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On the water quality degradation of the séraïdi springs, Edough mountain (NE of Algeria)

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Abstract

This work investigates the water quality characteristics of the Séraïdi springs using old and recently gathered analytical data in order to understand their vulnerability to pollution. The synthesis of analytical and multivariate statistics results allows a hydro geochemical and microbiological characterization of spring water in the Séraïdi region. The results show that this forested, humid and heavily fractured area contains a shallow aquifer highly vulnerable to pollution from anthropogenic sources. Physical and chemical analyzes of major elements indicate that the overall mineralization is low to moderate and is closely related to magnesium, calcium and sodium chloride salts with significant nitrate and sulfate contents. This global mineralization is controlled by soil leaching during high water periods, acid hydrolysis phenomena of underlying rocks and human activities. Recent microbiological test results highlight the presence of Escherichia coli, Clostridia and total coliforms in water. The outbreak of these microorganisms in some spring waters points out that groundwater is exposed to fecal microbiological pollution of human and/or animal origin. This water quality degradation tends to seriously impair the physical-chemical and microbiological quality of water. It constitutes a health risk to the local population and those in search of supposedly fresh and high quality water.

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Introduction

Throughout history, water springs have a special and important appeal. For many hydrologists, springs are the most obvious and interesting evidence of groundwater. Spring waters are associated with exceptional quality and have long been believed to possess therapeutic and medicinal value. However, spring waters are likely susceptible to contamination since they are fed by shallow groundwater, which usually flows through the ground for only a short period of time and may interact with surface water.

In the Séraïdi region, there are few comprehensive studies on the topic. Reported work includes some unpublished contributions (Alem *et al.*, 1991, Majour, 2010) and two published reports (Hani *et al.*, 1997, Benouara *et al.*, 2016) that mainly dealt with water quality using classical techniques. Due to urban development in the area and increasing demand on these on road spring waters, effective pollution control and sustainable water resources management are necessary to overcome the water quality challenges.

This work is an opportunity to investigate the spatial and temporal variability of quantitative and qualitative characteristics of the Séraïdi spring waters using available and recently recorded analytical data in order to better understand their vulnerability to pollution. It is an attempt to determine the level of contamination of the Séraïdi spring waters to generate reliable database for safe future use and to help, as a decision making tool, in implementing remedial policies to improve environmental conditions.

Materials and methods

Study area

The study area is entirely located in the Edough Massif, northeastern Algeria; a mountainous zone with an elevation that ranges from few to 1008 meters above sea level. It is bounded to the North and South by the Mediterranean Sea and the Annaba Plains, respectively. This forested, humid, steep and heavily fractured area contains a shallow water table aquifer that is mainly fed by excess rainfall; the mean annual precipitation is about 1200 mm (Fig. 1).

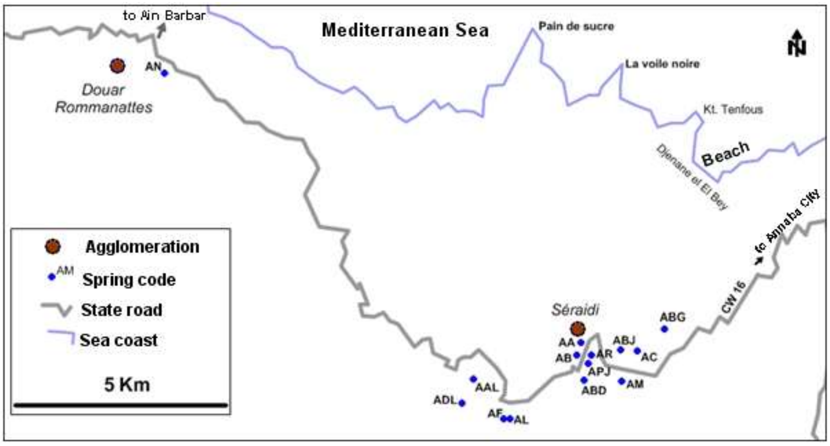


Fig. 1. Location map of the study area.

Heavy rainfall intensities and rugged topography confer to the study area a torrential river network whose flow during dry periods is sustained by the emergence of springs, of different magnitudes, located along the Séraïdi-Bouzizi-Ain Barbar axis.

Data collection

Extensive work has been carried out over the years to explore the spring water quality with respect to major and trace elements in the Séraïdi region (Alem *et al.*, 1991, Hani *et al.*, 1997, Majour, 2010). In all cases, test results pointed out that spring waters exhibited good water quality for human supply. Since the year 2000, a systematic monthly survey of major spring water quality has been conducted by the Société des Eauxd'Annabaet de Taref (SEATA) Central Laboratory in collaboration with Health and Hygiene Service of the municipality of Séraïdi. Hundreds of water quality analysis records are collected in their raw form and then compiled.

In the present work, weekly water discharge measurements were taken in 12 springs using the volume calibrated bucket and stopwatch method from January to May 2014. Appropriate sampling protocols for chemical and microbiological analyses are used and water samples are analyzed at the SEATA Central Laboratory (microbiology) and the Resources en Eau et Development Durable Laboratory in the Badji Mokhtar, Annaba University (major and trace elements). Water temperature, pH and electrical conductivity were taken in situ using HANNA pH/temperature HI991001 and EC/TDS HI99300 instruments, respectively. Springs geographical characteristics were obtained using a Garmin GPSmap 62stc unit (Table 1).

Table 1. Water springs nomenclature, codification and geographical coordinates.

Spring name	Sping code	Elevation (m)	Latitude	Longitude
Ain Bendjaballah (Abattoir)	AB	795	36°54'42.3"	7°40'7.28"
Ain Achour	AA	813	36°54'49.4"	7°40'12.6"
Ain Alleli Lahmadi (Ain Dar Lekhal)	AAL	863	36°54'24.3"	7°38'28.0"
Ain Berouaga	ABG	748	36°55'1.7"	7°41'28.2"
Ain Bouhadada (Fontaine de Curie)	ABD	816	36°54'24.9"	7°40'14.3"
Ain Boumendjel (El Ancer, 8 Mai)	ABJ	829	36°54'47.3"	7°40'49.2"
Ain Nechaa (Roumanattes)	AN	341	36°58'14"	7°33'31.5"
Ain Chifa	AC	795	36°54'45.6"	7°41'2.7"
Ain Dar Lahmame (Ain Dar el Gaied)	ADL	916	36°54'6.8"	7°38'16.0"
Ain Fedda	AF	805	36°53'57.9"	7°38'59.3"
Ain Lakchar	AL	928	36°53'54.3"	7°39'3.7"
Ain Mouhkim	AM	782	36°54'23.2"	7°40'46.5"
Ain El Rahma (Ain Parc au Jeux I)	AR	839	36°54'40.8"	7°40'15.7"
Ain Parc au Jeux II	APJ	837	36°54'40.3"	7°40'15.3"

Results and discussion

Physical and chemical characteristics of spring water

Major dissolved elements that characterize the water chemical analysis have not been measured simultaneously. Consequently, it is difficult to precise the temporal and spatial evolution of the chemical composition of the Séraïdi springs water.

During the January–May 2014 field survey, measures of water quality include temperature (T), pH, electrical conductivity (EC), concentration of the Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, $HCO3^{-}$, $SO4^{2-}$, $PO4^{3-}$, Mn^{2+}, $NO3^{-}$, $NO2^{-}$, $NH4^{+}$ions and bacteria. Furthermore, a literature review was undertaken to identify other sources of information; unfortunately, there are missing data in the study area due to a lack of analytical instruments and/or basic chemicals in the laboratories.

Despite these difficulties, the January 4th to May 12th, 2014 survey findings, in conjunction with previous works (Alem *et al*,1991; Hani *et al*, 1997; Majour, 2010) allowed to provide a relatively coherent and comprehensive overview of the mineralization of spring waters in the Edough Mountain hydrogeological complex. The overall mean values are listed in Table 2.

Table 2. Séraïdi springs physical and chemical water quality indices (2001-2014 mean values).

Spring code	AB	AA	AAL	ABD	ABJ	AN	AC	ADL	AF	AL	AM	AR
T (°C)	13.7	13.5	12.7	15.6	14.6	16.0	12.9	12.9	11.0	12.6	15.5	14.7
pH	6 .0	6.1	6.0	6.1	5.6	6.1	6.2	5.9	6.5	6.5	6.0	6.0
CE (µS/cm)	581.5	404.0	279.0	426.6	489.1	138.5	272.7	310.2	121.2	136.7	322.7	482.2
Ca^{2+} (mg/L)	27.25	17.4	10.9	45.65	26.45	6.61	17.9	22.29	10.19	7.62	21.78	38.78
Mg^{2+} (mg/L)	20.0	11.8	9.3	12.5	10.0	7.76	14.31	10.0	0.97	7.65	9.8	15.52
Na^{+} ((mg/L))	74.52	33.3	24.2	30.2	25.7	37.0	30.4	37.0	63.25	22.75	29.3	31.7
K^{+} ((mg/L)	16.5	3.3	2.3	26.0	17.5	18.0	15.0	41.5	0.66	3.0	12.67	84.67
Cl^{-} ((mg/L)	97.66	92.8	68.9	78.9	73.9	28.36	42.54	59.3	12.79	22.89	49.79	84.0
$HCO3^{-}$ (mg/L)	33.36	19.5	19.7	36.57	5.16	10.25	15.86	10.81	18.7	11.23	15.53	34.69
$SO4^{2-}$ (mg/L)	24.6	22.0	13.2	50.2	13.4	24.6	38.4	24.6	24.6	5.7	19.5	34.3
$NO3^{-}$ (mg/L)	49.07	3.2	1.6	44.02	43.39	22.52	36.06	47.82	33.2	19.83	50.29	47.38

Spring code	AB	AA	AAL	ABD	ABJ	AN	AC	ADL	AF	AL	AM	AR
NO_2^- (mg/L)	0.02	0.93	0.93	4.35	0.02	1.22	0.03	0.02	0.93	0.04	1.62	1.03
NH_4^+ (mg/L)	0.064	0.08	0.08	0.089	0.064	0.106	0.064	0.064	0.08	0.08	0.073	0.076
Mn^{2+} (mg/L)	0.4	0.4	0.4	0.5	0.6	0.35	0.2	0.3	0.35	0.35	0.35	0.25
PO_4^{2-} (mg/L)	2.0	1.18	1.18	1.4	1.2	0.65	1.3	0.8	1.18	1.18	1.3	0.75

The 1991 chemical analyses results showed two broad water types: sodium bicarbonate and magnesium chloride during the high and low flow periods, respectively (Alem *et al*, 1991). In most cases, major elements contents met the World Health Organization (WHO, 2011) and Algeria drinking water quality requirements. It is possible that higher values exist, but in any case, it would be rather exceptions. Recently, Benouara *et al*. reported that the overall Water Quality Index (WQI) values for groundwater revealed medium to good quality water for drinking and other domestic uses; 68≤ WQI≤ 86 for all samples (Benouara, 2016). This quality degradation is likely related to anthropogenic pollution due to an increase in population during the rural to urban migration of the 1990s that created informal settlements in water springs catchments areas.

Geological factors play a major role in the acquisition of water chemistry and the processes involved may be highlighted using multivariate analysis. In the present work, two complementary multivariate methods have been applied using Statistica7 and XLSTAT 2014 software packages for all computations: Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA). Theoretical considerations of these techniques are not presented in this study as they could be found in the literature (Ward, 1963; Jackson, 1991; Kaufman, 2005; Everitt, 2011). The 16 parameters (15 physicochemical elements and discharge) and the 12 measurement sites (springs) were respectively used as variables and cases inputs for PCA and HCA algorithms. Since water quality parameters and discharge have different magnitudes and scales of measurement, the data were standardized to produce a normal distribution of all variables in PCA (Davis, 1973).

PCA has been successfully applied to sort out the processes controlling the geochemical evolution of water and to explore the most important factors determining the spatial and temporal dynamics that governs the variation in the Séraïdi springs water quality. According to Kaiser's eigenvalue-one criterion λ (Kaiser, 1960; Chatfield *et al*, 1980), PCA has determined a reduced number of six principal components that explain about 92 % of the data set variance. Table 3 summarizes PCA main results.

Table 3. Eigenvalues or variances and related statistics.

Factor	λ	% Total	Cumulative λ	Cumulative λ (%)	Factor	λ	% Total	Cumulative λ	Cumulative λ (%)
F1	5.62	35.11	5.62	35.11	F4	1.97	12.34	12.53	78.34
F2	2.80	17.49	8.42	52.59	F5	1.17	7.32	13.71	85.66
F3	2.14	13.40	10.56	66.00	F6	1.01	6.31	14.72	91.97

The eigenvalues of the two first principal components (or factors) represent up to 53% of the total variance of the observations. This percentage rises up to 66% and 78% when taking into account three and four components, respectively. In order to easily and correctly interpret the results, the factor loadings for each variable on the nonrotated component factor planes F1-F2, F1-F3 and F1-F4 are only taken into account (Table 4 and Fig. 2); the remaining factors are viewed as trivial and, therefore, disregarded. Moreover, since PCA is performed to normally scaled data in which the factor loading can be defined as the correlation coefficient, it is possible to carry out a statistical test for factor loading in this analysis using the well-known fact that for a correlation coefficient (R), the statistic:

$$t_{\alpha,\vartheta} = R.\frac{\sqrt{N-2}}{\sqrt{1-R^2}} \quad (1)$$

has a t-distribution with (ν = N-2) degrees of freedom; N being the number of observations (Yamamoto *et al*, 2014). As a result, variables that have a statistically significant correlation to the PC score are selected to draw geochemical inferences.

If the significance level (α) for the correlation coefficient is set to 5%, a correlation value equal to or greater than |0.50| is deemed important. These significant correlations are in boldface in Table 4.

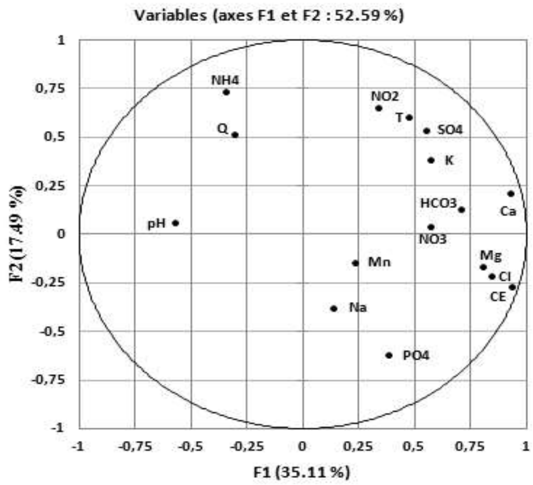
Table 4. Component loadings and contributions of variables.

Axis	T	pH	CE	Ca	Mg	Na	K	Cl	HCO3	SO4	NO2	NO3	Mn	NH4	PO4	Q
Component loadings																
F1	0.48	-0.57	0.93	0.93	0.80	0.14	0.57	0.84	0.70	0.55	0.33	0.57	0.23	-0.34	0.38	-0.31
F2	0.61	0.06	-0.27	0.21	-0.16	-0.38	0.38	-0.21	0.13	0.54	0.65	0.04	-0.14	0.74	-0.62	0.52
F3	-0.40	0.75	-0.18	0.06	0.00	0.59	-0.07	-0.20	0.61	0.46	0.27	0.08	-0.41	0.12	0.36	-0.15
F4	0.16	0.05	0.04	0.02	-0.21	-0.10	-0.57	0.17	0.15	-0.12	0.56	-0.44	0.75	0.42	0.36	-0.36
Contributions (%)																
F1	4.02	5.80	15.39	15.27	11.44	0.34	5.81	12.71	8.79	5.34	2.00	5.73	0.93	2.10	2.62	1.70
F2	13.19	0.12	2.61	1.62	0.97	5.04	5.26	1.59	0.60	10.25	15.21	0.06	0.73	15.21	13.81	9.55
F3	7.38	26.13	1.58	0.16	0.00	16.25	0.26	1.88	17.09	9.83	3.42	0.31	7.84	0.63	6.14	1.10
F4	1.23	0.15	0.10	0.02	2.17	0.50	16.54	1.55	1.09	0.74	16.05	9.67	28.19	8.85	6.64	6.51

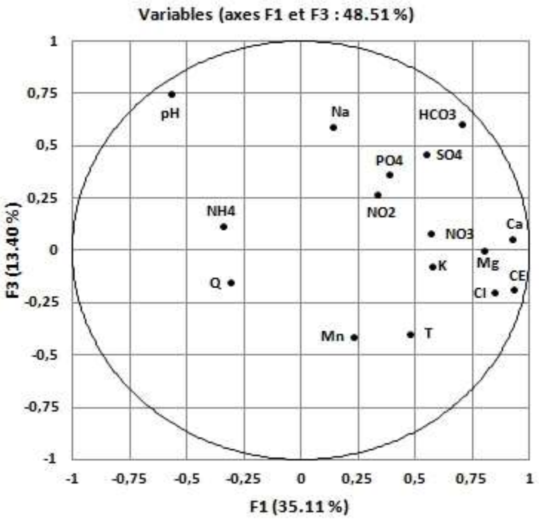
A close look at Table 4 and the F1-F2 factorial space (Fig. 2a) shows that, according to Guildford's rule of thumb for interpreting the Pearson product moment correlation (Guildford, 1973), the first component is moderately to strongly linked to major ions and water salinity (EC, Ca, Mg, Na, K, Cl, HCO3, SO4 and NO3). This clustering expresses the natural mineralization process consisting of alkaline earth salts due to the dissolution and weathering processes of calcitic and calco-silicate host rocks that are well represented in the Enough Mountain. Such processes take place in acidic media ($5.6 \leq pH \leq 6.5$). Moreover, the NH4, NO2, PO4, SO4 ions, temperature (T) and discharge (Q) contribute significantly to the construction of the second component (PC2). Hence, this factor reflects the existence of natural and anthropogenic pollution due to humus and decaying organic matter by leaching in a wet environment and to urban wastes. The F1-F3 factorial space (Fig. 2b) confirms that the first component expresses mineralization as related to the residence time of water in the shallow aquifer. However, the third one (F3), being linked to pH, bicarbonate (HCO3) and Sodium (Na), might be seen as the base exchange process. Finally, in the F1-F4 space (Fig. 2c), the fourth component (F4) increases with increasing divalent manganese and nitrites contents. High manganese contents, as well as the reduced and acid character of the water, appear to originate from the oxidation of leached minerals contained in the parent crystallophylian rocks (silicates, amphiboles, ferromagnesians, micas, etc.) abundant in the recharge area following mixing of infiltrated and oxygen-rich meteoric waters. Furthermore, the presence of manganese levels above the World Health Organization acceptability threshold of 0.1 mg/L (WHO, 2011) and the relatively high contribution of nitrites to the construction of this axis reflects water contamination by urban non treated waste water inputs from upstream areas. Table 5 shows that Ain Bouhadada, Ain Chifa and Ain El Rahma springs are well represented on this factor.

Table 5. Cases Contributions to factors (%).

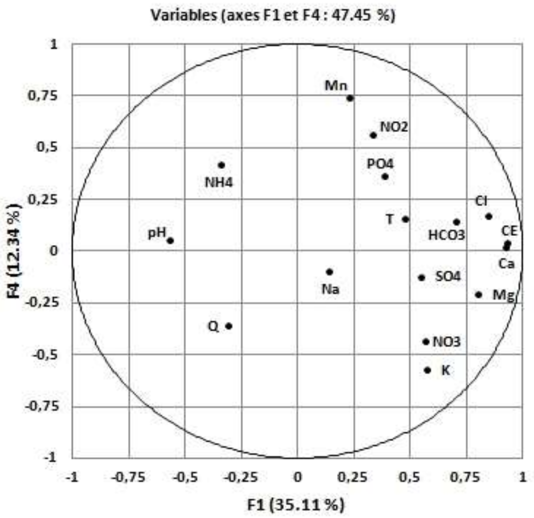
Spring	F1	F2	F3	F4
AA	0,01	1,52	0,48	8,40
AAL	2,78	2,03	1,82	8,64
ABD	18,00	20,45	7,01	23,93
ABJ	1,65	5,03	44,69	1,29
AN	11,18	32,96	2,96	0,12
AC	0,50	0,02	2,64	19,29
ADL	0,00	0,28	2,92	19,27
AF	15,74	1,24	27,60	0,12
AL	17,20	2,52	0,24	0,69
AM	0,11	0,14	1,29	0,18
AR	15,16	7,57	0,18	18,06



a - Factor-plane 1-2



b- Factor-plane 1-3



c- Factor-plane 1-4

Fig. 2. Projection of the variables on the factor-planes.

As a part of this study, the hierarchical cluster analysis (HCA) method, using the euclidean distance as a dissimilarity measure and Ward's method as a linkage rule, is applied to further assess the Edough Massif springs water quality. This technique generated four geochemically distinctive groups of cases with différent salinities (C1 to C4). According to Huygens theorem, this clustering corresponds to the optimal partition as the inter-cluster variability is close to 1.0 (Fig. 3). The dendrogram, which is a mathematical and pictorial representation of the complete clustering procedure, shows the repartition of the individual springs into each group and points out the abnormality of water quality at the Ain Bendjaballah (AB) spring, which makes one group as Cluster (C1). This one-case group is distinguished by water of relatively higher average mineralization (EC=580 µS/cm) with magnesium chloride and sodium chloride as major salts and high nitrates contents (Table 6).

While all spring categories share the same MgCl2 as the primary water salt, the discrepancy between groups lies in the hypothetical composition of secondary and tertiary salts, nitrate and excessive sodium contents and discharge due to dilution and leaching processes, anthropogenic pollution (likely leachate from livestock waste) and other interacting factors that led to decreasing conductivity values.

Table 6. Main water quality characteristics of each group of springs.

Cluster	C1	C2	C3	C4
Spring code	AB	AA, ABD, ABJ, AR	AF, AN-AL	ADL-AM-AAL-AC
EC (µS/cm)	581,5	450,5	296.0	132.0
Major cations	Na>Mg>Ca>K	Ca>Na>Mg>K	Na>Ca>Mg>K	Na>Mg>Ca>K
Major anions	Cl>NO3>HCO3>SO4	Cl>SO4>NO3>HCO3	Cl>NO3>SO4>HCO3	Cl>NO3>SO4>HCO3
Major salts	MgCl2-CaCl2-NaNO3	MgCl2-CaCl2-NaCl	MgCl2-NaCl-NaNO3	MgCl2-NaNO3-CaSO4
Q (L/s)	0.17	0.26	0.54	0.78
Na/Cl	1.2	0.6	0.8	3.0

Nitrogen exists in the environment in many forms and changes forms as it moves through the nitrogen cycle. However, excessive concentrations of nitrate-nitrogen or nitrite-nitrogen in drinking water can be hazardous to health, especially for infants and pregnant women. The adverse health effects of high nitrate/nitrite levels in drinking water are well documented (Craun *et al*, 1981; Madison*et al*, 1985; Avery, 1999; Mesinga *et al*, 2003; Manassaram *et al*, 2007; Gatseva *et al*, 2008; Bryan *et al*, 2011). According to the World Health Organization (WHO, 2011), the maximum acceptable nitrate concentration for drinking water is 50mg/L. However, groundwater with nitrate concentration exceeding the threshold of 20mg/L is considered contaminated as a result of human activities (Spalding *et al*, 1993).

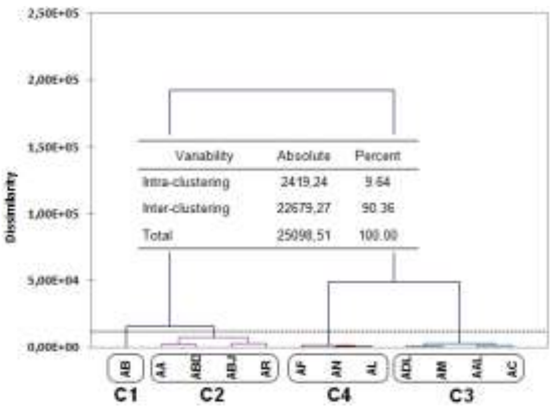


Fig. 3. Dendrogram of the hierarchical cluster analysis for the Séraïdi springs water quality parameters.

Following Madison and Brunett (Madison *et al*, 1985), nitrate contents in drinking water can be classified into four categories: less than 0.2mg-N/l (no human influence), between 0.21 and 3.0mg-N/l, (possible human activities influence), between 3.1 and 10mg-N/l, (very clear human activities influence but without apparent impact on health), greater than 10mg-N/l (major impact of human activities and possible health effects). Table 7 shows distribution of the Séraïdi springs water within each class.

Table 7. Evolution and influence of human activities and possible impact on health of various levels of nitrates in drinking water (Madison *et al*, 1985).

Drinking water nitrates content (mg-N/L)	< 0,21	0,21 – 3,0	3,1 – 10	> 10
Drinking water nitrates content (mg-NO_3^-/L)	< 1	1.0 – 13.3	13.3 – 44.3	> 44.3
Human activities influence	No	Possible with minor impact	Sure with moderate impact	Sure with major impact
Impact on human health	No	No	Not demonstrated	Possible
June 2005-May 2006 Analyses : mean values [3]				
Spring falling in the indicated class	AL	ABJ, AM, AA, AR, ABD, AC	No one	No one
Analyses : 2001 and 2014 (SEATA Central Laboratory)				
Spring falling in the indicated class	None	ABD, AN, AC	AB, ABD, ABJ, AC, ADL, AM, AL, AR	AB, ABJ, AN, AC, ADL, AM, AR

Since the NH4 content is below the prescribed drinking water limits, the classification of the Séraïdi spring waters with respect to nitrogen compounds is based on nitrates and nitrites concentrations. Because of the possibility of the simultaneous occurrence of these chemicals in drinking-water, the sum of the ratios of the concentration (C) of each to its guideline value (GV) should not exceed 1.0 (Spalding *et al*, 1993), i.e:

$$\frac{[C]_{NO3}}{GV_{NO3}} + \frac{[C]_{NO2}}{[CV]_{NO2}} \leq 1 \quad (2)$$

Statistical treatment of available water quality data show that up to November 2005, the maximum nitrates levels in the Séraidi spring waters were in most cases low (≤ 17.5mg/L). Nitrate levels above 3 and 10mg-N/L were respectively observed in 40% and 36% of the SEATA water analyses recorded between 2001 and 2014. These values show that the influence of anthropogenic activities is certain but the impact on health remains moderate (Table 7).

Ratios greater than one are found at Ain Bendjaballah (66.1 mg/L), Ain Nechaa (53.5mg/L) Ain Dar Lahmane (55.0mg/L) and Ain Mouhkim (56.5mg/L). The nitrite water concentrations evolve in the same way as those of nitrates. Likewise, old samples (February, 2001–April, 2010) show nitrite levels below the standard of 0.1mg/L. The maximum value being recorded at Ain El Rahma (0.08mg/L). However, recent sample analyses (February to March, 2014) carried out in the department of geology laboratory reveal nitrite levels that exceed drinking standards for some springs (Ain El Rhama: 3mg/L, Ain Nechaa: 6mg/L, Ain Mouhkim: 8mg/L and Ain Bouhadada: 13mg/L). Current studies suggest that the main issue may not only be nitrogen compounds, but also bacterial contamination of drinking water. Since the nitrate-nitrogen level exceeds the 10mg/L standard in some Séraidi spring waters, the bacterial safety of drinking water should be monitored by testing for coli form bacteria. Water samples for bacterial analyses are routinely collected by the *Health and Hygiene Service* of the Séraïdi municipality and analyzed in the *SEATA Central Laboratory* for total and fecal coli forms (TC and FC), fecal streptococci (FS), clostridium (CL) and total germs at 37°C (TG).

Recent microbiological test results, expressed in Colony-Forming Unit (CFU), highlight the presence of fecal coliform bacteria (Escherichia coli), Clostridia and total coliforms in some Séraïdi spring waters (Table 8).

Table 10. Coliform bacteria counts in spring water samples in the Séraïdi region (CFU/ 100mL).

Sampling date	14/04/2014					22/04/2014				05/05/2014				Observation
Spring name	TC	FC	FS	CL	TG	TC	FC	FS	CL	TC	FC	FS	TG	
Ain Chifa	0	0	0	0	100	4	4	0	0	28	0	9	35	Contaminated
Ain Boumendjel	0	0	0	0	9	0	0	0	0	0	0	0	0	Suspected
Ain Mouhkim	0	0	4	0	18	0	0	0	0	7	0	0	1	Suspected
Ain Bouhaddada	0	0	0	0	20	3	0	0	1	0	0	0	4	Contaminated
Ain El Rahma	0	0	0	0	8	0	0	0	0	0	0	0	37	Suspected
Ain Benjaballah	0	0	0	0	18	9	0	0	0	0	0	0	8	Contaminated
Ain Nechaa	-	-	-	-	-	0	0	0	0	0	0	0	8	
Ain Dr Lahmeme	-	-	-	-	-	4	0	0	4	3	0	0	31	Contaminated

Total coli forms are not useful as an indicator of fecal pathogens, but they can be used as a disinfection indicator. Their presence in distribution systems and water storage facilities can reveal bacteria regrowth and possible biofilm formation or contamination through ingress of foreign material into water intakes and distribution systems, including soil or plants (WHO, 2011). The outbreak of these microorganisms in Ain Chifa, Ain Bouhadda, Ain Dar Lahmame and to a lesser extent Ain Benjaballah, spring waters points out that groundwater is exposed to fecal microbiological pollution of human and/or animal origin that makes such water unsafe to drink; the maximum contamination level being 0 CFU/100ml.

Furthermore, the presence of aerobic and anaerobic heterotrophic bacteria (A.A.H.B) or total germs (TG) in Ain Boumendjel, Ain Mouhkim and Ain El Rahma spring waters, even though at low counts, serves as a pollution indicator for residual organic matter in the supply facilities and a valuable index for better water quality control.

Conclusion and recommendations

Located along a NE-SO and NO-SE axes on both sides of the Edough Mountain, the Séraïdi springs constitute the main water outlets of infiltrated excess rainfall in discontinuous shallow water table aquifers that overlay heavily cracked cristallophyllian rocks.

During dry periods, these on-road springs discharge at relatively low rates but sufficient enough to secure a perennial good quality water supply source for local populations. PCA findings show that the Séraïdi springs water geochemical variability is primarily governed by combined interactive natural (including dissolution, dilution, weathering, base exchange, oxidation of leached minerals and decaying organic matter) and anthropogenic factors (poor management of water intake and distribution facilities, and sanitation practices). The cluster analysis technique enabled to distinguish four different groups of springs characterized by decreasing average mineral composition (132 <EC<580µS/cm) with magnesium chloride as a major salt content and distinctive secondary and tertiary salts, nitrates and excessive sodium concentrations. Although the overall spring water quality is within the prescribed WHO drinking water quality guidelines for major chemicals, this shallow aquifer is, nevertheless, vulnerable to anthropogenic pollution (high levels of nitrates, nitrites, ortho-phosphates, and nickel) during high water periods. In addition, the presence of microorganisms such as fecal coliforms (Escherichia coli), clostridiums and total coliforms in water indicates that the recently monitored water springs are, in most cases, exposed to fecal microbiological contamination of human and/or animal origin that makes the water unsafe to drink.

Finally, the Séraïdi springs water quality is sufficiently high to merit development as freshwater source if means to bypass these contaminations are found. The most appropriate means of controlling undesired chemicals (nitrogen compounds, trace elements) and bacterial outbreaks in spring waters is the prevention of contamination (appropriate management of local agricultural practices, careful siting of pit latrines and septic tanks, sewer leakage control, fertilizer, animal manure application and storage).

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