

Characterization, classification, bacteriological, and evaluation of groundwater from 24 wells in six departments of Algeria

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Abstract This is a conducted study of the physicochemical and the bacteriological characteristics of groundwater from 24 wells in the six departments of Algeria: Mostaganem, Mecheria, Naama, Tiaret, Bechar, and Adrar. The six departments and surrounding areas depend heavily on water from wells as a resource for drinking water, as well as domestic, industrial, and agricultural uses. Understanding the groundwater chemistry provides insight into the interactions of water with the environment and contributes to better resource management. In total, 24 water samples from wells have been analyzed for major physical–chemical elements and metals. The results show that the water have pH values ranging between 7.1 and 8.2, salinity between 213 and 1,273 mg/L, and nitrate concentrations between 30 and 48.7 mg/L. The high concentration of nitrates is explained by the utilization of chemical fertilizers in agriculture. Almost all the samples are of type Na–SO₄ and Na–HCO₃, and the trace metal concentrations are within the admissible standard ranges. The bacteriological analysis of 24 samples analyzed showed that nine samples (nos. 3, 5, 8, 12, 14, 16, 17, 22, and 23) are contaminated. We conclude that the groundwater samples may safely be used for drinking, domestic, agricultural, and industrial

purposes with the exception of the following samples: nos. 3, 5, 8, 12, 14, 16, 17, 22, and 23.

Keywords Groundwater · Western and Southern Algeria · Physical–chemical elements · Bacteriological analysis

Introduction

The deterioration of the natural environment, in particular the aquiferous medium became gradually a world concern. In Algeria, the principal source of satisfaction in the demand for water is the subsoil water because of its easy exploitation. The demographic growth and the modernization of agriculture involve a major problem of deterioration of the quality of this underground source, already in limited quantity. Currently, the rivers of studied area permanently receive the urban rejections and industrialists charged with chemical and organic elements, often toxic. These polluting substances can affect in a dangerous way the public health, if it continues to be poured in nature without preliminary treatment. The mechanism of pollution of underground waters is an evolutionary process in space and time, not easily controllable. The geographical information systems make it possible to carry out a space analysis with an aim of having synthesis charts and of clearly seeing the deterioration of the quality of subsoil waters in the urban grouping of some localities in Western and Southern Algeria (Mostaganem, Mecheria, Naama, Tiaret, Bechar, and Adrar). The chemical composition of groundwater is impacted by several sources, such as atmospheric input, interaction of water with rocks, and human activities (Bahri and Saibi 2010).

The present study deals with the characterization, the classification, and the bacteriological evaluation of 24 groundwater samples collected during 2009 in the six departments in Algeria. We discussed also in the paper the

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possibility of utilization of these groundwaters in drinking, agriculture, and industry. Measurements are made on the concentrations of inorganic nonmetals (HCO_3^- , Cl^- , SO_4^{2-} , PO_4^{3-} , NO_3^- , and pH value), metals (Ca, Cr, Cu, Co, Fe, Na, K, Mg, Mn, Pb, Ni, Sr, and Zn), and the physical parameters of electrical conductivity (EC), total hardness (TH), and dissolved solids (DS).

Materials and methods

Sampling sites and sample collecting

The water samples were collected in September, October, and November of 2009 from the locations presented in Fig. 1 (Table 1). The samples were kept in polyethylene bottles that had been pre-cleaned to remove traces of previous samples, to leach any contaminations from vessel walls and, for trace analysis, to help prevent adsorption of species onto the bottle walls. The 1 L bottles were soaked in 10% nitric acid and washed many times in deionized water and finally washed with a proportion from the sampling water. All the samples were tightly sealed and transported immediately to the laboratory for analysis. The samples designated for heavy metal analyses were filtrated by using 0.45 μm filter membranes. The filtered samples acidified to pH 2 in order to keep the metals in solution. All the samples were stored in the dark at 4°C.

Measurements and analysis

All chemicals used were purchased from Sigma, Aldrich, and E. Merck (A.R., 99.9%). The various parameters were determined using standard procedures (AFNOR 1986, 1999). Measurements were taken in situ pH (pH meter, WTW, Multi Line, Type F/SET-3); conductivity (conductivity meter HI 8033, HANNA Instruments), CO_3^{2-} , and HCO_3^- (titrimetrically) were measured in situ as soon as the samples were collected. In addition, concentrations of Cl^- (Mohr's method), SO_4^{2-} (nephelometric method), PO_4^{3-} (colorimetric method), and NO_3^- (salicylate method) were analyzed after filtration of the water samples by following the procedures recommended by AFNOR (1986, 1999). Ca^{2+} , Mg^{2+} , and the TH were determined by complexometric titration. DS were determined by evaporating progressively 1 L of filtered water sample at 100°C. The residue was dried at 180°C for 2 h (AFNOR 1986, 1999). K, Fe, Cu, Cd, Co, Cr, V, Mn, Na, Sr, Ni, Pb, and Zn were determined with atomic emission spectroscopy (ICP-AE. S; Varian; Liberty Serie II, Observation aviale). The precision of the measurements was checked taking three replicates from the sample and including a blank in each batch.

Statistical analysis

The statistical analysis of the physicochemical parameters was performed using the Matlab program data, version 6.5, Tool Books.

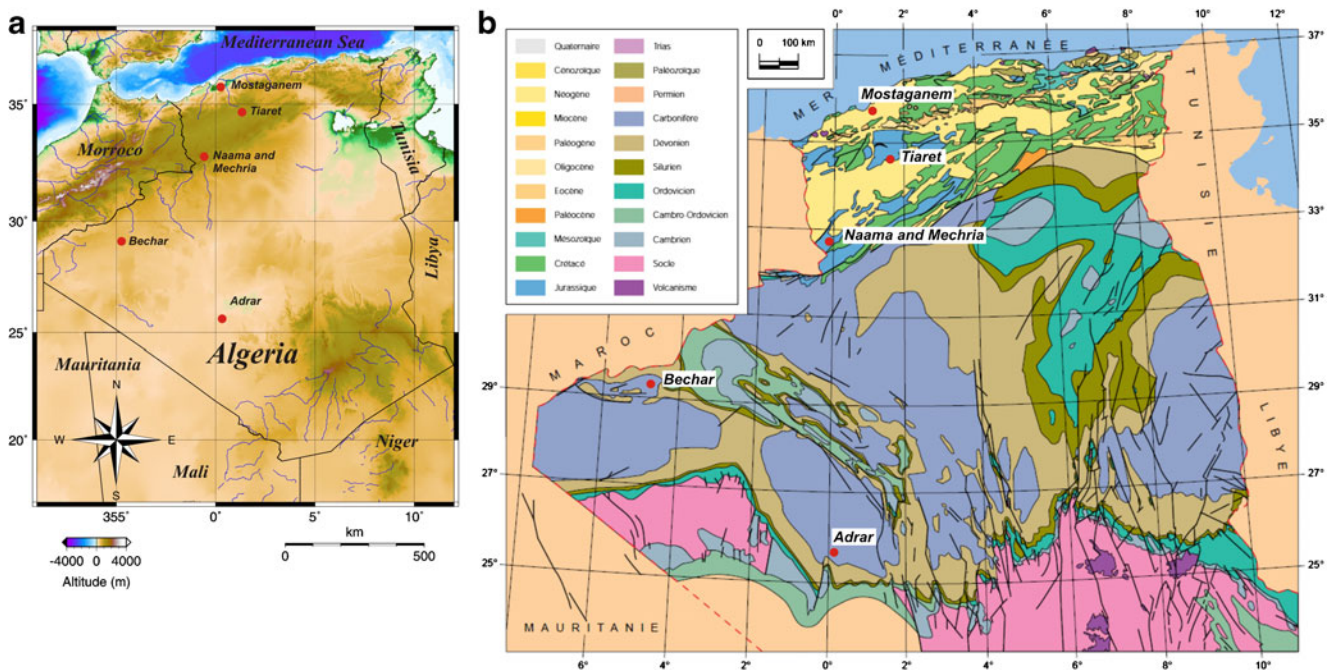


Fig. 1 **a** Geographical location of the sampled waters in the different departments of Algeria. **b** Location of the samples in the Algerian geological map. Mostaganem, Tiaret, Naama, and Mechria are located

in the Alpine Algeria domain in the north. Bechar and Adrar are located in the Saharan Platform in the south of the country (Askri et al. 1995)

Table 1 Location of 24 wells in six department of Algeria and date of sampling

Samples	City	Department	Region	Date of sampling
BM02	Cité Nigren	Mostaganem	Western Algeria	15.09.2009
BM03	Arssa	Mostaganem	Western Algeria	15.09.2009
BM04	Castor (1)	Mostaganem	Western Algeria	16.09.2009
BM07	Tidjditt(1)	Mostaganem	Western Algeria	17.09.2009
BM09	Chemouma	Mostaganem	Western Algeria	18.09.2009
BM10	Sayada (1)	Mostaganem	Western Algeria	17.09.2009
BM11	Achacha (2)	Mostaganem	Western Algeria	15.09.2009
BM15	Nouissy	Mostaganem	Western Algeria	14.09.2009
BM16	Mecheria	Mecheria	Southern Algeria	20.09.2009
BM17	Naama	Naama	Southern Algeria	19.09.2009
BM18	Sougueur	Tiaret	Southern Algeria	19.09.2009
BM20	Igli	Bechar	Southern Algeria	19.09.2009
BM21	Kenadsa	Bechar	Southern Algeria	19.09.2009
BM22	Boukayess	Bechar	Southern Algeria	16.11.2009
BM24	Taghit	Bechar	Southern Algeria	20.11.2009
BM25	Abadla	Bechar	Southern Algeria	06.10.2009
BM26	Benni-Abess	Bechar	Southern Algeria	02.10.2009
BM27	Debdeba	Bechar	Southern Algeria	06.10.2009
BM28	Lahmar	Bechar	Southern Algeria	03.10.2009
BM29	Benni-Ounif	Bechar	Southern Algeria	03.10.2009
BM30	400 Logts	Bechar	Southern Algeria	11.10.2009
BM31	Monghel	Bechar	Southern Algeria	03.11.2009
BM38	Centre-Ville	Adrar	Southern Algeria	03.11.2009
BM41	Kenadsa	Bechar	Southern Algeria	03.11.2009

The bacteriological quality of water

The water while playing an important role in the life, health, access to hygiene, and comfort, is another side of many a vector-borne diseases such as brucellosis, tuberculosis, typhoid fever, cholera, and diarrhea, to name only a few diseases that kill thousands of people each year worldwide (Ouahdi 1995). The physicochemical analysis alone cannot inquire about the status of water quality. Similar samples were subjected to bacteriological analysis at the Laboratory of Microbiology, Department of Biology (University of Mostaganem). Germs sought in this analysis are: total coliforms, fecal coliforms, fecal streptococci, sulfite-reducing *Clostridium*, *Salmonella*, and *Vibrio cholerae*.

Results and discussions

Characterization of the ground water samples

The average values for the various parameters are summarized in Table 2. The accuracy of analyses was obtained

from ion-balance error [15] according to the following equation:

$$e = \frac{rc - ra}{rc + ra} \times 100 \quad (1)$$

where: rc = cation sum as meq/L, ra = anion sum as meq/L, and e = error percent. Applying this equation on the present analyses indicates that the e values (ranged from 1.25 to 4.97) are less than the permissible limit (5%).

The examined ground water samples were characterized by slight to moderate alkalinity (pH values ranged from 7.1 to 8.2) and moderate salinity (DS=213–508 mg/L) except sample (3) with DS=635 mg/L, sample (5) with 642 mg/L, sample (6) with 1023 mg/L, sample (10) with 1,082 mg/L, sample (16) with 1,063 mg/L, sample (18) with 1,273 mg/L, sample (21) with 1,152 mg/L, and sample (23) with 1,085 mg/L.

The relatively high salinity may be due to the lithological composition of these localities and to the leaching and dissolution of soil salts and chemical fertilizers by irrigation waters. At the basin center of the studied area, gypseous conglomerates constitute the base of sandy and gray marls sedimentation.

Table 2 Standard limits and means values (September, October, and November 2009) of physical and chemical (mg/L) parameters of 24 ground water samples in six department of Algeria

Parameters	Samples	pH	EC ^a	HCO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	NO ₃ ⁻	Cl ⁻	TH	Ca	Mg	Fe	Na	K	Co	Cr	Cu	Mn	Ni	Pb	Zn	DS	V	Zn	F ⁻
1	7.1	658	279.2	0.28	62.3	1.22	75.6	297	79.5	20.5	0.17	42.5	24	0.005	0.007	0.021	0.055	0.005	0.007	0.007	0.23	447	0.002	1.45	0
2	6.8	703	265	0.25	65	0.12	62	300	80	21	0.12	40	22	0.006	0.007	0.009	0.065	0.006	0.007	0.007	0.32	465	0.002	1.25	0
3	7.5	922	232	0.25	118	19.5	154	283	69	25	0.25	117	36	0.006	0.007	0.009	0.101	0.007	0.015	0.55	635	0.002	1.19	0	
4	7.8	655	352	0.15	10.2	1.2	15.8	192	35	24	0.13	12	9.2	0.007	0.006	0.02	0.082	0.013	0.022	0.15	457	0.004	1.42	0	
5	7.8	928	274	0.35	169	48.7	444.3	551.6	152.7	42.8	0.15	201	62	0.008	0.009	0.022	0.098	0.007	0.014	0.73	642	0.003	0.78	0	
6	8	1,475	405	0.05	175	30	184.2	157	25.8	10.6	0.06	137	40.2	0.004	0.007	0.009	0.028	0.015	0.015	0.17	1,023	0.001	0.89	0	
7	7.4	652	282	0.38	63.2	1.9	79.5	312	85	23.5	0.27	51	32	0.006	0.007	0.017	0.055	0.013	0.014	0.35	458	0.001	0.56	0	
8	7.5	623	314	0.17	10.5	1.3	16.5	180	35	24.1	0.16	18	15.8	0.007	0.006	0.014	0.047	0.018	0.019	0.45	432	0.001	0.47	0	
9	7.2	736	276	0.22	64	6.5	65	282	77	22.5	0.17	42	24	0.006	0.005	0.011	0.03	0.008	0.031	1.25	508	0.002	1.12	0	
10	7.9	1,537	359	0.09	181.8	25.9	52.6	170	41.2	34.2	0.19	132	42	0.007	0.005	0.01	0.054	0.020	0.026	0.65	1,082	0.002	0.45	0	
11	7.1	683	252	0.17	52	0.1	62	296	79	23	0.15	42	24	0.006	0.005	0.025	0.075	0.024	0.012	0.22	475	0.001	1.15	0	
12	7.3	712	274.3	0.38	78	0.3	73.3	350.8	92.1	32.1	0.19	51.8	13.8	0.006	0.005	0.015	0.055	0.012	0.022	0.16	494	0.001	0.78	0	
13	7.1	314	200	0.04	8	1.2	18	185	42	26.8	0.18	17.8	9.5	0.006	0.005	0.011	0.065	0.012	0.019	0.14	213	0.001	1.12	0	
14	7.1	617	214	0.12	91	25	70.1	144	36.2	21.2	0.17	50	34	0.007	0.006	0.028	0.108	0.013	0.017	1.12	458	0.001	0.95	0	
15	7.7	647	335	0.05	7	0.8	12.5	187	35	24.2	0.17	14.2	9.2	0.005	0.007	0.012	0.082	0.012	0.015	0.23	442	0.001	0.48	0	
16	7.7	1,507	407	0.02	162.9	23	178.7	140	17.9	21.3	0.14	123	33.5	0.002	0.006	0.012	0.019	0.013	0.012	0.37	1,063	0.001	0.59	0.02	
17	8.1	555	364	0.18	11	2.5	22	332	82	26.3	0.14	14.6	18	0.007	0.007	0.019	0.105	0.012	0.019	0.20	389	0.001	0.25	0.12	
18	7.9	1,657	487	0.21	198.9	43	201.3	170	37.9	31.3	0.08	173	53.5	0.006	0.006	0.012	0.039	0.011	0.012	0.22	1,273	0.001	0.43	0.10	
19	7.2	600	200	0.18	80.2	14.7	58.7	102	24.2	10.2	0.07	38	23	0.006	0.005	0.013	0.014	0.008	0.018	1.25	432	0.001	0.37	0.15	
20	7.1	664	294	0.22	81.9	1.7	79.5	335	93.3	37.3	0.12	59	19.1	0.004	0.007	0.021	0.045	0.018	0.021	0.55	464	0.001	0.41	0.07	
21	8	1,658	368	0.15	201.2	28	51.24	198.7	35	28	0.14	152	48	0.002	0.005	0.013	0.034	0.010	0.016	0.76	1,152	0.001	0.89	0.15	
22	8.2	753	384	0.25	19.2	15.4	23.3	205.5	46.8	36.5	0.16	14.5	21.2	0.007	0.006	0.02	0.042	0.014	0.010	0.35	470	0.001	1.24	0.20	
23	7.9	1,562	435	0.08	192.9	35	200	167	35	12.1	0.09	147	48.5	0.002	0.006	0.012	0.032	0.018	0.022	0.25	1,085	0.001	0.58	0.05	
24	8.1	545	359.3	0.05	7.8	1.8	13.5	307.5	79.2	29.7	0.12	18	8.8	0.005	0.005	0.019	0.005	0.012	0.019	0.20	382	0.003	1.12	0.12	
WHO ^b	6.5–8.5	1,000	300	0.5	250	45	250	500	150	50	0.2	150	12		0.05	1	0.05	0.05	0.05	0.5					1.00

WHO World Health Organization

^a EC in $\mu\text{S}/\text{cm}$

^b Highest permissible limits

The utilization of nitrogen, phosphorous, and potash (potassium) fertilizers (local products of Algeria) are heavily used by farmers in large quantities (Bahri and Saibi 2010). Especially, the water for irrigation in some agricultural areas comes from the rivers that are affected by the waters coming from the sanitation network (Bahri and Saibi 2010).

The EC ranged from 314 to 1,658 $\mu\text{S}/\text{cm}$; these values are related to total DS. The primary anions in the groundwater samples are, in order, $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^-$, and the primary cations are $\text{Ca} > \text{Na} > \text{Mg} > \text{K}$. These are the rankings in most localities due to the lithological composition of this region (Polvêche 1960).

High concentrations of nitrate (30–48.7 mg/L) in different localities (sample nos. 3, 6, 18, and 23) result from the presence of cultivation zones surrounding these samples, where ammonium nitrate is used as a chemical fertilizer. The increases in other anions and cations occur due to the concentration of these ions by recycling the groundwater as irrigation water. This continuous cycle of groundwater is a result of the leaching and washing processes of the soil.

The phosphate concentrations in most of the ground water samples (0.02–0.1 mg/L) were relatively low, which may be due to the lithologic composition, but relatively high concentrations were measured at some of the cultivation regions (0.2–0.38 mg/L); these high values were due to the effect of the phosphate fertilizers.

With respect to trace metals, their concentrations (Co, 0.002–0.007 mg/L; Cr, 0.004–0.007 mg/L; Cu, 0.009–0.02 mg/L; Fe, 0.06–0.27 mg/L; Pb, 0.007–0.031 mg/L; Mn, 0.005–0.108 mg/L; Ni, 0.005–0.024 mg/L; V, 0.001–0.004; Zn, 0.25–1.45 mg/L; and F^- , 0–0.20 mg/L) are within the permissible limit (AFNOR 1986). Relatively low values of trace elements in these samples indicate that the samples of groundwater under study are far from pollution sources, so these values represent ordinary or background conditions (for the lithologic composition of these regions).

Classification of the groundwater samples

Groundwater samples were classified according to total DS (AFNOR 1999). Most samples (19) are freshwater samples, but the water from the five samples (nos. 10, 12, 14, 16, and 18) is brackish (Table 3). With respect to water hardness (Handler 1968), the water samples were classified as moderately hard water (predominant class, 17 samples), very hard water (sample nos. 4, 10, 12, 14, 16, and 18), and soft water (sample no. 24).

Based on Cl^- , SO_4^{2-} , and $\text{HCO}_3^- + \text{CO}_3^-$ concentrations (Journal de la République Algérienne Démocratique et Populaire (JORADP) 2000), the samples were classified as normal chloride (<7 meq/L), normal sulfate (<2.5 meq/L),

and normal carbonate and bicarbonate (3–7.86 meq/L) water types (Table 3). According to base exchange (Matthes 1982), the predominant water type of sample nos. 4, 5, 7, 8, 10, 14, 16, 17, 18, 20, 22, and 23 is Na– SO_4 , while the Na– HCO_3 water type is predominant in other samples (nos. 1, 2, 3, 6, 9, 11, 12, 13, 15, 19, 21, and 24). The classification of water samples into two types (Na– SO_4 and Na– HCO_3) is due to the geological composition of these regions. The presence of a calcareous sandstone crust on the surface could explain the presence of bicarbonate in the sampling waters in the studied area. The presence of sulfate is explained by the dissolution of anhydrite in the circulating waters.

The values of hydrochemical parameters $r\text{K}/r\text{Cl}$, $r\text{Na}/r\text{Cl}$, $r\text{Mg}/r\text{Cl}$, $r\text{Ca}/r\text{Cl}$, and $r\text{SO}_4/r\text{Cl}$ of the groundwater samples under study (24 samples; $r=\text{meq}/\text{L}$ for these parameters in the sample) are greater than the standard values of sea water (Polvêche 1960). This is an indication of the meteoric genesis (Table 3) of groundwater in these localities. According to the classification of the meteoric genesis of groundwater into two types, the sample nos. 1, 4, 5, 7, 8, 12, 14, 16, 17, 18, 20, 21, 22, and 23 are characterized by deep meteoric water percolation, and the sample nos. 2, 3, 6, 9, 10, 11, 13, 15, 19, and 24 are characterized by surface and shallow meteoric water percolation types.

Evaluation of the groundwater samples

Suitability of the groundwater for drinking and domestic purposes

According to the World Health Organization (WHO; 2004) standards, results of the sample analyses indicate that the samples are suitable for drinking and domestic uses.

Suitability of the groundwater for drinking and domestic purposes

The sodium adsorption ratio (SAR) is used as an index referring to the suitability of water for irrigation. If we have high amounts of sodium in the soils, this could impact plant growth by (1) specific toxicity to sodium-sensitive plants, (2) nutrient deficiencies or imbalances, (3) high pH, and (4) spread of soil particles that causes poor physical condition of soil. A SAR plot was added, which presents the salinity hazard vs the sodium hazard. It is represented as follows:

$$\text{SAR} = \text{Na}^+ / [(\text{Ca}^{2+} + \text{Mg}^{2+}) / 2]^{1/2} \quad (2)$$

The ionic symbols indicate concentrations of the ions in the irrigation water in milliequivalents per liter (Ciaccio 1971). The calculation of the SAR for a given water source provides a useful index of the sodium hazard to soils and crops. Applying this index on the sample yields excellent

Table 3 Classification of ground water samples according to different criteria Na⁺ K⁺ SO₄²⁻ Cl⁻

Criteria samples	Cl ⁻		HCO ₃ ⁻ + CO ₃ ²⁻		SO ₄ ²⁻		Hardness		DS		Base exchange		Genèse météorique		Sat. index		
	meq/L	Class	meq/L	Class	meq/L	Class	meq/L	Class	mg/L	Class	r, meq/L ^a	Class	r, meq/L ^b	Class	Values ^c	SAR	
1	4.4	Normal	6	Normal	1.47	Normal	8.50	Mod hard	558	Fresh	>1	B	<1	Deep	0.30	1.95	Good
2	4.36	Normal	5.87	Normal	1.5	Normal	9.00	Mod hard	648	Fresh	>1	B	>1	Surface	0.42	1.67	Good
3	5.72	Normal	6.37	Normal	1.58	Normal	9.00	Mod hard	675	Fresh	>1	B	>1	Surface	0.51	2.11	Good
4	7	Normal	7.18	Normal	1.88	Normal	11.00	Very hard	725	Fresh	<1	A	<1	Deep	0.67	2.53	Good
5	6	Normal	6.87	Normal	1.41	Normal	8.6	Mod hard	666	Fresh	<1	A	<1	Deep	0.45	2.34	Good
6	5.86	Normal	6.17	Normal	0.59	Normal	9.00	Mod hard	615	Fresh	>1	B	>1	Surface	0.30	2.34	Good
7	3.72	Normal	4.47	Normal	0.86	Normal	8.00	Mod hard	575	Fresh	<1	A	<1	Deep	0.35	1.78	Good
8	2.85	Normal	4	Normal	0.84	Normal	6.70	Mod hard	589	Fresh	<1	A	<1	Deep	0.29	1.85	Good
9	2.18	Normal	3.44	Normal	0.55	Normal	6.00	Mod hard	472	Fresh	>1	B	>1	Surface	0.25	1.33	Good
10	5.71	Normal	6.44	Normal	0.55	Normal	13	Very hard	1045	Brakish	<1	A	>1	Surface	0.31	3	Good
11	3	Normal	3.93	Normal	0.14	Normal	7.60	Mod hard	437	Fresh	>1	B	>1	Surface	-0.09	1.75	Good
12	3.97	Normal	7.92	Normal	0.74	Normal	18.40	Very hard	1345	Brakish	>1	B	<1	Deep	0.39	3	Good
13	1.93	Normal	3	Normal	0.2	Normal	6.00	Mod hard	450	Fresh	>1	B	>1	Surface	-0.15	1.1	Good
14	5.67	Normal	6.75	Normal	1.97	Normal	15.6	Very hard	1045	Brakish	<1	A	<1	Deep	0.46	2.9	Good
15	3.31	Normal	6	Normal	0.45	Normal	8.50	Mod hard	667	Fresh	>1	B	>1	Surface	-0.08	1.63	Good
16	4.64	Normal	7.86	Normal	2.42	Normal	17.50	Very hard	1210	Brakish	<1	A	<1	Deep	0.48	2.57	Good
17	3.91	Normal	4.5	Normal	1.92	Normal	8.50	Mod hard	645	Fresh	<1	A	<1	Deep	0.41	2.31	Good
18	3.8	Normal	7.5	Normal	2.3	Normal	14.50	Very hard	1051	Brakish	<1	A	<1	Deep	0.55	2.79	Good
19	4.81	Normal	5.41	Normal	0.7	Normal	9.10	Mod hard	687	Fresh	>1	B	>1	Surface	0.38	2.1	Good
20	4.55	Normal	5.17	Normal	2.11	Normal	7.50	Mod hard	447	Fresh	<1	A	<1	Deep	0.25	2.4	Good
21	4.32	Normal	5.44	Normal	2.3	Normal	6.50	Mod hard	575	Fresh	>1	B	<1	Deep	0.46	2.66	Good
22	2.64	Normal	4.72	Normal	0.67	Normal	4.62	Mod hard	447	Fresh	<1	A	<1	Deep	0.31	1.91	Good
23	5.50	Normal	7.67	Normal	0.67	Normal	10.00	Mod hard	775	Fresh	<1	A	<1	Deep	0.58	2.89	Good
24	4.33	Normal	5.45	Normal	0.71	Normal	2.30	Soft	324	Fresh	>1	B	>1	Surface	0.33	1.62	Good

A Na-SO₄ type, B Na-HCO₃ type

$$^a r = \frac{Na^+ + Cl^-}{SO_4^{2-} + Na^+} \text{ meq/L}$$

$$^b r = \frac{SO_4^{2-} + Na^+ - Cl^-}{SO_4^{2-}} \text{ meq/L}$$

^c - values that indicate that they are suitable for industrial purposes, + values that indicate that they are unsuitable for industrial purposes

results (SAR values ranged from 1.0 to 3), such that the sampled waters can be recommended for irrigation purposes on any soil type (Table 3).

Suitability of the groundwater for industrial purposes

The saturation index is an important factor introduced to test water quality (Rhoades and Bernstein 1971), indicating the extent to which waters flowing through pipes will precipitate or dissolve calcium carbonate. This index is defined as the actual pH of water (pH_w) minus the calculated pH at which the water would be in equilibrium with calcium carbonate (pH_c) as follows:

$$\text{Sat. Index} = \text{pH}_w - \text{pH}_c \quad (3)$$

pH_c is calculated by the following equation:

$$\text{pH}_c = (\text{pK}_2 - \text{pK}_s) + \text{pCa}^{2+} + \text{pAlk}, \quad (4)$$

From the negative logarithm of the second dissociation constant of H₂CO₃ (pK₂), the solubility product constant of calcium carbonate (pK_s), the molar concentration of CO₃²⁻ plus HCO₃⁻ (pAlk). If the saturation index is positive, CaCO₃ will precipitate, and if it is negative, CaCO₃ will dissolve. Applying this index to the sample data (Table 3) showed that sample nos. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 17, 18, 19, 20, 21, 22, 23, and 24 exhibit a tendency for CaCO₃ precipitation (positive values), while the other samples, nos. 11, 13, and 15, exhibit a tendency for the dissolution of CaCO₃ (negative values).

The statistical analysis of the physicochemical parameters

A statistical analysis of the groundwater samples (Table 4) exhibits excellent positive correlation values ($r > 0.9$) between EC, DS, and SO₄²⁻ and also, high positive correlation ($r = 0.84$) between EC and Na. This is due to the conductivity being dependent on total DS, the main constituents of which are Na and SO₄²⁻ in our samples.

Also excellent correlation value ($r = 0.95$) between Na and SO₄²⁻, indicate that the main water type in samples is Na–SO₄²⁻. High positive correlations (r ranged from 0.95 to 0.79) are observed between Na and SO₄²⁻, Na and NO₃⁻, K and SO₄²⁻, and Na and Cl⁻; this indicates that these soluble salts are predominant in the most samples. Also, high positive correlations (r ranged from 0.99 to 0.55) are observed between Ca and TH, Mg and TH, and Ca and Mg; this is due to the presence of Ca and Mg as dolomite (CaMg CO₃) in sandstone, and in addition, the Ca and Mg are main causes for hardness (TH). The positive and significant correlation coefficient values between Ca and PO₄³⁻ ($r = 0.69$) may be due to the presence of chlorapatite mineral [Ca₅ (PO₄)₃ Cl] in the rocks, which is surrounding

these wells (Fig. 2). Cl⁻ shows positive correlation with K ($r = 0.79$); this may be due to the presence of these metals as chloride in some samples. High positive correlation coefficients ($r = 0.90$ – 0.76) are observed between electric conductivity and SO₄²⁻, Na, K, and NO₃⁻ and indicate the high mobility of these ions. The data show positive correlation coefficient between the chemical in the well waters (Zn and K, Zn and Na, Mg and Mn, and Ca and Fe); this indicates that these metals may exist as soluble nitrates, sulfates, chlorides, and bicarbonates or humates (Rashed et al. 1995).

Bacteriological quality

The bacteriological analysis of the 24 samples showed that five samples (nos. 1, 8, 12, 13, and 18) are contaminated. Table 5 below includes all the germs encountered.

The results show that contamination of waters studied coliforms differs from one region to another (Table 5). The sample nos. 3, 5, 8, 12, 14, 16, 17, 22, and 23 are more contaminated than the other samples with, respectively, 42, 22, 24, 34, 54, 15, 42, 42, and 54 CT/100 ml. As for fecal coliforms, no germ was detected in the sample nos. 1, 4, 6, 7, 5, 10, 13, 15, 19, 20, 21, and 24. The highest contamination with these germs has been observed (12 to 19 CF/100 ml) in the following samples: nos. 3, 5, 8, 14, 17, 22, and 19. For fecal streptococci, low contamination was revealed in sample nos. 3, 5, 8, 12, 14, 16, 17, 22, and 23. No withdrawals were positive for the spores of sulfite-reducing *Clostridium*, nor for the genus *Salmonella*, or *V. cholerae* for the species in all samples studied.

According to Champiat and Larpent (1988), the fecal contamination is due to infiltration of fecal organic matter. Indeed, the composition of the bacterial flora depends on the richness of nutrients from human waste and animals. The number of the total coliforms and the fecal coliforms in the waters analyzed sometimes exceeding standards recommended by WHO (2004) and the Algerian standards (PNAE-DD 2002; 10 CT in 100 ml of the sample and 0 CF in 100 ml of the sample) shows the pollution of sample nos. 3, 5, 8, 12, 14, 16, 17, 22, and 23. These results confirm the impact of discharges of domestic sewage and industrial.

Conclusions

The results obtained from the 26 analyzed samples show that the groundwaters in some localities in Western and Southern Algeria area exhibit slight to moderate alkalinity with medium salinity, due to the characteristics of the superficial aquifer lithology. The samples of groundwater in some localities in Western and Southern Algeria area are far

Table 4 Correlation coefficients of physicochemical parameters for 24 groundwater samples

	pH	EC	Cl ⁻	HCO ³⁻	TH	NO ₃ ⁻	PO ₄ ³⁻	SO ₄ ²⁻	Ca ²⁺	Mg ²⁺	Fe	Co	Cr	Cu	Mn	Ni	Pb	Zn	Sr	V	F	DS	Na ⁺	
EC	0.50																							
Cl ⁻	0.16	0.46																						
HCO ₃ ⁻	0.77	0.71	0.17																					
TH	-0.11	-0.30	0.41	-0.25																				
NO ₃ ⁻	0.45	0.76	0.78	0.42	-0.08																			
PO ₄ ³⁻	-0.28	-0.25	0.23	-0.31	0.66	-0.08																		
SO ₄ ²⁻	0.26	0.90	0.67	0.41	-0.10	0.85	-0.05																	
Ca ²⁺	-0.21	-0.36	0.38	-0.34	0.99	-0.10	0.69	-0.12																
Mg ²⁺	0.21	-0.07	0.16	0.05	0.57	0.09	0.37	-0.03	0.55															
Fe	-0.22	-0.32	-0.17	-0.44	0.30	-0.31	0.41	-0.26	0.31	0.31														
Co	-0.13	-0.54	-0.07	-0.41	0.32	-0.16	0.42	-0.45	0.37	0.37	0.31													
Cr	0.05	-0.04	0.58	0.02	0.53	0.23	0.36	0.09	0.48	0.18	0.08	0.16												
Cu	-0.10	-0.43	-0.02	-0.23	0.35	-0.13	0.24	-0.31	0.38	0.30	0.08	0.32	0.15											
Mn	-0.17	-0.34	0.09	-0.38	0.36	-0.05	0.26	-0.21	0.34	0.25	0.45	0.55	0.48	0.37										
Ni	0.16	0.16	-0.19	0.25	-0.25	-0.06	-0.35	0.01	-0.24	0.03	-0.08	-0.10	-0.31	0.20	-0.09									
Pb	0.08	-0.02	-0.19	-0.03	-0.08	-0.07	-0.18	-0.02	-0.06	0.04	0.04	0.06	-0.43	-0.16	-0.12	0.26								
Zn	-0.26	-0.01	0.09	-0.41	-0.09	0.26	0.10	0.21	-0.01	-0.07	0.02	0.13	-0.15	0.05	-0.05	-0.24	0.35							
Sr	-0.04	-0.09	-0.22	0.12	-0.01	-0.23	-0.02	-0.21	-0.03	-0.09	-0.17	-0.08	0.01	0.02	-0.14	0.26	-0.11	-0.18						
V	0.12	-0.15	0.14	-0.05	0.37	-0.02	0.10	-0.13	0.34	0.23	0.04	0.33	0.18	0.14	0.16	-0.31	0.15	-0.02	-0.13					
F	0.48	0.11	-0.18	0.34	-0.17	0.14	-0.05	0.01	-0.17	0.14	-0.39	-0.15	-0.23	0.09	-0.39	-0.06	-0.10	0.11	0.10	0.10	-0.21			
DS	0.48	1.00	0.47	0.71	-0.31	0.77	-0.25	0.91	-0.36	-0.07	-0.33	-0.52	-0.05	-0.41	-0.34	0.15	-0.01	0.00	-0.11	-0.16	0.11			
Na ⁺	0.34	0.84	0.82	0.41	0.09	0.90	0.02	0.95	0.05	0.13	-0.20	-0.32	0.26	-0.27	-0.09	-0.04	-0.07	0.12	-0.21	-0.01	-0.04	0.84		
K ⁺	0.29	0.77	0.79	0.33	0.09	0.92	0.13	0.91	0.08	0.08	-0.14	-0.19	0.31	-0.12	0.00	-0.06	-0.14	0.26	-0.16	-0.06	0.02	0.77	0.94	

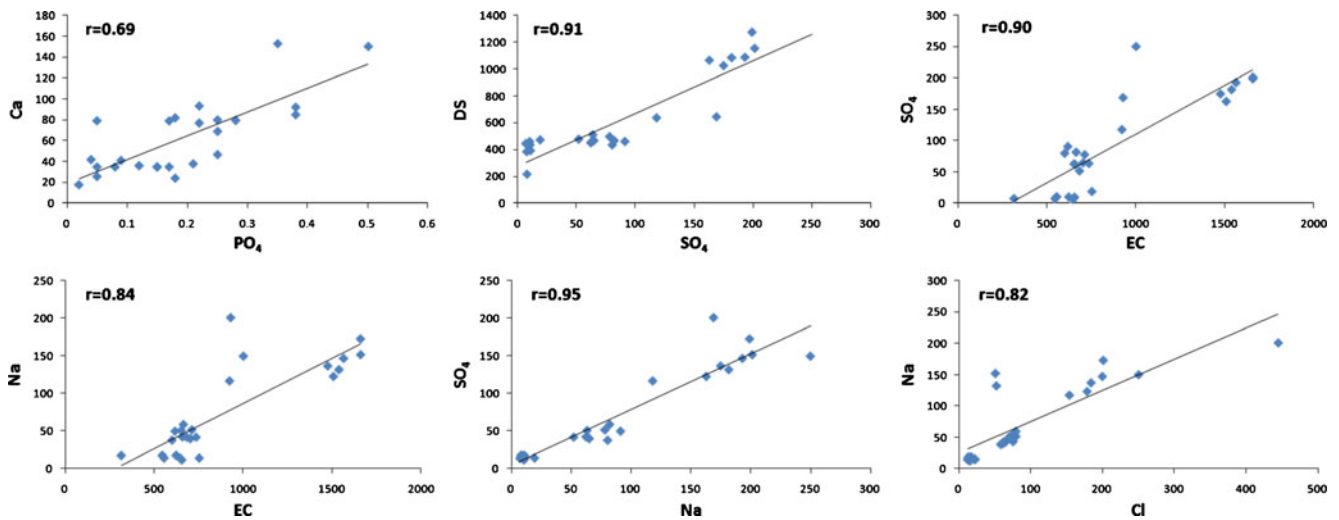


Fig. 2 Statistical relations with high correlation coefficient between various ions for 24 groundwater samples

Table 5 Results of bacteriological tests

Germ samples	Total coliforms 37°C/100 mL	Fecal coliforms 44°C/100 mL	Fecal streptococci 37°C/100 mL	Sulfite-reducing <i>Clostridium</i> 20 mL	<i>Salmonella</i> 100 mL	<i>Vibrio cholerae</i> 100 mL
1	–	–	–	–	–	–
2	–	–	–	–	–	–
3	42	19	3	–	–	–
4	–	–	–	–	–	–
5	22	17	2	–	–	–
6	–	–	–	–	–	–
7	–	–	–	–	–	–
8	24	17	2	–	–	–
9	7	2	–	–	–	–
10	–	–	–	–	–	–
11	3	1	–	–	–	–
12	34	9	2	–	–	–
13	–	–	–	–	–	–
14	54	17	2	–	–	–
15	–	–	–	–	–	–
16	15	4	1	–	–	–
17	42	12	2	–	–	–
18	5	2	–	–	–	–
19	–	–	–	–	–	–
20	–	–	–	–	–	–
21	–	–	–	–	–	–
22	42	17	2	–	–	–
23	54	19	2	–	–	–
24	–	–	–	–	–	–
PNAE-DD (2002) Algerian Standards	< 10/100 mL	10/100 mL	0/100 mL	0/20 mL	0/100 mL	0/100 mL
WHO (2004)	10/100 mL	0/100 mL	0/100 mL	0/20 mL	0/100 mL	0/100 mL

– not detected

from the obvious pollution sources. The samples were classified as moderately hard water, normal chloride (<6 meq/L), normal sulfate (<2 meq/L), and normal carbonate and bicarbonate (3.36–7.13 meq/L) water types. The predominant water types (according to base exchange) of samples are Na–SO₄, and Na–HCO₃. Values of the hydrochemical parameters indicate the meteoric genesis of these samples (surface, shallow, and deep meteoric water percolation). The groundwaters in some localities in Western and Southern Algeria area can be concluded to be suitable for drinking and domestic, agricultural, and industrial uses. Statistical analysis confirms the results of the chemical analyses and exhibits good and interesting correlations that lead to the interpretation these results.

The presence of indicator organisms of fecal contamination and the presence of other bacteria responsible for infections transmitted by water is undoubtedly a threat to the inhabitants of sample nos. 1, 8, 12, 13, and 18. A monitoring network must be taken to avoid any health risk.

References

- AFNOR (1986) Eaux, méthodes d'essais, recueil de normes Française. (in French language)
- AFNOR (1999) La qualité de l'eau. Recueil Environnement. AFNOR Edition, volume 3. (in French language)
- Askri H, Belmecheri A, Benrabah B, Boudjema A, Boumendjel K, Daoudi M, Drid M, Ghalem T, Docca AM, Ghandriche H, Ghomari A, Guellati N, Khennous M, Lounici R, Naili H, Takherist D, Terkmani M (1995) Geology of Algeria. In: Delsol D (ed) Well Evaluation Conference Algeria. Schlumberger, Houston, TX, pp 1–93
- Bahri F, Saïbi H (2010) Characterisation, classification, and evaluation of some groundwater samples in the Mostaganem area of northwestern Algeria. *AJG* 3(1):79–89
- Champiat D, Larpent JP (1988) Biologie des eaux; méthodes et techniques. Masson Edition, Paris, pp 374. (in French language)
- Ciaccio LL (1971) The water and water pollution handbook, 1st edn. Marcel Dekker, New York, p 149
- Journal de la République Algérienne Démocratique et Populaire (JORADP) (2000) Les eaux minérales naturelles. N°51 du 20 Août 2000. (in French language)
- Handler J (1968) Le livre de la santé « Médecines parallèles, thermalisme, le médecin et son malade », Monte-Carlo: Rencontre Edition, André Sauret. 19, 113. (in French language)
- Matthes G (1982) The properties of groundwater. Wiley, New York, p 397
- Ouahdi A (1995) Les maladies à transmission hydrique—santé plus Alger N°45. (in French language)
- PNAE-DD (2002) Plan d'Actions pour l'Environnement et le Développement Durable (PNAE-DD). Ministère de l'Aménagement du territoire et de l'Environnement, pp 148. (in French language)
- Polvêche J (1960) Contribution à l'étude géologique de l'Ouarsenis Oranis Tome I et II. Bulletin N°24. Publications du service de la carte géologique de l'Algérie. (in French language)
- Rashed MN, Awadallah RM, Soltan ME, Hassan SM (1995) Interrelationship between major, minor and trace elements in Kalabsha wells and High Dam Lake waters. *J Environ Sci Health, A: Environ Sci Eng* 30(10):2205–2219
- Rhoades JD, Bernstein L (1971) Chemical, physical and biological characteristics of irrigation and soil waters. In: Ciaccio LL, Richards LA (eds) Water and water pollution handbook, 1. Marcel and Dekker Incorporation, N.Y, pp 141–215
- World Health Organization (WHO) (2004) Guidelines for drinking-water quality. Vol. 1. Recommendation, 3rd edn. World Health Organization, Geneva