Full Length Research Paper

Groundwater quality and its suitability for drinking and agricultural use in Ain Azel plain, Algeria

L. Belkhiri[1]*, A. Boudoukha[2] and L. Mouni[3]

[1]Department of Hydraulics, University of Hadj, Lakhdar 05000, Batna, Algeria.
[2]Research Laboratory in Applied Hydraulics, University of Hadj, Lakhdar 05000, Batna, Algeria.
[3]Laboratory of Technology of Materials and Genius of Precede, University of Bejaia, Targa- Ouzemour 06000, Algeria.

Hydrochemistry of groundwater in Ain Azel plain, Algeria was used to assess the quality of groundwater for determining its suitability for drinking and agricultural purposes. Interpretation of analytical data shows that Ca-Mg-HCO_3 and Ca-Mg-Cl-SO_4 are the dominant hydrochemical facies in the study area. Factor analysis generated three significant factors. Factor 1 includes EC, Ca^{++}, Mg^{++}, Na^+ and Cl^-, factor 2 has high loading values of K^+ and HCO_3^- and the factor 3 includes SO_4^- and NO_3^-. The US salinity diagram illustrates that most of the samples fall in C3S1 quality with high salinity hazard and low sodium hazard. The groundwater of Ain Azel plain is low concentration of nitrogenous elements (NO_3^- and NO_2^-) and the higher concentration of trace elements (Pb^{++} and Fe^{++}) may entail various health hazards.

Key words: Groundwater, drinking and irrigation water quality, factor analysis, US salinity laboratory diagram, Ain Azel, Algeria.

INTRODUCTION

The Ain Azel alluvial plain of northern Algeria is a region of intensive agriculture. Over the few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for agriculture and domestic activities. Due to inadequate availability of surface water, to meet the requirement of human activities, groundwater remains the only option to supplement the ever-increasing demand of water. Groundwater is the primary source of water for domestic, agricultural and industrial uses in many countries, and its contamination has been recognized as one of the most serious problems in Algeria. Each groundwater system in an area is known to have a unique chemistry, which is acquired as a result of chemical alteration of the meteoric water recharging the system (Back, 1966; Drever, 1982). The chemical alteration of meteoric water depends on several factors such as soil-water interaction, dissolution of mineral species, duration of solid-water interaction and anthropogenic sources (Stallard and Edmond, 1983; Faure, 1988; Subba Rao, 2002). Importance of hydrochemistry of groundwater has led to a number of detailed studies

on geochemical evolution of groundwaters (Garrels, 1967; Paces, 1973; Sarin et al., 1989). Presentation of geochemical data in the form of graphical charts as the US Salinity diagram and Wilcox salinity diagram help to recognize the various hydrochemical types in a groundwater system. It further helps in evaluation of the suitability of groundwater for irrigation purposes. Hence, the present work had the objective of understanding the spatial and temporal distribution of hydrochemical constituents of groundwater related to its suitability for agriculture and domestic use. The trace elements and nitrogenous ions elements in this water are determined to check the quality of the water.

DESCRIPTION OF THE STUDIED AREA

The area of study is located in the East of Algeria characterized by a semi-arid climate and an average precipitation and temperature of about 296 mm/year and 15.2°C respectively (Belkhiri, 2005). Most of its inhabitants are concentrated in the town of Ain Azel with more than 30000 inhabitants working mainly in the production of cereals (barley, corn etc.). According to many authors (Savornin, 1920; Galcon, 1967; Guiraud, 1973; Vila, 1980) the area of concern is distinguished by two sets.

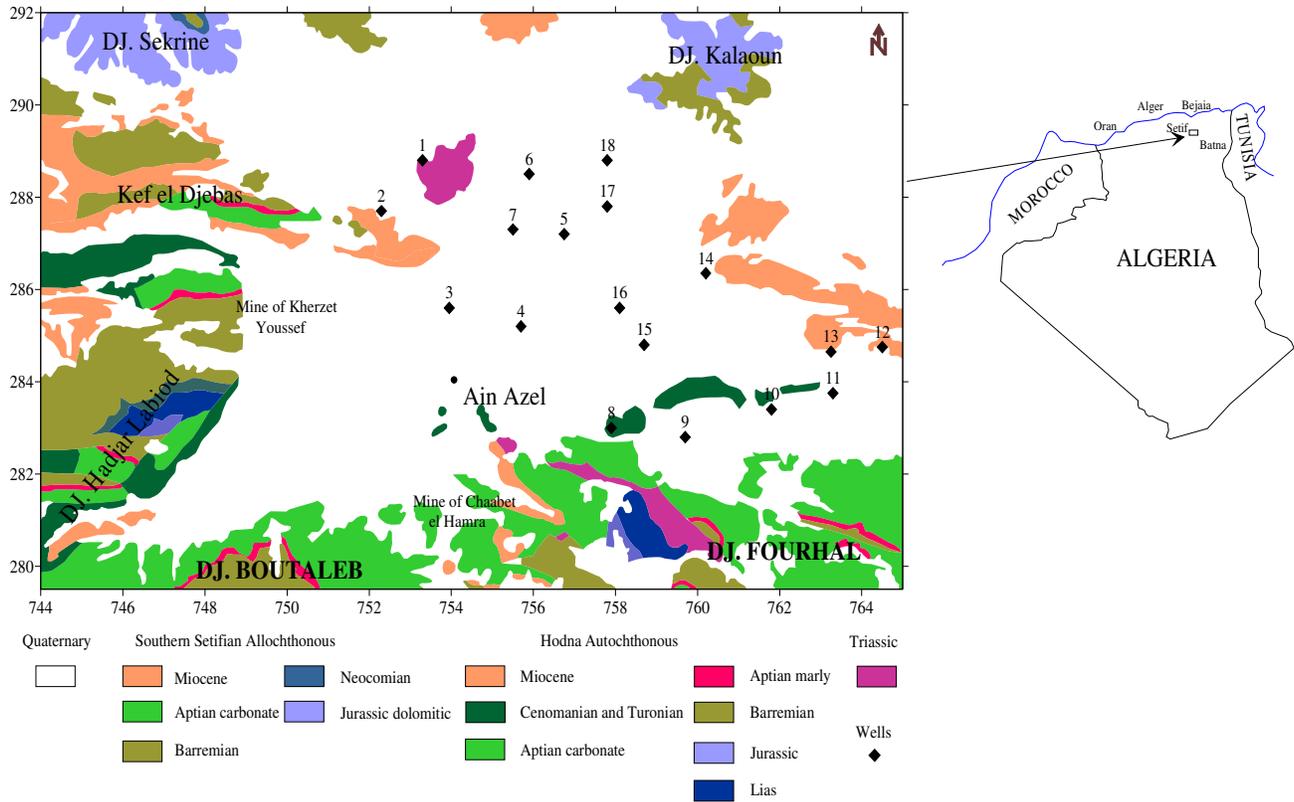*Corresponding author. E-mail: belkhiri_Laz@yahoo.fr.

Figure 1. Map showing the water sampling locations and geology of the study area.

In the South, carbonated autochthonous of Jurassic and Cretaceous age are mainly observed in the Hodna mounts constituted by Djebels Boutaleb, Djebel Hadjar Labiod and Fourhal (Figure 1). In the North, the nappe domain is represented by the Southern Setifian allochthonous formed by the inferior unit of Djebel Kalaoun and the flake of Djebel Sekrine. The lithostrati-graphic study of Ain Azel area makes it possible to identify the following two formations (Table 1). The first is a carbonated formation of about 700 m thick presenting fracture porosity and constitutes the Barremian. The second is an alluvial one of about 250 m thick corresponding to Mio-Plio-Quaternary formation with interstitial porosity.

The studied area is situated in the alluvial plain of the Mio-Plio-Quaternary (Figure 1) showing a very hete-rogeneous continental detrital sedimentation (Attoucheik, 2006; Belkhiri, 2005; Boutaleb, 2001). This aquifer is directly fed by the streaming water coming from different relief's surrounding the inter-mountainous depression of Ain Azel. These main outlets are represented by Sebkhet el Hamiet and Chott el Beida. The plain hosts a large number of water-wells with depths varying from 8 to 38 m. Most of these wells supply water for drinking and irrigation. The pumping tests on different wells showed high transmissivity (30 - 36 m^2/day) indicating high potential aquifer systems (Belkhiri, 2005).

MATERIALS AND METHODS

Sample collection and analysis

Eighteen wells currently in use were selected based on the preliminary field survey carried out to understand the overall distribution of the various types of wells in the studied area (Figure 1). The selected wells are used for domestic, agricultural, and domestic/agricultural purposes and were found uniformly distributed over the area of concern. Groundwater samplings were performed three times in 2004: June, September, and December and a total of 54 groundwater samples were collected during this period. The samples were collected after 10 min of pumping and stored in Polyethylene bottles at 10°C. Immediately after sampling, pH, electrical conductivity (EC) and total dissolved solids (TDS) were measured in the field using a multi-parameter WTW (P3 MultiLine pH/LF-SET).

Thereafter the samples were analyzed in the laboratory for their chemical constituents such as calcium, magnesium, sodium, potassium, chloride, bicarbonate, sulfate, nitrate, nitrite, lead, iron, zinc and copper. This was achieved using standard methods as suggested by the American Public Health Association (APHA, 1989, 1995a, 1995a). Ca^{++}, Mg^{++}, HCO$_3^-$ and Cl$^-$ were analyzed by volumetric titrations. Concentrations of Ca^{++} and Mg^{++} were determined by using standard EDTA and those of HCO$_3^-$ and Cl$^-$ by H$_2$SO$_4$ and AgNO$_3$ respectively. Concentrations of Na$^+$ and K$^+$ were measured using a flame photometer (Model: Systronics Flame Photometer 128) and that of Sulfate by turbidimetric method (Clesceri et al., 1998). Nitrate and nitrite concentrations were estimated using UV-Visible spectrophotometer (Rowell, 1994). Standard solutions for the above analysis were prepared from the respective salts of analytical reagents grades. Trace metals were determined by

Table 1. Statistical summary of hydrochemical parameters of groundwater.

	June 2004 (n= 18)				September 2004 (n= 18)				December 2004 (n= 18)			
	Min	Max	Average	SD	Min	Max	Average	SD	Min	Max	Average	SD
EC	545	1783	1012	374	470	2203	1092	533	629	2578	1304	604
TDS	549	2035	1017	401	646	2039	999	369	603	2043	1040	378
pH	6.7	7.9	7.1	0.3	6.8	7.6	7.2	0.2	6.8	7.9	7.1	0.3
T	14.0	18.0	16.1	1.1	14.0	18.0	15.6	1.1	11.0	16.0	13.5	1.5
Ca^{++}	64.13	232.46	134.13	45.76	64.12	256.51	132.84	46.67	62.52	250.09	128.49	45.53
Mg^{++}	35.88	181.20	84.20	41.54	35.88	184.20	87.42	46.42	35.45	192.21	83.96	39.96
Na^{+}	18.50	143.70	61.73	37.89	16.70	145.30	58.36	36.40	12.80	109.10	52.95	33.44
K^{+}	6.14	148.70	20.31	32.20	5.14	149.20	19.57	32.53	4.20	132.30	18.66	28.57
Cl^{-}	56.80	337.25	166.66	94.82	10.65	330.15	149.30	93.45	63.90	337.25	170.99	94.91
SO_4^{--}	14	309	114	82	18	312	118	82	37	368	134	90
HCO_3^{-}	131.76	1348.10	392.70	256.52	176.90	1342.00	421.58	240.37	183.00	1335.90	433.32	242.17
NO_3^{-}	0.3	98.0	36.9	32.3	0.2	94.0	7.0	21.8	0.3	75.0	13.9	18.7
NO_2^{-}	0.011	85.750	6.311	20.333	0.016	67..030	4.521	15.730	0.018	48.412	4.027	11.537
Pb^{++}	0.030	1.830	0.609	0.530	0.290	1.790	0.913	0.452	0.017	0.292	0.087	0.069
Fe^{++}	0.023	0.338	0.149	0.082	0.067	0.789	0.410	0.211	0.089	0.645	0.325	0.133
Zn^{++}	0.081	0.304	0.163	0.062	0.076	0.302	0.163	0.061	0.045	0.276	0.148	0.060
Cu^{++}	0.068	0.431	0.256	0.091	0.067	0.430	0.251	0.093	0.056	0.430	0.241	0.102
SAR	0.30	1.89	0.89	0.46	0.31	1.75	0.93	0.43	0.15	1.84	0.89	0.51
Na%	6.86	29.15	15.19	5.86	5.86	20.44	14.24	4.77	1.98	26.45	14.14	6.74

All values are in mg/l except pH, T (°C), SAR (meq/l), Na% (%) and EC (µS/cm).

Graphite Furnace Atomic Absorption Spectrophotometer (Perkin-Elmer AAnalyst 700) using multi element Perkin-Elmer standard solutions.

Factor analysis

The usual procedures of interpretation of chemical quality of groundwater with the help of plots of different ions and pairs of ions do not define simultaneously the similarities or otherwise between all ions or samples (Dalton and Upchurch, 1978). Factor analysis offers a powerful means of detecting such similarities among the variables or samples. The purpose of factor analysis is to interpret the structure within the variance-covariance matrix of a multivariate data collection. The technique which it uses is extraction of the Eigen values and Eigen vectors from the matrix of correlations or covariance's (Davis, 1973). Thus, factor analysis is a multivariate technique designed to analyze the interrelationships within a set of variables or objects. The factors are constructed in a way that reduces the overall complexity of the data by taking advantage of inherent inter-dependencies. As a result, a small number of factors will usually account for approximately the same amount of information as do the much larger set of original observations. The interpretation is based on rotated factors, rotated loadings and rotated Eigen values. Hydrochemical results of all samples were statistically analyzed by using the software STATISTICA®.

RESULTS AND DISCUSSION

Hydrochemical characteristics

The chemical compositions of the groundwater samples were statistically analyzed and the obtained results are summarized in Table 1. EC values of the groundwater samples of the studied area ranged from 470 to 2578 µS/cm and the pH values varied from 6.7 to 7.9 (average values from 7.1 to 7.2) indicating that the water was slightly alkaline during the three campaigns. The total dissolved solids (TDS) ranged from 549 to 2043 mg/l and all samples exceeded the desirable limit (500 mg/l) as per WHO standard (WHO, 1993). According to Table 1 it is clearly observed that the order of abundance of the major cations is $Ca^{++} \geq Mg^{++} > Na^{+} > K^{+}$ and all samples exceeded the desirable limit of Ca^{++} for drinking water (75 mg/l) except sample 10, but only 78% of them exceeded that of Mg^{++} (50 mg/l). The abundance of the major anions is $Cl^{-} \geq HCO_3^{-} > SO_4^{--}$ and almost 28 % of the samples exceeded the desirable limit of Cl^{-} (200 mg/l), but the Sulfate values of the samples were less than the prescribed one (WHO). During the second and the third the nitrates showed an important decrease as compared to the first campaign which is likely due to the slow infiltration rate of these elements through the soil.

During all campaigns, the percentage of the samples containing nitrites varied between 28 and 39%. The concentration of lead during the three campaigns ranges from 0.017 to 1.83 mg/l. All samples exceed the WHO guideline limit of 0.01 mg/l. The concentration of lead during the three campaigns ranges from 0.017 to 1.83 mg/l and all samples exceeded the WHO guideline limit of 0.01 mg/l. In the case of iron, the concentration of Fe^{++}
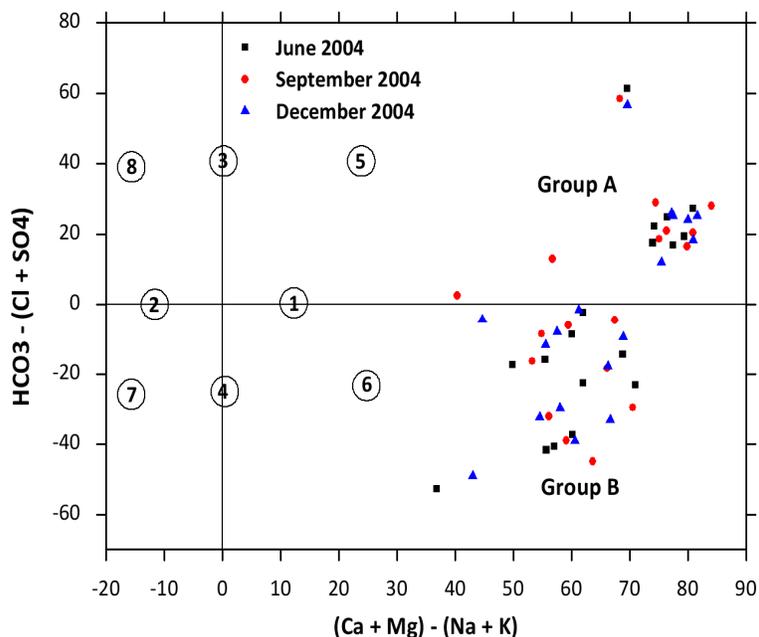
Figure 2. Groundwater analysis plotted on Chadha diagram.

in many of the samples was higher than the WHO permitted limit of 0.3 mg/l and the percent samples ranges from 60 to 83% during the three campaigns. The Cu^{++} values ranges from 0.05 to 0.431 mg/l with an averages values range from 0.241 to 0.256 mg/l during the three campaigns. The concentration of Cu^{++} is well within the WHO guideline limit of 1.0 mg/l. Zinc ranges from 0.081 to 0.304 with an average of 0.163 mg/l during June. September demonstrates 0.076 to 0.302 with an average of 0.163 mg/l and December demonstrates 0.045 to 0.276 with an average of 0.148 mg/l. The concentration of Zinc during the three campaigns has not crossed the prescribed limit of 3 mg/l. The groundwater of Ain Azel plain is low concentration of nitrogenous elements (NO_3^- and NO_2^-) and the higher concentration of trace elements (Pb^{++} and Fe^{++}) may entail various health hazards.

Water chemical facies of the groundwater

To classify the groundwater and to identify the hydrochemical processes, a Chadha diagram (Chadha, 1999) is used (Figure 2). This diagram is a somewhat modified version of the Piper diagram (Piper, 1944) and the expanded Durov diagram (Durov, 1948). The difference is that the two equilateral triangles are omitted (Dindane et al., 2003; Escolero et al., 2005). This diagram shows that most of the groundwater samples analyzed fall in the field of Ca-Mg-HCO_3 (Group A) and Ca-Mg-Cl-SO_4 (Group B) water types of water and that the alkaline earths ($Ca^{++} + Mg^{++}$) exceeded alkali metals

($Na^+ + K^+$) and the strong acidic anions ($Cl^- + SO_4^{--}$) slightly exceeded weak acidic anions ($CO_3^- + HCO_3^-$).

Factor analysis

In this study, water quality variables were grouped using FA. The correlation matrix of variables was generated and factors extracted by the Centroid method, rotated by Varimax (Gupta et al., 2005; DeCoster, 1998). Factor loading, communalities for each variable, percentage of the variance of each factor and cumulative percentage of variance of the three factor scores are given in Table 2. The communalities of all the ions except the SO_4^{--} and NO_3^- are greater than 0.70. The higher Eigen values for the first three factors ranged from 76.8 to 81.3% of the variance. The factor analysis model is assumed to provide an adequate representation of the over all variance of the data set. Hence, in the factor matrix only these three factors are considered. Factor 1, which is associated with the variables EC, Ca^{++}, Mg^{++}, Na^+ and Cl^- and explains from 45.8 to 48.8% of the variance. This factor reflects the signatures of natural water recharge and water-rock interaction. Factor 2 accounts from 20.3 to 22.8% of total variance, with the high loading for K^+ and HCO_3^-. The HCO_3^- can come from the dissolution of carbonate minerals. The factor 3 explains only of 9.7 to 14.2% of variance with the loading for SO_4^{--} and NO_3^-. Nitrate has no significant lithologic source in the study area and it must be associated with the anthropogenic activities. Hence, factors 1 and 2 are assumed to be indicative of the natural processes and water-rock interaction.

Table 2. Factor loadings and communality of the variables after Varimax rotation.

	June 2004				September 2004				December 2004			
	F 1	F 2	F 3	C*	F 1	F 2	F 3	C*	F 1	F 2	F 3	C*
EC	0.921	0.159	0.019	0.984	0.938	0.220	0.027	0.978	0.974	0.078	0.038	0.991
Ca^{++}	0.758	-0.043	0.280	0.952	0.780	-0.063	0.331	0.934	0.797	-0.102	0.266	0.941
Mg^{++}	0.898	-0.136	-0.067	0.952	0.781	-0.268	-0.152	0.941	0.918	-0.189	0.274	0.979
Na^+	0.807	-0.308	0.185	0.977	0.897	-0.345	0.082	0.957	0.458	-0.233	-0.518	0.768
K^+	0.366	0.810	-0.032	0.976	0.420	0.832	-0.236	0.963	0.487	0.765	-0.204	0.973
Cl^-	0.813	-0.297	0.034	0.987	0.866	-0.229	-0.027	0.964	0.835	-0.476	-0.177	0.963
SO_4^{--}	0.369	-0.478	-0.727	0.714	0.154	-0.254	0.391	0.809	0.230	-0.359	0.250	0.655
HCO_3^-	0.463	0.820	-0.161	0.973	0.387	0.876	-0.059	0.977	0.562	0.756	-0.065	0.939
NO_3^-	0.017	-0.270	0.449	0.695	0.194	-0.437	-0.752	0.936	0.073	-0.319	-0.518	0.437
Eigen value	4.392	2.050	0.872		4.174	2.048	1.282		4.122	1.830	0.959	
% Total variance	48.795	22.782	9.686		46.379	22.758	14.248		45.794	20.337	10.651	
Cumulative %	48.795	71.577	81.263		46.379	69.137	83.384		45.794	66.131	76.783	

C*: Communality.

The NO_3^- and SO_4^{--} of factor 3 are influenced by the contaminant source of the agricultural fertilizers and the geological formation.

Irrigation water quality

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^{++}) and magnesium (Mg^{++}) ions in a sample. Sodium hazard of irrigation water can be well understood by knowing SAR. The sodium adsorption ratio (SAR) values for each water sample were calculated by using following equation (Richard, 1954).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \qquad (1)$$

Where the concentrations are reported in meq/l. Sodium adsorption ratio varied from 0.15 to 1.89 meq/l (Table 1). All samples fall in low sodium class (Table 3). The analytical data plot on the US salinity diagram (Wilcox, 1948) 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 (Figure 3).

Salinity hazard

Electrical conductivity is a good measurement of salinity hazard to crop as it reflects the TDS in groundwater. All

sampling points found suitable with respect to EC for irrigation purposes. According to Wilcox classification (Wilcox, 1955), the groundwater in the study area are ranging between good to permissible for irrigation uses except samples 2, 14 and 18 are doubtful during the two last campaigns (Table 3). The primary effect of high EC reduces the osmotic activity of plants and thus interferes with the absorption of water and nutrients from the soil.

Sodium percentage **(Na%)**

Sodium percentage values reflected that the water was under the category of 'good' (20 - 40 Na%), 'permissible' (40 - 60 Na %) and 'doubtful' (60 - 80 Na%) class (Wilcox, 1955). The sodium percentage is calculated as follows:

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

Here all the concentrations are expressed in meq/l. The values of sodium percent are varying from 1.98 to 29.15% (Table 1). All sampling points falling under between excellent to good category (Table 3). When the concentration of sodium ion is high in irrigation water, Na^+ tends to be absorbed by clay particles, displacing magnesium and calcium ions. This exchange process of sodium in water for Ca^{++} and Mg^{++} in soil reduces the permeability and eventually results in soil with poor internal drainage.

Residual sodium carbonate (RSC): In water having high concentration of bicarbonate there is tendency for calcium and magnesium to precipitate as carbonates. To qualify this effect an experimental parameter termed as residual sodium carbonate (Eaton, 1950) was used. RSC
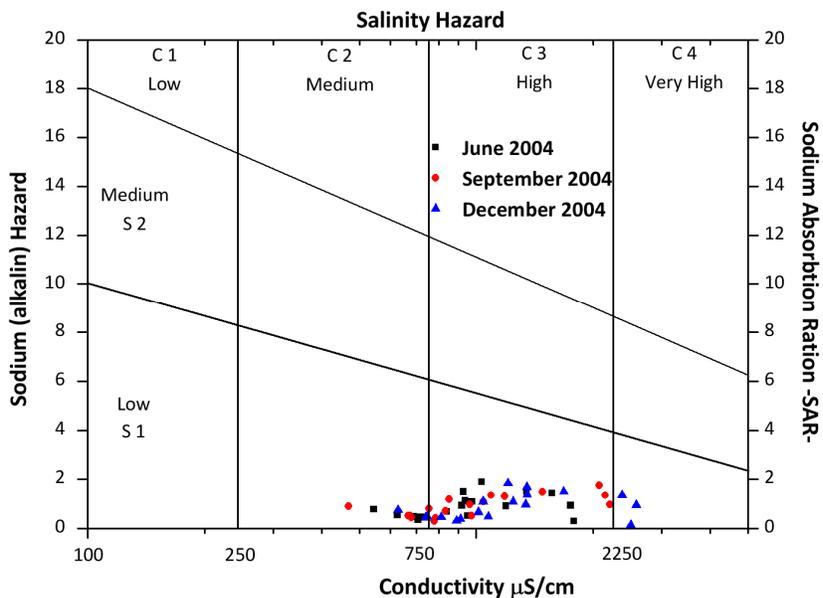
Figure 3. Water classification according to EC and SAR values.

Table 3. Classification of groundwater on the basis of Na%, SAR, EC, RSC and TDS.

Parameters	Range	Water class	% Samples		
			June 2004	**September 2004**	**December 2004**
Na%	20	Excellent	83	89	78
	20-40	Good	17	11	22
	40-60	Permissible	Nil	Nil	Nil
	60-80	Doubtful	Nil	Nil	Nil
	80	Unsuitable	Nil	Nil	Nil
SAR	10	Excellent	100	100	100
	18	Good	Nil	Nil	Nil
	18-26	Doubtful	Nil	Nil	Nil
	26	Unsuitable	Nil	Nil	Nil
EC	250	Excellent	Nil	Nil	Nil
	250-750	Good	33	22	17
	750-2.000	Permissible	67	61	66
	2.000-3.000	Doubtful	Nil	17	17
	3.000	Unsuitable	Nil	Nil	Nil
RSC	<1.25	Good	95	95	95
	1.25-2.50	Doubtful	Nil	Nil	Nil
	2.5	Unsuitable	5	5	5
TDS	<1.000	Fresh	67	67	67
	1.000-3.000	Slightly saline	33	33	33
	3.000-10.000	Moderately saline	Nil	Nil	Nil
	10.000-35.000	High saline	Nil	Nil	Nil

is calculated as follows:

$$RSC = (HCO_3 + CO_3) - (Ca+Mg) \qquad (3)$$

All the samples fall in excellent category except sample 14, which fall in poor category (Table 3).

Conclusion

Interpretation of hydrochemical analysis reveals that the groundwater of study area is alkaline in nature. Two major hydrochemical facies Ca-Mg-Cl-SO$_4$ and Ca-Mg-HCO$_3$ were identified using Chadha diagram. The abundance of the major ions is as follows: $Ca^{++} \geq Mg^{++} > Na^+ > K^+ = Cl^- \geq HCO_3^- > SO_4^{--}$ during the three campaigns. The data obtained were subjected to factor analysis. Three factors were extracted. Factor 1, which is associated with the variables EC, Ca^{++}, Mg^{++}, Na^+ and Cl^- and explains from 45.8 to 48.8% of the variance. Factor 2 accounts from 20.3 to 22.8% of total variance, with the high loading for K^+ and HCO_3^-. The factor 3 explains only of 9.7 to 14.2% of variance with the loading for SO_4^{--} and NO_3^-. Hence, factors 1 and 2 are assumed to be indicative of the natural processes and water-rock interaction. The NO_3^- and SO_4^{--} of factor 3 are influenced by the contaminant source of the agricultural fertilizers and the geological formation. The US salinity 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. The groundwater of Ain Azel plain is low concentration of nitrogenous elements (NO_3^- and NO_2^-) and the higher concentration of trace elements (Pb^{++} and Fe^{++}) may entail various health hazards and the use of such wells should be avoided.

REFERENCES

APHA-AWWA-WPCF (1995a). Standard methods for the examination of water and waste water (19th ed.). New York, USA.

APHA (1989). Standard methods for examination of water and wastewater, 17th edn. Am. Public Health Assoc., Wash., DC.

APHA (1995b). Standard methods for the examination of water and wastewater, 19th edn. Am. Public Health Assoc., Wash., DC.

Attoucheik L (2006). Etude géochimique des rejets du complexe minier de Kherzet Youssef (SETIF) et son impact sur l'environnement. Mémoire de magistère, IST. USTHB, Algérie.

Back W (1966). Hydrochemical facies and groundwater flow pattern in northern part of Atlantic Coastal Plain. US Geol. Survey Professional Paper 498A.

Belkhiri L (2005). Etude hydrogéologique et problème de la qualité des eaux souterraines de la plaine de Ain Azel. Wilaya de Sétif Est Algérien, Mémoire de magistère, Université de Batna, Algérie.

Boutaleb A (2001). Les minéralisations à Pb-Zn du domaine Sétifien-Hodna : Gitologie, pétrographie des dolomies, microthermométrie et implications métallogéniques. Thèse de docteur d'état en géologie minière, IST. USTHB, Algérie.

Chadha DK (1999). A proposed new diagram for geochemical classification of natural waters and interpretation of chemical data.

Hydrogeol. J., 7: 431-439.

Clesceri LS, Greenberg AE, Eaton AD (1998). Standard methods for the examination of water and wastewater, 20th edn. Am. Public Health Assoc., Am. Water Works Assoc., Water Environ. Fed., Wash.

Dalton MG, Upchurch SB (1978). Interpretation of hydrochemical facies by factor analysis. Groundwater, 16: 228-33.

Davis JC (1973). Statistics, data analysis in geology. New York: Wiley, p. 550.

DeCoster J (1998). Overview of factor analysis. Retrieved May 24 2006 from http://www.stat-help.com/notes.html.

Dindane K, Bouchaou L, Hsissou Y, Krimissa M (2003). Hydrochemical and isotopic characteristics of groundwater in the Souss Upstream Basin, southwestern Morocco. J. Afr. Earth Sci. 36: 315-327.

Drever JJ (1982). The geochemistry of natural waters. Prentice-Hall, Englewood Cliffs, p. 388.

Durov SA (1948). Natural waters and graphic representation of their compositions. Akademiya Nauk SSSR Doklady. 59: 87-90.

Eaton FM (1950). Significance of carbonates in irrigation waters. Soil Sci. 69: 123-133.

Escolero O, Marín LE, Steinich B, Pacheco JA, Molina-Maldonado A, Anzaldo JM (2005). Geochemistry of the hydrogeological reserve of Mérida, Yucatán, Mexico. Geofís. Int. 44 (3) : 301-314.

Faure G (1988). Principles and applications of geochemistry. 2nd edn Prentice-Hall, Engle Wood Cliffs.

Galcon J (1967). Recherches sur la géologie et les gîtes métallifères du Tell Sétifien. Thèse Doct. Sc. Nat. Publ. Serv. Géol. D'Algérie. Bull. n° 32. 2t.

Garrels RM (1967). Genesis of some groundwaters from igneous rocks. In: Abelson PH (ed) Researches in geochemistry. Wiley, New York, pp. 405-420.

Guiraud R (1973). Evolution post-triasique de l'avant pays de la chaîne Alpine de l'Algérie. d'après l'étude du bassin d'El Eulma et les régions voisines. Thèse Sc. Nat. Nice. France.

Gupta AK, Gupta SK, Patil RS (2005). Statistical analyses of coastal water quality for a port and harbour region in India. Environ. Monit. Assess. 102: 179-200.

Paces T (1973). Steady state kinetics and equilibrium between groundwater and granite rock. Geochim Cosmochim Acta. 37: 2641-2663.

Piper AM (1944). A graphic procedure in geochemical interpretation of water analyses. Am. Geophys. Union Transactions. 25: 914-923.

Richard LA (1954). Diagnosis and improvement of saline and alkali soils. Agric. handbook 60, Wash., USDA, DC, p. 160.

Rowell DJ (1994). Soil science: methods and applications. Longman Sci. Tech., Lond.

Sarin MM, Krishnaswami S, Killi K, Somayajulu BLK, Moore WS (1989). Major ion chemistry of the Ganga-Brahmaputra River basin system: weathering processes and fluxes to the Bay of Bengal. Geochim Cosmochim Acta. 53: 997-1009.

Savornin J (1920). Etude géologique du Hodna et du plateau Sétifien. Thèse Sc. Nat. Lyon. France.

Stallard RF, Edmond JN (1983). Geochemistry of the Amazon-II. The influence and the geology and weathering environment on the dissolved load. J. Geophys. Res., 88 (C14): 9671-9688.

STATISTICA® 5.0 for Windows (1998). StatSoft, Inc., Tulsa OK. USDA, Natural Resources Conservation Services, 1999. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys. Agric. Handbook No. 436, p. 871.

Subba Rao N (2002). Geochemistry of groundwater in parts of Guntur district, Andhra Pradesh, India. Environ. Geol. 41 : 552-562.

Vila JM (1980). La chaîne Alpine d'Algérie orientale et des confins Algéro-Tunisiens. Thèse de doctorat es-sc. Nat. Paris VI. France.

WHO (1993). Guidelines for drinking water quality. Vol. 1, Recommendations (2nd ed.). Geneva: WHO, p. 130.

Wilcox LV (1948). The quality of water for irrigation use. U.S. Dept. Agric., Tech. Bull. 962, Wash., U.S. Dept. Agric., DC, p. 40.

Wilcox LV (1955). Classification and use of irrigation waters. U.S. Dept. Agric. Circular 969 , Wash., U.S. Dept. Agric., DC, p. 19.