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Physico-Chemical Quality of Groundwater Used for Irrigation in The Hassi Khalifa Region (Eloued- Algeria)

Zid Insaf [1] & Rezkallah Chafika [2]

1.Department of Agronomy, Faculty of Nature and Life Sciences, University of El-Oued, Algeria.
Laboratory of Biology, Environment and Health, University of El-Oued, Algeria.
Email: zid-insaf@univ-eloued.dz, zid_insaf@yahoo.fr
2.Department of Biology, Faculty of Science Exacte and Natural Live, University of Tebessa, Algeria.
Laboratory of Applied Chemistry and Environment, University of El-Oued, Algeria.
Email: chafirez@yahoo.fr

Abstract

The wilaya of Eloued's contribution to the national economy is significantly influenced by agriculture, hence, the waters needs for irrigation are increased, and this increase causes the degradation of these waters quality. In this study we sought to provide an overview of the physico-chemical quality of groundwater used for irrigation in the Hassi Khalifa region (north-east of the Eloued wilaya). Water analyses were carried out for the physico-chemical parameters. For this purpose, 25 samples were collected from 25 agricultural boreholes on 10 farms in the study area. The obtained results show that the groundwater of this region is characterized by a neutral pH, a very high electrical conductivity (EC) with a high concentration of ions, namely K^+, Na^+, Ca^{+2}, NO_3, SO_4^{-2} and Cl^-, which are of lithological and agricultural origin, also, these waters are highly rich in sulphate accompanied by calcium and sodium, this explains the presence of two chemical facies such as sodium sulphate and calcium sulphate. The SAR method was used to classify these waters to highly mineralized, very hard and saline, which limits their agricultural use and give a vision on their suitability for irrigation,

Keywords: *Physico-Chemical Quality, Groundwater, Irrigation, Hassi Khalifa.*

1. INTRODUCTION

The Algerian Sahara, which covers two-thirds of the country's surface area, contains groundwater resources in two large Intercalary Continental (IC) and Terminal Complex (TC) aquifers **(Ballah A., 2016)** (fig.01). Groundwater is a very valuable resource in arid and semi-arid areas where surface water and precipitation are scarce **(A.Naz et al., 2016 in L.Komar et al., 2022).** Although these resources are readily available, their quality continues to be a limiting factor for economic and demographic development due to the increased needs associated with population growth and the accelerated development of agricultural activities **(Bouselsal B et al., 2014)**. According to **Rouabhia A.E.K et Djabri L., 2010**, intensive cropping practices and installation of different irrigation systems can both reduce groundwater quality.

The Hassi khalifa region is an agricultural region par excellence. In recent years, farmers in this region have noticed a decline in yields of certain crops, which has led us to make the following assumptions: poor choice of seeds used, lack of fertilization, not respecting the technical routes and poor choice of the phytosanitary treatment protocol. After our investigations with farmers on 10 most productive farms located in the south of the studied region, we managed to eliminate the assumptions made previously and conclude that the main cause is the quality of the water used in irrigation.

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The aim of this work was to provide an overview of the physico-chemical characteristics, chemical facies and the suitability for agricultural use of groundwater in the Hassi Khalifa region (Eloued-Algeria).

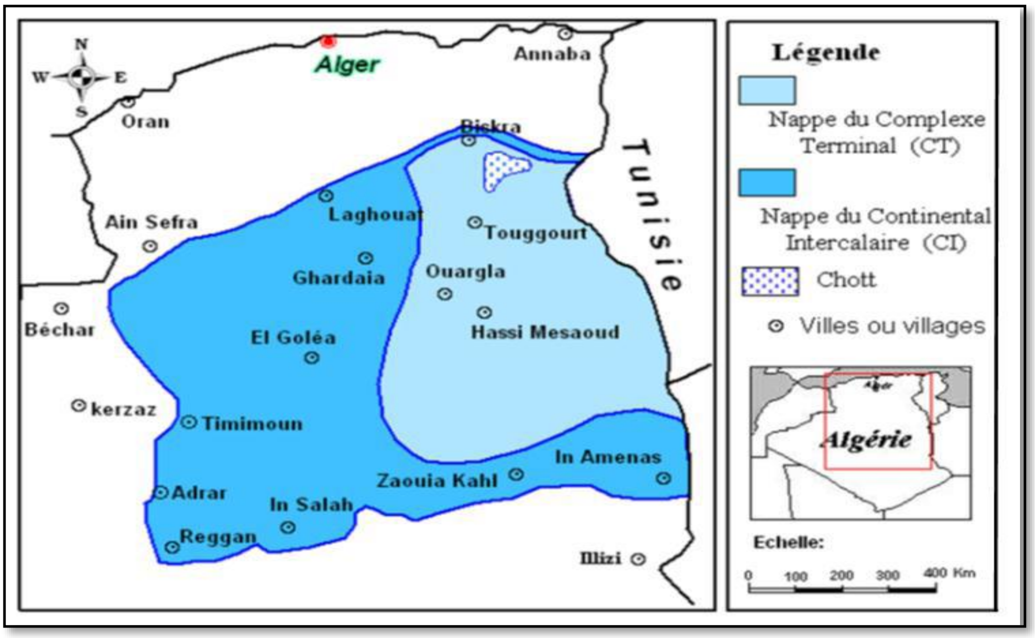

Fig 01: Groundwater Resources Map (Intercalary Continental and Complex Terminal) (UNESCO, 1972 *in* Ballah A., 2019)

2. MATERIAL AND METHODS

2.1 The study area presentation

The Hassi Khalifa daira is located in the north of the Eloued wilaya headquarters (30km), it covers an area of 1112 km2 (fig.02). This area is characterized by an arid climate of Saharan type, with low rainfall that does not exceed 100 mm throughout the year.

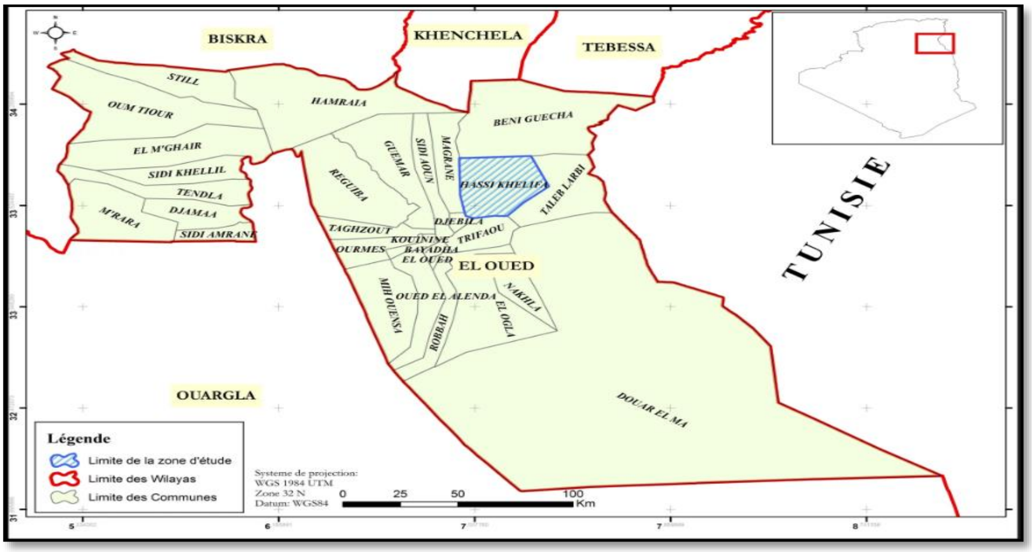

Fig 02: Location of the Hassi Khalifa Valley

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2.2 Condition and method of sampling

To confirm and interpret the quality of irrigation water in the area, 25 water samples were taken at a depth of 25 to 30 m from 10 different sites (fig. 03). The samples were collected in labeled plastic bottles with a capacity of 1 liter and rinsed with distilled water then stored in coolers until arriving to the laboratory of Algerienne Des Eaux (ADE) (fig.04). A conductimetre and pH meter was used to measure the electrical conductivity and pH at the sites.

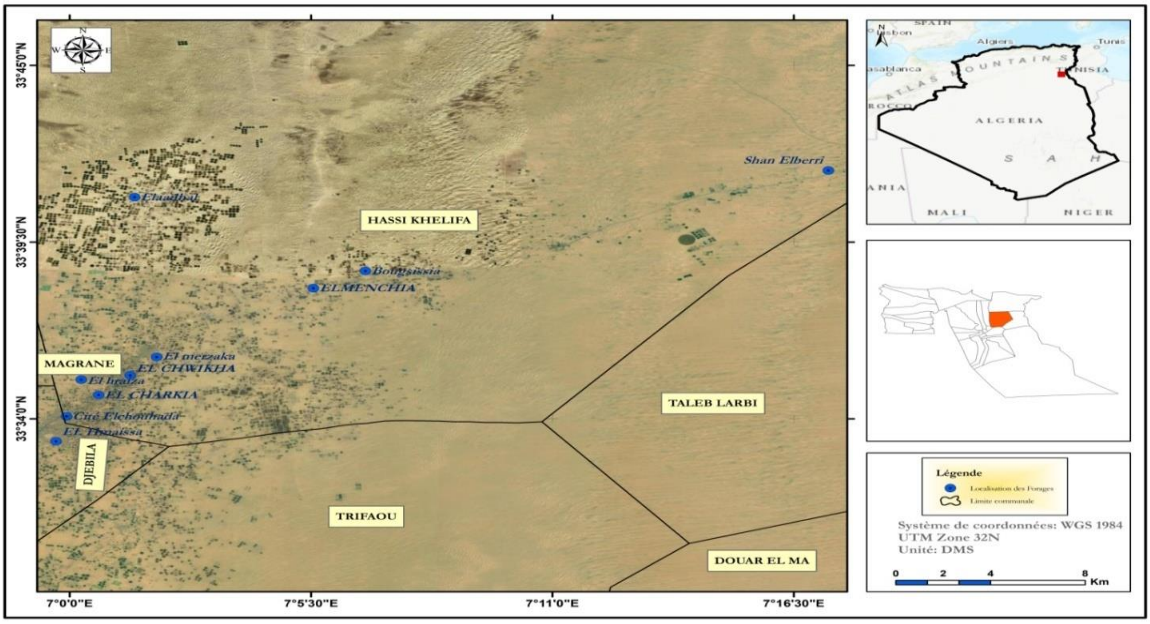

Fig 03: Sampling Site Distribution Map

The 25 studied drillings are distributed as follows;

Sites 1(Elmenchia): 6 samples

Sites 2 (Elmerzaka): 3 samples

Sites 3 (Elhraiza): 5 samples

Sites 4 (Elchwaikha): 1 sample

Sites 5 (Elaadhal): 1 sample

Sites 6 (Bougsissiaa): 1 sample

Sites 7 (Elhmaissa): 3 samples

Sites 8 (Elcharkiya): 1 sample

Sites 9 (City elchouhada): 1 sample

Sites 10 (Shan Elberri): 3 samples

Fig 04: Sampling method

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2.3 Physico-chemical analyses

Groundwater characterization is mainly concerned with the analysis of basic parameters (pH, temperature (T°), hardness and electrical conductivity (EC) and major ions (K^+, Na^+, Mg^{+2}, Ca^{+2}, HCO^{3-}, NO_3, SO_4^{-2} and Cl^-).

The analytical methods that were used are:

Colorimetric method for ions: HCO^{3-}, NO_3, SO_4^{-2} and Cl^-.

Atomic absorption spectrophotometry method for ions: K^+, Na^+, Mg^{+2} and Ca^{+2}.

3. RESULTS AND DISCUSSION

The results of the physico-chemical analyses of the waters used for the 25 boreholes irrigation are given in the following table (Table 01). Parameter means were calculated to facilitate discussion of the results obtained;

Table 01: Physico-chemical analysis summary table

Parameters / Sites	T (C°)	pH	The hardness °F	EC (µs /cm)	Soluble cations (mg/l)				Soluble anions (mg/l)			
					Ca^{+2}	Na^+	K^+	Mg^{+2}	Cl^-	HCO_3^-	SO_4^{-2}	NO_3^-
Site 1	12.8	7.5	233	3725	574.5	642.6	34.7	206.1	479.8	109.6	2232.5	55.38
Site 2	13.7	7.5	221	3960	550.4	683	34.7	203.3	716	165.5	2436.6	73
Site 3	14.8	7.5	245	7300	584.4	1055	30	193.5	716	186	2786	97.8
Site 4	15	7.2	170	4340	485	299	29	119	205.6	112.2	1800	98.15
Site 5	15.5	7.5	175	4960	565.14	447	23.6	82.6	134.7	102.5	2415	115
Site 6	15.3	7.5	226	6470	661.32	781	37	148.2	631	125.7	2225	93.7
Site 7	14.7	7.5	229	4776.6	573.7	345	25.6	209.5	441.9	128.5	2571.6	90
Site 8	15.6	7.2	137	5130	513	368	40	22	560.1	270.8	2285	49.6
Site 9	13.7	7.3	172	4770	549	289	34	85	631	183	2135	44.1
Site 10	15.5	7.5	185	6060	514.36	821	31.6	137.7	1270	109.8	2681.6	57.6

3.1 Physico-chemical characteristics of the water:

pH: It is an element that indicates acidity or alkalinity. After the measurement of PH using a field pH meter directly, findings show that all the study sites are characterized by a neutral pH with an average between 7.2 and 7.5.

Temperature: It oscillates between 12.8 C° and 15.6 C°, the measures were influenced by the external climate (Saharan climate) since they were taken in December (winter season).

Electrical conductivity (EC): It is measured using a field conductimetre, the values vary between 3725 µs/cm for the waters of site 1 (Elmenchia) which includes the boreholes F1, F2, F3, F4, F5 and F6 and 7300 µs/cm for the waters of site 3 (Elhraiza) which includes the boreholes F10, F11, F12, F13 and F14.According to **Tabouche N. et Achour S., 2004** the EC is measured to give an estimate on the total mineralization of the waters. The obtained results indicated that the waters are loaded with salt.

Hardness: Hardness refers to the amount of calcium and magnesium contained in water. Expressed as ppm (mg/l) calcium carbonate ($CaCO_3$) **(Couture I., 2004)**.

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Table 02: Relative level of water hardness according to carbonate Calcium amount (CRAAQ, 2003. *in* Couture I., 2004)

Hardness (ppm $CaCO_3$)	Relative degree of hardness
0-50	Super-soft
50-100	Soft
100-200	Moderately soft
200-300	Hard
300 et plus	Super hard

Based on the obtained data, we noted that the hardness of the studied samples is greater than 30°F (1°F = 10 ppm), ranging from 137°F to 245°F, which reveals that the waters analyzed are very hard, promoting the appearance of clogging of the irrigation system **(Hadfi A et al., 2011)**.

3.2 Soluble salts distribution

3.2.1 Cations

The concentration of Na^+ was very important, ranging around 368 mg/l for the waters of Site 8 (Elcharkiya) F21 and 1055 mg/l for the waters of Site 3 (Elhraiza), which includes the F10, F11, F12, F13, and F14 boreholes. This high concentration is probably due to Base Exchange and evaporation, in this case the water intended for irrigation can be toxic for salinity sensitive crops. **Benaissa A. et Bissati S., 2017** demonstrated that the high sodium content causes degradation of the soil structure and becomes impermeable.

Moreover, the concentration of K^+ showed also important levels, in the vicinity of 23.6 mg/l for the waters of site 5 (Elaadhal) F16 and around 40 mg/l for the waters of site 8 (Elcharkiya) F21. The presence of potassium comes from the direct alteration of silicate rocks and also leaching of fertilizers used by farmers (NPK). The analyses results revealed that the concentration of Ca^{+2} is very high, it varies between 485 meg/l for the waters of site 4 (Elchwaikha) F15 and 661 mg/l for the waters of site 6 (Bougsissiaa) F17. The high calcium content is resulting from the formation of gypsum.

On the other hand, the measured content of magnesium Mg^{+2} is low compared to other cations, ranging from 22 meg/l for Site 8 (Elcharkiya) F21 to 209.5 mg/l for Site 7 (Elhmaissa) which includes the F18, F19 and F20 boreholes. It has geological origin since it is obtained by the dissolution of carbonates.

3.2.2 Anions

The recorded levels of chloride Cl^- show important values, they range from 134.7 meg/l for the waters of site 5 (Elaadhal) F16 to 1270 mg/l for the waters of site 10 (Shan Elberri) which includes the drilling F23, F24 and F25. Chloride is found in natural waters as sodium (NaCl) and potassium (KCl) salt **(Nouayti N et al., 2015).**

Sulfate SO4-2 is present in the water in significant concentrations, with values ranging from 1800 mg/l in the Elchwaikha site 4 borehole F15 to 2786 mg/l in the Elhraiza site 3 boreholes F10, F11, F12, F13, and F14. This high concentration is possibly due to the dissolution of gypsum **(Gouidia L., 2008)** and the formation of salifers. Further, it has been reported by **Rezekellah C., 2017**, that another source of sulphates can be attributed to the infiltration of fertilizers or pesticides used by farmers.

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On the contrary, we noted a less important concentration of HCO^{3-}, they vary between 102.5 meg/l for the waters of site 5 (Elaadhal) F16 and 270.8 mg/l for the waters of site 8 (Elcharkiya) F21. NO3 nitrate values range from 44.1 mg/l for Site 9 (City elchouhada) F22 to 115 mg/l for Site 5 (Elaadhal) F16. As showed by **Karnath K.R., 1987** ***in*** **Rajaveni S.P et al., 2018**, the high concentration of nitrates is related to the successive use of fertilizers.

3.3 The chemical families of the analyzed waters

Piper diagrams are widely used to study the chemical types of groundwater, which can simply and effectively reflect comprehensive information about the chemical types of water **(Liu J et al., 2020b** ***in*** **Wang X et al., 2022)**

The representation of the chemical elements from different samples on the Piper diagram (fig.06) showed that the groundwater of the Hassi Khalifa region belong to 2 types of chemical families of geological nature. Sulphate (SO_4^{-2}), sodium (Na^+) and calcium (Ca^{+2}) levels predominate;

- The predominant chemical facies is sodium sulphate (22 samples) of type $Na^+ > Ca^{+2} > Mg^{+2} > K^+$ for cations and $SO_4^{-2} > Cl^- > HCO^{3-} > NO_3$ for anions. These samples may be the source of the dissolution of gypsum.
- 3 samples have calcium sulphate chemical facies of type $Ca^{+2} > Na^+ > Mg^{+2} > K^+$ for cations and $SO_4^{-2} > Cl^- > NO_3 > HCO^{3-}$ for anions. These samples may be responsible for the formation of halites.

According to **Pant et al., 2018** ***in*** **Wang X et al., 2022**, Na^+,Ca^{+2}, Mg^{+2}, K^+ and HCO^{3-} ions were produced by dissolved silicates and carbonates; while, SO_4^{-2} and Cl^- ions were resulted from the dissolution of the evaporating rock.

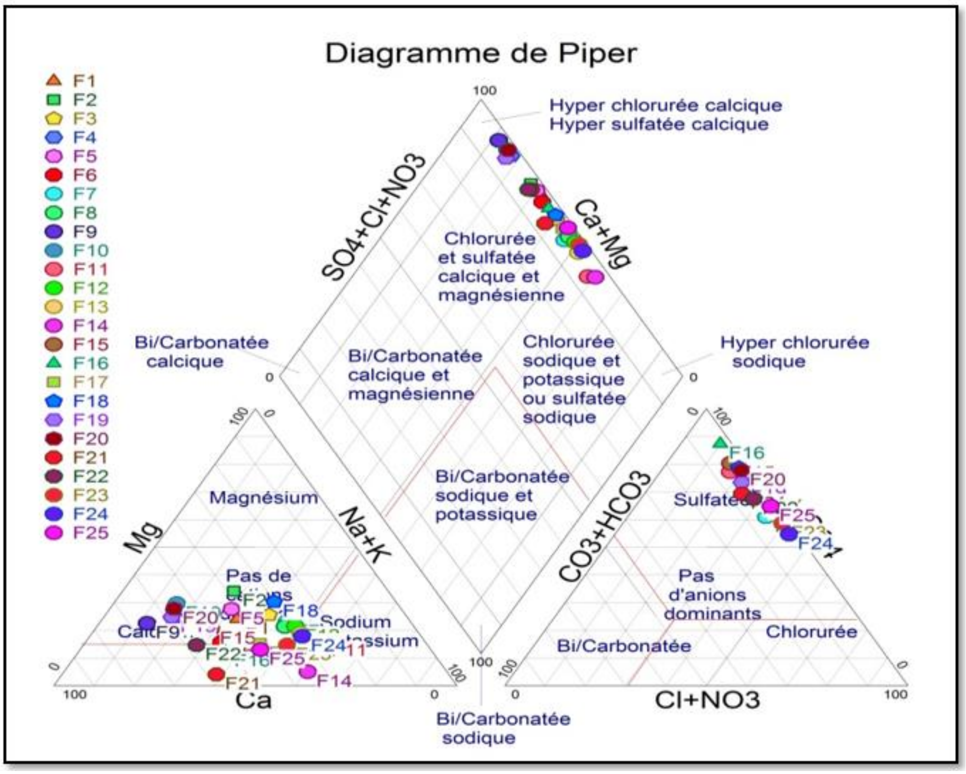

Fig 05: Piper Diagram (Piper A.M. 1954)

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3.4 Anions/ cations relationship

In order to better understand the origin of cations and anions, we explored the correlation between them. The relationship between anions and cations in groundwater provides insight into the key factors controlling groundwater hydrochemistry **(Wu et al., 2018 *in* Wang X et al., 2022**).

3.4.1 (Na^{+}/ SO_4^{-2}) relation

A simultaneous evolution of sodium and sulfate is depicted in the graph (fig. 06), which could be the reason why gypsum is dissolving. This relationship explains why the sulphate-sodium facies predominates (88% of the examined samples).

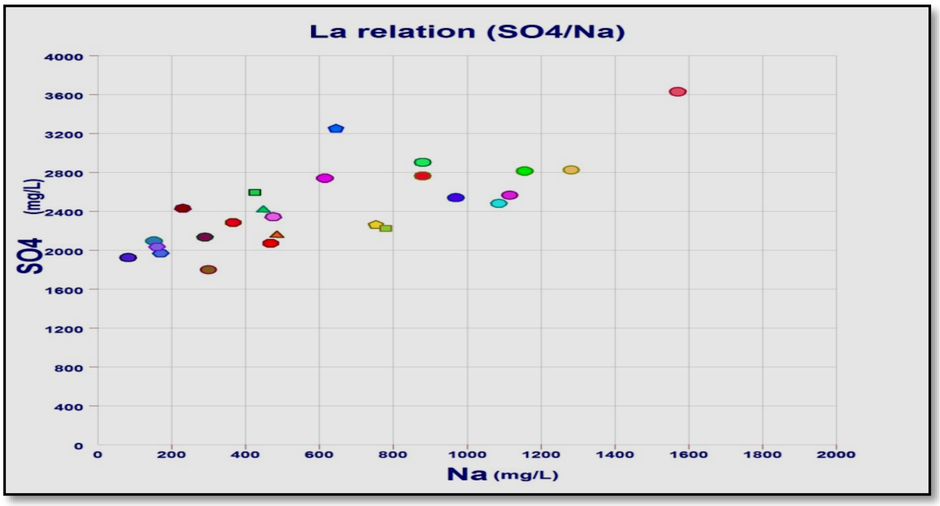

Fig 06: (Na^{+}/ SO_4^{-2}) relation

3.4.2 (Ca^{+2}/ SO_4^{-2}) relation

A simultaneous evolution of calcium and sulphate, which may be the source of the formation of halites, is represented in the graph (fig.07). Sulphate-calcium facies are present in 12% of the analyzed samples, and this relationship explains their prevalence.

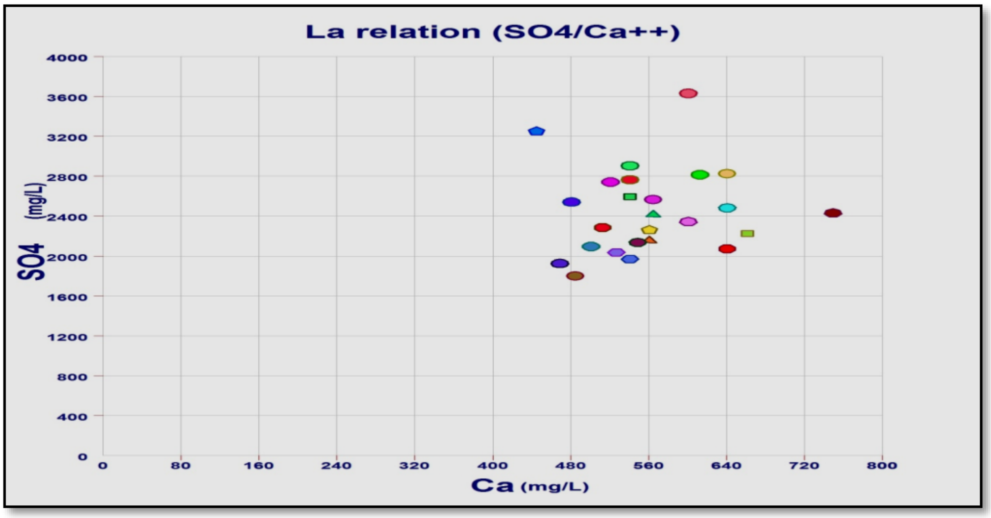

Fig 07: (Ca^{+2}/ vSO_4^{-2}) relation

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3.5 Classification o in the study area waters

Sodium content (Na %) and sodium adsorption rate (SAR) are typically used to evaluate the possibility of using groundwater for agricultural irrigation **(Wang X et al., 2022).** Different classes of water have been defined on the basis of adsorbable sodium (**Chaib W et al., 2013).** The Riverside method is based on the combination of electrical conductivity and alkalinity, the SAR is defined by the following equation:

$$SAR = \frac{(\mathrm{Na}^{+} + \mathrm{K}^{+})}{\sqrt{\frac{\mathrm{Ca}^{+2} + \mathrm{Mg}^{+2}}{2}}}$$

S: Sodium; A: Adsorption; R: Ratio

Na^{+}, Ca^{+2}, K^{+} and Mg^{+2} ions represent concentrations in (mg/l), values of SAR were calculated from chemical analysis data

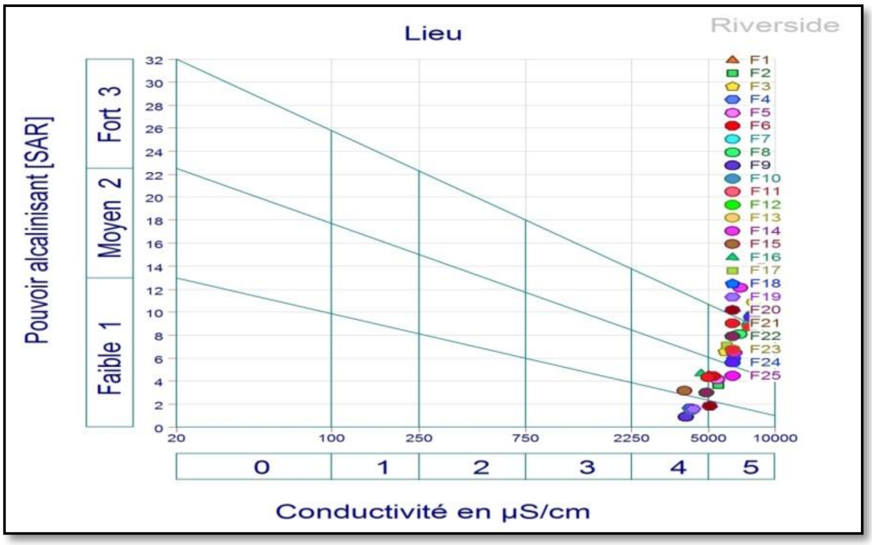

Fig 08: Water classification according to Riverside diagram

The diagram in figure 09 demonstrates that the groundwater of the study area is of poor quality, highly mineralized and not suitable for irrigation of species that do not support high salinity levels; these waters fall into the following classes:

- ✓ C4S1: represent 16% of drilling.
- ✓ C4S2: represent 12% of drilling.
- ✓ C5S1, C5S2: represent for 24% of drilling.
- ✓ C5S3, C5S4: represent 48% of drilling.

4. CONCLUSION

The groundwater physico-chemical characteristics study of Hassi Khalifa region shows that the major mineral elements (K^{+}, Na^{+}, Mg^{+2}, Ca^{+2}, HCO^{3-}, NO_3, Cl^{-} and SO_4^{-2}) are of various origin; which explains the dominance of two facies, namely sodium sulphate and calcium sulphate. In addition, the electrical conductivity was found to be very high in all the studied

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sites with a value of 7300 µs/cm in site 3 (Elhraiza), the increment of EC is well explained by the elevation in concentrations of Ca^{+2} K^{+}, Na^{+},Cl^{-} and SO_4^{-2}.

According to the interpretation of the results obtained by the S.A.R (Riverside) method of the samples taken The majority of the boreholes in the Hassi Khalifa region are in classes C5S1, C5S2, C5S3, and C5S4 (72%) and are extremely hard, have high salinity, and are not suitable for irrigation of certain sensitive crops, which explains the low yields. In this context, the following requirements are proposed to solve the problem and improve the quality of irrigation water:

- Establish physico-chemical analyses to better understand the soil richness before planting crops in order to minimize fertilizer inputs.
  - ✓ Select salt tolerant varieties
  - ✓ Rational use of fertilisers to avoid pollution of the groundwater.
  - ✓ Need to identify plant water needs and encourage farmers to improve cropping practices.
  - ✓ Install a drainage system that washes away excess mineral elements.

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