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Thermodynamic modeling of the salinity of groundwater in the basin of Ouargla (Algerian Sahara)

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Abstract

An underground reservoir of considerable water capacity encloses the Ouargla basin located in the southeast of Algeria. It is distributed along with deep and wide depression, corresponding to the lower valley of one of the largest Saharan fossil rivers: the Oued Mya. Given this situation which marks the importance of the water volume of this reservoir, monitoring of the water quality of the groundwater (surface water) was undertaken in a naturally bare plot, without anthropogenic actions and without possibilities of emptying into the drainage network. The main results show that the waters of this aquifer have an extremely high salinity attested by eclectic conductivity values, which vary, from upstream to downstream in the direction of flow, from 25.7 dS/m to 171.9 dS/m. In addition, the results of anionic and cationic analyzes show a remarkable superiority of sodium among the cations (its content increases from 168.48 meq/l upstream to 978.26 meq downstream) and of chlorine among the anions (its content increases from 218.31 meq/l to 1225.35 meq), which gives these waters a dominant chemical facies of sodium chloride. The study of the saturation index of the halite, anhydrite and aragonite components shows that the dissolution of the gypsum formations is due to the increase in the alcanization of the waters and the precipitation of aragonite, calcite and dolomite. The sensitivity of minerals to the saturation index highlights a priority precipitation of carbonate elements followed by gypsites and finally halite.

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Introduction

Different processes can contribute to soil degradation (erosion, salinization, contamination, drainage, acidification, alteration and loss of soil structure, or a combination of these factors). Salinization, one of the most important phenomena that cause soil degradation, is the concentration of sodium salts, for example, abnormally high in soils due to evaporation.

Ouargla is one of the main oases of the Algerian Sahara. It is like many other agglomerations of the Algerian Sahara currently affected by the strong salinization of its soils. This salinization is due to the upwelling of water from the surface water table discharges of drainage water and urban wastewater.

These scourges have been the subject of a good number of previous studies (Servant, 1978; Guendouz *et al.*, 1992; Daoud and Halitim, 1994; Nezli *et al.,* 2007; Anrh, 2003; Idder, 2006; Idder *et al.,* 2021).

The water table, which is located at a shallow depth below the surface of the soil, plays a very important role in accentuating the phenomenon of soil salinization by its highly saline character (Idder *et al.,* 2012). For that, this work will be devoted to the interpretation and the discussion of the results obtained by using the geochemical model (PHREEQC) and to the definition of the order of precipitation of minerals.

Materials and methods

The determination of the influence of saline precipitation, resulting from the water table, on soil degradation in the basin of Ouargla, as well as with the highlighting of the order of precipitation of the salts formed, is estimated using the IS saturation indices of the PHREEQC thermodynamic model at 25 ° C, such that IS = log (IAP / K), where IAP is the product of ionic activity and K is the equilibrium constant.

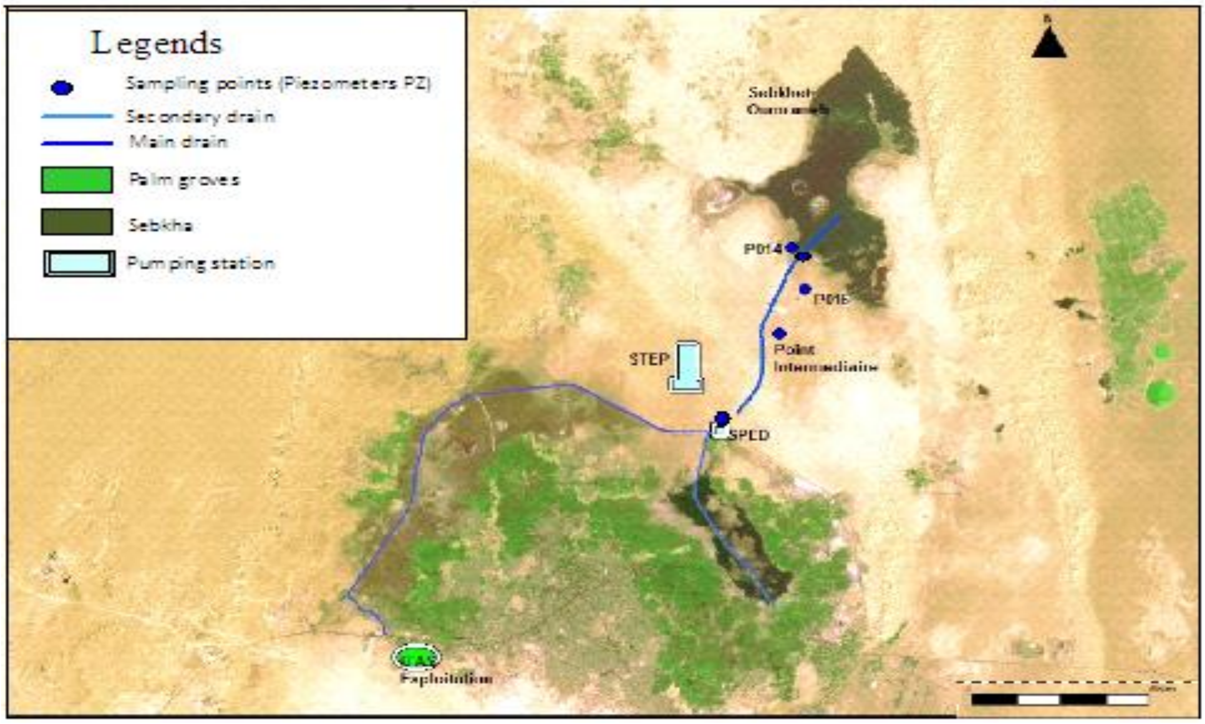

Fig. 1. Situation map of the water table sampling points.

This work was carried out in two uncultivated sites. The first is located at the farm of the University of Ouargla (Lat. 31°94'11''N, Long. 5°29'54''E) and the second at the Sebkha of Oum Erraneb (Lat. 32°02'56''N, Long. 5°38'50''E), located northeast of the city of Ouargla (Fig. 1). The soils of these two sites are bare soils subject only to the influence of climatic factors and the rise of the water table. This aquifer follows a south-north-oriented flow. Eight groundwater samples were taken to determine their physicochemical quality. Sampling points are distributed as shown in Fig.1.

The dosage of the chemical elements is carried out with a DR3900 Spectrophotometer (HACH) and the electrical conductivity of the aqueous extract 1/5 with a conductivity meter**.**

Results and discussion

The ionic characterization (Table 1) of groundwater carried out on the study site according to a South/ North oriented top sequence shows that in all the sampling points, sodium among all the major cations (K^+, Mg^{2+}, Ca^{2+}) displayed the concentrations the most important (168.48 meq/l upstream to 978 meq/l downstream) Fig. 2.

Among the major anions (SO_4^{2-}, HCO_3), chlorine recorded the highest concentrations (218.31 to 1225.35 meq/l upstream to downstream) Fig. 3.

Table 1. Ionic water balance (Piezometers).

Settings		Pz1	Pz2	Pz3	Pz4	Pz5	Pz6	Pz7	Pz8
CE (dS / m) at 25 ° C		25.70	37.10	40.90	26.40	26.20	68.70	171.9	98.99
Textural class		Sandy-silt							
Ionic balance of the aqueous extract 1/5 (m/l)	Na^+	168.48	271.74	184.87	206.52	222.83	521.74	304.35	978.26
	It $^{++}$	207.93	146.77	232.39	171.23	183.46	403.62	53.82	53.82
	K^+	14.10	10.26	19.23	8.33	8.97	8.97	9.62	2.98
	Mg $^{++}$	200	127.30	210.53	88.42	86.32	400	235.77	578.95
	Cl^-	218.31	352.11	353.89	246.48	232.39	1126.76	409.10	1225.35
	$SO4^{--}$	242.19	204.17	203.13	188.80	218.79	187.50	258.33	218.75
	$HCO3^-$	6.90	6.25	7.57	7.35	7.25	6.10	7.35	2.50

The saline profile of the eight water points analyzed in the toposequence studied attests to the very poor quality of these waters for irrigation. The electrical conductivity values vary between a minimum of 25.7 dS/m and a maximum of 171.9 dS/m Fig. 4. These values place these waters in the C4S5 class (Very poor quality, according to Durand, 1958).

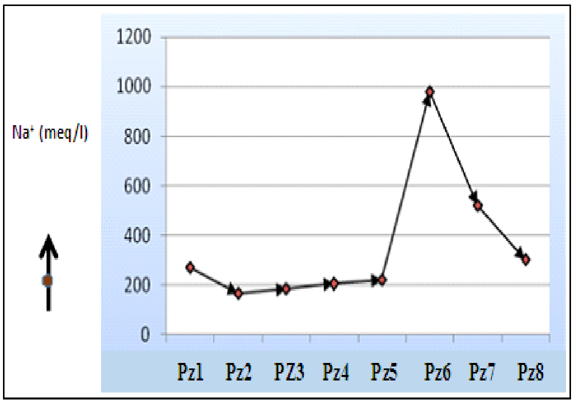

Fig. 2. Ionic profile of the evolution of sodium concentrations in the water table.

The saturation indices of the main phases Anhydrite ($CaSO_4$), Aragonite ($CaCO_3$), Calcite ($CaCO_3$), Dolomite (CaMg) $(CO_3)_2$, Halite (NaCl), Gypsum ($CaSO_4{:}2H_2O$), (CO_2) and (H_2O) of the sampled waters are shown Fig. 5.

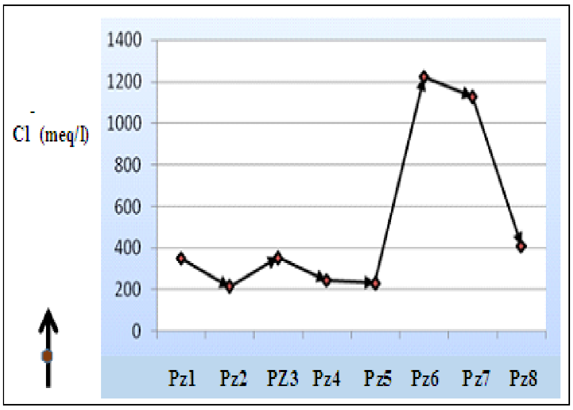

Fig. 3. Ionic profile of the evolution of chlorine concentrations in the water table.

These indices of saturation of the minerals dissolved in the water of the groundwater are calculated from the formula. They show the sensitivity of carbonate minerals, in this case, dolomite, calcite and aragonite to precipitation. This is also the case for evaporitic minerals, in particular gypsum and anhydrite.

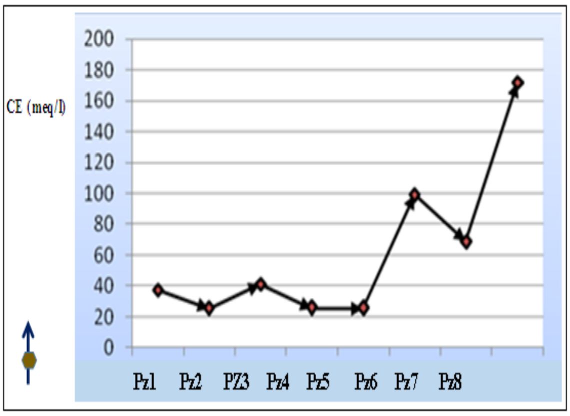

Fig. 4. Saline profile of groundwater.

Carbonate minerals have different saturation indices. That of calcite varies from 0.37 to 2.12, followed by that of aragonite, which varies from 0.18 to 1.94, and finally that of dolomite, which varies from 1.44 to 4.53.

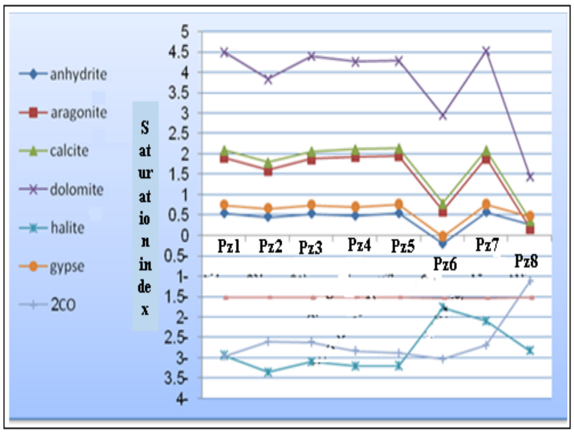

Fig. 5. Evolution of the saturation indices of groundwater salts.

If we admit that the state of equilibrium is in the interval of -0.5 to +0.5 (Droubi *et al.,* 1976), we can say that the three elements have reached their state of saturation or supersaturation in most of the waters analyzed.

Evaporitic minerals with reference to gypsites undergo precipitation after less soluble carbonates. Gypsum and anhydrite from evaporitic minerals record saturation indices which vary between -0.2 and +0.58, thus promoting the triggering of precipitation. Finally, halite, whose saturation indices vary from -3.34 to -1.76, therefore remains under-saturated, despite the dominance of its chemical components (Na^+ and Cl^-) in concentration. This undersaturation, explained by its high solubility, is expressed by the combined action of the capillary rise of the water table in the slices of the soil and the intense seasonal evaporations.

Fig. 6. Saline manifestations were observed on the study sites.

The most obvious manifestation is that of whitish blooms and sometimes crusts on the surface of the soil Fig. 6.

Conclusion

This work consists in measuring the salinity of groundwater as well as the behavior of chemical elements through the geochemical characterization and the process of accumulation of salts and their influences on the soil.

The results obtained show that groundwater or surface water is extremely salty and its electrical conductivities are very high, up to 171.9 dS/m. This evolution of salinity follows the direction of groundwater flow. The application of the saturation index through the PHREEQC software for the various minerals present in groundwater shows a precise order of precipitation of these minerals. Carbonates precipitate first, followed by gypsites and finally halite.

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