is therefore becoming more and more important in our daily lives.

In arid zones, the use of groundwater is inevitable for all human activities. This category differs from the surface one because of the geological formations [1], in sediments and rocks forming an underground reservoir or aquifer into which groundwater can be stored and transmitted. The sustainable exploitation of groundwater and its management is based on a perfect understanding of the geological and hydrological conditions and the hydrogeological properties governing this resource [2]. Its quality and quantity are also a determining factor for its use.

Like other arid regions, the Oued Bechar watershed, being an area with arid to hyperarid climate, faces the problems of water resources. Its water resources remain conditioned by the high demand resulting from population growth and agricultural development. In order to adopt better strategies to meet the demand for water supply, without altering its quality, we will try to qualitatively assess it according to global standards.

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## 2. Materials and methods

To achieve the objective of this work, we have gathered a database of the National Water Resources Agency (ANRH), 2013 Campaign (the latest updated database). We can distinguish on this database 6 piezometers, 11 wells exploiting the groundwater of the area; 10 wells are exploited, there are also 46 boreholes including 5 unexploited, these boreholes are pumps equipped, and are used for irrigation.

A set of 62 groundwater samples located in the Bechar aquifer in southwestern Algeria (Fig. 1) were analyzed for 11 physical and chemical parameters including major ionic concentrations ($Ca^{+2}$, $Mg^{+2}$, $Na^+$, $K^+$, $Cl^-$, $SO_4^{2-}$, $HCO_3^-$, $NO_3^-$), electrical conductivity and pH.

All the samples were taken in clean and certified bottles (Adrar ANRH). The date and time of sample collection were recorded. Electrical conductivity (EC) and pH were measured in the field using a multi-parameter WTW (P3 Multi-Line pH/LFSET). All samples were kept under refrigerated conditions before analyzes. For the chemical analysis, 500 ml of water were collected in polyethylene bottles, filtered and then acidified. The chemical elements analyzed are calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), potassium ($K^+$), chloride ($Cl^-$), bicarbonate ($HCO_3^-$), sulfate ($SO_4^{2-}$) et nitrates ($NO_3^-$). The methods used are those recommended by Rodier in 1996[3]. The ionic balance is generally + 5%.

The chemical analysis data of the water samples were plotted on the Piper and Durov diagrams using the Aquachem V 4.0 geochemistry software. In addition, for the evaluation of the water quality parameters, we used the sodium percentage (% Na) characterization modules, the total hardness (in $CaCO_3$), the Kelly ratio (KR), the permeability (PI) and the magnesium hazard (MH).Values of groundwater springs and samples were also determined using the Aquachem V 4.0 software and some mathematical calculations.

### *2.1. Study area*

The Bechar region is located in southwest Algeria, with more than 180,000 inhabitants. The climate is arid that is very cold in winter and very hot in summer. The region has a much more administrative than agricultural character except the region of Ouakda where the majority of its villagers is focused on agriculture. Precipitation is irregular and extends from October to March with an annual average of 106 mm. The average temperature varies from 9 to 35°C [4]. The area is characterized by a very low vegetation cover generally represented by desert grasses and a very low percentage of palms. The dominant soil texture is between silt and sand and is composed mainly of quartz and feldspar as a mineral composition.

### *2.2. Geology and hydrogeology*

The geology of the region is composed of four geological units: (1) Quaternary, (2) Upper Eocene-Miocene, (3) Cretaceous and (4) Carboniferous. The Quaternary is located in the northeastern part and in the southern part of the studied zone, this unit is composed of alluvial and colluvial deposits of lacustrine limestones (Fig. 2). The Upper Eocene-Mio-

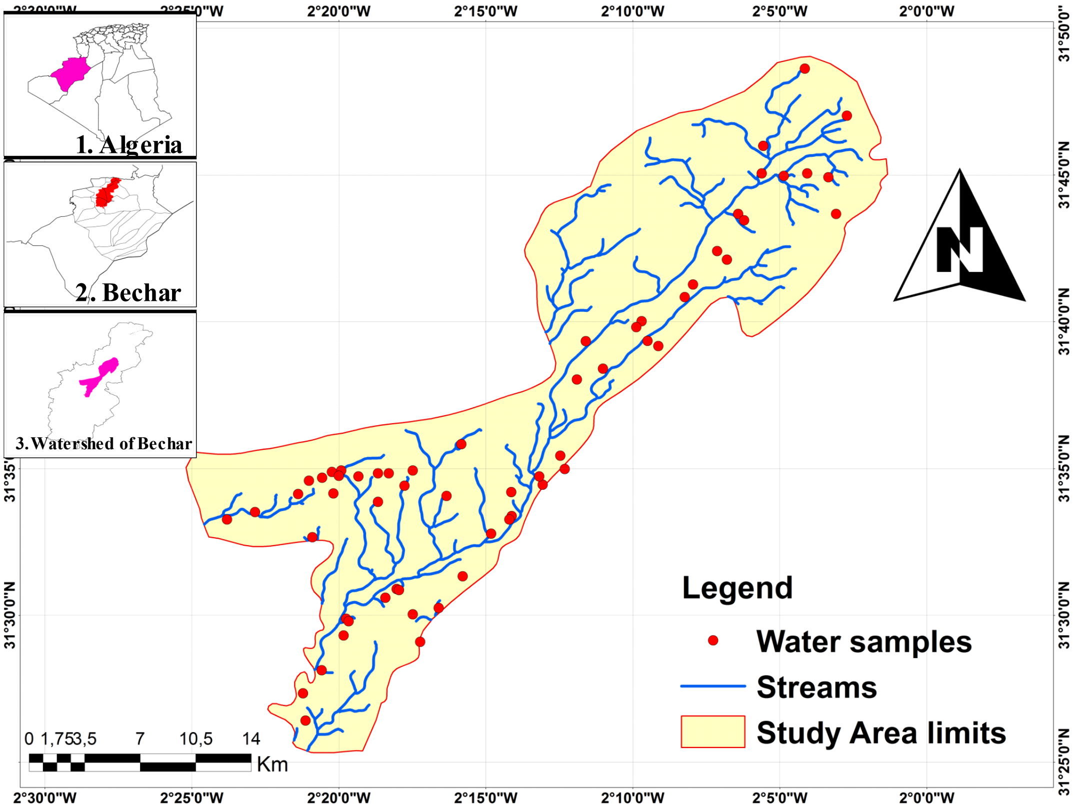


Fig. 1. Map of the study area includes the water points used in the study.

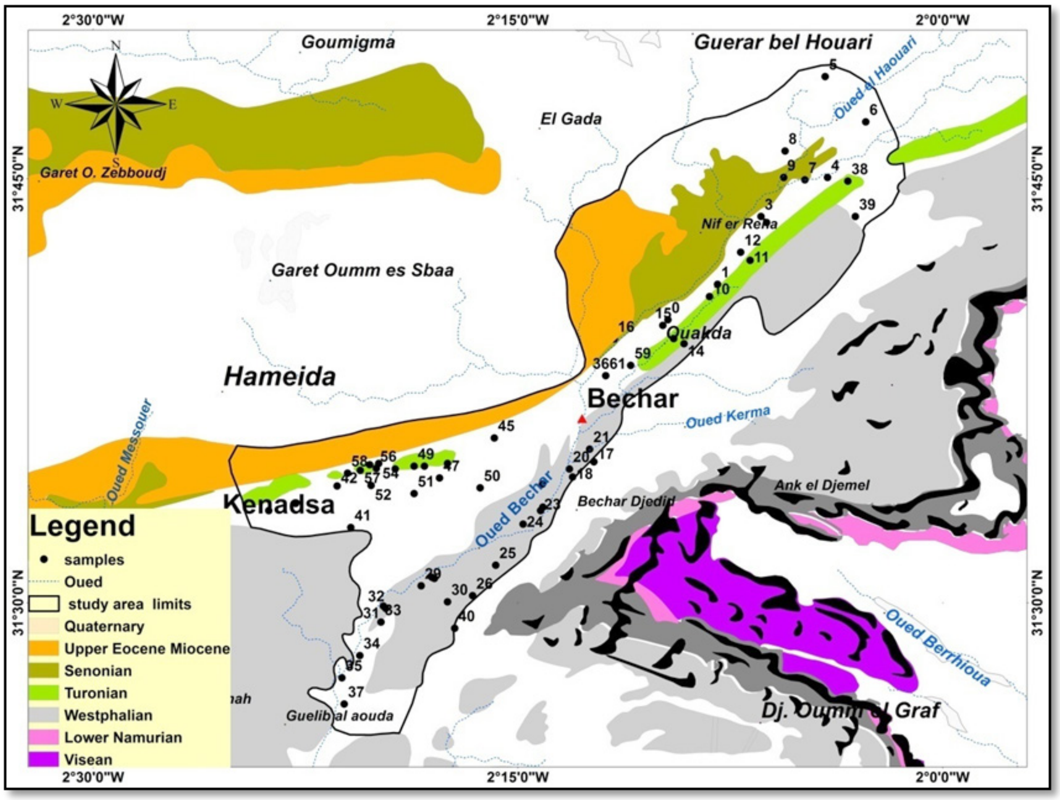


Fig. 2. Location of water points on the geological map of the region.

cene is mainly located in the northern part of the study area and consists of sandy red marls, yellow or pink clay, with levels of lacustrine limestone. The Cretaceous unit is composed of two subunits (Senonian and Turonian), the Senonian is concentrated in the northern area and contains variegated gypsum marl. The Turonian is characterized by thin layers in the North and contains white, gray or pink, more or less dolomitic, limestone. The fourth geologic unit is the Carboniferous and contains three sub-units: Westphalian, Lower Namurian and Visean. The Westphalian is composed of sandstones with quartzitic levels, detrital marls, recrystallized limestones. The Lower Namurian is composed of predominant organo-detritic dolomitic limestones, with marly-sand stone levels. The Visean is composed of limestones and reef dolomites in places[5].

The main source of groundwater recharge is the infiltration of rainfall and water from the wadis during the torrential season, especially Oued Bechar, the third largest wadi in the region after Guir and Zousfana wadis.

## 3. Results and discussion

### 3.1. Groundwater chemistry

Table 1 presents the descriptive summary of all the parameters analyzed, as well as the corresponding standard WHO limits. The electrical conductivity of the samples varies from 530 to 35,830 µS/cm near Oued Bechar precisely in the agricultural zone of Ouakda as well as in the agricultural zone of Kenadsa with an average value of 4195.83 µS/cm. Salinity is increasing in the direction of groundwater flow from North to South, particularly in the Oukada and Bechar areas because of dissolution of geologic layers and also because of the anthropogenic sources characterized in the sewer system in that area . The pH is between 4.55 and 7.85 with an average value of 7.26 (Table 1), which shows that the groundwater in the study area is balanced between alkaline and acidic. $Cl^-$ and $SO_4^{2-}$ are the main anions and $Ca^{2+}$ and $Na^+$ are the main cations in Bechar groundwater. The relative abundance of ions was in the order of $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ (on the molar basis) and $Cl^- > SO_4^{2-} > HCO_3^- > NO_3^-$ (Table 1). The maximum concentrations of $Ca^{2+}$ (800 mg/L) and $Na^+$ (5797.5 mg/L) are, however, well above WHO standards (75 and 200 mg/L respectively for Ca and Na).

The source of calcium in groundwater could be the calcareous sandstones or dolomite. Mean magnesium and potassium concentrations in groundwater are 164.14 and 6.69 mg/L, respectively.

$Cl^-$ chloride is the dominant anion in our waters, the chloride value in the study area is between 30 and 7800 mg/L. Possible sources of chloride are seawater [6], sediment, or the dissolution of sandstone minerals with quartzitic levels, detrital marls, intercalated recrystallized limestone.

Sulphateis the second most abundant anion, the average sulphate value is 715.68 mg/L, and the presence of sulphate may be due to the dissolution of sedimentary rocks such as gypsum ($CaSO_4$, $2H_2O$) and anhydrite ($CaSO_4$)[7]. Subsequent addition of sulphates to groundwater may result

Table 1
Summary of chemical results for groundwater in the study area

| | EC | pH | TDS | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $Cl^{-}$ | $SO_4^{2-}$ | $HCO_3^{-}$ | $NO_3^{-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Min | 530 | 4.55 | 392 | 20 | 23 | 17 | 0.7 | 30 | 60 | 46 | 0 |
| Max | 53800 | 7.85 | 18616 | 800 | 663 | 5797.5 | 47.5 | 7800 | 4200 | 415 | 140 |
| Mean | 4195.83 | 7.26 | 2547.38 | 137.21 | 164.14 | 497.25 | 6.69 | 779.2 | 715.86 | 212.15 | 34.75 |
| SD | 5559.85 | 0.43 | 3098.56 | 135.68 | 150.76 | 892.42 | 8.310 | 1296.26 | 814.68 | 63.44 | 30.21 |
| Cv | 91.30 | 5.92 | 121.63 | 98.88 | 91.84 | 179.47 | 124.21 | 166.40 | 113.80 | 29.90 | 86.93 |
| WHO (2006) standards | 1500 | 6.5–9.2 | 1000 | 75 | 30 | 200 | 200 | 250 | 250 | NS | |

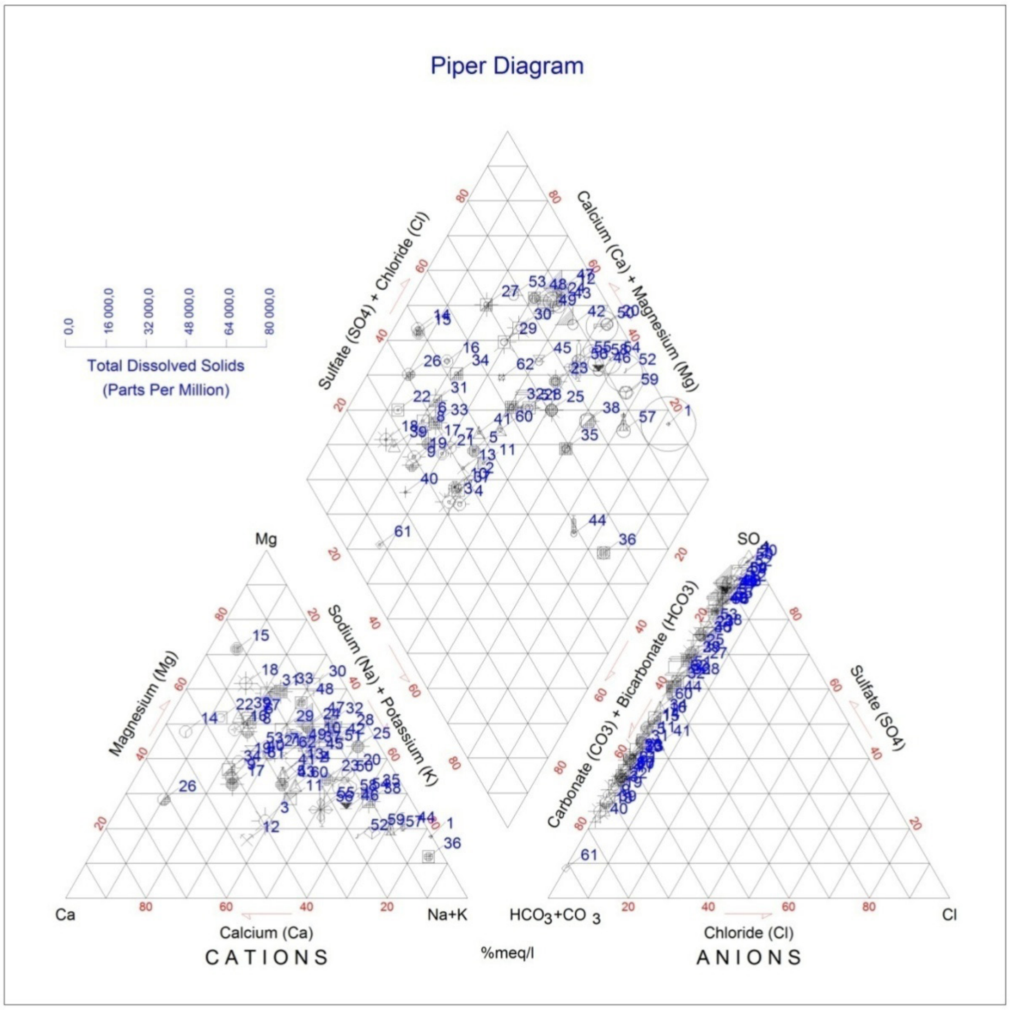


Fig. 3. Piper diagram.

from the decomposition of organic matter in the soil and the addition of leachable sulfates to fertilizers in intensively cultivated areas.

The presence of bicarbonate ions $HCO_3^-$ in groundwater may have derived from soils and from the dissolution of carbonated rocks. The bicarbonate ion is the third dominant anion in the study area. The concentration of $HCO_3^-$ in most of the study is approximately 221.15 mg/L. Nitrate $NO_3^-$ is the last anion tested and is between 0 and 140 mg/L. More than 20% of the tested samples are above the recommended 50 mg/L drinking water limit [8]. Nitrate concentration is high in areas close to leaking sewage networks, agricultural and industrial areas.

The classification of the hydro-chemical facies is used to distinguish the water identity according to the water-rock interaction, the geology and also the influences of the sources of contaminations on the identity of the water. The Piper diagram (Fig. 3) [9], allowed us to identify four dominant hydrochemical facies: Mg-Cl-$SO_4$; Mg-Ca-Cl-$SO_4$; Mg-$SO_4$-Cl; and Mg-Ca-$SO_4$-Cl.

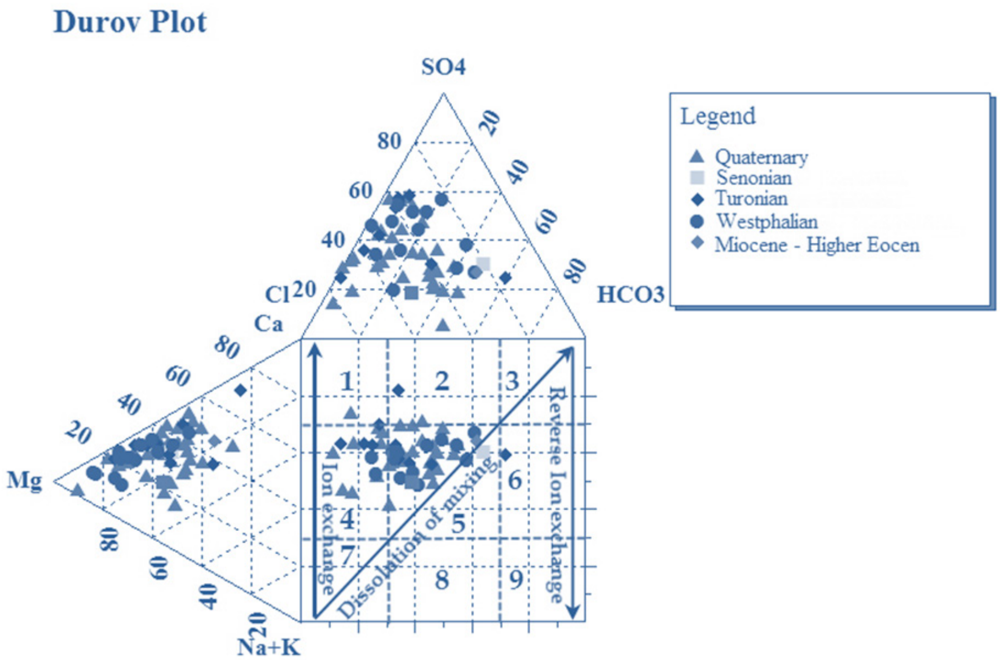


Fig. 4. Durov diagram.

The Durov diagram (1948) is another diagram used to help understand the assessment of the quality of water types [10,11]. This diagram is composed of 2 ternary diagrams where cations are plotted against anions and where we can distinguish the process of ion exchange and inversion ion exchange. (Fig. 4). This diagram shows that 72% of the samples are located in the mixing zone (Field 5), where the Mg-Cl-$SO_4$ and Mg-Ca-Cl-$SO_4$ water types are the most dominant in this zone.

### 3.2. Drinking water quality

#### 3.2.1. Total dissolved solids (TDS)

Total dissolved solids give the total concentration of all dissolved mineral constituents in the water and are related to the problem of excessive water hardness [12]. A high concentration of TDS in drinking water may cause adverse taste effects. Water containing TDS < 500 mg/L may be considered as fresh water [13]. The main constituents are usually calcium, magnesium, sodium and potassium cations, as well as carbonate, calcium hydrogen carbonate, chloride, sulfate and nitrate anions [14], which have TDS less than 1000 mg/L. The average value of TDS is 2547.38 mg/L, ranging from 392 to 18616 mg/L. Only two samples have values below 500 mg/L, and considered as fresh water and 33% of the water samples are acceptable for drinking water.

#### 3.2.2. total hardness (TH)

Determining water hardness is a useful test for measuring water quality for domestic, agricultural and industrial purposes. High levels of total hardness have no known adverse effects. However, there is some evidence of its role in heart disease and the inadequacy of hard water for domestic use [15]. Hardness levels between 80 and 100 mg/L ($CaCO_3$) are generally acceptable in drinking water and are considered tolerable by consumers. TH was calculated as follows :

$$TH\left(CaCO_3\right) = \left(2.497\right)Ca + \left(4.115\right)Mg \quad (1)$$

Table 2 shows total hardness values that exceed 100 mg/L, classifying these waters as not acceptable for drinking water.

### 3.3. Irrigation water quality

#### 3.3.1. Sodium adsorption rate(SAR)

This is the ratio between sodium $Na^+$ with calcium $Ca^{2+}$ and magnesium $Mg^{2+}$, this ratio is important for growing plants, its prediction is essential for the management of irrigation water quality [16]. By standards, water with a SAR value less than 3 is safe for crops. On the other hand, water with a SAR greater than 13 can cause major problems on fine textured soils [17]. The SAR is calculated as follows:

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

The results show that 68% of this water is not suitable for irrigation, particularly because of the silty soil of the region.

The diagram in Fig. 6 is used to plot SAR and conductivity measurement to distinguish the interaction of different ions on the quality of irrigation water.

Table 2
Summary of Water quality parameters in the study area

| No | Sample | TDS | | TH | | SAR | Na | KR | PI | MH |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | PZ02 | 18616 | not acceptable | 2 778,19 | very hard | 313.72 | 89,54 | 8,49 | 89,58 | 97,07 |
| 2 | PZ03 | 679 | acceptable | 317,38 | very hard | 14.43 | 51.61 | 1.04 | 58.09 | 50.00 |
| 3 | PZ04 | 701 | acceptable | 319.97 | very hard | 12.27 | 45.95 | 0.83 | 52.60 | 25.45 |
| 4 | PuitsCHENIKRI | 1102 | not acceptable | 501.63 | very hard | 18.76 | 52.28 | 1.08 | 56.57 | 50.99 |
| 5 | Forage20km | 656 | acceptable | 323.53 | very hard | 12.26 | 46.66 | 0.85 | 53.21 | 39.81 |
| 6 | Puits sondaAFOUNMUSTAFA | 554 | acceptable | 336.33 | very hard | 5.49 | 28.62 | 0.39 | 37.60 | 51.49 |
| 7 | FLAYACHIMABROUK | 606 | acceptable | 311.64 | very hard | 9.24 | 40.77 | 0.67 | 47.75 | 48.42 |
| 8 | F2ZAABAT | 548 | acceptable | 311.64 | very hard | 5.51 | 29.47 | 0.40 | 39.95 | 48.42 |
| 9 | PAYATBOUDJEMMA | 687 | acceptable | 398.30 | very hard | 7.04 | 31.09 | 0.44 | 38.47 | 33.59 |
| 10 | PAYATBOUDJEMMA | 668 | acceptable | 335.17 | very hard | 13.42 | 49.71 | 0.97 | 56.36 | 61.46 |
| 11 | PIEZO4ANCIENHYCOBAR | 625 | acceptable | 278.12 | hard | 13.42 | 50.60 | 1.00 | 57.26 | 36.67 |
| 12 | FDRM4BEK1 | 2958 | not acceptable | 1 536.91 | very hard | 24.08 | 43.16 | 0.72 | 43.35 | 17.75 |
| 13 | FDRM4BEK3 | 694 | acceptable | 336.47 | very hard | 12.68 | 47.40 | 0.88 | 54.38 | 47.57 |
| 14 | F3TEGHALIENE | 1172 | not acceptable | 939.29 | very hard | 2.18 | 8.37 | 0.09 | 12.34 | 38.54 |
| 15 | F5TEGHALIENE | 1119 | not acceptable | 879.61 | very hard | 2.59 | 10.80 | 0.12 | 16.71 | 66.67 |
| 16 | F7TEGHALIENE | 1442 | not acceptable | 1 026.90 | very hard | 7.96 | 24.85 | 0.32 | 27.18 | 46.52 |
| 17 | F9TEGHALIENE | 392 | fresh water | 217.00 | hard | 5.33 | 32.33 | 0.44 | 43.01 | 31.94 |
| 18 | F11TEGHALIENE | 533 | acceptable | 344.28 | very hard | 3.55 | 20.93 | 0.25 | 33.36 | 60.61 |
| 19 | P1BECHARDJIDID | 722 | acceptable | 418.73 | very hard | 7.07 | 30.79 | 0.43 | 38.81 | 38.81 |
| 20 | F16BEHARDJIDID | 3220 | not acceptable | 1 294.87 | very hard | 48.12 | 64.34 | 1.78 | 64.71 | 64.93 |
| 21 | F17BECHARDJIDIDTORKI | 689 | acceptable | 377.02 | very hard | 9.59 | 39.20 | 0.63 | 46.74 | 46.55 |
| 22 | F23BECHARDJDID | 410 | fresh water | 263.74 | hard | 2.67 | 18.26 | 0.21 | 31.38 | 46.91 |
| 23 | F25BECHARDJDID | 2000 | not acceptable | 810.50 | very hard | 30.97 | 58.68 | 1.41 | 60.65 | 53.53 |
| 24 | P28BECHARDJDID | 4920 | not acceptable | 2 754.48 | very hard | 35.63 | 47.70 | 0.91 | 48.73 | 66.19 |
| 25 | P35BECHARDJDID | 3433 | not acceptable | 1 456.91 | very hard | 50.24 | 64.73 | 1.82 | 66.19 | 82.63 |
| 26 | F49BECHARDJDID | 1122 | not acceptable | 769.65 | very hard | 3.44 | 13.10 | 0.15 | 17.91 | 21.85 |
| 27 | F59ELAKIDLOTFI | 1237 | not acceptable | 808.14 | very hard | 7.27 | 28.82 | 0.33 | 29.58 | 52.07 |
| 28 | P67AOUINETHAMOUAISSA2 | 1902 | not acceptable | 837.48 | very hard | 28.47 | 59.49 | 1.35 | 60.93 | 78.83 |
| 29 | F68AOUINETHAMOUAISSA2 | 1681 | not acceptable | 953.93 | very hard | 15.24 | 39.75 | 0.65 | 42.85 | 56.99 |
| 30 | F71AOUINETHAMOUAISSA2 | 1514 | not acceptable | 879.23 | very hard | 16.82 | 44.44 | 0.79 | 47.40 | 82.97 |
| 31 | F76ELAKIDLOTFI | 755 | acceptable | 472.13 | very hard | 6.79 | 30.03 | 0.41 | 37.61 | 63.43 |
| 32 | P84ENNABKA | 1538 | not acceptable | 781.49 | very hard | 23.92 | 54.25 | 1.17 | 57.43 | 77.88 |
| 33 | F86ENNABKA | 1237 | not acceptable | 834.95 | very hard | 11.12 | 34.37 | 0.52 | 38.65 | 68.10 |
| 34 | P88GALBELAOUDA | 1020 | not acceptable | 625.88 | very hard | 7.92 | 28.85 | 0.39 | 33.57 | 35.29 |
| 35 | P90GALBELAOUDA | 2233 | not acceptable | 727.08 | very hard | 49.39 | 71.07 | 2.44 | 73.20 | 64.88 |
| 36 | P93GALBELAOUDA | 3334 | not acceptable | 406.01 | very hard | 132.45 | 89.88 | 8.77 | 91.60 | 65.79 |
| 37 | F101MOSQUEELHODA | 635 | acceptable | 306.37 | very hard | 13.49 | 50.80 | 1.01 | 58.14 | 58.43 |
| 38 | F110GALBELAOUDA | 6192 | not acceptable | 2 191.93 | very hard | 90.22 | 71.97 | 2.54 | 72.48 | 61.05 |
| 39 | F40INFMECAQG | 510 | acceptable | 301.66 | very hard | 3.93 | 24.42 | 0.29 | 35.93 | 50.55 |
| 40 | F40INFMECADCA | 585 | acceptable | 311.04 | very hard | 7.14 | 34.71 | 0.51 | 43.74 | 41.84 |
| 41 | F40INFMECA61RIM | 825 | acceptable | 394.50 | very hard | 11.91 | 46.94 | 0.76 | 50.33 | 43.90 |
| 42 | F40INFMECATRANSPORT | 2601 | not acceptable | 1 179.55 | very hard | 33.00 | 56.98 | 1.30 | 57.58 | 70.68 |
| 43 | F5KENADSA | 3086 | not acceptable | 1 534.93 | very hard | 27.24 | 46.87 | 0.87 | 48.08 | 39.67 |
| 44 | F26KENADSA | 2033 | not acceptable | 411.00 | very hard | 70.91 | 82.49 | 4.66 | 84.28 | 64.66 |
| 45 | F49KENADSA | 1952 | not acceptable | 945.70 | very hard | 25.23 | 52.14 | 1.07 | 54.46 | 56.68 |
| 46 | F51KENADSA | 2837 | not acceptable | 890.40 | very hard | 46.22 | 66.57 | 1.98 | 68.01 | 47.25 |
| 47 | F70KENADSA | 3639 | not acceptable | 1 949.26 | very hard | 30.51 | 48.46 | 0.93 | 49.54 | 70.02 |
| 48 | F76KENADSA | 2563 | not acceptable | 1 496.97 | very hard | 20.98 | 42.64 | 0.73 | 44.34 | 71.88 |

(*Continued*)

Table 2 (*Continued*)
Summary of water quality parameters in the study area

| No | Sample | TDS | | TH | | SAR | Na | KR | PI | MH |
|---|---|---|---|---|---|---|---|---|---|---|
| 49 | F82KENADSA | 2669 | not acceptable | 1 464.67 | very hard | 24.72 | 45.84 | 0.84 | 47.26 | 54.73 |
| 50 | F86KENADSA | 9129 | not acceptable | 3 785.32 | very hard | 78.36 | 62.73 | 1.67 | 63.02 | 58.74 |
| 51 | F95KENADSA | 2346 | not acceptable | 1 051.25 | very hard | 31.34 | 56.68 | 1.29 | 58.71 | 66.67 |
| 52 | F96KENADSA | 12184 | not acceptable | 3 771.17 | very hard | 120.92 | 71.11 | 2.44 | 71.25 | 35.01 |
| 53 | F115KENADSA | 2481 | not acceptable | 1 547.45 | very hard | 15.14 | 33.04 | 0.49 | 35.09 | 43.69 |
| 54 | F137KENADSA | 9260 | not acceptable | 3 433.22 | very hard | 96.72 | 68.49 | 2.16 | 68.74 | 57.23 |
| 55 | F140KENADSA | 3463 | not acceptable | 1 412.25 | very hard | 44.15 | 59.96 | 1.48 | 60.89 | 40.94 |
| 56 | F145KENADSA | 3733 | not acceptable | 1 487.02 | very hard | 45.42 | 59.90 | 1.47 | 60.89 | 39.16 |
| 57 | F147KENADSA | 3287 | not acceptable | 691.62 | very hard | 78.64 | 79.77 | 3.86 | 81.09 | 52.17 |
| 58 | F158KENADSA | 4708 | not acceptable | 1 784.96 | very hard | 61.08 | 65.45 | 1.87 | 66.02 | 51.49 |
| 59 | F162KENADSA | 4050 | not acceptable | 1 078.46 | very hard | 77.15 | 75.00 | 2.98 | 75.49 | 44.05 |
| 60 | BECHARPIEZO1 | 1056 | not acceptable | 502.93 | very hard | 18.00 | 50.58 | 1.01 | 54.81 | 42.41 |
| 61 | BECHARPIEZO4 | 617 | acceptable | 345.86 | very hard | 8.09 | 35.41 | 0.55 | 44.65 | 40.00 |
| 62 | BECHARMOSQUEELHODAP | 1319 | not acceptable | 672.81 | very hard | 15.59 | 43.74 | 0.77 | 47.73 | 49.51 |

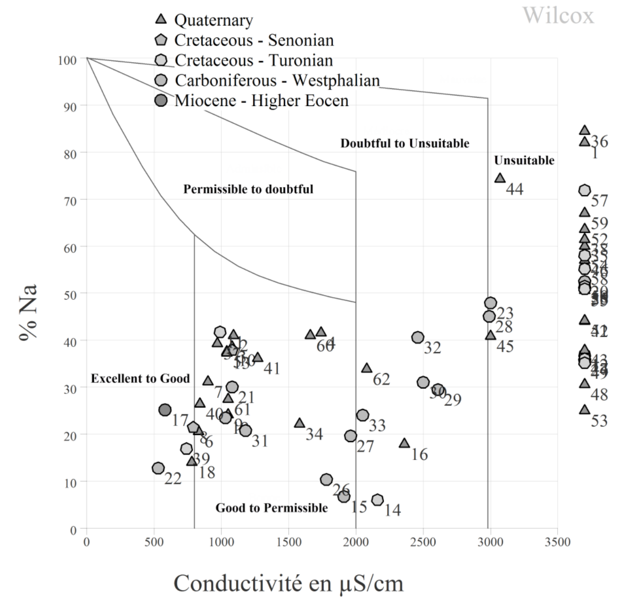


Fig. 5. Diagram of percentage of sodium relative to electrical conductivity.

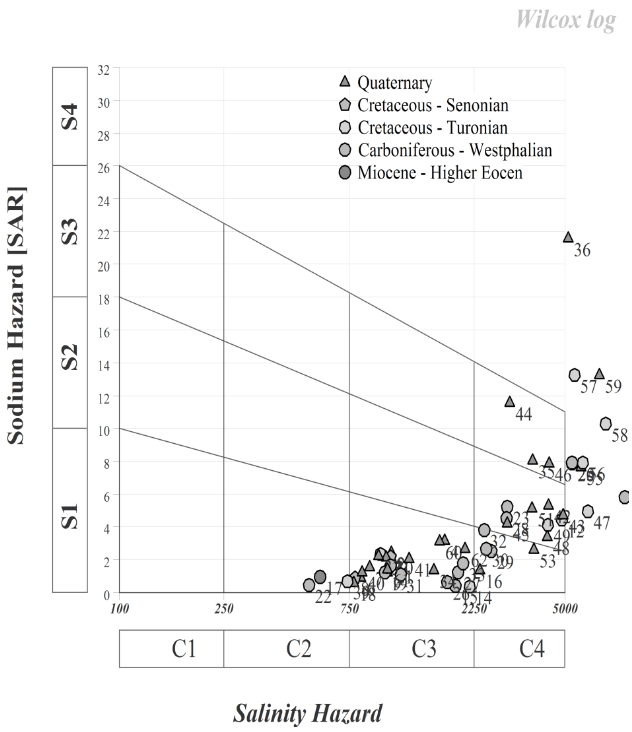


Fig. 6. Wilcox USSL 1954 groundwater classification for irrigation.

This diagram is divided into four categories, horizontally and vertically, which respectively illustrate the salinity of the water and the risk of sodium. From this diagram, we can distinguish six classes of water samples: 3 samples are located in class C2-S1 located in the Westphalian water table; 25 samples in the C3-S1 class with high salinity and low sodium risk (14 samples are located in the Quaternary water table and the other samples in the water table in the Westphalian), this class requires the use of processes to reduce salinity to avoid influence on crop development. The third, fourth and fifth classes, respectively C4-S1; C4-S2 and C4-S3, are in the category of very high salinity and gradual risk of sodium, which tends to avoid the use of these classes water since it is not appropriate for the irrigation and will affect soil characteristics due to high sodium levels.

### *3.3.2. Sodium concentration (Na%)*

This is an important factor in the classification of irrigation water quality as it can react with soil, resulting in clogging of cavities between soil particles, reducing the permeability and reduces the breathing of plant roots [18], that has an impact on the normal growth of plants % Na is calculated as follows:

$$Na\% = \frac{Na + K}{\left(Ca + Mg + Na + K\right)} \times 100 \quad (3)$$

The results (Table 2) show that 65% of the samples are classified as unsuitable for irrigation, these waters are concentrated in the area of Kenadsa in the Miocene-Upper Eocene as well as the area of Guelb al Aouda (Quaternary). %Na is rated as excellent (< 20%), good (20–40%), admissible (40–60%), questionable (60–80%) and unsuitable (> 80%) [19].

The Wilcox diagram is divided into four groups (excellent to unsuitable for irrigation) according to the sodium % values. The table shows the results obtained: 0.08% of the samples have an excellent water quality and are concentrated in the South-East zone of the study area and precisely in the Westphalian groundwater. Six samples were taken from the Quaternary aquifer, 1.6% of the samples fall into the category of questionable to inadequate irrigation water. Finally, 34% of the samples have good water quality.

### 3.3.3. Kellyratio (KR)

The KR is a parameter that can be used to determine the suitability of water for irrigation [20]. Kelly's ratio at over 3 is considered unsuitable for irrigation, while those with a higher than 1 ratio indicate an excess of $Na^+$. Water with a value of KR < 1 is considered suitable for irrigation [21]. The KR is calculated as follows:

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

According to the results obtained, more than 56% of the samples are suitable for irrigation, more than 37% of the waters are acceptable for irrigation but they have an excess in sodium.

### 3.3.4. Permeability index PI

It is similar to the Kelly report, which concerns the groundwater capacity for irrigation, the PI index gives three classes: the first class ( >75%) and the second class (25–75%) are ranked as good for irrigation, the third (<25%) is ranked as insufficient for irrigation [22]. The PI is calculated as follows:

$$PI = \frac{Na + \sqrt{HCO_3}}{Ca + Mg + Na} \times 100 \quad (5)$$

The results show that 95% of the water samples are suitable for irrigation, but there are only 3 samples in the Ouakda region, one in the water table that is in the Turonian and two in the Westphalian water table.

### 3.3.5. Magnesium hazard (MH)

Magnesium is an important element in the hydro-chemical constitution of water, but the excess of this element tends towards the alkalinity of the soil, which influences the agricultural yield. The MH value must be < 50 to classify that water as good for irrigation [23]. It is calculated as follows:

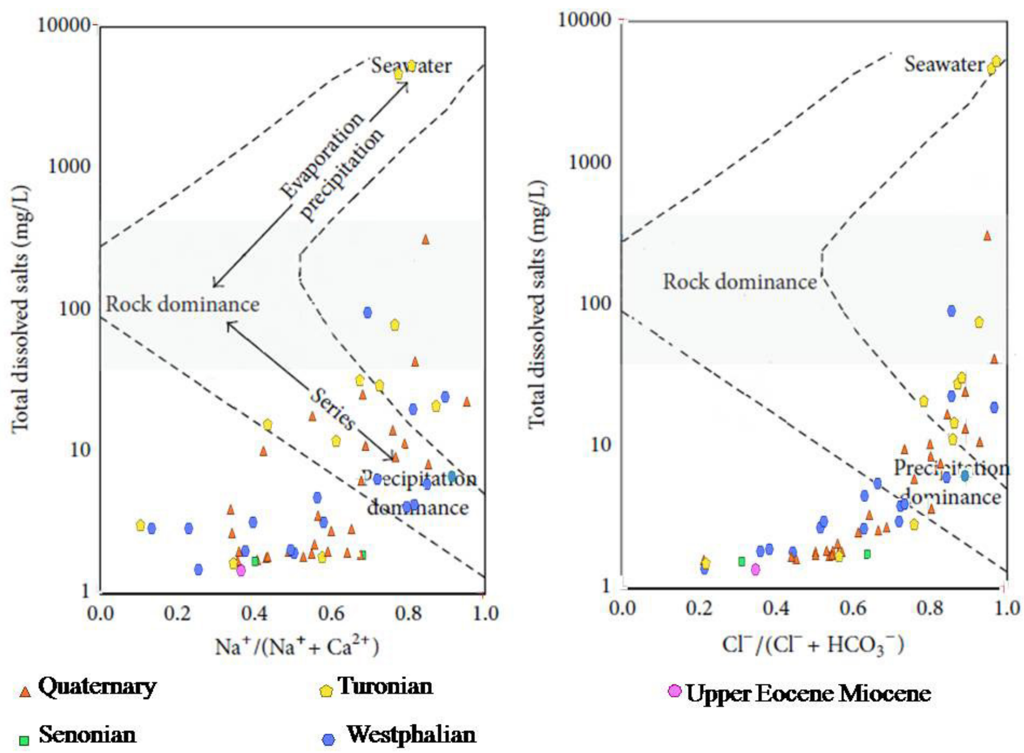


Fig. 7. Gibbs graphic.

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

The MH values of the study area vary between 17.75 and 97.07%. 28 water points are below the normalized value 50. This shows that about 45% of the water samples are suitable for irrigation.

### *3.4. Mechanisms controlling groundwater chemistry*

The Gibbs diagram (1970) is one of the best methods to analyze the relationship between water compositions and the respective lithological dispositions of the aquifer and to provide significant information on the relative importance of three main natural mechanisms of the surface water chemistry control [24,25]. The Gibbs plot is based on the concentration of the following parameters: Na, K, Ca, Cl and $HCO_3$. The ionic concentrations are expressed in meq/L and are divided according to TDS (mg/L) where the following equations are applied:

Gibbs Ratio I

$$Cation = \left[ \left( Na^+ + K^+ \right) / \left( Na^+ + K^+ + Ca^{2+} \right) \right]$$

Gibbs Ratio II

$$Anion = \left[ Cl- / \left( Cl- + HCO3- \right) \right]$$

There are three main areas that govern the Gibbs diagram: 1) domination of evaporation, 2) domination of precipitation and 3) domination of rocks. The representation of the results obtained from the application of Eqs. (7) and (8) based on the data of the water points studied on the Gibbs diagram, shows that there are two main mechanisms that control groundwater chemistry. The first is characterized by the interaction of groundwater by water from the precipitation, the other mechanism that results from the water-rock interaction. This result also confirms that precipitation is the primary source of high TDS values.

### *3.5. Cluster analysis*

To illustrate the relationships between the groundwater samples, we used the dendrogram (Fig. 8) resulting from the cluster analysis (hierarchical tree structure), we used the software SPSS V.19 [26,27]. A correlation matrix was generated in the same cluster analysis process (Table 3) for the physico-chemical parameters pH, EC, TDS, $HCO_3^-$, $Cl^-$, $SO_4^{2-}$, $NO_3^-$, $Ca^{2+}$, $Mg^{2+}$, $Na^+$ and $K^+$ of the dendrogram. It can be noted that most of the samples are classified in the first end of the second group (Group I and Group II), with a very strong correlation between $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$ and $SO_4^{2-}$ with CE and TDS. The third group consists of $NO_3^-$, $HCO_3^-$ and pH, this group reflects the influence of nitrate on water quality and could come from anthropogenic sources such as runoff water sources and agricultural practices.

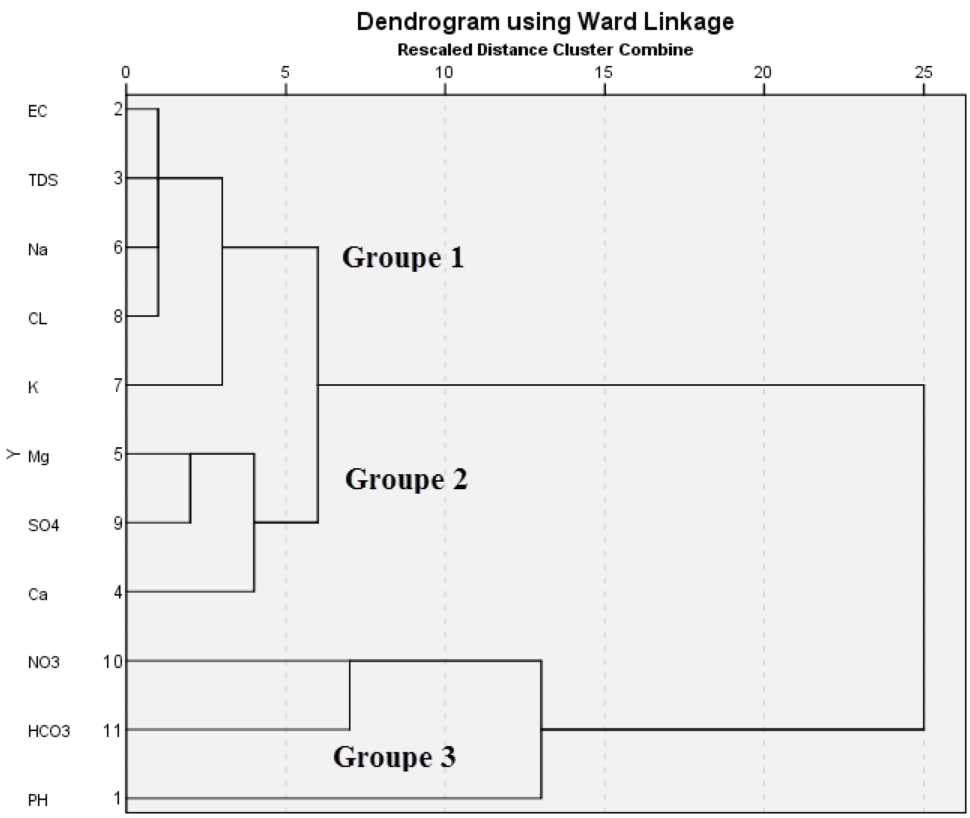


Fig. 8. Dendrogram for the grouping of groundwater according to its physico-geochemical parameters.

Table 3
Correlation matrix of physicochemical parameters

| Parameter | pH | EC | TDS | Ca | Mg | Na | K | CL | $SO_4$ | $NO_3$ | $HCO_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | |
| EC | –.680 | 1 | | | | | | | | | |
| TDS | –.636 | .995 | 1 | | | | | | | | |
| Ca | –.018 | .483 | .550 | 1 | | | | | | | |
| Mg | –.407 | .852 | .866 | .553 | 1 | | | | | | |
| Na | –.711 | .987 | .979 | .409 | .772 | 1 | | | | | |
| K | –.608 | .812 | .810 | .384 | .585 | .829 | 1 | | | | |
| CL | –.667 | .982 | .982 | .487 | .813 | .986 | .798 | 1 | | | |
| $SO_4$ | –.529 | .924 | .936 | .610 | .890 | .868 | .740 | .856 | 1 | | |
| $NO_3$ | .070 | –.110 | –.112 | –.109 | –.069 | –.114 | –.160 | –.124 | –.125 | 1 | |
| $HCO_3$ | .397 | –.305 | –.285 | –.120 | –.195 | –.298 | –.162 | –.317 | –.282 | .208 | 1 |

## 4. Conclusion

This work has shown results that could help the groundwater resource managers in the region to well manage it according to the characteristics of each area. The hydro-geochemical study reveals that the groundwater is between alkaline and acid where pH varies between 4.55 and 7.85 and with an average value of 7.26. The highest conductivity value (EC) of the Wadi is near Bechar (city). We have four main types of water: Mg-Cl-$SO_4$, Mg-Ca-Cl-$SO_4$, Mg-$SO_4$-Cl and Mg-Ca-$SO_4$-Cl. The composition of the major cations and anions and the different hydro-chemical facies of the studied water samples suggests that the groundwater characteristics of the study area are influenced by precipitation and rock-water interaction and this has been confirmed by the Gibbs diagram. The results of the Durov diagram show that 72% of the groundwater samples are concentrated in the dissolution mixing zone with the predominance of the Mg-Cl-$SO_4$ and Mg-Ca-Cl-$SO_4$ types. The water hardness varies from hard and very hard. In most of the samples, the water is estimated as not drinkable. Water classification according to the United States Salinity Scheme (Wilcox) showed that most of thewater samples were in three classes: C4-S1, C4-S2 and C4-S3; with high salinity and a progressive risk of excess sodium that suggest avoiding the use of these groundwater for irrigation practices.

Based on the results obtained in sodium concentration (% Na), we concluded that only 34% of the studied groundwater is of good quality, on the other hand 64% of the water samples have a value more than 80% (Na% threshold ) and classified as unsuitable for irrigation practices. The results of Sodium Absorption Ratio (SAR) calculations also confirm that only 32% of groundwater is acceptable for irrigation. Cluster analysis showed a strong correlation between $Mg^{2+}$, $Na^+$, $K^+$, $Cl^-$ and $SO_4^{2-}$ ions and EC and TDS. The existence of high rates of nitrates ($NO_3^-$) is due to anthropogenic sources (use of agricultural fertilizers). This work shows the need for immediate action to properly manage groundwater use in the study area using scientific approaches to increase water quality in order to provide adequate water for drinking and irrigation.

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