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CONTRIBUTION TO GEOSPATIAL CLASSIFICATION BY USING QUALITY INDICES FOR IRRIGATION WATER IN ARID ZONES, CASE OF OUARGLA REGION, SOUTH EAST ALGERIA

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Abstract: *The purpose of this study is to evaluate the quality of groundwater used for irrigating agricultural areas in the region of Ouargla by using several quality indices and to map the spatial distribution of these indices. This spatial mapping will help create a model for the classification of these resources according to their suitability for irrigation. For this purpose, physicochemical analyses were carried out on samples from 38 wells distributed over the entire territory of the studied region. These include 27 wells that capture Mio-Pliocene groundwater (Terminal Complex) and 11 wells in the Albian groundwater (Intercalary Continental). The thematic maps were developed using a geographic information system (GIS). In this study, we used the following eight indices: potential salinity (PS); residual sodium carbonate (RSC); electrical conductivity (EC); magnesium percent (%Mg^{2+}); sodium percent (%Na^+); permeability index (PI); Kelley's ratio (KR); sodium adsorption ratio (SAR). The global qualitative study of the water used for irrigation shows that these resources fall into three categories (good, permissible, and poor for irrigation). Water quality analysis shows that, based on the magnesium percent (%Mg^{2+}), 18% of the wells can be considered to be of good quality, 74% of the wells are of medium quality (permissible for irrigation), and 8% are of poor quality (unsuitable for irrigation). According to the Wilcox diagram, the waters used in the Ouargla region are of very poor quality. Very excessive mineralization, expressed by the electrical conductivity, was observed for the Mio-Pliocene and Albian waters, where it varies with values in the range of 2340 µS/m to 6520 µS/m and 2330 µS/m to 3840 µS/m, respectively. This conductivity presents a high risk of alkalinization.*

Keywords*: Quality index, Groundwater, Irrigation, suitability, GIS, Classification.*

1. Introduction

The Sahara is known for its arid climate; arid and hyperarid lands account for 84% of Algeria's territory [1]. The northern part of its territory contains significant groundwater resources stored in the two major aquifers, mainly the Intercalary Continental (IC) and the Terminal Complex (TC) [2].
Water is a raw resource that is partially renewable, like air, and is considered vital to human life [3]. Water resource challenges have long existed in sub-Saharan Africa, but their impacts have been exacerbated by recent trends such as increasing urbanization, industrialization, agriculture, and climate change [4]. Agriculture is the largest consumer of water resources, with irrigation accounting for up to 95% of all water use in sub-Saharan African countries [5]. Food needs are the main factor inducing the extension and intensification of agricultural practices, an intensification that is made possible by a sufficient supply of water for irrigation [6]. Thus, the future agricultural development strategies of most of these countries depend on maintaining, improving, and expanding irrigated agriculture. In the face of demographic and urban development on the one hand and agricultural and industrial

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development on the other, demand for water in the Algerian Sahara is rapidly increasing. However, years of successive drought, accompanied by the scarcity and irregularity of annual supplies of both surface water and groundwater, are delaying development and creating difficulties in the management of water resources. Groundwater is straightforward to extract and represents a unique and essential resource in dry regions [7, 8]. This has led water managers to explore and develop more boreholes, wells, and hydraulic works.

Water quality plays an important role in promoting agricultural production and improving human health standards. The overexploitation of groundwater has detrimentally affected groundwater in terms of quality and quantity [9]. The effect of irrigation water quality on crops and soil is a concern for agronomists and economists responsible for the development of arid and semi-arid areas because water plays a critical role in food production and food security.

In arid lands, salt-affected soils are also present in areas where salinity is caused by the poor quality of irrigation water [10]. When the quality of water and soil is poor, special management practices are necessary to overcome the issues of reduced crop yields and quality [11]. Good water quality has the potential to maximize crop yield under good soil and water management practices [12].

This work was carried out based on data collected from physicochemical analyses of Mio-Pliocene and Albian groundwater used for irrigation in the Ouargla region. The objective of this research is to determine the spatial classification of the physicochemical quality of water used for agricultural purposes in our study area by evaluating its suitability for irrigation and therefore its impact on the environment using a set of quality indices.

2. Materials and methods

2.1. Description of Study area

Ouargla province is located in the southeast of Algeria, 790 km from the capital Algiers, and the northeast of the northern part of the Sahara (5° 19' E; 31° 57' N), with an area of 211,980 km^2. Ouargla is bounded to the north by the province of Biskra, to the south by Tamanrasset, to the north-west by Djelfa, to the west by Ghardaïa, and to the east by the provinces of El Oued and Tunisia, and finally to the southeast by the province of Illizi [13], (Fig 1). The total population of the province was estimated in 2020 at 849,672 inhabitants, with a density of 4 inhabitants per km^2.[14] Ouargla is in a depression and belongs, according to the administrative division, to the "Lower Sahara", which is part of the Saharan Platform. The latter, together with the Saharan Atlas and the Tellien Atlas, form the main geo-structural units of Algeria. Ouargla is thus sunk into the depression of Oued M'ya, which offers a low topography (-40m) below sea level at Chott Melrhir (in the north) [15]. The geology of the Saharan platform has been investigated through field studies at outcrops, but mainly through oil and gas drilling. The Precambrian Shield forms the base (substratum) of the Saharan platform; it is composed of eruptive and metamorphic rocks, which are abundant in the Central Sahara (Hoggar Massif) and Western Sahara (Eglab Massif) [16]. In the Northern Sahara basin, there are aquifer formations that can be used for the underground circulation of water. This is the aquifer system of the Northern Sahara, which includes the Intercalary Continental (IC) and the Terminal Complex (TC). Its surface area is about 1,000,000 km^2, shared between Algeria, Tunisia, and Libya [2].

The IC is an aquifer extending from north to south, from the Saharan Atlas to the Tassili of Hoggar, and from west to east, from the valley of Guir and Saoura (Bechar) to the Libyan Desert (Fig 2).

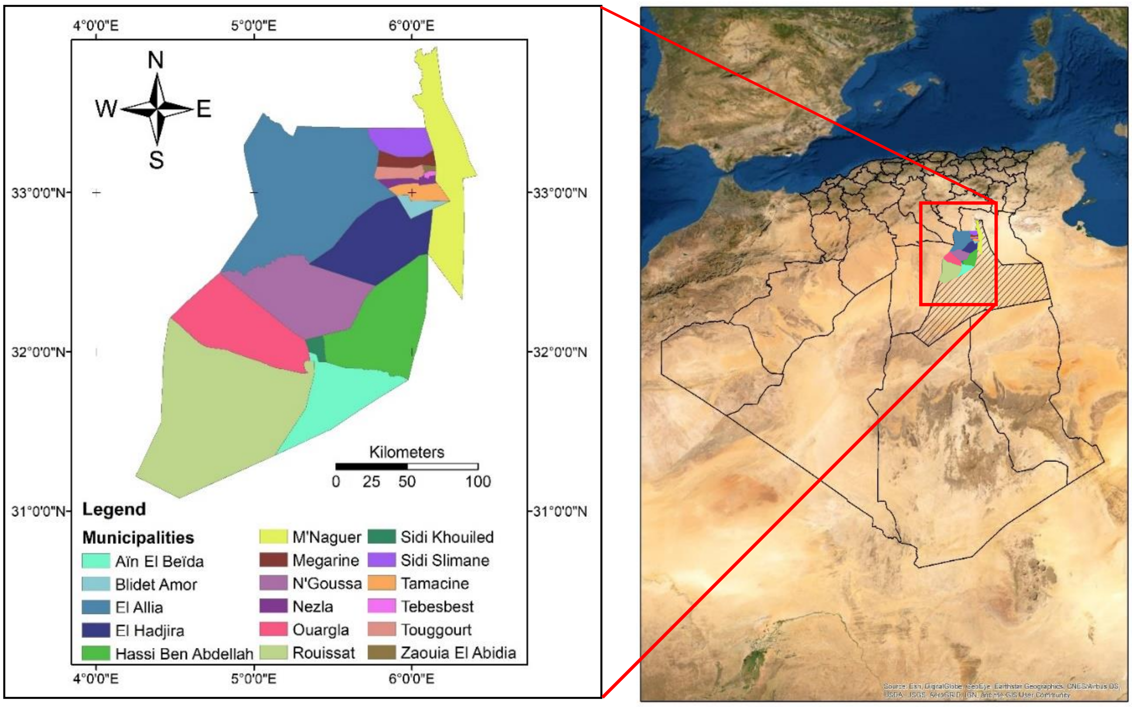


Fig 1. Geographical location and administrative division of the study area

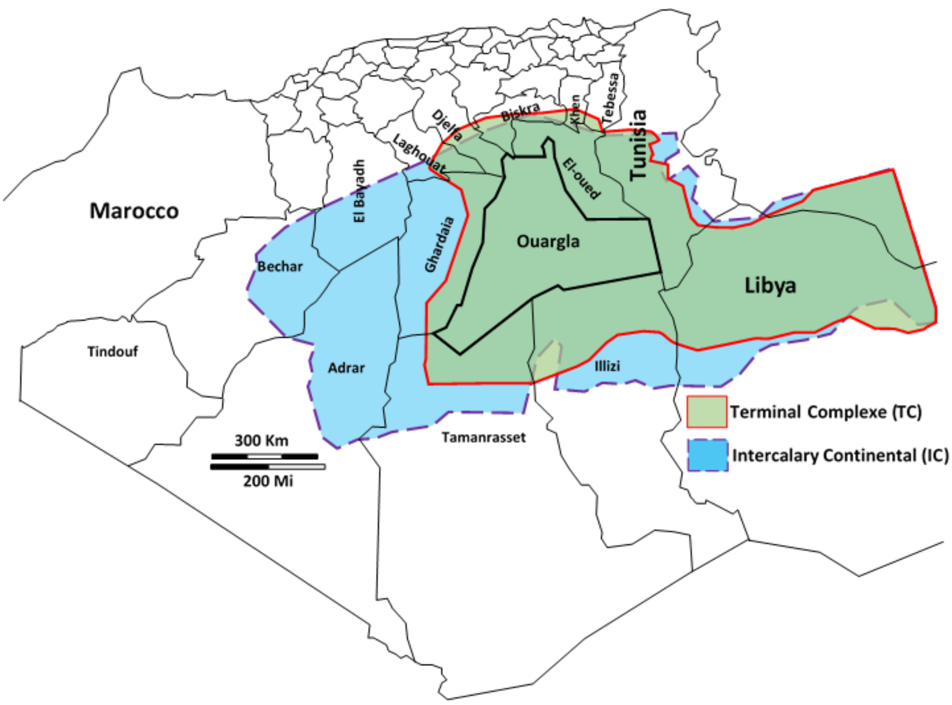


Fig 2. Hydrogeological map of the IC and TC aquifer system[2]

It occupies sandy and clay-sandstone soils of the Neocomian, Barremian, Aptian, and Albian [17]. Its water supply comes from the Piedmont of the Saharan Atlas in the northwest with a flow rate of 7.7 m3/s, from Tinrhert in the south, Dahar in the east, Jebel Nafusa in the northeast, and Jebel Hassawna in the south [18].

Classically, and according to the definition of K. Killian, the term "continental terminal" designated the sandy and clayey continental formations of the Mio-Pliocene. But according to Bel and Demargne (1966), "theTerminal Continental aquifer contained in the Miopliocene sands is more or less related to the Eocene, Senonian, and Turonian aquifers, so that on the scale of the entire Sahara, these different levels can be considered to form the same aquifer, the Continental Terminal aquifer, as opposed to the Intercalary Continental [2].
The climatic data, provided by the metrological station of the Aerodrome of Aïn El Beida (Ouargla) by the national office of meteorology over an observation period from 2009 to 2019, show that the study area is characterized by a hyper-Saharan climate, which is arid with temperate winters, and by a permanent dryness where the precipitations are always lower than the double of the temperatures. Potential evapotranspiration is almost 60 times that of rainfall, reflecting a water deficit throughout the year. Atmospheric precipitation in Ouargla is very low. They are of the order of 39 mm/yr for several rainy days of 25 days. The maximum temperature often exceeds 40 °C during July (Pmaxavg 43.6 °C) and August (Pmaxavg 43.43 °C), thus reflecting strong evaporation of 509.5 mm in July, 100.4 mm in December, and 2756.42 mm per year.

2.2. Methodology and used data

To classify and spatialize the quality of irrigation water in the study area, the following eight quality indices were used: potential salinity (PS); residual sodium carbonate (RSC); electrical conductivity (EC); percentage of magnesium (%Mg^{2+}); percentage of sodium (%Na^{+}); permeability index (PI); Kelley's report (KR); sodium adsorption rate (SAR). The evaluation and visualization of the results were carried out using Diagram and Excel 2013 software and GIS geographic information system software (ArcGIS). The spatial distribution map for each index was determined using the inverse interpolation technique (IDW).

2.2.1. Quality Index

This study identified classifications for assessing water suitability for irrigation purposes using eight indices:

a) Potential salinity (PS)

Soil salinity consists of all salts of sodium chlorides and magnesium sulfates; therefore, the potential salinity (PS) could be estimated by [19, 20].

$$PS = Cl^{-} + \sqrt{SO_4^{2-}} \quad (1)$$

Cl^{-}, SO_4^{2-} expressed in meq/l

- If PS < 5 Class1(C_1): Water excellent to good for irrigation;
- If 5 < PS <10 Class2 (C_2): Good to mediocre water;
- If PS >10 Class3 (C_3): Mediocre to poor water.

b) Residual sodium carbonate (RSC)

The excess of carbonate and bicarbonate in groundwater in favor of the amount of calcium and magnesium also influences the unsuitability of groundwater for irrigation. This is called residual water alkalinity (RSC). The RSC is calculated using the formula given below: [9, 21]

$$RSC=\left[\left(HCO_3^{-}+CO_3^{2-}\right)-(Ca^{2+}+Mg^{2+})\right] \quad (2)$$

Concentrations in milliequivalents per litre.

- If RSC<1.25 no risk;
- If 1.25 <RSC<2.5 moderate risk;
- If RSC>2.5 severe risk.

c) Electrical conductivity (EC)

Electrical conductivity is commonly used for indicating the total concentration of the ionized constituents of natural water. In the classification of waters discussed in the next section, conductivity is the measure of the salinity hazards involved in the use of the water for irrigation [22].

- If EC < 250 µS/cm, C_1: Low salinity water. It can be used for most crops on most soils;
- If 250 < EC < 750, C_2: Water with medium salinity. It can be used if moderate leaching occurs;
- If 750 < EC < 2250, C_3: High salinity water. It cannot be used on poorly drained soils. Even when drainage is sufficient;
- If 2250 < EC < 5000, C_4: Water with very high salinity. It is not suitable for irrigation under ordinary conditions.

d) Magnesium percent (%Mg)

Magnesium percent or magnesium hazard ratio expresses the extent of the effect of magnesium in irrigation water. Excess magnesium affects soil quality, which can result in low crop yields [23]. The $\%Mg^{2+}$ is calculated as follows:

$$\%Mg^{2+}=\left(\frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})}\right)\times 100 \quad (3)$$

Concentrations in milliequivalents per litre.

- If $\%Mg^{2+}<50$: the water is good for irrigation;
- If $\%Mg^{2+}>50$: the water is bad for irrigation

e) Sodium percent ($\%Na^+$)

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability [9]. Excess sodium in water produces undesirable effects by changing soil properties and reducing soil permeability [24-26]. This is why the percentage of sodium is considered an important index for the evaluation of water intended for irrigation[21]. The $\%Na^+$ is calculated according to the formula below:

$$\%Na^{+}=\left(\frac{(Na^{+}+K^{+})}{(Ca^{2+}+Mg^{2+}+Na^{+}+K^{+})}\right)\times 100 \quad (4)$$

Concentrations in milliequivalents per litre.

- If $\%Na^+ < 20$ very good quality;
- If $20 < \%Na^+ < 40$ good quality;
- If $40 < \%Na^+ < 60$ acceptable quality;
- If $60 < \%Na^+ < 80$ Poor quality;
- If $\%Na^+ > 80$ bad quality.

f) Permeability index (PI)

Soil permeability is affected by long-term use of irrigation water with high salt content as influenced by the Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents of the soil [27]. PI is defined by the following equation:

$$PI=\left(\frac{\left(Na^{+}+\sqrt{HCO_3^{-}}\right)}{(Ca^{2+}+Mg^{2+}+Na^{+})}\right)\times 100 \quad (5)$$

Concentrations in milliequivalents per litre.

- If IP > 75%: Good irrigation water
- If 25% < IP < 75%: permissible water under certain conditions for its use;
- If IP < 25%: Poor irrigation water

g) Kelley's ratio (KR)

Kelly index is used to indicate the suitability of groundwater for irrigation in agriculture; irrigation water containing more sodium affects soil structure and hence the rate at which water moves into the soil [28]. When the Kelly index is greater than 1, it means the water has an excess sodium level and is therefore considered unsuitable for irrigation purposes [29]. It is expressed as:

$$KR=\frac{Na^{+}}{Ca^{2+}+Mg^{2+}} \quad (6)$$

Concentrations in milliequivalents per litre.

- If KR>1: Poor irrigation water;
- If KR<1: Good for irrigation.

h) Sodium adsorption ratio (SAR)

The Sodium Adsorption Ratio refers to the degree to which sodium will be absorbed in the soil [28]. It is an important parameter for determining the suitability of irrigation water because it is a measure of alkali and sodium hazards for crops [9]. It is expressed in milliequivalents per litter:

$$SAR=\frac{Na^{+}}{\sqrt{\frac{Ca^{2+}+Mg^{2+}}{2}}} \quad (7)$$

- If the SAR < 10 Class (S_1): Low sodium water (Excellent quality)
- If the 10 < SAR < 18 Class (S_2): Medium sodium water (Good quality)
- If the 18 < SAR < 26 Class (S_3): High sodium water (permissible quality)
- If the SAR > 26 Class (S_4): Very high sodium water (poor quality)

3. Results and discussion

The data used in this study include the results of physicochemical analyses of groundwater irrigation in the Mio-Pliocene aquifer and the deep Albian aquifer in the Ouargla region (Table 1). The 38 agricultural boreholes were carefully chosen, which allowed for the collection of representative data on the spatial variability of groundwater quality for the two aquifers studied. (Fig 3)

The physicochemical analyses of irrigation water covered pH, dry residue, electrical conductivity EC, and chemical parameters Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, and Cl^- .Physical parameters pH and EC were measured in the field using a HI98199 multiparameter. The dry residue is measured by stoving at 105 °C for 24 hours, after filtration, to evaluate the residue, which corresponds to the dissolved salts. The molar titration of calcium and magnesium ions was carried out using a solution of disodium acid salt (EDTA). Sodium and potassium were determined by flame photometry (dr Lange Jenway). The determination of chlorides is carried out by the reaction of chloride ions with silver ions to form insoluble silver chloride, which is quantitatively precipitated. The sulfates were assayed by the DR 2800 spectrophotometer. The bicarbonate and carbonate assay is carried out by determining the alkalimetric title (AT) and the complete alkalimetric title (CAT).

3.1. Geochemical facies

The projection of the various points on the diagram (Mg^{2+}/Na^+ and SO_4^{2-}/Cl^-) provides an overview of the spatial distribution of geochemical facies at the level of the aquifers in the study region (Fig 4).

The results of the various physico-chemical analyses of the irrigation groundwater of the region of Ouargla are shown in Table 1. The latter shows a very high concentration of chlorides, followed by sulfates with fairly similar levels. Regarding the concentrations of cations, it can be seen that sodium is present in large quantities.

The order of abundance to be retained for anions and cations is the following: Cl- $>SO_4^{2-} > HCO_3^-$, and $Na^+ > Mg^{2+} > Ca^{2+} > K^+$.

Table 1.

Results of physicochemical analyses of selected wells in the region of Ouargla

Element	Unity	Miopliocene Water (TC)			Water Albian (IC)		
		Max	Min	Aver	Max	Min	Aver
EC	mS/cm	6.52	4.14	4.99	3.84	2.33	2.93
DR	g/l	6,11	2.11	3.96	3.04	1.50	2.27
pH		8.10	6.62	7.67	8.37	7.22	8.00
Na^+	meq/l	40.52	17.43	29.19	19.02	8.02	12.03
K^+		1.13	0.24	0.58	1.13	0.36	0.52
Ca^{2+}		26.45	10.88	17.62	9.44	5.54	7.55
Mg^{2+}		29.65	7.90	16.16	9.09	3.76	5.40
HCO_3^-		3.44	0.25	1.83	3.70	0.71	1.82
Cl^-		57.68	15.50	34.98	18.31	10.31	15.39
SO_4^{2-}		30.21	6.77	15.51	10.21	5.07	7.89

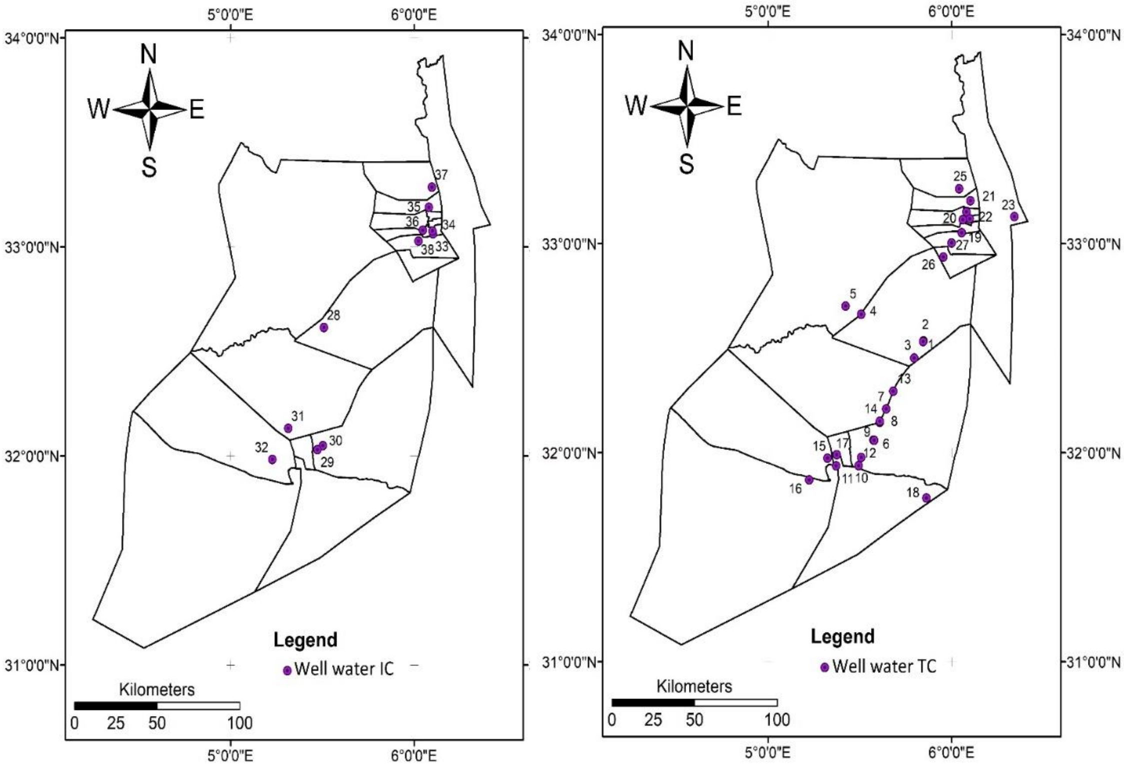


Fig 3. Geographic distribution of water wells studied for IC and TC in the Ouargla region

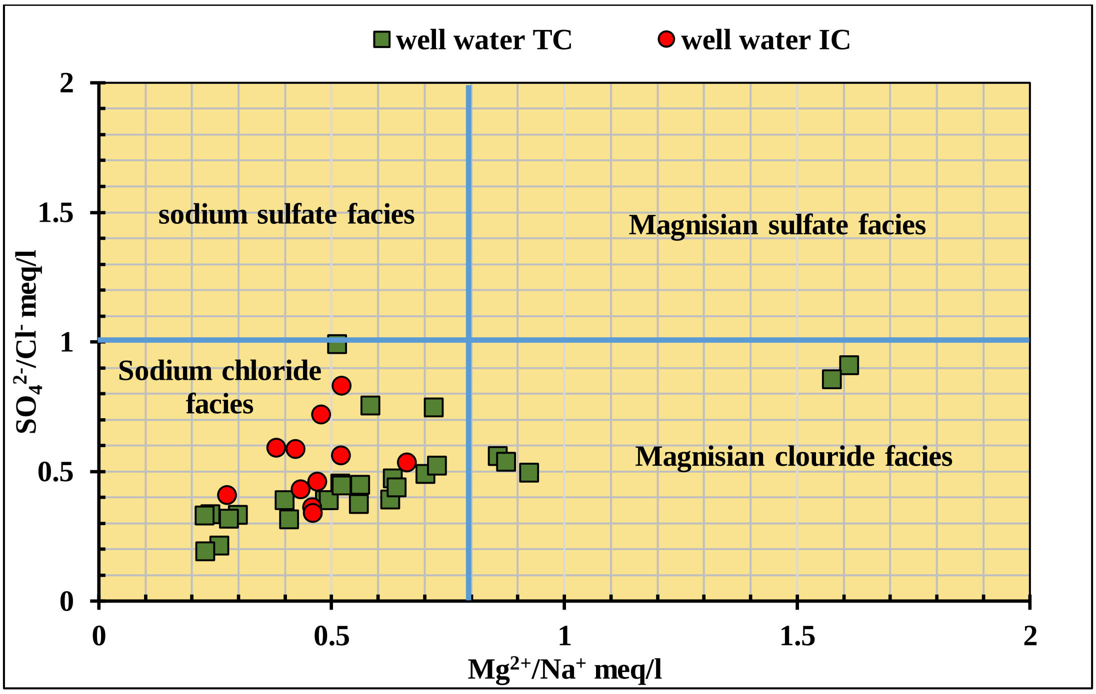


Fig 4. Geochemical facies of Mio-Pliocene and Albian water by the Mg^{2+}/ Na^+ and SO_4^{2-}/ Cl^- ratios

The most dominant facies in Mio-Pliocene water are sodium chloride (81.48% of samples) and, to a lesser degree, a secondary magnesium chloride facies (18.52% of samples), with the absence of sulfate facies magnesium and sodium sulfate. For Albian irrigation water (IC), the dominant ion is sodium chloride, and this applies to the majority of samples.

3.2. Classification of Groundwater for Irrigation Purposes

The results of the various water quality indices calculated for agricultural use, broken down by aquifer exploited in the Ouargla region, are recorded in Table 2.

Table 2.

Calculation results of the irrigation water quality indices in the Ouargla region

N° of well	quality indices SAR (meq/l)	Na$^+$ (%)	RSC (meq/l)	PI (%)	Mg^{2+} (%)	KR (meq/l)	PS (meq/l)	EC (µs/cm)
Water wells TC								
W1	7.19	43.95	-41.64	45.35	55.34	0.77	38.06	6520
W2	4.03	30.89	-40	32.75	71.19	0.44	38.74	4290
W3	5.75	42.39	-30.63	44.21	65.17	0.7	33.97	5240
W4	4.72	39.52	-25.92	41.59	37.45	0.64	20.35	5296
W5	7.03	43.71	-42.07	44.48	38.86	0.76	19.64	4862
W6	9.18	52.52	-32.65	54.41	53.41	1.09	42.99	6010
W7	7.37	49.78	-27	51.7	60.91	0.96	33.61	5210
W8	4.08	31.09	-40.13	33.05	70.23	0.45	40.7	4360
W9	8.52	49.17	-37.44	50.82	59.89	0.95	44.09	5940
W10	8.85	51.06	-34.41	52.85	57.72	1.03	43.66	6000
W11	5	41.29	-26.01	42.63	43.78	0.68	18.1	4987
W12	8.16	54.59	-22.92	56.11	35.24	1.17	35.77	5124
W13	6.26	46.85	-24.74	49.02	59.86	0.85	30.07	4562
W14	8.65	53.88	-26.75	55.62	58.89	1.13	36.4	4350
W15	10.88	60.25	-23.45	62.59	36.4	1.5	61.35	4166
W16	8.42	56.53	-20.85	58.12	35.69	1.27	37.77	4522
W17	8.41	48.16	-40.54	49.33	37.74	0.92	53.95	4875
W18	10.09	56.98	-26.49	59.3	34.02	1.31	56.35	5122
W19	9.47	53.78	-32.71	54.96	26.39	1.15	53	5122
W20	7.02	44.25	-39	45.45	38.75	0.78	44.46	4932
W21	7.53	48.01	-34.35	48.25	36.29	0.9	41.31	4215
W22	11.66	62.97	-22.83	64.43	38.58	1.68	60.99	5213
W23	5.13	41.34	-23.91	44.94	36.27	0.69	31.53	6112
W24	6.18	42.19	-35.75	43.59	40.47	0.72	38.43	5147
W25	5.23	38.7	-34.9	40.03	44.7	0.61	31.28	4136
W26	4.99	36.73	-38.08	37.88	48.22	0.56	30.78	4158
W27	4.8	35.73	-37.68	37.15	47.52	0.54	32.12	4235
Water wells IC								
W28	3.84	44.55	-12.25	47.3	35.42	0.74	13.16	2840
W29	4.97	48.28	-14.25	50.77	59.94	0.9	21.44	3840
W30	3.56	45.29	-9.43	48.83	41.16	0.79	18.87	2550
W31	6.59	53.79	-13.32	58.42	43.76	1.14	19.91	3770
W32	7.18	59.68	-10.25	63.71	38.66	1.4	21.04	3630
W33	3.54	42.81	-11.55	45.68	33.72	0.71	17.33	2520
W34	3.83	44.12	-11.96	47.19	32.88	0.75	20.26	2580
W35	6.23	52.11	-13.5	56.94	45.12	1.06	20.66	3270
W36	3.79	47.95	-8.39	52.23	40.43	0.88	16.39	2340
W37	3.86	44.76	-8.72	52.46	40.9	0.78	13.23	2520
W38	3.9	48.07	-8.81	52.16	40.79	0.88	17.72	2330

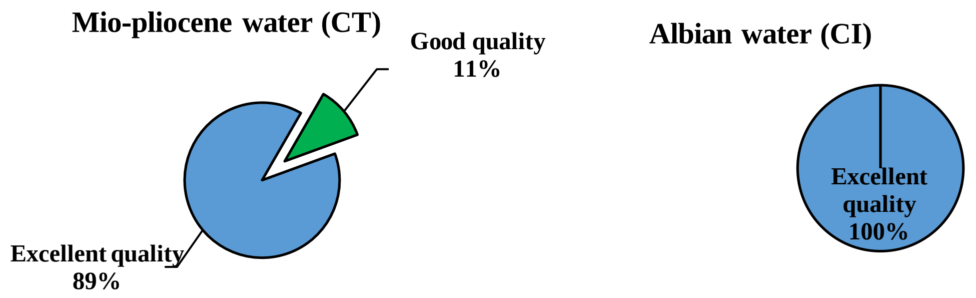
The SAR of irrigation waters reaches low values in most of the samples, where the maximum value recorded is 11.66 in Mio-Pliocene waters. This value indicates that alkalinity is medium, whereas in 89% of the samples, the risk of alkalinity is low. Calculated SAR values make it possible to classify these waters into two classes: S_1 and S_2 (Table 3).

Table 3.

Quality of irrigation water according to the SAR index

Class	SAR value	Water quality	percentage
S_1	SAR <10 meq/l	Excellent quality irrigation water; low danger of alkalization.	88.89% TC 100 % IC
S_2	10 < SAR < 18 meq/l	Good quality irrigation water; medium danger of alkalization.	11.11% TC 0% IC

Quality sectors



According to the SAR values, all the wells that capture the Albian aquifer have their water in class S_1. The latter is of excellent quality for agricultural use, which means that it can be used for irrigation without the risk of alkalinization for almost any floor. More than 88% of Mio-Pliocene waters are in the same class (S_1), thus they can be used for irrigation in most soils. The rest (11%) represents class S_2 of good-quality waters containing a medium amount of sodium. However, this presents some disadvantages when irrigating coarse-textured soils or organic soils that absorb water well.

The classification of irrigation waters according to conductivity shows that all of these waters are in the last class (C_4), which is characterized by very high salinity (Table 4). The conductivity varies between 4136 and 6520 µS/cm for the Mio-Pliocene water and from 2330 to 3840 µS/cm for the Albian one (table 4). The uncontrolled use of water at a level of salinity that is too high for irrigation can have harmful consequences on the structure of the soil and on the plant by reducing its capacity to absorb water, which leads to decreased yields, wilt, leaf scorch, and other symptoms. Therefore, these waters are not suitable for irrigation under ordinary conditions. Since the quality of these saline waters is essential to avoid these serious consequences, it is possible to consider balancing the concentration of the elements during the storage and distribution stages. Taking into consideration the evolution of conductivity with respect to SAR according to the log Wilcox diagram (Fig 5), (Table 5), the waters studied belong to four classes: C_4S_1; C_4S_2; C_4S_3; and C_4S_4. These waters are characterized by poor quality for the irrigation of most cultivated species, except if intense leaching is practiced and for very tolerant crops; otherwise, the water is unusable because it is very dangerous on poorly drained soils and may pose a hazard to most crops.

Table 4.

Quality of irrigation water according to the electrical conductivity (EC)

Class	EC value	Water quality	percentage
C_4	2250 < EC < 5000 µS/cm	Very high salinity water is not suitable for irrigation under ordinary conditions	100% TC 100% IC

Table 5.

Quality of irrigation water according to the SAR and EC coupling

Class	Percentage	Water quality
C_4S_1	63.64% IC	**Poor water** In general, highly mineralized water may be suitable for the irrigation of certain crops with good salt tolerance and on well-drained and leached soils.
C_4S_2	36.36 % IC 40.75 % TC	
C_4S_3	55.55 % TC	
C_4S_4	3.70% TC	

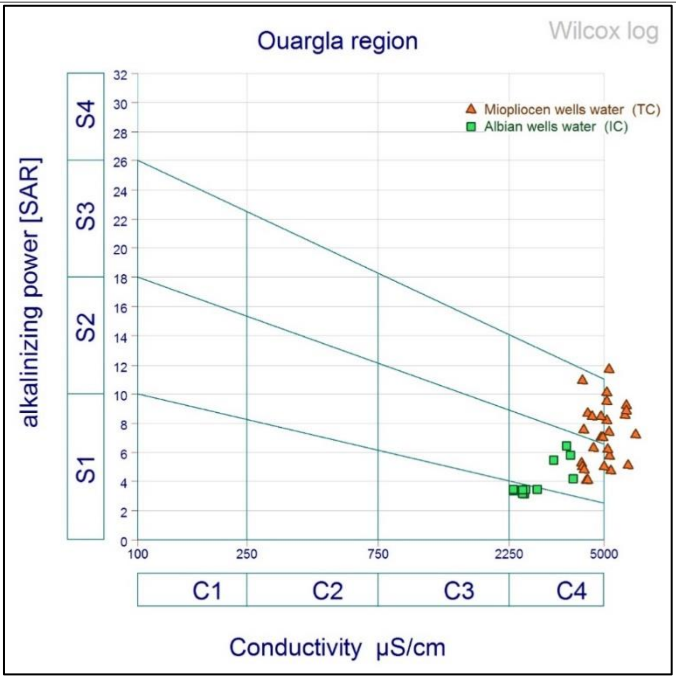


Fig 5. Evolution of the conductivity compared to the SAR according to Wilcox log

Agricultural yields are generally low in lands irrigated with water that belong to an unsuitable category. This is probably due to the presence of excess levels of sodium salts, which cause osmotic effects on the soil-plant system. When sodium concentration is high in irrigation water, sodium ions tend to be adsorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions through a base exchange process. This process of exchanging Na in the water for Ca and Mg in the soil reduces permeability and ultimately results in soils with poor internal drainage. As a result, air and water circulation are limited in wet conditions, and these soils are generally hard when dry. It has been found that waters permissible for irrigation dominate both good and poor-quality waters. Indeed, according to the sodium percent of the irrigation waters, the permissible Mio-Pliocene waters represent a proportion that exceeds 74% and reaches

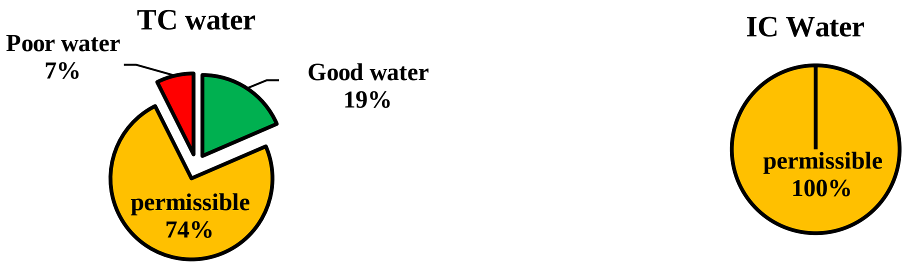
100% for the Albian waters. On the other hand, waters of good quality (C_2) represent 18.52% of Mio-Pliocene waters (TC). The poor-quality waters (C_4) account for 7.41% (Table 6).

Table 6.

Quality of irrigation water based on the sodium percent

Class	% Na	Water quality	Water Percentage
C_2	20 < %Na < 40	Good irrigation water	18.52% TC 0% IC
C_3	40 < %Na < 60	Water permissible for irrigation	74.07% TC 100% IC
C_4	60 < %Na < 80	Poor irrigation water	7.41% TC

Quality sectors



The classification according to the PI values gives class C_2. These waters, used for agriculture in the region of Ouargla, have a permeability index in the range of 32.75 to 64.43%. For TC waters, it varies between 45.68 and 63.79% (Table 7).

Table 7.

Permeability index (PI) quality of irrigation water

Class	PI	Water Quality	Water Percent
C_2	25% < PI < 75%	Permissible water under certain conditions for its use.	100% TC 100 % IC

The RK calculation results for Mio-Pliocene waters show values ranging from 0.44 to 1.68 meq/L, with an average of 0.90 meq/L. For albian waters, they are between 0.71 and 1.40 meq/L, with an average of 0.91 meq/L (Table 8). The groundwater in the study area belongs to two classes: good and bad-quality waters for irrigation.

Concerning magnesium percent, (table 9) one can see that good waters predominate, with more than 60% in the Mio-Pliocene waters and up to 90% in the Albian. On the other hand, waters of bad quality (C_2) account for 37% of the Mio-Pliocene waters, and this percentage decreases to a minimum value of 9.09% in the Albian.

The classification based on potential salinity results shows that the waters of the region fall into the last class (C_3). These waters are characterized by poor to bad quality; the PS index varies between 18.10 and 61.35 meq/l for TC waters and between 13.16 and 21.44 meq/l for Albian waters (table 10).

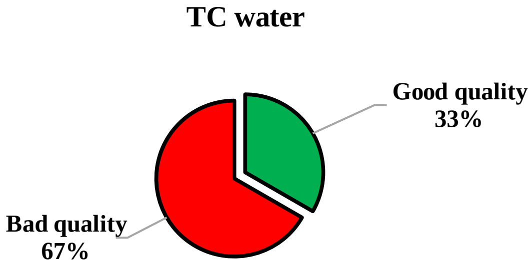
The results of the residual sodium carbonate calculation indicate that the irrigation waters studied are in the first class (C_1), (table 11) where the risk of residual alkalinity is zero because calcium and magnesium concentrations are much greater than the contributions of carbonate and bicarbonate. In this case, these waters are of good quality according to the RSC index. The latter varies from -8.39 to -42.07 meq/l for TC waters and between -8 and -14.25 meq/l for IC waters.

Table 8.

Quality of irrigation water according to the Kelly ratio (KR)

Class	KR	Water Quality	Water Percent
C_1	KR > 1	Bad quality ;	33.33% TC 27.27% IC
C_2	KR < 1	Good quality.	66,67% TC 72.73 % IC

Quality sectors



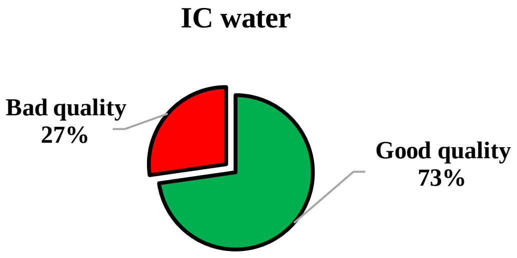
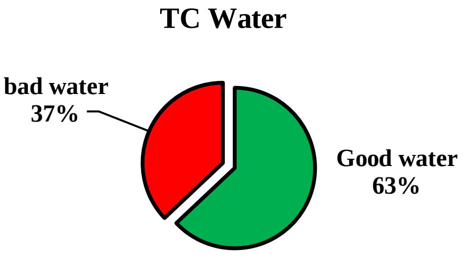


Table 9.

Quality of irrigation water according to the magnesium percent

Class	% Mg	Water quality	Water percent
C_1	Mg^{2+} < 50%	Good quality	62.96% TC 90.91 IC
C_2	Mg^{2+} > 50%	bad quality	37.04% TC 9.09 % IC

Quality sectors



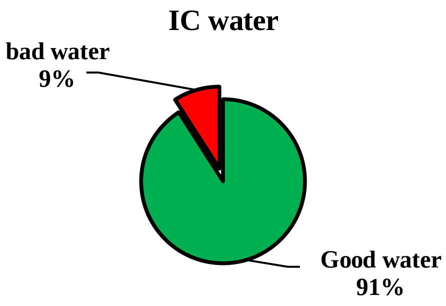


Table 10.

Irrigation water Quality based on potential salinity index (PS)

Class	PS	Water quality	Water percent
C_3	PS > 10 meq/l	Poor to bad quality	100% TC 100 % IC

Table 11.

Irrigation water Quality according to the residual sodium carbonate index (RSC)

Class	RSC	Water quality	Water percent
C_1	RSC < 1,25 meq/l	No risk of the residual alkalinity	100% TC 100 % IC

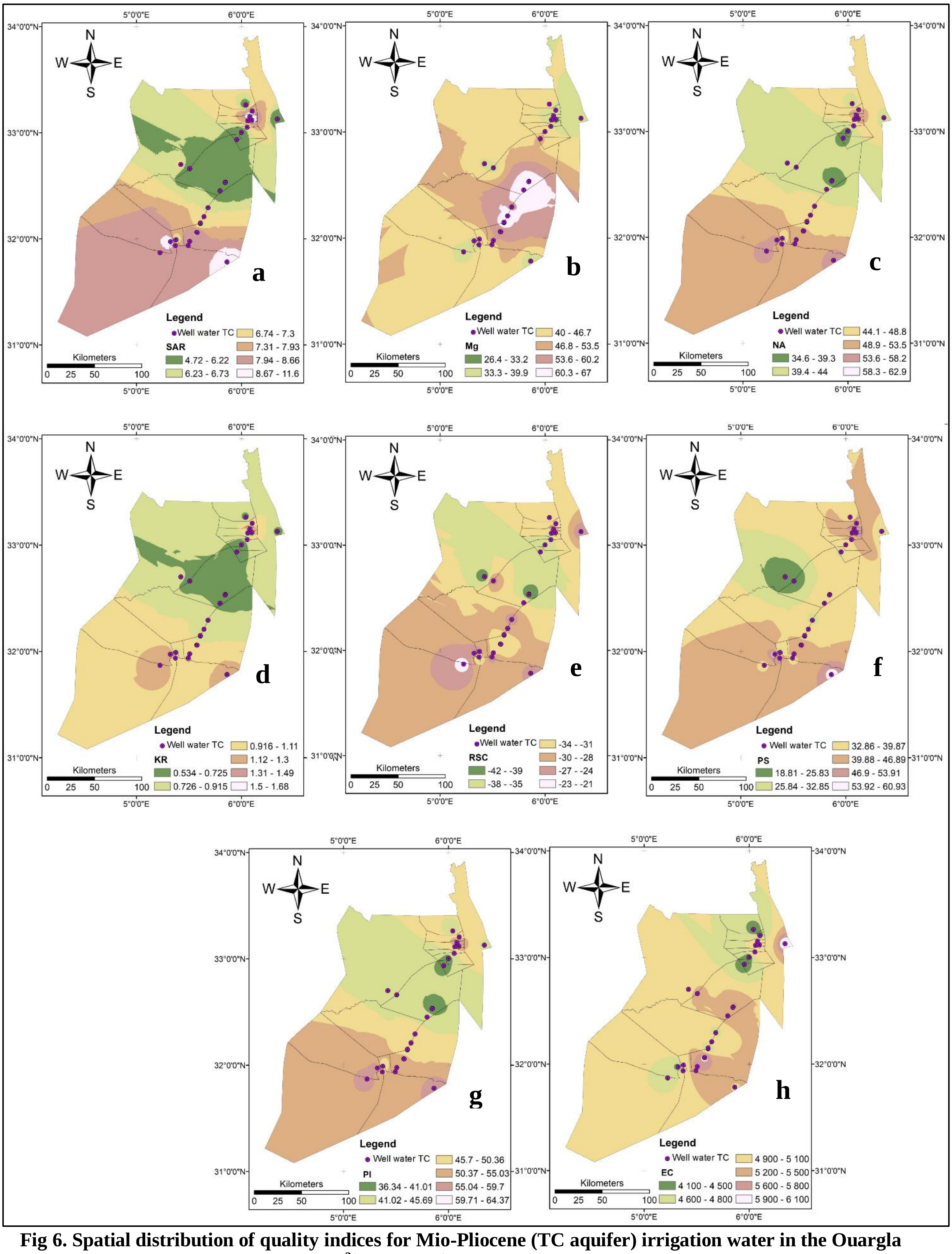


Fig 6. Spatial distribution of quality indices for Mio-Pliocene (TC aquifer) irrigation water in the Ouargla region (a) SAR ; (b) %Mg^{2+}; (c) %Na^{+}; (d) KR, (e) RSC; (f) PS; (g) PI et (h) EC.

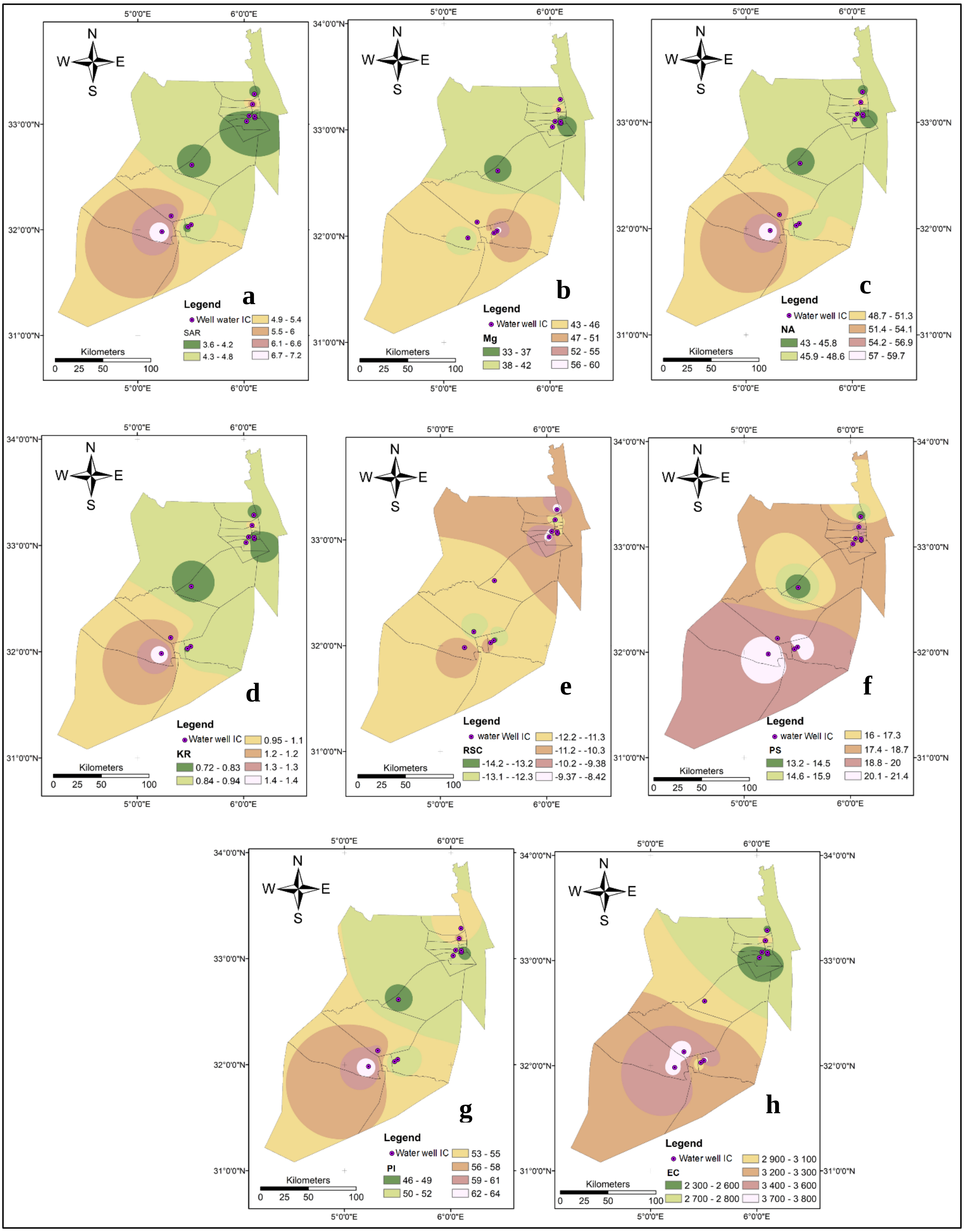


Fig 7. Spatial distribution of quality indices for Albian (IC aquifer) irrigation water in the Ouargla region (a) SAR ; (b) %Mg^{2+}; (c) %Na^{+}; (d) KR, (e) RSC ; (f) PS ; (g) PI et (h) EC.

3.3. Overall quality assessment

This evaluation is based on an overall qualitative quantification of the individual classification of each of the wells according to all the indices considered in this study [30]. For this purpose, we designate by the (+) sign the permissible irrigation water together with good and excellent qualities and by the (-) sign for poor and bad quality waters. To obtain an overall classification, we propose the following scale:

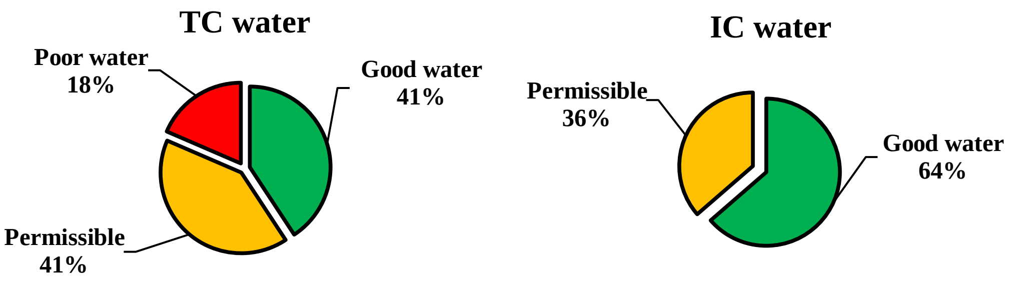
- If $\sum(+) = 7$ the water is of excellent quality.
- If $\sum(+) = 6$ the water is of good quality.
- If $\sum(+) = 5$ the water is permissible for irrigation.
- If $\sum(+) = 4$ the water is poor for irrigation.
- If $\sum(+) = 3$ the water is of bad quality for irrigation.

Table.12:

Global qualitative evaluation of irrigation water in the Ouargla region

Well water N°	**Individual classification**								**Global classification**
	SAR	Na	RSC	PI	Mg	KR	PS	EC	
				TC water					
W1	+	+	+	+	-	+	-	-	Permissible
W2	+	+	+	+	-	+	-	-	Permissible
W3	+	+	+	+	-	+	-	-	Permissible
W4	+	+	+	+	+	+	-	-	Good
W5	+	+	+	+	+	+	-	-	Good
W6	+	+	+	+	-	-	-	-	Poor
W7	+	+	+	+	-	+	-	-	Permissible
W8	+	+	+	+	-	+	-	-	Permissible
W9	+	+	+	+	-	+	-	-	Permissible
W10	+	+	+	+	-	-	-	-	Poor
W11	+	+	+	+	+	+	-	-	Good
W12	+	+	+	+	+	-	-	-	Permissible
W13	+	+	+	+	-	+	-	-	Permissible
W14	+	+	+	+	-	-	-	-	Poor
W15	+	-	+	+	+	-	-	-	Poor
W16	+	+	+	+	+	-	-	-	Permissible
W17	+	+	+	+	+	+	-	-	Good
W18	+	+	+	+	+	-	-	-	Permissible
W19	+	+	+	+	+	-	-	-	Permissible
W20	+	+	+	+	+	+	-	-	Good
W21	+	+	+	+	+	+	-	-	Good
W22	+	-	+	+	+	+	-	-	Poor
W23	+	+	+	+	+	+	-	-	Good
W24	+	+	+	+	+	+	-	-	Good
W25	+	+	+	+	+	+	-	-	Good
W26	+	+	+	+	+	+	-	-	Good
W27	+	+	+	+	+	+	-	-	Good
				IC water					
W28	+	+	+	+	+	+	-	-	Good
W29	+	+	+	+	-	+	-	-	Permissible
W30	+	+	+	+	+	+	-	-	Good
W31	+	+	+	+	+	-	-	-	Permissible
W32	+	+	+	+	+	-	-	-	Permissible
W33	+	+	+	+	+	+	-	-	Good
W34	+	+	+	+	+	+	-	-	Good
W35	+	+	+	+	+	+	-	-	Permissible
W36	+	+	+	+	+	+	-	-	Good
W37	+	+	+	+	+	+	-	-	Good
W38	+	+	+	+	+	+	-	-	Good

global quality Sectors



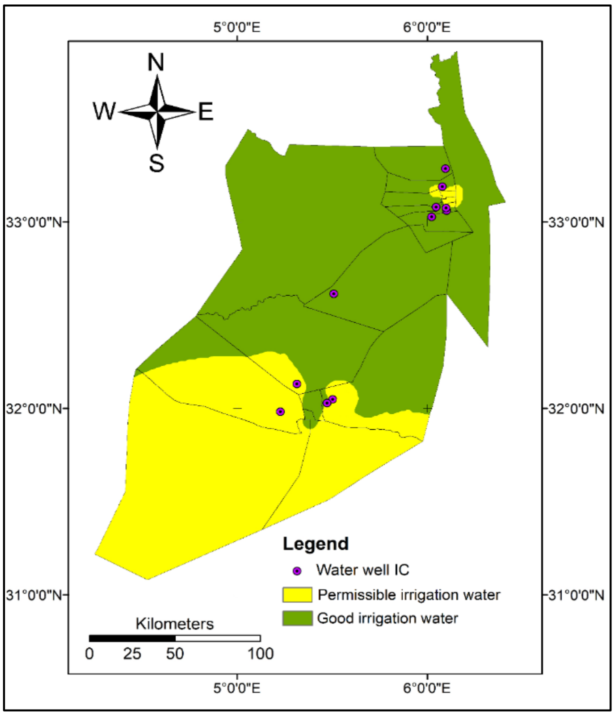


Fig 8. Final map of Albian (IC water) irrigation water quality in the Ouargla area

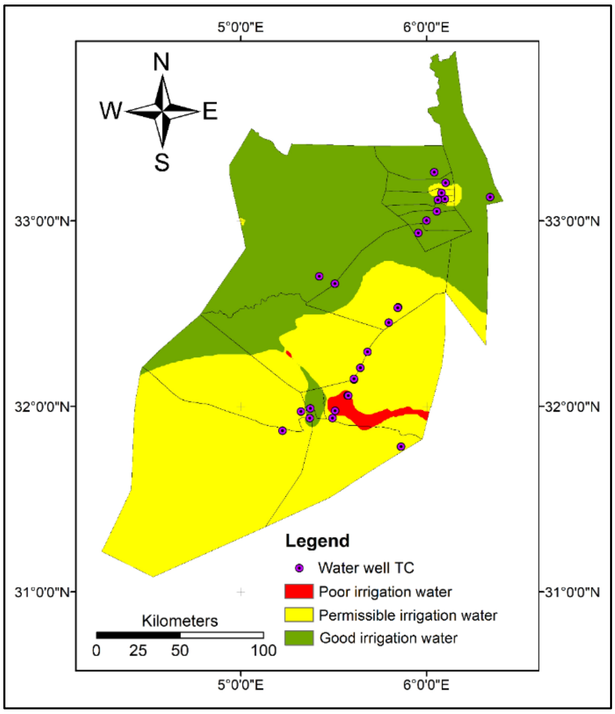


Fig 9. Final map of Mio-Pliocene (TC water) irrigation water quality in the Ouargla area

Three classes are represented on the final Mio-Pliocene water quality map (Fig 9). The qualitative quantification and spatial distribution of these indices give a map that varies from good to permissible to poor-quality water for irrigation going from north to south. In albian waters, two classes are represented, from good to permissible (Fig 8). According to the results obtained, 82% of the samples from the TC aquifer are of good quality and are permissible for irrigation. The remaining 18% are of poor quality. For the IC aquifer, good-quality waters represent 64%, whereas acceptable-quality waters account for 36% (Table 12).

4. Conclusion

In this study, we attempted to assess the quality of groundwater used in irrigation in the Ouargla region by using eight indices of water quality intended for agricultural activity, including PS, SRC, EC, $\%Mg^{2+}$, %Na, IP, KR, and SAR. In addition to the criteria, we used the diagrams (Mg^{2+}/Na^{+} and SO_4^{2-}/Cl^{-}) to determine the dominant chemical facies and the log Wilcox diagram to find the classification of water with respect to irrigation. The results of the electrical conductivity (EC) show that the waters of the Albian aquifer (IC), (Fig 6) and the Mio-Pliocene aquifer (TC), (Fig7) are characterized by very strong mineralization and present a high risk of soil salinization and alkalinization. It can be said that these waters are not suitable for irrigation under ordinary conditions. Furthermore, these waters are characterized by a maximum value of sodium absorption rate for both exploited aquifers. This rate exceeds 11 meq/l, with an average of 7.21 meq/l for Mio-Pliocene waters (Fig 6) and an average of 4.66 meq/l for Albian waters (Fig 7). Based on this index, the majority of samples fall into the category of excellent waters. On the other hand, when we linked the SAR with the EC using the Wilcox log diagram (Fig 5), we found that the irrigation waters located in the class of poor waters (C_4S_1; C_4S_2; C_4S_3; and C_4S_4) could be suitable for the irrigation of certain salt-tolerant crops on well-drained and leached soils (table 5). According to the average value of the Kelly ratio, most of the values are less than one (RK < 1) (Fig 6, 7). The majority of groundwater is of excellent quality for agriculture. According to the $\%Na^+$, 70% of TC water and 90% of IC water are acceptable for agricultural use. As can be seen from the calculation of the percentages of magnesium, good-quality waters predominate, with more than 60% of the samples for the Mio-Pliocene (Fig 6) and up to 93% for the Albian (Fig 7). On the other hand, in the C_2 class, the waters of poor quality represent 37.04%, and this percentage decreases in the Albian until it reaches a minimum of 9.09%. Calculation of the potential salinity shows that all the waters studied are in the last class (C_3). They are characterized by poor quality; the PS index is in the range of 18.10 to 61.35 meq/l for TC waters and between 13.16 and 21.44 meq/l for IC waters. The classification from the residual sodium carbonate index indicates that the irrigation waters are in the first class (C_1), with no risk of residual alkalinity on the irrigated soils. In this case, these waters can be classified as being of good quality according to the RSC; this index varies between -8.39 and -42.07 meq/l for TC waters and between -8 and -14.25 meq/l for IC waters. The permeability index indicates that the waters of the two exploited aquifers are in the C_2 class, in which water is permissible for agriculture in the Ouargla region. The average value of this index is 48.17 meq/l for Mio-Pliocene waters (TC) and 52.34 meq/l for Albian waters (IC).

The two overall classification models proposed for the two aquifers (Fig 8, 9), developed using GIS, allow identifying and locating the potential risks related to the quality of irrigation water at the regional scale in order to take preventive and corrective measures, which requires thoughtful management of these resources.

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