

## Assessment of groundwater quality and its suitability for irrigation: the case of Souf Valley phreatic aquifer

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### ABSTRACT/RESUME

**Abstract:** In arid regions, groundwater is the major freshwater source for agriculture. Actually, groundwater quality is a major issue for irrigation in many arid regions such as the Algerian Sahara. The present study assesses the quality of the groundwater of the Souf Valley phreatic aquifer for irrigation, using the common parameters for irrigation water. 36 samples were taken in two agricultural areas in this valley. Samples temperature (T), pH, electrical conductivity (EC), major cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>) and major anions (Cl<sup>-</sup>, SO<sub>4</sub><sup>2-</sup>, HCO<sub>3</sub><sup>-</sup>, NO<sub>3</sub><sup>-</sup>) were analyzed according to the American Public Health Association Standards. Piper diagram showed that this water is Ca-Cl (78%) and SO<sub>4</sub>-Ca (14%) dominant. The chemical Souf Valley Groundwater composition is altered by evaporation and contamination by hypersaline surface water. Also by Carbonate minerals precipitation and evaporites dissolution, according to saturation indices derived by the PHREEQC thermodynamic model. According to water quality for irrigation parameters (Na%, MH, PS, CE) in addition to Riverside and Wilcox diagrams, this aquifer is of poor water quality for irrigation. The majority of analyzed samples present a weak danger of alkalization and a low percentage of magnesium. However, their salinity is very high for all samples which results in a high risk of soil salinization, this level of salinity may threaten the sustainability of agriculture in this area. The results presented in this paper can be used to develop a sustainable irrigation management in this area.

### I. Introduction

Worldwide, 30% of agricultural irrigated lands are supplied by groundwater [1]. This natural resource is the primary supply for agriculture in arid regions, such as the Algerian Sahara, where groundwater exploitation is a critical component and a serious concern for agriculture [2]. However, the chemical composition of groundwater as well as its suitability for agriculture uses is influenced by various natural and anthropogenic factors [3].

In arid regions, groundwater is frequently linked to

high salinity levels, caused by the geological environment or by the continuous accumulation of salts in endorheic basins [4]. Salt accumulation in the surface layers of the soil is amplified by rainfall scarcity and excessive evaporation. Other anthropogenic factors may be added in the case of intensive farming, like the management of natural resources for short-term benefits [5]. Secondary soil salinization is currently regarded as the primary cause of soil degradation; 1030 million hectares are impacted worldwide, leading to a loss of 27 billion dollars [6].

Algeria is one of the most impacted countries by soil salinization with 3.2 million hectares affected by various soil salinization degrees [7]. A high percentage of these salt-affected soils is found in the country's Saharan regions, where 4,300 ha are harmed every year [8]. Many researchers attribute soil salinization in Saharan regions to groundwater's high salinity and the poor management of irrigation [9,10]. In such conditions, the study of the hydrochemical properties of irrigation water is necessary for the sustainable farming [11].

The Souf Valley, is regarded as one of the most valuable agricultural areas of the Algerian Sahara, with more than 60,000 ha mainly by the phreatic aquifer [12]. Despite of its importance for agricultural sector in Algeria, agriculture in this region raises many ecological issues. Even if irrigation water is a major issue, its quality and suitability for irrigation is less studied in the irrigation perimeters of this valley. Therefore many researchers reported the poor quality of this aquifer near the urban areas of the valley [13,14]. The main objectives of this paper are the characterization of the hydrochemical properties of the Souf Valley phreatic aquifer, which is the main water source for irrigation and the assessment of its suitability for irrigation.

## II. Materials and methods

### II.1. Location

The Souf Valley as a part of EL Oued state is located on the eastern side of Algeria, precisely on the Algeria-Tunisia border (Figure 1), at 630 km from the capital of the country. This valley covers an area of 11738 km<sup>2</sup>, situated between 6.20 and 7.5 decimal longitudes, 32.5 and 34.2 decimal latitudes. The population in this area is around 500,000 people [15]. Its climate is typical Saharan, known for scarce precipitations, along with hot and dry summer and moderate winter [16]. Climatic data from 1990 to 2011 indicated an average rainfall of 79 mm per year and evapotranspiration of 1731 mm·year<sup>-1</sup>. The average daily temperature is 20.15°C, ranging from 10.8°C in June to 33.7°C in August [17].

### II.2. Geological and hydrogeological setting

The Souf Valley is a part of Saharan platform geology, specifically to its northeastern part. The geological formations in this area are of sedimentary origin. At the surface, only Quaternary and Mio-Pliocene-age terrains may be found. From a hydrogeological aspect, the Souf Valley is a component of the northern Sahara aquifer system [18]. It is known by two major aquifers; The Albian aquifer and the Terminal Complex. The phreatic aquifer is found at the surface, in recent geological formations. The latter aquifer is less important than from area 1 and 18 samples from area 2. All these water points are constantly used for irrigation and they collect water from the phreatic aquifer. Their

the two previous aquifers, although it is widely used in the agricultural sector. Geological and hydrogeological descriptions of these aquifers are summarized as follows:

- The Albian aquifer is enclosed in the Lower Cretaceous continental layers (Barremian and Albian), where detrital lithology is dominant. This aquifer is captive and limited at the base by an impermeable substratum composed of Neocomian and Portlandian clays and upwards by clay and marly roof of the Cenomanian. Its average thickness in the Souf Valley is 400 m, while its average depth is 1700 m.
- Terminal Complex is made up of two aquifer systems: the sand table and the limestone table. The carbonate formation from Senono–Eocene age at the base and the clay formation of the Mio-Pliocene at the top. In the Souf Valley, Mio-Pliocene layers are represented by sands and gravels attributed to the Pontian with an average thickness of 50 m.
- The phreatic aquifer is situated at the top. Water is contained in fine aeolian-type sandy deposits of the Quaternary that are locally intercalated by clayey sand and sand-gypsum crusts towards the northeastern part of the valley. Geophysical prospecting data of the boreholes revealed that this water table is of a free surface [19], it shows also variable thicknesses ranging from few meters to few hundred meters (figure 2). Sandstones succussed by friable gypsum cement give way to sandy clays under this sandy layer. This aquifer is the primary supply of irrigation water, with more than 30,000 boreholes [14]. Its substratum depth is between 50 and 90 m, and groundwater flows from south to northeast. This aquifer's recharge takes place from torrential rains, and from the return of irrigation and household water [19]. This aquifer's electrical conductivity ranges between 2,700  $\mu\text{S cm}^{-1}$  to 17,000  $\mu\text{S cm}^{-1}$  [20].

## II.3. Methodology

### II.3.1. Sampling methods

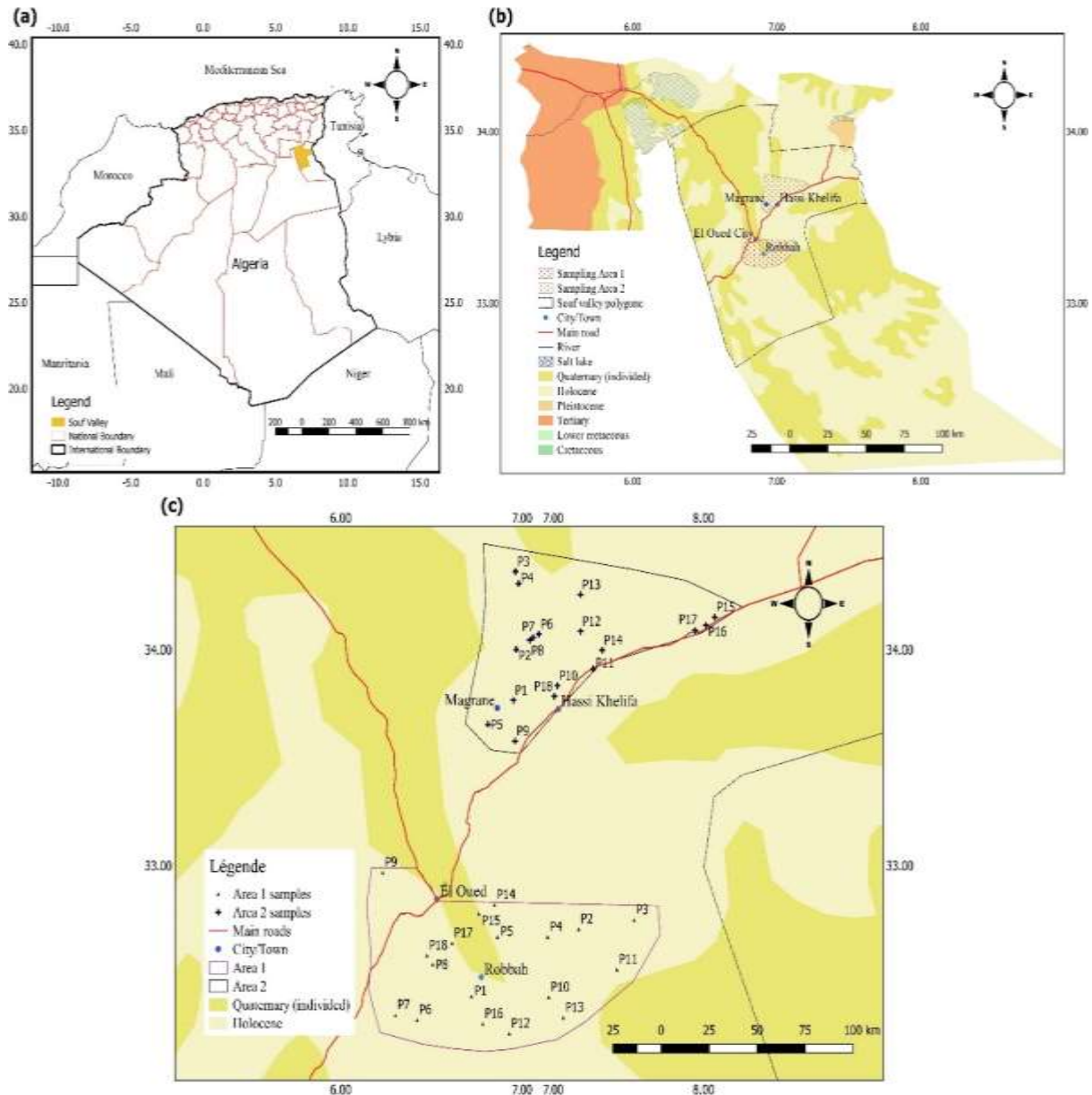
Two areas were selected for sampling due to their agricultural importance and their locations with respect to groundwater flow direction (Figure 1). The first area is located in the south of the valley and includes three irrigated perimeters belonging to three municipalities (El Biadha, Robbah and El Ogla). The second area is located in the north of the valley (Figure 1), it consists of two irrigated perimeters located in two communes (Hassi Khelifa and Magrane). In total, 36 water points (boreholes and wells) were sampled, including 18 samples

depths vary between 20 m and 42 m, whilst their pumping rates vary between 15 m<sup>3</sup> h<sup>-1</sup> and 32 m<sup>3</sup> h<sup>-1</sup>. The sampling and analysis period is from January 1

to 21, 2019.

The GPS technology (Global Positioning System) was used to determine the boreholes coordinates. Samples were collected in a polyethylene container that had cleaned with distilled water and filled to the

brim so with no air bubbles remained inside. For less than 24 hours, all samples were transported to the laboratory in a cooler box at temperatures below 4°C. In order to have representative water samples of the phreatic aquifer, water was pumped for 30 minutes before collecting a sample.



**Figure 1.** Maps of the study area (a, b) and samples location (c)

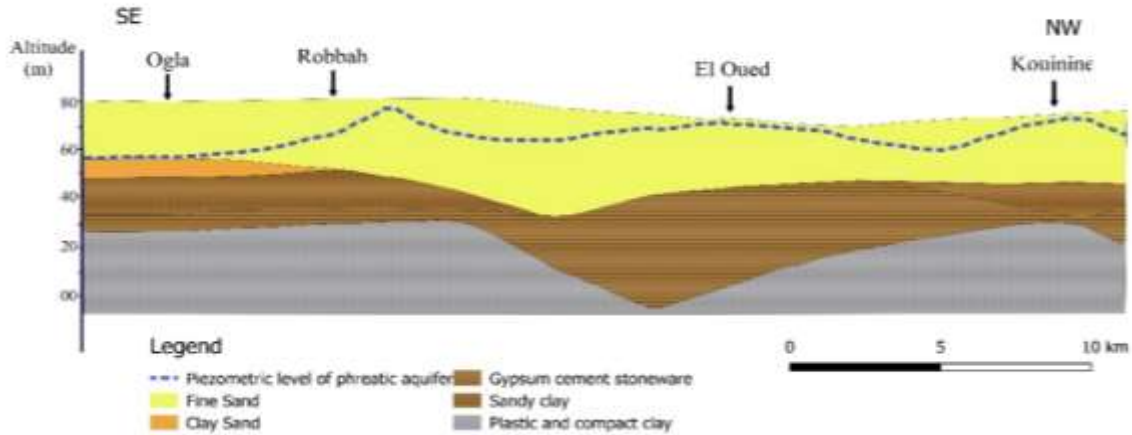


Figure 2. Geologic cross-section of the study area [21]

**II.3.2. Hydrogeochemical parameters analysis**

Temperature, pH, and Electric Conductivity were measured in-situ after three tests with the Hanna HI 991301 multi-parameter. Major ions were analyzed at the Algerienne des Eaux laboratory located in El Oued city according to the American Public Health Association’s techniques [22]. Volumetric titration is used to measure calcium (Ca<sup>2+</sup>), magnesium (Mg<sup>2+</sup>), bicarbonate (HCO<sub>3</sub><sup>-</sup>), and chloride (Cl<sup>-</sup>) concentrations. Whereas, the flame photometer is used for sodium (Na<sup>+</sup>) and potassium (K<sup>+</sup>). Otherwise, the UV spectrophotometer is used for sulfates (SO<sub>4</sub><sup>2-</sup>) and nitrates (NO<sub>3</sub><sup>-</sup>) analyses.

**II.3.3. Water quality parameters**

Piper diagram [23] was used to define chemical facies. Gibbs diagram [24] is used to define the geochemical processes that impact water properties.

Saturation indexes (SI) of different minerals as well as chloro-alkaline indexes CAI-1 and CAI-2 are used to understand Interactions between groundwater and its geological environment [25]. Water’s quality for irrigation is evaluated using the following Parameters: Sodium Hazard (Na%), Magnesium Hazard (MH%), Potential Salinity (PS), Electrical Conductivity (EC), Sodium Adsorption Ratio (SAR), Total Hardness (TH), chloride concentration (Cl<sup>-</sup>) as well as Riverside and Wilcox diagrams [3, 26].

Maps were made using QGIS 2.18 [27]. Riverside diagrams, as well as ionic formulas were made using FREEWAT hydrochemical plug-in integrated on QGIS 2.18 software [28]. Saturation indexes (SI) were calculated by the thermodynamic model of the PHREEQC software [29]. Table 1 displays all used parameters and their appropriate formulas.

Table 1. Interpretation parameters and their appropriated formulas

Parameter	Formula
Saturation indexes (SI)	$SI = \frac{LOG K_{IAP}}{LOG K_{SP}} \quad (1)$ <p>KIAP: ionic activity coefficient of the mineral KSP: is its solubility coefficient.</p>
Chloro-alkaline indexes (CAI-1 and CAI-2)	$CAI\ 1 = \frac{(Cl^- - (Na^+ + K^+))}{Cl^-} \quad (2)$ $CAI\ 2 = \frac{(Cl^- - (Na^+ + K^+))}{SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^-} \quad (3)$
Sodium Hazard (Na%)	$Na\% = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \quad (4)$
Magnesium Hazard (MH%)	$MH\% = 100 \times \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \quad (5)$

Potential Salinity (PS)	$PS = Cl^- + \left(\frac{1}{2}\right) SO_4^{2-}$ (6)
Sodium Adsorption Ratio (SAR)	$SAR = \frac{Na^+}{\sqrt{1/2(Ca^{2+} + Mg^{2+})}}$ (7)
Total Hardness (TH)	$TH = (Ca^{2+} + Mg^{2+}) \times 50$ (8)

*All ions Concentrations are In meq L<sup>-1</sup>*

Sodium hazard (Na%) assesses groundwater quality by the comparison of sodium concentration to other cations concentrations. Excess of sodium reduces soil permeability, and then deteriorates soil's physical properties. As it can limit plant growth by interfering in many physiological functions such as absorption and solution transport [30]. Magnesium Hazard (MH%) evaluates the quality of water based on Magnesium's proportion to divalent cations using Szabolcs and Darab [31]. PS is proposed by Doneen [32] for water quality assessment by the evaluation of soil salinization risks, caused mainly by the Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> ions. The TH index is a hydro-chemical parameter that evaluates clogging issues in pressurized irrigation systems [33].

CE and SAR are the most commonly used metrics for quantifying groundwater salinity. There are various standards for groundwater classification based referring to its EC, the most used are Riverside [34] and Todd [35] standards. They are based on long-time salinity's effects on the physical and chemical properties of soils under normal conditions.

Riverside [34] and Wilcox [36] diagrams shown in Figure 5 are used to assess water suitability for irrigation by the evaluation of soil salinization and alkalization risks. Riverside diagram classifies water samples by combining the EC and the SAR parameters. On the horizontal axis, samples are categorized into 4 classes based on their EC,

according to the same standards of Riverside shown in Table 5. On the vertical axis, samples are categorized according to their alkalinities expressed by SAR, which is calculated by formula 7, where all concentrations are in meq L<sup>-1</sup>. In this diagram, SAR interpretation standards depend on the CE value. If the EC is smaller, the same SAR value has a bigger influence on the soil [34]. Wilcox diagram classifies samples according to their suitability for irrigation by the combination of EC and Na%.

Toxic ions, particularly chlorides, are critical in determining irrigation water quality because they can damage plants in a variety of ways when their tolerance limits are exceeded. The buildup of this ion in leaves has a direct impact, causing leaf necrosis and defoliation in extreme situations. The indirect impact is through the interruption of the plant's nutritional balance [37]. Table 5 categorizes irrigation water based on its Cl<sup>-</sup> content [38].

### III. Results and discussion

#### III.1. Hydrogeochemical parameters

##### III.1.1. General descriptions

Descriptive statistical parameters (Mean, Minimum, Maximum, Standard deviation, Coefficient of variation) of the T, pH, EC, TDS, major cations and major anions concentrations of the analyzed samples are presented in Table 2.

**Table 2.** Average, Minimum, Maximum, Standard deviation and coefficient of variation of hydrochemical parameters

Parameter	Area 1					Area 2				
	Min	Max	Average	σ	CV (%)	Min	Max	Average	σ	CV (%)
T °C	20.9	23.7	22.4	0.82	3.67	19.8	24	22.6	1.33	5.89
pH	7.2	7.6	7.4	0.13	1.8	6.9	7.5	7.2	0.14	1.97
EC (μS cm <sup>-1</sup> )	2656	9060	3872	1447	37.39	4683	10178	6298	1364	21.67
TDS (mg L <sup>-1</sup> )	1677	5379	2446.5	943.55	38.56	3214	5653	3695	692.35	18.7

Ca <sup>2+</sup> (mg L <sup>-1</sup> )	449	733	593	79.83	13.45	549	789	677.6	74.72	11.03
Mg <sup>2+</sup> (mg.L <sup>-1</sup> )	41.3	51.4	46.25	5.04	10.91	94.8	289.2	188.6	59.25	31.41
Na <sup>+</sup> (mg L <sup>-1</sup> )	130	690	276	123.7	44.79	125	470	230.2	82.42	35.81
K <sup>+</sup> (mg L <sup>-1</sup> )	17	54	30.04	10.32	34.36	19	40	27.4	6.4	23.35
Cl <sup>-</sup> (mg L <sup>-1</sup> )	550	1968	860	317	36.92	787	1723	1249	268	21.49
SO <sub>4</sub> <sup>2-</sup> (mg L <sup>-1</sup> )	200	550	391	133.6	34.12	209	2416	1131	688	60.84
HCO <sub>3</sub> <sup>-</sup> (mg L <sup>-1</sup> )	80.2	528	125.6	107.3	85.43	67.1	123.22	96.8	17.5	18.1
NO <sub>3</sub> (mg L <sup>-1</sup> )	68	82.5	75.25	10.26	13.63	31	175.08	96.0	39.78	41.45

Min : Minimum, Max : Maximum,  $\sigma$ : Ecart-type, CV = Coefficient of Variation

According to table 2, the temperatures range from 20.9°C to 23.7°C in area 1, from 19.8°C to 24°C in area 2, these values indicate that temperature is ambient and weekly variable. pH is neutral and weakly variable, its values are between 7.2 and 7.6 for area 1, and between 6.9 and 7.5 for area 2. EC values show that the analyzed samples contain high salinity and higher salinity in area 2. EC varies between 2656  $\mu\text{S cm}^{-1}$  and 9060  $\mu\text{S cm}^{-1}$  in area 1 with an average of 3872  $\mu\text{S cm}^{-1}$  and a CV of 37.39%. In the second area, EC varies between 4683  $\mu\text{S cm}^{-1}$  and 10178  $\mu\text{S cm}^{-1}$  with an average of 6298  $\mu\text{S cm}^{-1}$  and a lower coefficient of variation (21.67%). TDS ranges from 1677 mg L<sup>-1</sup> to 5379 mg L<sup>-1</sup> in area 1 with an average of 2446.5 mg L<sup>-1</sup>, while in area 2 TDS ranges from 3214 mg L<sup>-1</sup> to 5653 mg L<sup>-1</sup> with an average of 3695 mg L<sup>-1</sup>. TDS levels show that the analyzed samples are moderately saline according to Rhoades classification [39].

Monovalent cations concentrations (Na<sup>+</sup> and K<sup>+</sup>) are greater in area 1. However, divalent cations (Mg<sup>2+</sup> and Ca<sup>2+</sup>) are more concentrated in area 2. Ca<sup>2+</sup> concentrations are clearly greater than the other cations, their average concentrations are 593 mg L<sup>-1</sup> in area 1 and 677.6 mg L<sup>-1</sup> in area 2. K<sup>+</sup> concentrations are the lowest, with an average value

of 30.04 mg L<sup>-1</sup> and 27.4 mg L<sup>-1</sup> respectively in area 1 and area 2. Coefficients of variation of the cations indicate that the most variable cation is Na<sup>+</sup> (CV= 44.79%) whereas the least variable cations are Mg<sup>2+</sup> for area 1 (CV = 10.91%) and Ca<sup>2+</sup> for area 2 (CV = 11.03%).

Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup> and SO<sub>4</sub><sup>2-</sup> concentrations are greater in area 2, while those of the anion HCO<sub>3</sub><sup>-</sup> are greater in area 1. The most concentrated anion is Cl<sup>-</sup> with an average value of 860 mg L<sup>-1</sup> in area 1 and 1249 mg L<sup>-1</sup> in area 2. The least concentrated anion is NO<sub>3</sub><sup>-</sup> with an average value of 75.25 mg L<sup>-1</sup> in area 1 and 96 mg L<sup>-1</sup> in area 2. Coefficients of variations of the anions indicate that HCO<sub>3</sub><sup>-</sup> is the least variable ion for area 1 (CV= 85.43%), while SO<sub>4</sub><sup>2-</sup> is the most variable one for area 2 (CV= 60.84%). The least variable anions are NO<sub>3</sub><sup>-</sup> for area 1 and HCO<sub>3</sub><sup>-</sup> for area 2 (CV = 18.1%).

### III.1.2. Chemical facies

Piper diagram [23] defines water type by the combination of two triangles. The first triangle represents major anions percentages and the second represents major cations percentages. Figure 3 illustrates the projection of the analyzed samples in Piper.

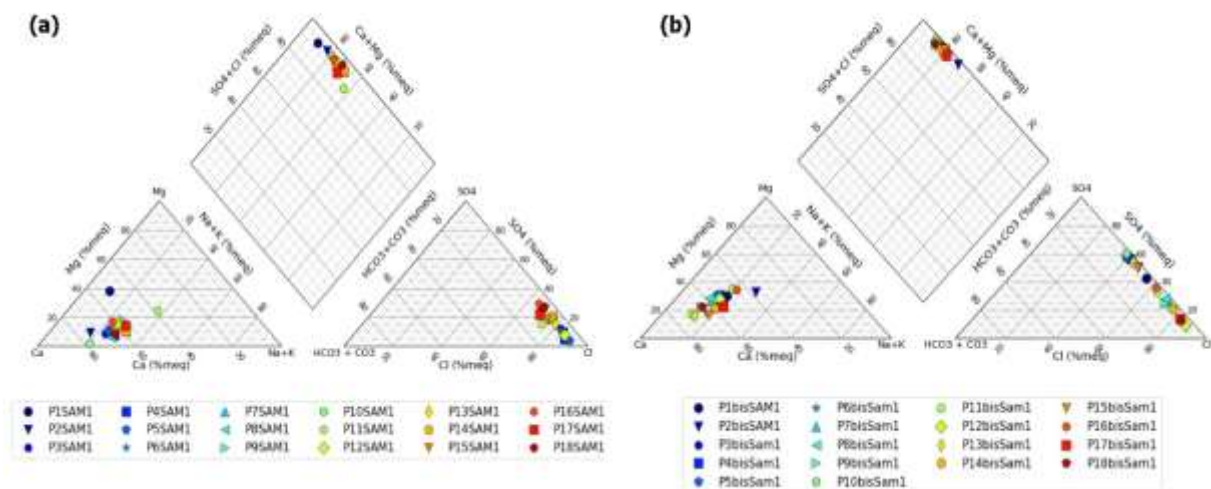


Figure 3. Piper Diagram for area 1 (a) and area 2 (b)

All area 1 samples belong to Ca-Cl type, except sample 10, which is of mixed type. In area 2, half of the samples belong to Ca-Cl type, 28% belong to SO<sub>4</sub>-Ca type, and 22% are of mixed type. At the scale of both areas, 78% of the samples belong to Ca-Cl type, 14% (mainly located in the North of area 2) belong to SO<sub>4</sub>-Ca type, the remaining samples are of mixed type. Figure 3 also shows the predominance of the earth alkaline metals (Ca<sup>2+</sup> + Mg<sup>2+</sup>) over the alkali metals (Na<sup>+</sup> + K<sup>+</sup>), and strong acids radicals predominance (Cl<sup>-</sup> + SO<sub>4</sub><sup>2-</sup>) over weak acids radicals (CO<sub>3</sub><sup>2-</sup> + HCO<sub>3</sub><sup>-</sup>).

In area 1, Ca<sup>2+</sup> is the dominant ion for 94% of the samples. The most common formulas are Ca<sup>2+</sup> > Na<sup>+</sup> > Mg<sup>2+</sup> > K<sup>+</sup> and Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > HCO<sub>3</sub><sup>-</sup>. In area 2 Cl<sup>-</sup> the major ion for half of the samples, SO<sub>4</sub><sup>2-</sup> for 33% of the samples, and Ca<sup>2+</sup> for 17% of samples. The most common formulas in area 2 are Ca<sup>2+</sup> > Mg<sup>2+</sup> > Na<sup>+</sup> > K<sup>+</sup> and Cl<sup>-</sup> > SO<sub>4</sub><sup>2-</sup> > HCO<sub>3</sub><sup>-</sup>.

### III.1.3. Gibbs diagram

The Gibbs diagram [24] aids in identifying geochemical processes that act on groundwater's hydrochemical properties [40]. Projection of the analyzed samples on Gibbs diagrams (Figure 4) shows that the Souf Valley phreatic aquifer groundwater is influenced by evaporation.

This process is favored by the Saharan climate prevailing in this study Saharan area, shallow water depth, and high transmissivity of the Quaternary geological formations, which are dominated by aeolian sand [41, 42, 43].

Area 2 samples are within the seawater phenomenon, which can be explained by surface water contamination [40]. Since this area is close to Melghir Chott which is extremely saline (Figure 1).

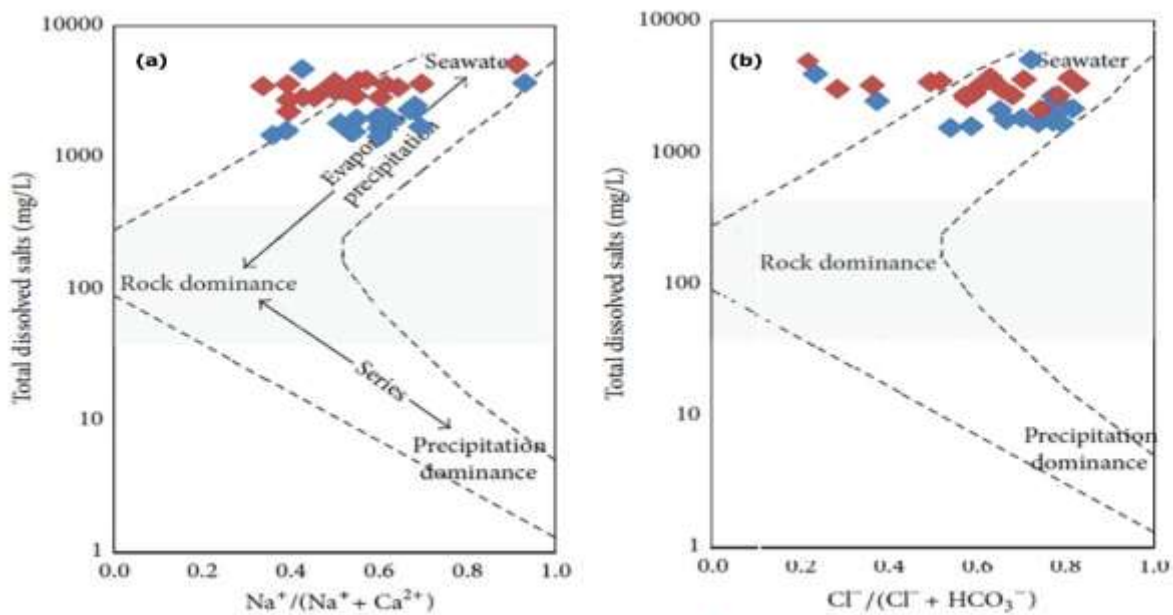


Figure 4. Gibbs Diagram for the analyzed samples

### III.1.4. Saturation index (SI)

Saturation Index (SI) analyzes the balance between solution and mineral forms of the concerned ion, allowing the researcher to investigate the development of ions concentrations because of minerals precipitation and dissolution [25]. Saturation indexes of different minerals are expressed by equation (1) (Table 1), KIAP is the ionic activity coefficient of the mineral while KSP is

its solubility coefficient.

Positive values of SI reflect the precipitation tendency of the ion in solution form. Negative values indicate the dissolution tendency of the mineral. SI = 0 means that the solution form is in equilibrium with the mineral form. Table 3 displays saturation index values (SI) values for six minerals (aragonite, calcite, dolomite, anhydrite, gypsum, and halite) for area 1 and area 2 samples.

**Table 3.** Average, Minimum, Maximum, Standard deviation and coefficient of variation of saturation indexes

Mineral	Area 1				Area 2			
	Min	Max	Average	CV	Min	Max	Moy	CV
Anhydrite	-2.15	-0.03	-1.10	-0.43	-1.12	-0.20	-0.54	-0.53
Aragonite	-0.06	0.74	0.28	0.59	-0.31	0.24	-0.01	-16.42
Calcite	0.09	0.89	0.43	0.39	-0.17	0.39	0.14	1.02
Dolomite	-1.39	1.70	0.17	3.72	-0.44	0.40	0.02	14.02
Gypsum	-1.92	0.20	-0.87	-0.55	-0.90	0.02	-0.32	-0.91
Halite	-5.80	-4.58	-5.34	-0.05	-5.67	-4.82	-5.27	-0.04

Table 3 shows that the values halite’s SI are negative and represent the lowest values for all the samples, they vary between -5.8 and -4.58 with an average value of -5.34 in area 1, and they vary between -5.67 and -4.82 with a value of -5.27 in area 2. This explains halite’s high dissolution tendency in both areas. Anhydrite and gypsum SI are both negative for all samples, but their values are closer to zero than halite’s SI values, particularly in area 2.

However, calcite’s (CaCO<sub>3</sub>) SI are positive for all area 1 samples and 89% of area 2 samples, their values are greater in area 1 where they range between 0.09 and 0, 89 with an average of 0.43. This shows the precipitation tendency of calcite in Area 1. While in area 2, values of calcite’s SI are lower, they vary between -0.17 and 0.39 with an average of 0.14, which indicates that calcite, has a slight tendency for precipitation.

The dolomite’s tendency is variable but close to equilibrium in both areas. The dominant tendency for aragonite in Area 1 is precipitation, whereas its tendency is variable in Area 2.

Carbonate minerals (calcite, aragonite, and dolomite) tend to precipitate, whilst evaporites (gypsum, halite, and anhydrite) tend to dissolve. This

explains the origin of high concentrations of chloride and sulfates in Souf Valley’s aquifer and it agrees with the results obtained for the same aquifer but in a nearby area [44].

**III.1.5. Chloro-Alcalins Indexes (CAI-1 and CAI-2)**

Chloro-alkaline indexes CAI-1 and CAI-2 calculated by Equations 2 and 3 (Table 1), proposed by Schoeller [45] are used to appreciate the ionic exchange between groundwater and its geological substrate [46]. Positive values of these indexes indicate that alkali metals (Na<sup>+</sup> and K<sup>+</sup>) of groundwater are exchanged by earth alkaline metals (Ca<sup>2+</sup> and Mg<sup>2+</sup>) of the geological substrate, negative values indicate the inverse process [47]. Table 4 displays CAI-1 and CAI-2 values for the analyzed samples.

CAI-1 and CAI-2 results in Table 4 are all positive. This implies that the geological context's calcium and magnesium have replaced sodium and potassium in groundwater. This is consistent with earlier findings that indicate calcium's dominance over other cations

**Table 4.** Classification and descriptive parameters of CAI-1 et CAI-2 indexes

	Area	CAI > 0	CAI < 0	Min	Max	Average	SD
CAI-1	Area 1	18 (100 %)	0	0,32	0,64	0,48	0,08
	Area 2	18 (100 %)	0	0,14	3,77	1,67	1,05
CAI-2	Area 1	18 (100 %)	0	0,55	0,81	0,70	0,07
	Area 2	18 (100 %)	0	0,39	3,27	1,37	0,97

**III.2. Assessment of groundwater quality for irrigation**

Groundwater quality is critical in arid and

semi-arid environments for agricultural sustainability [4]. In certain locations, intense evaporation produces salt deposition and



buildup in the topsoil. This process contributes to soil deterioration as well as a decrease in crop growth and production [38,48]. Table 5

displays both area 1 and 2 samples classification based on irrigation water quality indexes: Na%, MH%, PS, EC, TH, Cl-, Wilcox and Riverside diagrams.

**Table 5.** Classification of groundwater for irrigation

Parameter	Range	Area 1 Samples <sup>a</sup>	Area 2 samples <sup>b</sup>	Water Class
Na% [49]	<20	2 (11%)	15 (83%)	Excellent
	20–40	16 (89%)	3 (17%)	Good
	40–60	0	0	Acceptable
	60–80	0	0	Doubtful
	>80	0	0	Unsuitable
MH% [31]	<50	18 (100)	18 (100)	Suitable
	>50	0	0	Unsuitable
PS meq L <sup>-1</sup> [32]	1–3	0	0	safely used in fine, medium and coarse textured soils
	3–15	0	0	safely used in medium and coarse textured soils
	15–20	2 (11%)	0	safely used only in coarse textured soils
	> 20	16 (89%)	18 (100%)	Unsafe
EC μS cm <sup>-1</sup> [34]	<250	0	0	Low-salinity water
	250–750	0	0	Medium-salinity water
	750–2250	0	0	High salinity water
	>2250	18 (100)	18 (100)	Very-high salinity water
EC μS cm <sup>-1</sup> [35]	<250	0	0	Excellent
	250–750	0	0	Good
	750–2250	0	0	Acceptable
	2250-5000	16 (89)	4 (22)	Doubtful
	>5000	2 (11)	14 (78)	Unsuitable
TH [33]	<75	0	0	Soft
	75–150	0	0	Moderately hard
	150–300	0	0	Hard
	>300	18 (100%)	18 (100%)	Very hard
	Cl (meq L <sup>-1</sup> ) [50]	< 2	0	0
2-4		0	0	Acceptable
4-10		0	0	Doubtful
>10		18 (100%)	18 (100%)	Unsuitable

<sup>a</sup> Number of area 1 samples (percentage per all area 1 samples), <sup>b</sup> Number of area 2 samples (percentage per all area 2 samples)

### III.2.1. Sodium hazard (Na%)

Sodium hazard (Na%) classification is presented in

Table 5, according to Raghunath [49] standards. It demonstrates that the majority of area 1 samples are of good quality for irrigation while the majority of

samples from area 2 are of excellent quality. In terms of Na%, all the analyzed samples are safe to use for irrigation.

**III.2.2. Magnesium Hazard (MH%)**

Magnesium hazard (MH%) classification in Table 5 shoes that all samples of both areas are suitable for irrigation, referring to their magnesium concentrations.

**III.2.3. Potential salinity (PS)**

From Table 5, we notice that 89% of area 1 samples and all area 2 samples are likely to cause secondary salinization for all soil types. Only two samples belonging to area 1 do not present a salinization risk for coarse soils.

**III.2.4. Electrical Conductivity (CE) and Sodium Adsorption Ratio (SAR)**

According to Todd [35], the majority of area 1 samples are of doubtful use for irrigation while the majority of area 2 samples are unusable.

According to the Riverside diagram shown in Figure 5 (a and b), all samples belong to class C4 which has very high salinity and should not be used for irrigation under ordinary conditions owing to the great risks of soil salinization. Their usage necessitates special management including the application of the leaching fraction as well as the selection of

salt-tolerant plants [34]. We note that 83% of area 1 samples belong to class S1. This indicates that the groundwater in zone 1 has a minimal risk of alkalization of the soil.

In area 2, 55% of samples have moderate alkalinity, 39% have low alkalinity and just one sample (located in the extreme north of this zone) has high alkalinity. Given that the research region is characterized by sandy soil with poor cation exchange capacity, this suggests a minimal danger of soil alkalization. Wilcox [36] diagram presented in figure 6 (c and d) shows that all area 2 samples and the majority of area 1 samples are unsuitable for irrigation because of their high salinity.

Irrigation with saline water causes salts accumulation in the topsoil, especially in arid areas where H<sub>2</sub>O evaporates and salt settle on the surface layers of soils [51]. When EC surpasses a crop's tolerance level, it has an influence on plant development and yield by restricting absorption via the hyperosmotic effect [52]. Several studies have estimated yield losses of different crops, in terms of water and soil EC [38,50,53]. Other publications mentioned that irrigation with same EC level had created a number of ecological issues and considerable losses in adjacent regions such as Oued Righ Valley and Tozeur Oasis [54, 55].

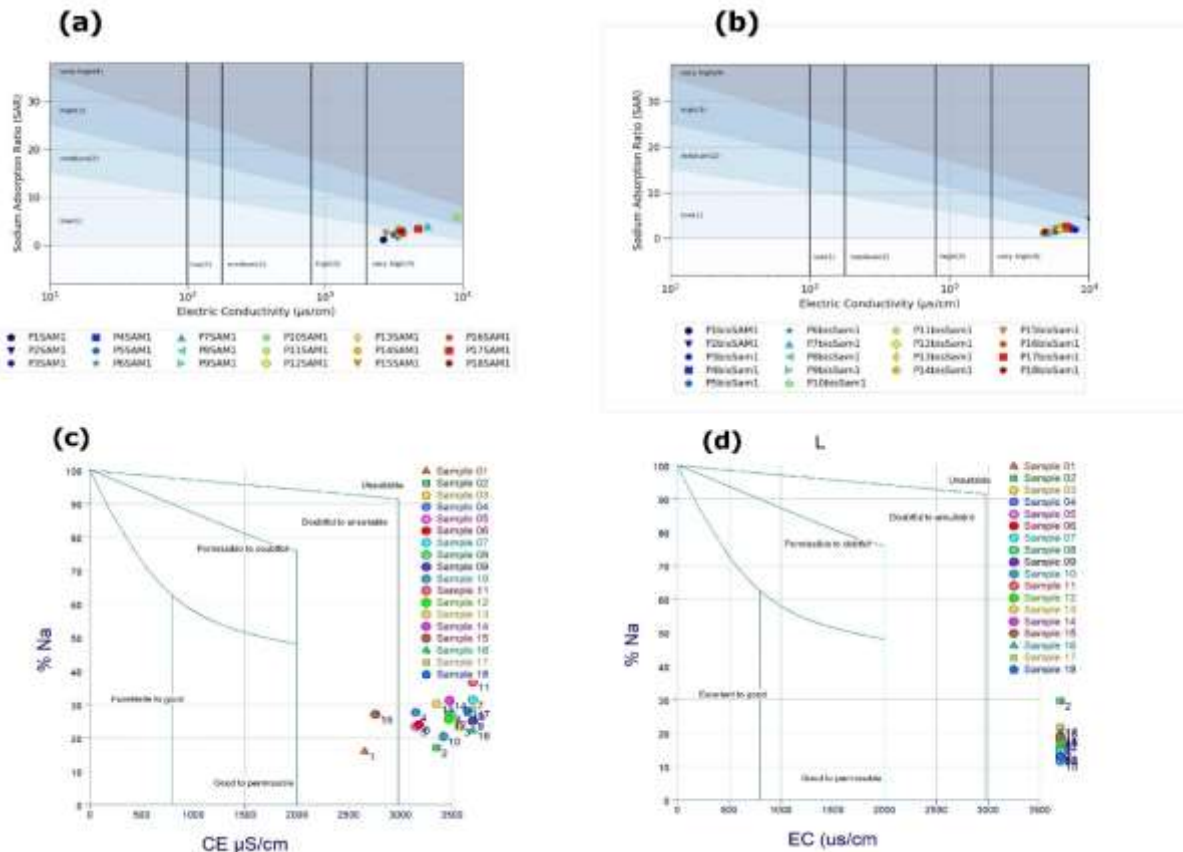


Figure 5. Riverside (a and b) and Wilcox (c and d) diagrams for 1 (a, c) and area 2 (b, d) samples

### III.2.5. Total Hardness (TH)

From Table 5, we notice that all samples have very high hardness. The use of this water may cause scaling in irrigation pipes and irrigation ramps, and clogging of drip networks and water filters [56].

Excess calcium concentrations can have a detrimental impact on plant germination and growth, as evidenced by the formation of yellowish spots (calcium oxalate crystals) on both leaves and fruits [57].

### III.2.6. Chloride (Cl<sup>-</sup>)

Chloride concentrations are high in all samples, according to the data shown in Table 5. Sprinkler watering may amplify the chloride impact on plants because it enhances salt absorption on the leaf surface [58]. Sprinkler irrigation should have a chloride content of less than 3 meq L<sup>-1</sup>, according to Ayers and Westcot [59].

## IV. Conclusion

### V.

The fundamental objective of this research is the hydrogeochemical characterization of the Souf Valley phreatic and the assessment of its water quality and suitability of irrigation. The obtained results showed that this groundwater is saline, its EC varies between 2656  $\mu\text{S cm}^{-1}$  and 10178  $\mu\text{S cm}^{-1}$  and increases from south to north within the flow direction.

Piper diagram indicates that the two main water types are Ca-Cl for 78% of the samples, and SO<sub>4</sub>-Ca for 14% of the samples. According to the Gibbs diagram, the chemical composition of Souf Valley Groundwater is altered by evaporation and hypersaline surface water contamination. This water composition can be also explained by Carbonate minerals precipitation and evaporite dissolution, according to saturation indices derived by the PHREEQC thermodynamic model.

According to water quality indices, Wilcox and Riverside diagrams, this groundwater contains low to medium alkalinity and does not pose a significant danger of soil alkalization. On the other hand, its salinity is high, indicating a significant danger of soil salinization. Salt accumulation in the topsoil is heightened by excessive evaporation and rainfall scarcity. The total hardness of the tested samples reveals that this groundwater is extremely hard, posing a considerable danger of dripper clogging and pipe scaling in the event of pressurized irrigation.

According to the findings, sustainable agricultural management in the Souf Valley necessitates the development of a new agricultural plan as well as specific irrigation management in accordance with the water quality described in the current research

paper.

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