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Characterization of Algerian Sahara groundwater for irrigation and water supply: Adrar region study case

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Abstract

Groundwater hydrochemistry of Algerian Sahara (Southwest, Algeria) was used to assess groundwater quality to determine its suitability for drinking and agricultural purposes. A total of 26 groundwater samples were analysed for 14 parameters. Standards laboratory methods were used to determine physicochemical groundwater properties. This study shows that these pH, electric conductivity, total hardness, bicarbonate, and phosphate were within WHO limits. The concentration of magnesium ranging from 30.49 to 120 mg·dm^{-3} with an average value of 67.21 mg·dm^{-3}. 38.56% of the water points analysed have a concentration lower than the value set by the WHO at 75.00 mg·dm^{-3}. It also showed that 70% of the points studied have potassium concentrations that exceed World Health Organization standards. Groundwater of Algerian Sahara is low in nitrogen (NO_3^-) and the higher concentration may result in various health risks. The result for this study showed that the water was to be found suitable for drinking purposes except for few samples. Piper diagram indicates that groundwater in Adrar belongs to chlorinated-sulphated, sodium and magnesium facies. The groundwater samples of Adrar present high salinity and low alkalinity fall into the field of C3S1 and C3S2. Based on the RSC values, all samples had values less than 1.25 and were good for irrigation.

Key words: *Adrar area, Algerian Sahara, drinking water, groundwater, hydrochemical, irrigation water, Piper diagram*

INTRODUCTION

Groundwater is one of the main water sources used for drinking, industrial and irrigation purposes. A growing population imposes countless demands on natural water resources. Groundwater is essential for protecting the ecological environment of arid and semi-arid regions [KENDOUCI *et al*. 2019; KHELFAOUI *et al*. 2020]. The good quality water for drinking purposes is important for future planning and management [MEBARKI *et al*. 2021]. Algerian Sahara occupied by a large population distributed over vast urban agglomerations and oases. The Wilaya of Adrar has witnessed in recent years a rapid population growth followed by an important human activity that covers almost all fields (Agriculture, Industry, Urbanization and Tourism) in parallel; the needs for water have increased. To meet the needs of growing water demand, numerous drillings have been carried out, adding to the traditional catchment system [BENHAMZA 2013]. The catchment field that supplies the city of Adrar with drinking water consists of 26 boreholes. According to hydrogeological surveys carried out in this region, the groundwater reserves are considerable; this is the Continental Intercalaire. This water table supports all kinds of activities (agricultural, industrial, and drinking water supply).

Accelerated development and increased local and regional exploitation rates of this reservation have resulted in problems related primarily to water quality, and the subsequent drop in the water table that has resulted in the draining of some drilling numbers in recent years, which has influenced the stability of ecosystems in the region.

The chemical quality of these waters plays an important role in determining its use. Therefore, it is necessary to have rigorous and legible information on this quality in order to preserve it against all kinds of pollution and better management of this resource, and to make decisions on any development.

The purpose of this study is to assess the quality of groundwater in the Sahara (Adrar region) of Algeria. The collected data were compared with Algerian and WHO standards to determine if this water was suitable for drinking and irrigation purposes.

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MATERIALS AND METHODS

GEOGRAPHIC LOCATION

In the heart of Algerian Sahara, the wilaya of Adrar is located in the southwest of the country, more than 1200 km from Algiers. Its total area is 427,368 km^2, or about 18% of Algeria's total area. It is limited to the north by the wilayas of El Bayedh and Ghardaïa, to the west by the wilaya of Bechar and Tindouf, to the east by the wilaya of Tamanrasset and to the south by Mauritania and Mali (Fig. 1).

CLIMATE

The climate of the Adrar region is monitored by a weather station located in longitude 00°10'0" N and in latitude 27°50'00" W and with an altitude of 772 m, indexed by 13 01 32. The station is managed by the National Water Resources Agency. The data used refer to the period from 1991 to 2019, 27 years of observations. This weather station is located 15 km east of the city of Adrar.

The climate of the Adrar region is a particularly mixed climate; it is characterized by a dry and arid climate. The aridity is expressed not only by high temperatures in summer and low rainfall, but also by the importance of evaporation due to dry air.

The maximum average annual rainfall appears in October under a precipitation of 1.94 mm, the minimum in July is 0.48 mm, and the monthly average is in the order of 1.10 mm per month (Fig. 2). The rainy season runs from October to March, with a peak in November. The analysis of the histogram of the average monthly temperature (Fig. 3) shows that the warmest month is July with an average temperature of 38.33°C, while the coldest month is January with an average temperature of 13°C, the average monthly temperature is 26°C.

GEOLOGY

Our zone of study belongs to the basin of the Great Western Erg (Fig. 4), including its major part, the aquifer of the Continental Intercalaire, which is one of the most extensive aquifers on the planet.

The Continental Intercalaire water table, more often than not called albian water table corresponds to a lower level. It is defined by the lower Cretaceous continental

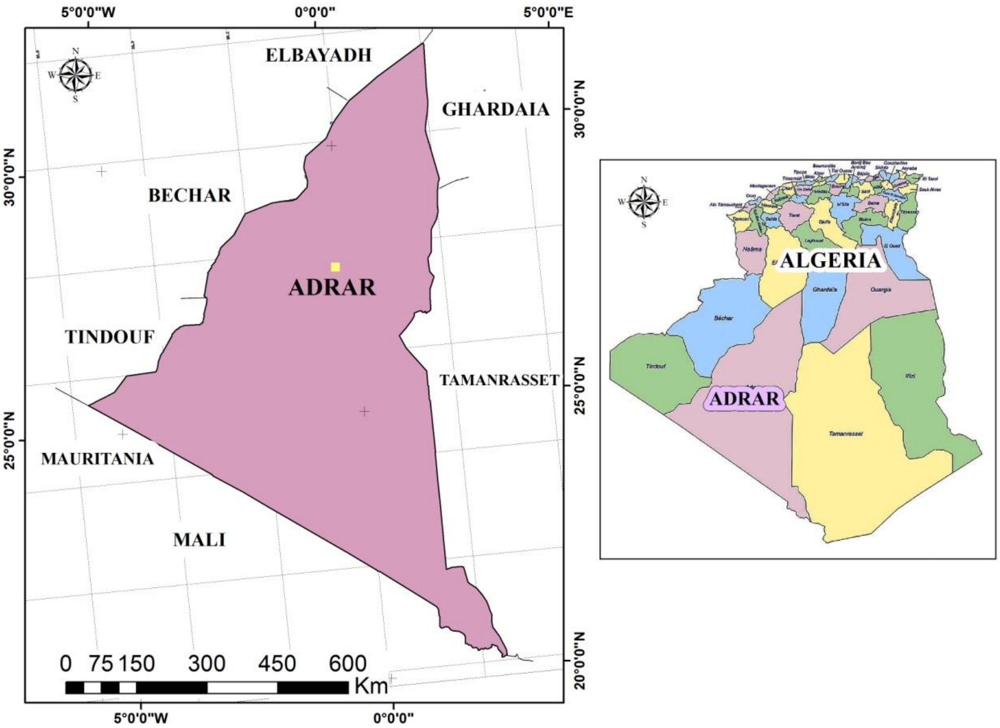

Fig. 1. Geographic location of the study area (Adrar region); source: own elaboration

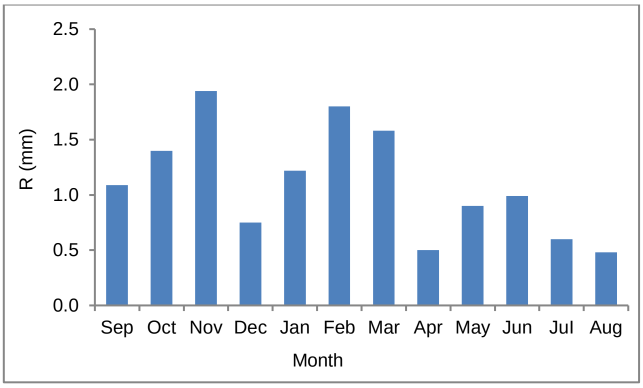

Fig. 2. Rainfall (*R*) in Adrar city during the period 1991–2019; source: own elaboration based on data of [ANRH 2019]

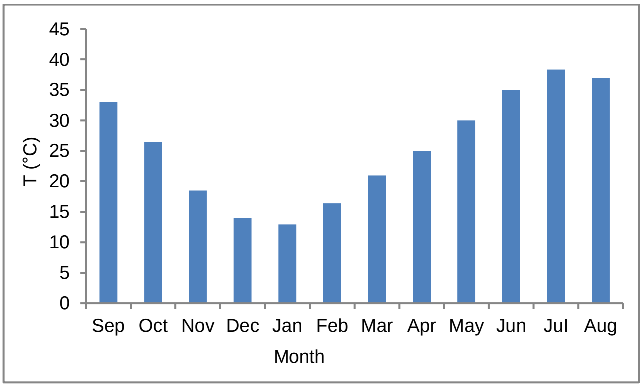

Fig. 3. Temperature (*T*) in Adrar city during the period 1991–2019;
source: own elaboration based on data of [ANRH 2019]

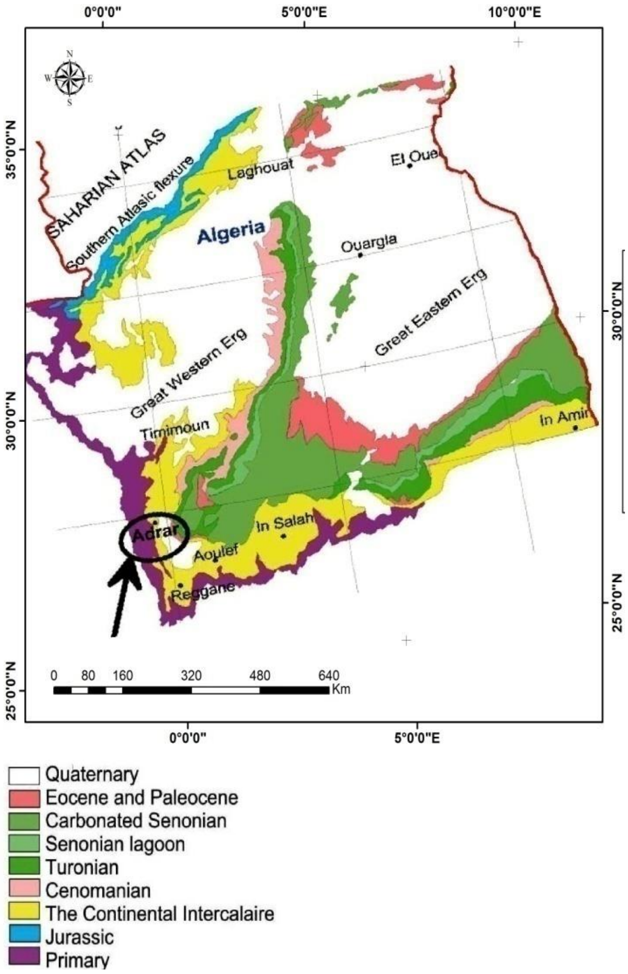

Fig. 4. Geological map of the northern Sahara aquifer system in Algeria; source: KHELFAOUI *et al*. [2020], modified

formations between Neocomien and Cenomanien, which consist of sand, sandstone with clay intercalations. The base consists of primary Paleozoic grounds, which are very rugged by Hercynian orogenesis. The roof is most often formed by the deposits of the upper Cretaceous, namely the Clayey Cenomanians and the Turonians, and sometimes by the tertiary or quaternary lands [BANACEUR 2016].

The current recharge of the Continental Intercalaire is by infiltration of precipitation along the western basin, along the wadis that descend from the mountainous massifs, notably the Saharian Atlas in the North-West and the Dahar in the East; Running on the outskirts of the estate, all along the wadi that descend from the mountainous massifs, notably the Saharan atlas, sometimes the Tademaït plateau, exceptional years of rain on the great western Erg.

HYDROGEOLOGY

The study area is located in the southwest of the North Sahara hydrogeological unit. The Adrar plain is part of this sub-basin and is located on its southern western edge. The Continental Intercalaire detritic formations are found in angular discordance on a primary-age substratum that appears in the depression of the Saoura Valley (Wadi Messaoud) in the west. In the east, however, they are covered by gypsy argilo formations of the transgression of the Cenomanians themselves are overcome by a limestone slab of the Turonian and Senonian [ANRH 2016].

The role played by the Continental Intercalaire is important in the middle part of the study area or it is widely reported. It also contains the most important aquifer of the Sahara, whose emergence determines the existence of palm groves of Touat, which further increases the interest of its study.

The analysis of the lithological sections of the boreholes drilled in the study region shows that there is not a large lateral change of facies in the boreholes, the majority of the holes have almost the same lithology, which can be found from top to bottom:

- a very hard slab of limestone or dolomitic limestone, or quartz stone;
- a clay and clay layer with multicoloredclay;
- a layer of sand and gravel;
- a layer of sandy clay with gypsum or anhydrite;
- a layer of red or brown plastic clay.

The hydrodynamic parameters depend on the nature of the formations that make up the water table. The Continental Intercalaire of the region being made up of soft greaves, its permeability is great. The transmissivity is between $2 \cdot 10^{-2}$ and $2.25 \cdot 10^{-3}$ $m^2 \cdot s^{-1}$, the storage coefficient is $4.25 \cdot 10^{-4}$. The depth of the drilling varies between 120 and 175 m. The operating rate of a well-completed drilling operation varies between 40 and 50 $dm^3 \cdot s^{-1}$.

METHODS

Taking a water sample is a rather delicate operation to which the greatest care must be taken; it determines the analytical results and the interpretation that will be given, the sample must be homogeneous, representative and obtained without modifying the physico-chemical characteristics of the water. It is therefore necessary to use a methodology adapted to each case and to use the appropriate material.

A set of 26 groundwater samples was selected for analysis of physical and chemical parameters, and samples were taken after 10 min of pumping. Special attention should be paid to sampling equipment. We used plastic bottles (1.5 dm^3) blocked with polyethylene caps. The samples collected, carefully labelled and stored at 4°C were transported to the laboratory within a time interval not exceeding 24 h.

In this work, the parameters that were checked are: temperature, pH, conductivity, dry residue, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulphate, total hardness (*TH*) nitrate and phosphate.

Analytical methods are based on measurements of physical quantities, or chemical reactions (dosing). Some physical parameters were measured *in situ*, such as pH, electrical conductivity, and temperature, using a thermometer-coupled pH-meter and a WTW 197 conductimeter, the dry residue was determined after evaporation at 180°C, using method NF T 90-029. Calcium and magnesium levels of the samples are determined by (volumetry) complexometric titration, with the disodium salt of ethylene-diaminetetracetic acid (EDTA) NFT90-003, molecular absorption spectrophotometry was used for the determination of sulphates, chlorides and nitrates. Flame spectrophotometry for the determination of potassium and sodium content. The bicarbonate present in the water sample is calculated from the measured total alkalinity value, which is determined by neutralizing a certain volume of water with a diluted mineral acid in the presence of a coloured indicator.

RESULTS AND DISCUSSION

The biological production of water is directly related to the temperature of the water, because it affects the physical and chemical properties of water. In particular the speed of chemical and biochemical reactions. The average temperature of groundwater samples is 24°C. The hydrogen potential of water represents that its acidity or alkalinity is related to the nature of the terrain being traversed. The pH of the waters studied varied from 7.37 to 7.97 with an average value of 7.55. These waters are more or less alkaline for most of the samples (Tab. 1). These results are in good agreement with WHO's recommendations and also with the Algerian standard 6.5 to 8.5. Electric conductivity is a measure of water capacity to convey electric current; it allows evaluating the overall mineralization of water. Electric conductivity of groundwater varies between 1047 and 2270 $\mu S \cdot cm^{-1}$ whose average is 1508.31 $\mu S \cdot cm^{-1}$. It should be noted that the majority of the analyses show values below the 2800 $\mu S \cdot cm^{-1}$ threshold of the World Health Organization standard [WHO 2008].

Table 1. Physicochemical parameters of investigated water samples

Parameter	Value			
	min.	max.	mean	*SD*
T (°C)	24	26.5	24.35	0.67
pH	7.37	7.97	7.55	0.23
EC ($\mu S \cdot cm^{-1}$)	1047	2270	1508.31	417.25
DR ($mg \cdot dm^{-3}$)	660	2010	766.54	112.49
TH($mg \cdot dm^{-3}$)	27	43	32.23	4.49
Ca^{2+} ($mg \cdot dm^{-3}$)	49.7	156	87.82	37.46
Mg^{2+} ($mg \cdot dm^{-3}$)	30.94	120	67.21	35.36
Na^{+} ($mg \cdot dm^{-3}$)	110	358	190.65	79.70
K^{+} ($mg \cdot dm^{-3}$)	7	28.6	15.256	7.32
Cl^{-} ($mg \cdot dm^{-3}$)	148	504.38	258.79	130.83
SO_4^{2-} ($mg \cdot dm^{-3}$)	139.4	400	252.67	61.79
HCO_3^{-} ($mg \cdot dm^{-3}$)	119	249.49	164.72	46.49
NO_3^{-} ($mg \cdot dm^{-3}$)	15	29.28	23.97	3.75
PO_4^{3-} ($mg \cdot dm^{-3}$)	0.01	0.3	0.013	0.059

Explanations: *SD* = standard deviation, *T* = temperature, *EC* = electrical conductivity, *DR* = dry residue, *TH* = total hardness.
Source: own study.

The total hardness is mainly due to the dissolved salts of calcium and magnesium. Their concentration is too high, the water becomes very hard. The hardness of natural water depends on the geological structure of the soil through which it passes. It is considered an indicator of limestone content in water [AMADOU *et al*. 2014]. Virtually all values of total hardness are found in the range of (27–43 $mg \cdot dm^{-3}$). All samples are within the recommended limit set by WHO with less than 500 $mg \cdot dm^{-3}$. Groundwater in the region of Adrar is moderately mineralized with levels ranging from 660 to 1090 $mg \cdot dm^{-3}$. Bicarbonate levels in unpolluted groundwater range from 50 to 400 $mg \cdot dm^{-3}$, whereas groundwater in the Adrar region has values of 119.00 to 249.49 $mg \cdot dm^{-3}$, which are well within the range mentioned above.

Calcium is the fifth most abundant natural element, is the main component of water hardness and is usually the main element of drinking water. The content changes mainly according to the nature of the land that is crossed. Calcium concentrations in the water points analysed range from 49.7 to 156.0 $mg \cdot dm^{-3}$. The WHO limits the maximum allowable drinking water limit to 50 $mg \cdot dm^{-3}$ [WHO 2008]. Given the lithological nature of the aquifer (dolomitic limestone), calcium is caused by the dissolution of calcium carbonate in the limestone in the geological structure of the Continental Intercalaire.

Magnesium is an important mineral and cofactor in the control of more than 300 enzyme systems. These enzyme systems control various biological reactions of the human body. Magnesium levels range from 30.94 to 120.00 $mg \cdot dm^{-3}$. 38.56% of the water points analysed have a magnesium concentration higher than the standard recommended by WHO at 75.00 $mg \cdot dm^{-3}$. Their existence is generally linked to the contact of water with the calcaro-dolomitic rocks of the aquifer. High concentration of calcium and magnesium is the major contributor to hardness of the water. The calcium and magnesium have nothing to do with health, unless the drinking water contains high levels of them.

Sodium is a mineral naturally found in the earth's crust and drinking water. The presence of sodium in natural water depends on the presence of anions in the system and the regional temperature. High levels of sodium can give drinking water a taste and may cause high blood pressure and cardiovascular disease. Analysis at the studied water level recorded sodium concentrations between 110 and 358 $mg \cdot dm^{-3}$. This enrichment reflects the dissolution of NaCl; 61.54% of the water analysed have a concentration lower than the value set by the WHO at 200 $mg \cdot dm^{-3}$ [WHO 2011].

Potassium plays a vital role in the metabolism of living organisms. It is also an essential micronutrient. Potassium is in the order of 7.00–28.60 $mg \cdot dm^{-3}$. The WHO and the indicative Algerian standard set a maximum value of 12.00 $mg \cdot dm^{-3}$ as an allowable drinking water limit [WHO 2008], and well also with the Algerian standard. Higher concentrations may cause kidney, lung and cardiovascular disease [LANJWANI *et al*. 2019].

Sulphate ion (SO_4^{2-}) is easily soluble in natural water. Their minerals produce many SO_4 ions through the oxidation process. Sulphate is also present in industrial waste. Sulphates range from 139.4 to 400.0 $mg \cdot dm^{-3}$, largely satisfying the requirements of World Health Organization (WHO). The increase of concentration is obviously due to intensive agricultural occupations, such as the use of chemical fertilizer by farmers. The chloride naturally occurs in varying concentrations in groundwater as well as surface water, usually in the form of salts; halite (NaCl) and sylvine (KCl). The excess concentration of chloride in water is known to be indicator of contamination. The higher value of chloride may be due to the nature of the formations it crosses and it may be due to improper treatment of sewage waste. Chloride concentrations range from a minimum of 148.00 $mg \cdot dm^{-3}$ to a maximum of 504.38 $mg \cdot dm^{-3}$. Some values are in not accordance with WHO standards (250 $mg \cdot dm^{-3}$). High concentration of chloride cause steel to corrode and give water a salty taste, and reduce the strength of concrete.

Nitrates are one of the main causes of degradation of groundwater quality. They are mainly from diffuse agri cultural pollution, domestic and urban releases contribute locally to nitrate contamination of the table, but fertilization through the application of nitrogen-based chemical or organic fertilizers and intensive livestock farming (animal waste) are the main cause. Nitrates themselves do not pose a particular health risk, it is their transformation into nitrites in the stomach that can be toxic [BENDIDA 2019; KENDOUCI 2018]. The water analysed in the Adrar region showed that nitrate values range from 15.00–29.28 $mg \cdot dm^{-3}$. These values are consistent with the World Health Organization (50 $mg \cdot dm^{-3}$) standards [BENDIDA *et al*. 2013; KENDOUCI *et al*. 2016].

Phosphate (PO_4) exists in water and soil in different inorganic forms. High values of phosphates have been originating from domestic water and sewages. The phosphorus (P) strongly adsorbed by soil particles, does not leach to groundwater readily. The concentration of phosphate was found from 0.01 to 0.3 $mg \cdot dm^{-3}$. High levels of phosphorus can cause health problems such as osteoporosis and kidney damage.

CORRELATION COEFFICIENT

Correlation is used to determine how close different variables are. This analysis attempts to establish the nature of the relationship between variables. Table 2 shows the correlation matrix of the variables. The pH was negative correlated with Mg^{2+} and Na dry residue $^{+}$ but was less correlated with TH and SO_4^{2-} (<0.5). Electrical conductivity was good correlated with Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-} and HCO_3^{-} (>0.85), which confirms the impact of the clay layers of the "Continental Intercalaire" aquifer on the mineralization of its waters. The correlation between NO_3^{-}, PO_4^{3-} and HCO_3^{-} is low, due to the large depth of these drillings, which greatly reduces enriched in these nitrogen and phosphorus compounds in agricultural and sewage sources. Bicarbonate was good correlated with EC, Ca^{2+}, Mg^{2+}, and chloride. Potassium was good correlated with chloride. Chloride was good correlated with Ca^{2+}, Mg^{2+} and Na^{+}. Occurrence of good correlation between calcium and chlorides (0.93) indicates about the total hardness of water. Sulphate was good correlated with *TH* and dry residue (<0.6) but less correlated with Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} (<0.5). The strong to perfect correlation between the chemical parameters is an indication of common source.

Table 2. Correlation determination of the parameters

Parameter	*T*	pH	*EC*	*DR*	*TH*	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	HCO_3^{-}	NO_3^{-}	PO_4^{3-}
T	1.000													
pH	0.096	1.000												
EC	–0.061	–0.416	1.000											
DR	–0.037	0.091	0.240	1.000										
TH	0.066	0.116	0.356	0.894	1.000									
Ca^{2+}	0.067	–0.414	0.961	0.207	0.352	1.000								
Mg^{2+}	–0.122	–0.541	0.940	0.108	0.247	0.922	1.000							
Na^{+}	–0.031	–0.550	0.909	0.130	0.183	0.865	0.921	1.000						
K^{+}	–0.133	–0.494	0.896	0.071	0.112	0.849	0.868	0.909	1.000					
Cl^{-}	0.048	–0.471	0.940	0.082	0.223	0.932	0.909	0.851	0.823	1.000				
SO_4^{2-}	–0.345	0.174	0.359	0.692	0.625	0.233	0.238	0.270	0.191	0.190	1.000			
HCO_3^{-}	0.157	–0.437	0.832	0.000	0.142	0.870	0.867	0.855	0.762	0.877	0.142	1.000		
NO_3^{-}	0.308	0.227	0.012	0.085	0.146	0.052	–0.033	–0.007	–0.027	0.058	0.137	0.146	1.000	
PO_4^{3-}	0.424	0.074	–0.241	–0.132	–0.059	–0.220	–0.227	–0.043	–0.240	–0.185	–0.168	0.074	0.286	1.000

Source: own study.

CLUSTER ANALYSIS

Multivariate statistical techniques can provide more insights into the infrastructure of the data set, and the use of these techniques may require further analysis to identify different groups. [BELKHIRI MOUNI 2012; DAVIS 1973]. Cluster analysis divides similar objects into several categories, where the number of groups and their forms are unknown. Hierarchical clustering is the most common method, which provides an instinctive similarity relationship between any sample and the entire data set. Therefore, it is usually described by a tree diagram. The tree diagram shows the pictures of these groups and their closeness to each other, while the dimensionality of the original data is greatly reduced [WUNDERLIN *et al*. 2001].

Use cluster analysis method to sample 26 water samples in this area to understand the similarity between sampling locations (Fig. 5). It was observed that the samples are grouped into clusters in dendrogram. Group A is based on 12 samples with samples numbers 10, 11, 1, 5, 7, 3, 6, 2, 9, 8, 13, 12 and showed similarity of samples; B group contains 4 samples with numbers 15, 16, 4, 14. The cluster C comprises four groups C1, C2, C3 and C4, the C1 contains two samples 18, 19, C2 contains two samples 22, 23, C3 contains four samples 24, 26, 25, 21, and C4 contains two samples 17, 20. It can be seen that most of the parameter values of the samples in group C are higher than those in groups A and B.

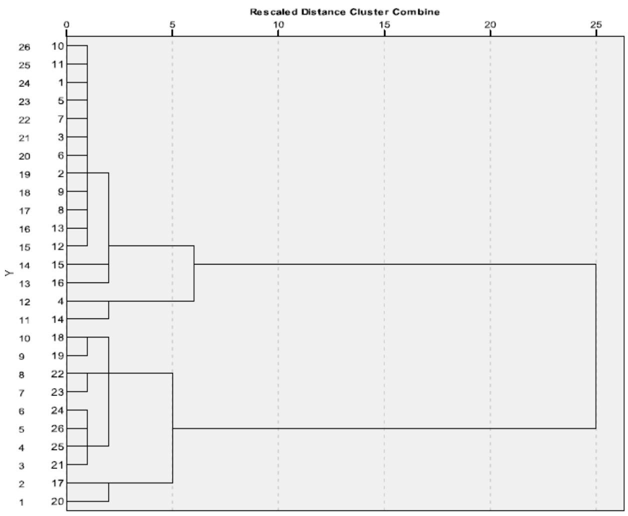

Fig. 5. Cluster analysis dendrogram using average linkage (between groups) of the samples; source: own study

HYDROGEOCHEMICAL FACIES

During their journey, according to several modification phenomena, the chemical composition of groundwater evolved by crossing different geological faults [MANSOUR 1993]. According to their chemical composition, we can use Piper's logarithmic diagram to classify them into families. The Piper logarithm diagram consists of two triangles representing the distribution of anions and cations, and a rhombus representing a synthetic distribution of major ions. This diagram reveals similarities and differences among water samples because water samples of similar quality are often drawn together in groups [BENMOUSSA *et al*. 2020; MAKOBA, MUZUKA 2019].

The representation of chemical results of waters taken from the region of Adrar on Piper diagram shows that the water is a predominantly chemical facies that are chlorinated and sulphide sodium and magnesian, and that tend towards chlorinated and sulphate calcium and magnesian facies (Fig. 6).

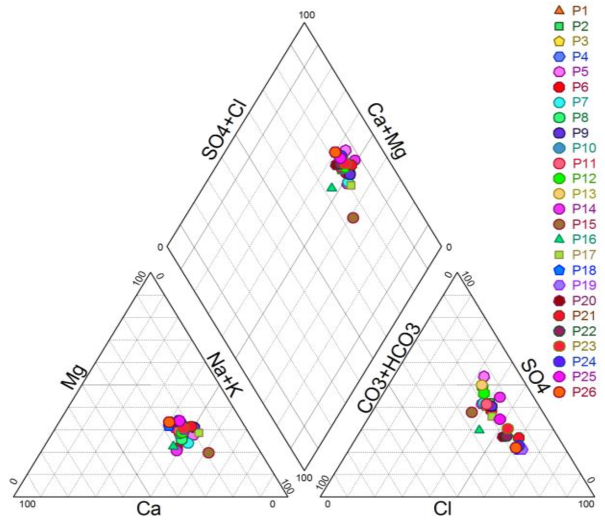

Fig. 6. Piper diagram for water samples (P1–P26) of Adrar groundwater; source: own study

IRRIGATION WATER QUALITY

Whether groundwater is suitable for agricultural use depends on the impact of the mineral composition of the water on plants and soil. The influence of salinity on the soil leads to changes in soil structure, permeability and aeration and indirectly affects plant growth. In the Adrar region irrigation is provided by groundwater. The chemical study of irrigation water was necessary to identify any hazards that may arise from certain chemical elements.

ALKALINITY HAZARD

The sodium/alkali hazard is typically expressed as the sodium adsorption ratio (*SAR*). This index quantifies the proportion of sodium (Na^+) to calcium (Ca^{2+}) and magnesium ($Mg^{2+)}$ ions in a sample. The classification of water according to the percentage of sodium absorbed by water (Richards method) allows to well classified the water according to the electrical conductivity at 25 °C and the *SAR* in water. The *SAR* value is determined by following equation.

$$SAR = \frac{\mathrm{Na}^{2+}}{\sqrt{(\mathrm{Ca}^{2+}+\mathrm{Mg}^{2+})/2}} \tag{1}$$

SAR values ranged from 2.85 to 5.88 with an average of 3.93±0.79 (Tab. 3). Most samples belong to the low sodium class S1. This implies that no alkali hazard is expected for crops. If the *SAR* value is greater than 6–9, the irrigation water will cause swelling of the clay soil type and swelling permeability problems [BELKHIRI, MOUNI 2012; SALEH *et al*. 1999].

Table 3. Suitability of water for irrigation

Parameter	Value			
	min.	max.	mean	*SD*
SAR	2.85	5.88	3.93	0.79
Na%	39.84	64.51	46.59	9.75
RSC	–12.70	–1.12	–6.26	3.99
KI	0.69	1.89	0.96	0.37
PI%	48.51	79.97	60.30	8.09
Cl^-/HCO_3^-	1.41	4.04	2.59	0.71
Cl^-/SO_4^{2-}	0.60	3.00	1.42	0.73

Explanations: *SD* = standard deviation, *SAR* = sodium adsorption ratio, *RSC* = residual sodium carbonate, *KI* = Kelly index, *PI*% = permeability index.
Source: own study.

The suitability of irrigation water use can be determined by using the US salinity diagram [BELKHIRI *et al.* 2010; BENMOUSSA *et al.* 2020]. The estimated values of *EC* and *SAR* in Adrar groundwater samples belong to the C3S1 and C3S2 field, indicating that the salinity is very high and the alkalinity is very low, and cannot be used under normal conditions; drainage must be applied adequately and the soil must have rapid permeability (Fig. 7). These waters present an appreciable risk of salinity and a low risk of alkalinity; therefore, they are waters to be used for irrigation by providing leaching doses and require drainage to prevent salt deposition and consequently soil salinity.

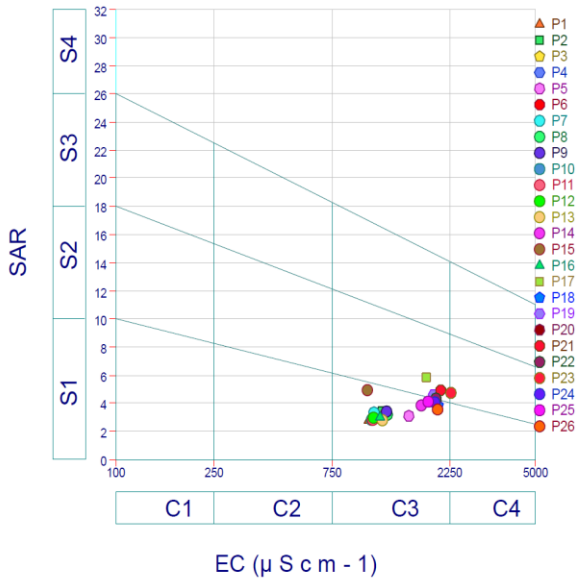

Fig. 7. United States Salinity Laboratory diagram for classification of irrigation waters; source: own study

SODIUM PERCENTAGE (NA%)

The Na% is extensively applied for evaluating the suitability of groundwater for the irrigation using reported method. The sodium percentage value reflects that the water is classified as of good (20–40 Na%), permissible (40–60 Na%) and doubtful (60–80 Na%) class [WILCOX 1955]. The sodium percentage is calculated as follows:

$$Na\% = \frac{Na^+}{Ca^{2+}+Mg^{2+}+Na^++K^+}100 \qquad (2)$$

Sodium percentage values range from 39.84 to 64.51% (Tab. 4). All sampling points falling under between good to doubtful category (Tab. 4). When sodium concentration is high in irrigation water, sodium ions tend to be absorbed by clay particles, displacing Mg and Ca ions. This process of sodium exchange in water against Ca and Mg in soil reduces permeability and ultimately leads to soil with poor internal drainage. As a result, the circulation of air and water is limited in wet weather and these soils are usually hard when dry.

Table 4. Water quality parameters for irrigation

Parameter	Range	Water class	Representing wells	
			No. of samples (*n*)	% of samples
pH	6.5–8.5	good	26	100
EC (µS·cm^{-1})	< 250	excellent	0	0
	250–750	good	0	0
	750–2250	doubtful	26	100
	> 2250	unsuitable	0	0
SAR	<10	excellent	26	100
	10–18	good	0	0
	18–26	doubtful	0	0
	>26	unsuitable	0	0
Na%	<20	excellent	0	0
	20–40	good	1	3.85
	40–60	permissible	24	92.30
	60–80	doubtful	1	3.85
	>80	unsuitable	0	0
RSC	<1.25	good	26	100
	1.25–2.5	doubtful	0	0
	>2.5	unsuitable	0	0
KI	<1	suitable	18	69.23
	>1	unsuitable	8	30.76
PI%	>75	excellent	0	0
	75–25	good	26	100
	<25	unsuitable	0	0
Cl^-/HCO_3^-	<1	suitable	0	0
	>1	unsuitable	26	100
Cl^-/SO_4^{2-}	<1	suitable	13	50
	>1	unsuitable	13	50

Explanations: *SAR*, *RSC*, *KI* and *PI*% as in Tab. 3.
Source: own study.

In addition to *SAR* and Na%, the sum of carbonate and bicarbonate in groundwater exceeds the sum of calcium and magnesium, which will also affect the unsuitability of groundwater for irrigation. This is residual sodium carbonate (*RSC*), which is calculated as follows [RAGUNATH 1987]:

$$RSC = (HCO_3^- + CO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad (3)$$

According to the U.S. Department of Agriculture, water containing more than 2.5% *RSC* is not suitable for irrigation. We stated that *RSC* values ranged from –12.7 to –1.12 with an average of –6.26 ± 3.99 (Tab. 3). All samples had *RSC* values below 1.25 and were considered good for irrigation.

KELLY INDEX

KELLY [1940] introduced factor based on the concentration of Na^+ to Ca^{2+} and Mg^{2+} to evaluate the quality and classification of irrigation water. Kelly index (*KI*) value was determined by following equation.

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

Water with a *KI* value <1 is considered suitable for irrigation, while those with higher values is regarded unsuitable [MOHAMMAD *et al*. 2016; PALANISAMY *et al*. 2020]. *KI* in the investigated area was from 0.69 to 1.89 meq·dm^{-3} with an average of 0.96±0.37 (Tab. 3). According to the present study, eight samples were unsuitable for irrigation (Tab. 4).

PERMEABILITY INDEX

Soil permeability depends on several factors such as the total water concentration, the amount of sodium, the concentration of bicarbonates and the nature of the soil itself. All of these terms are combined into a single formula giving the so-called permeability index (*PI%*) defined by the relation:

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

Water can be divided into class I, class II and class III in terms of permeability index. Class I (>75%, excellent), class II (25–75%, good) and class III (<5%, unsuitable) [KISHAN *et al*. 2018; NAGARAJU *et al*. 2014].

From the results of the Table 4. The permeability index values vary between 48.51% and 79.97% with an average of 60.30±8.09 indicating good quality (Tab. 4). From the results of the Table 4. The permeability index values vary between 48.51 and 79.97% with an average of 60.30± 8.09 indicating good quality (Tab. 4).

CHLORIDE BICARBONATE RATIO

Chloride bicarbonate ratio (Cl^{-}/HCO_3^{-}) is applied to measure the suitability of water for irrigation and agriculture [LANJWANI *et al*. 2020].

If chloride bicarbonate ratio is greater than 1, the water sample is salty and not suitable for irrigation. The chloride bicarbonate content in the study area is between 1.41 and 4.04 meq·dm^{-3} with an average of 2.59±0.71 (Tab. 3). The 26 samples indicated chloride bicarbonate ratio above than one.

CHLORIDE–SULPHATE RATIO

The ratio of chloride to sulphate (Cl^{-}/SO_4^{2-}) is used to measure the suitability of irrigation water [LANJWANI *et al*. 2020].

If Cl^{-}/SO_4^{2-} is less than 1, it means that the sample is suitable for irrigation; if the value of Cl^{-}/SO_4^{2-} is greater than 1, it means that the sample is salty and not suitable for irrigation. The chloride–sulphate content in the study area is between 0.60 and 3.00 meq·dm^{-3} with an average of 1.42 ± 0.73 (Tab. 3). The 13 samples of the present study indicated chloride–sulphate ratio greater than one, and thirteen samples were less than one.

The calculations of all the above equations were based on the concentration unit milliequivalent per dm^3.

CONCLUSIONS

This study was conducted to evaluate the groundwater quality for its drinking and irrigational suitability purposes. Twenty six groundwater samples have been collected from Adrar area (southwest of Algeria) for hydrochemical investigations to assess the chemical quality of the groundwater. The analysed samples were compared with standard values of WHO for drinking water. The results of electrical conductivity (*EC*) and pH value of all samples was within limits. The concentration of magnesium and potassium for some samples was above the limits. The concentration of chloride and sulphate of all samples was within limits. The groundwater of Adrar area is low concentration of nitrogenous elements (NO_3^{-}). Cluster analysis was applied to groundwater quality data sets, and generated four clusters (groups C1, C2, C3 and C4). According to pH, *EC* and permeability index, the groundwater samples is suitable for irrigation, especially if rapid permeability is guaranteed which. The United States Salinity Laboratory diagram illustrates that most of the groundwater samples fall in the field of C3S1, indicating high salinity and low sodium water, which can be used for irrigation on almost all type of soil with little danger of exchangeable sodium. According to the residual sodium carbonate (*RSC*) value, all samples are classified as suitable for irrigation.

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