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Impact of Anthropic Pressure on the Quality and Diversity of Groundwater in the Region of Sighus Oum-El-Bouaghi and El Rahmounia, Algeria.

IMPACT OF ANTHROPIC PRESSURE ON THE QUALITY AND DIVERSITY OF GROUNDWATER IN THE REGION OF SIGHUS OUM-EL-BOUAGHI AND EL RAHMOUNIA, ALGERIA

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ABSTRACT

Groundwater of Oum-El-Bouaghi and its surroundings hosts a variety of microflora and fauna. This study investigated the relationship between the effect of human activity and the biodiversity and distribution of aquatic fauna in two semi-arid regions Sighus region (Oum-El-Bouaghi) and El Rahmouni (Constantine) in north-eastern Algeria. Fourteen wells and six springs were studied in two hydrographic basins, that of Constantine and Seybouse Melegue. Significant differences were revealed between the wells and springs in the two watersheds, making it possible to distinguish four groups of wells and two groups of springs. The overall faunal richness of the stations appeared to be weakly correlated with water quality, but on the other hand, the specific richness of the stygoby fauna, and even more so the abundance of stygoby species, decreased when water quality deteriorated.

Keywords: Anthropogenic pressure, aquatic fauna, catchments, subterranean water, water pollution.

INTRODUCTION

In Algeria, as in many African countries, the supply of drinking water in sufficient quantities for the population remains a major problem. This quantitative insufficiency of water distributed by the public network forces many inhabitants of the town of Sigus and its surroundings to resort to the most accessible and closest groundwater, that of traditional wells and springs, often without worrying about their quality as much as would be desirable (Nola et al., 1998). Rapid population growth very often results in considerable production and discharge of liquid and solid wastes into the natural environment (Dejoux, 1988), which is an important factor in the pollution of underground aquatic environments. The latter represents a vital but limited natural resource that is particularly vulnerable to pollution (Boutin, 1984; Boutin, 1987; Boutin and Dias, 1987).

Stygobiology, which studies underground aquatic animals, can, in some cases, provide data that may be used to assess water quality. Indeed, stygobiological species are generally much more sensitive than other aquatic species, especially epigootic species, to overall water pollution (Notemboom, 1991; Notemboom et al., 1994; Maucaire, 1999).

Studies on African groundwater fauna have been carried out mainly in Southern Africa (Messana, 2003), and in Northern Africa (Perritaz, 2003), notably in Morocco (Boutin and Boulanouar, 1984; Boulal et al., 2009) and very recently in Algeria (Merzoug et al., 2008; Merzoug et al., 2011; Khaldoun et al., 2013; Hadjab et al., 2018; Khammar et al., 2019). It emerges from this faunistic work devoted to groundwater that it hosts numerous stygobic organisms that can very often be used as good palaeogeographic tracers but above all as good indicators of water quality (Boulanouar, 1995; Fakher et al., 1998; Messana, 2003).

Recent work undertaken on the groundwater of Oum-El-Bouaghi and its surroundings revealed that this water hosts a varied bacterial microflora composed, among others, of faecal bacteria and opportunistic pathogenic bacteria. However, very little attention has been paid to the faunal settlement of the underground aquatic environments of eastern Algeria in general (Juberthie and Decu, 1994) and Oum-El-Bouaghi in particular. However, there are a few known works (Merzoug et al., 2002; Merzoug et al., 2007; Merzoug et al., 2008; Merzoug et al., 2011; Hadjab et al., 2018) which reveal the interest in studying this underground fauna in Algeria, but which mainly concern the Sigus catchment area, that covers almost the entire urbanized area.

It emerges from this work that the physicochemical characteristics of water of the different stations studied in the Sigus Basin generally show a significant level of pollution, mechanical or chemical. It has also emerged that the stygobian fauna of these separate, though contiguous, catchment areas, both located in the same river networks area, includes two isopod crustaceans of the family Stenasellidae, i.e. two species belonging to the same genus (*Metastenasellus*). This study was conducted to contribute to a wider knowledge of the underground aquatic fauna of Algeria and to evaluate the effect of anthropic pressure on underground aquatic organisms, it seemed useful to us to carry out this study comparatively in two basins in the region of Oum-El-Bouaghi (Sigus and Oued Rahmoun), one of which is strongly anthropised, that of Sigus, while the other is not, or is much less so, than that of the region of El Rahmounia.

MATERIALS AND METHODS

Study Area

The town of Sigus is located on the eastern edge of the South-Constantine plateau, approximately 3°5′ north latitude and 11°3′ east longitude, and 150 km from the Mediterranean coast. The average altitude of this plateau is close to 750 m, its surface is very undulated as one observes there an alternation of numerous hills and humid valleys, covered with scattered vegetation which separates outside the town into more or less isolated dwellings.

The hydrographic network of the region is constantinois, with two watersheds: the Sigus and the Rahmounia in its upstream part (Figure 2). The Sigus Basin is located between 3°50′ and 3°41′ north latitude and between 11°26′ and 11° 30 east longitude and has an approximate surface area of 50 km^2, it drains all the districts of the city of Sigus. The northern part of the catchment area of the Rahmounia upstream of its confluence with Sigus lies immediately west of the previous one (Figure 2) and extends between 3°60′ and 3°41′ north latitude and between 11°18′ and 11°21′ east longitude; with a surface area of about 50 km^2, it drains very partially the extreme west of the town of Sigus and extends mainly over the Department of Constantine to the south.

The two watersheds are contiguous and enjoy the same Mediterranean-type climate with 4 seasons of unequal importance. This climate is characterized by abundant rainfall, which sometimes reaches 600 mm/year and an average temperature of 23 °C.

Three types of soils are found in the region of Oum-El Bouaghi and are present in the study area: hydromorphic soils and poorly evolved soils (Merzoug, 2011). These soils all derive from more or less micaceous quartz-feldspathic materials from the erosion of the African craton. The main constituent minerals are kaolinite, goethite, quartz and gibbsite. The hydrogeological characteristics of the two basins do not differ and the groundwater in the two basins have the same general characteristics.

Choice of Stations

Twenty sampling stations were selected, comprising 6 springs, designated as SF1, SF2, SF3 in the Sigus watershed and SM1, SM2, SM3 in the El Rahmounia watershed and 14 wells (designated as PF1 to PF7 in the Sigus watershed and PM1 to

PM7 in the Rahmounia watershed). These sites were chosen in different districts, according to the importance of these water points for the populations and their ease of access, but also to cover the whole of each of the two study areas to allow meaningful comparisons (Figure 2).

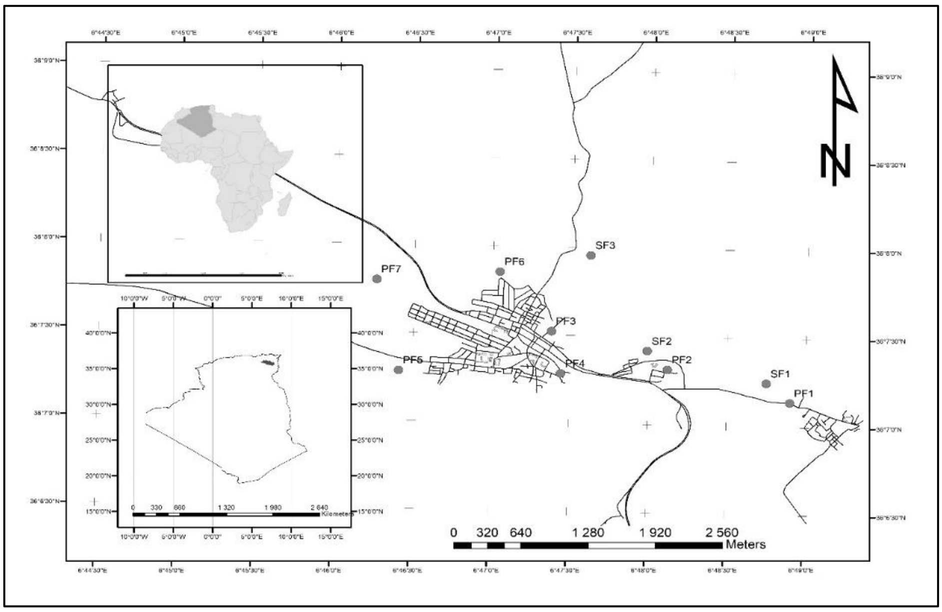

Figure 1: Map of the Sigus watershed with the name of most districts. The Wady of Sigus is the Lake of Sigus City, close to the centre of the city.
PF: wells, SF: springs

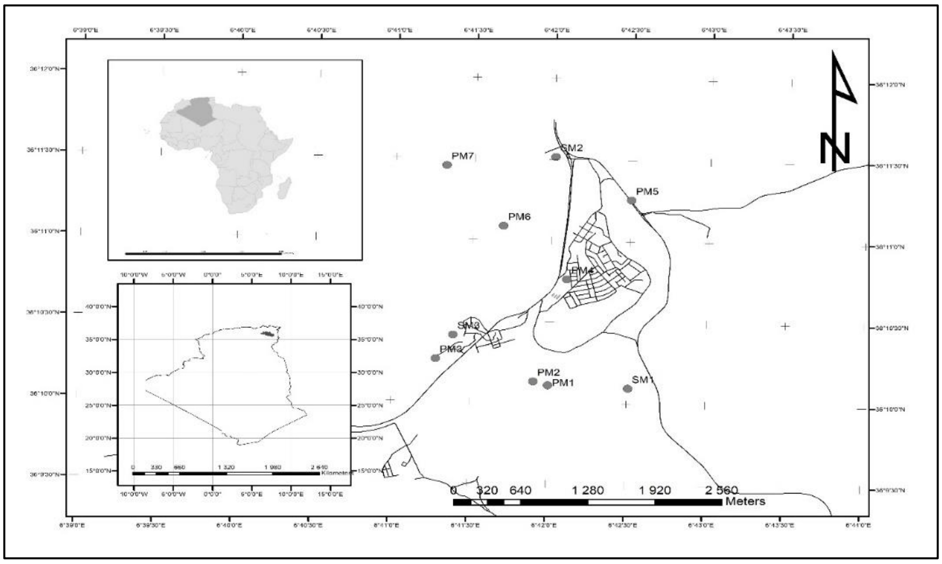

Figure 2: Map of the El Rahmounia watershed area.
PM: wells, SM: spring

Sampling and Analysis Techniques

Monthly sampling campaigns were conducted in the wells and springs of both basins during a period from September 2018 to June 2019. Samples for Physico-chemical water analysis were collected from the wells using a 5 L bucket before wildlife harvesting, transported in doublecapped 1 L polyethylene bottles and returned to the laboratory on the same day in a refrigerated insulated cabinet. Samples from the sources were collected directly from the 1 L vials.

The fauna in the wells was then harvested by making a minimum of 10 round-trips using a phreatobiological net (Cvetkov, 1968) modified by Mittelberg and Boutin (1968-1983) and by installing a trap of the trap type nasse, for a period of 10 to 18 h, in which a red meat bait was introduced, following the recommendations of Boutin and Boulanouar (1983). In the sources, organisms were sampled by passive direct filtration for 6 to 8 hrs. And whenever possible, filtration of the water collected from the spring was done after "sweeping" the collection pipe. Samples containing animal organisms were fixed directly on-site, in ethanol to 96% before being returned to the laboratory for extraction, enumeration and identification.

The temperature, pH, electrical conductivity and dissolved oxygen content of the water were measured in the field using a 1/10°C mercury thermometer and portable electrical devices; Schöt-Gerate portable pH meter (HANDYLAB HL100), HACH Conductivity meter (WTW 340i), Oximeter (WTW 340i). Colour and Suspended Solids were measured in the laboratory by spectrophotometry using a spectrophotometer (HACH DR-EL 2000). Calcium hardness was measured in the laboratory by volume. The concentrations of ammonia, nitrate, nitrite, and orthophosphate ions were obtained by spectrophotometry using Aminot (1983); Aminot (2007); Rodier (2009) protocols. BOD_5 was evaluated by respirometry in a suitable incubator at a temperature of 20 °C (Rodier, 2009).

In the laboratory, wildlife samples were washed under tap water and examined in successive fractions in petri dishes for sorting and extraction of animal organisms, under a stereomicroscope (Wild M5) equipped with an episcopic illumination. Taxonomic identification was made using identification keys by Chappuis (1951); Chappius (1952); Magniez (1979); Magniez (1986); Lincoln (1972); Durand and Levêque (1980); Argano (1994); Coineau et al. (1994); Delvare and Aberlenc (1989); Tachet et al. (2000); Pinkster (1993).

Statistical Analysis

To synthesize the information contained in the set of variables measured at each station, mean values were calculated and then dendrograms and Principal Component Analyses (PCAs) were performed. The dendrograms were made from averages of the physicochemical data to perform a classification of the sampled stations according to Ward's (Ward, 1963) criteria to show the various groups of wells and sources. PCAs were also carried out based on all the biological data (presence and total abundance of taxa) to reveal any ecological significance of the presence of the organisms observed. Data analysis was carried out using SPSS 26.0 (Zheng et al, 2019)

RESULTS

Abiotic Well Variables

The results of the physico-chemical measurements carried out are shown in Table 1. In both catchment areas, the average temperature of the well water remained above 22 °C. The water from all the wells in both catchments was relatively acidic, except for the water from the southern-most well, located in the Rahmounia Basin (PM6), which remained closer to neutral (the average value of the measured pH values reached 6.8). The electrical conductivity of the water remained above 1000 $\mu S.cm^{-1}$ in wells PF2, PF3, PF6 of the Sigus Basin and in wells PM2 and PM6 of the Rahmounia watershed, and was below 500 $\mu S.cm^{-1}$ in wells PF4, PM1, PM3, PM4 and PM7.

Table 1: Main physico-chemical characteristics of the water from the 14 studied wells. Each data is the mean value of all measured values during the study

	Sigus Watershed							El Rahmounia Watershed						
	PF1	**PF2**	**PF3**	**PF4**	**PF5**	**PF6**	**PF7**	**PM1**	**PM2**	**PM3**	**PM4**	**PM5**	**PM6**	**PM7**
Temperature (°C)	23.3	25	25	23.7	23.3	25	25.5	23.2	23.4	23.4	25.8	24.8	26.2	22.7
pH (en U.C.)	5.2	5.7	6	5.2	5.3	5.3	6	5.6	5.1	5.2	5.3	5.8	6.8	6
Electric Conductivity (µS/cm)	997	1052	1027	455	915	1085	695	445	1277	438	437	862	1122	424
Suspended Matter (mg. L^{-1})	57	18	20	35	14	18	104	3	3	5	14	10	93	14
Colour (UPl. Col.)	27.7	35	37.7	288	19.3	67.3	1050	3.7	31.7	25.7	84	52.7	1071	66.3
Dissolved O_2 (%)	64	65	62	32	82	51	67	29	31	33	37	32	40	34
Hardness Cal (mg. L^{-1} $CaCO_3$)	5.3	48	24	42	10	12.7	17.3	3.3	10	12.7	12.7	6.7	20.7	20
Nitrite NO_2^- (Mg. L^{-1})	0.37	0.01	0.07	0.1	0.02	0.02	0.12	0.14	0.03	0.03	0.024	0.01	0.06	0
Nitrate NO_3^- (Mg. L^{-1})	0.06	0.03	0.72	0.5	0.31	0.12	0	0.01	0.02	0.02	0.03	0.02	0.12	0.05
Ammonia (NH_4^+ mg. L^{-1})	1.04	0.74	19.98	0.44	4.91	6.09	0.62	0.55	1.38	0.1	0.43	1.91	2.15	0.07
Phosphates (PO_4^{3-} mg. L^{-1})	1.86	0.59	0.38	0.48	0.39	5.8	1.26	0.17	0.2	0.14	0.39	0.35	1.21	0.03
BOD_5	63	55	93	67	68	72	15	123	58	40	38	62	38	105

BOD_5: Biochemical Oxygen Demand for five days

Suspended solids were generally present at concentrations below 10 mg. L^{-1} in the PM1, PM2 and PM3 wells in the Rahmounia Basin but above this value, even exceeding 90 mg.L^{-1} in the two (PM6 and PF7) wells located in the downstream part of the two basins. The average dissolved oxygen content of the well water was generally above 50% saturation in the Sigus Basin, but always below this value in the Rahmounia Basin. On the other hand, calcium hardness was greater than or equal to 20 mg.L^{-1} in wells PF2, PF3 and PF4 in the Sigus Basin and wells PM6 and PM7 in the Rahmounia Basin, and below this value in the other wells. The concentration of nitrite ions was generally low (always less than 0.40 mg.L^{-1} of NO^{2-} and generally less than 0.1 mg.L^{-1} on average). Similarly, the concentration of nitrate ions was very low, with averages generally below 0.5 mg.L^{-1}, except in well PF3 where the average level was 0.72 mg.L^{-1}.

The concentration of ammonium ions was less than 1 mg.L^{-1} NH_4^+ in wells (PF2 and PF7) in the Sigus watershed and wells (PM1, PM4 and PM7) in the Rahmounia watershed, and higher than this value in the other wells, but surprisingly high in well PF3 in the Sigus with a value of approximately 20 mg.L^{-1} of NH_4^+. On the other hand, the concentration of phosphate ions remained generally higher than 0.5 mg. L^{-1} of PO_4^{3-} in wells PF1, PF6 and PF7 of the Sigus Basin and well PM6 of the Rahmounia watershed, but in the other wells, it was much higher than this value. The average BOD_5 value was generally greater than 40 mg.L^{-1}, but much lower than this value in the Sigus Basin PF7 well and equal to or slightly lower in the PM3, PM4 and PM6 wells in the Rahmounia Basin.

A hierarchical classification of the wells, based on the average value of the physico-chemical data of the two watersheds, appears on the dendrogram (Figure 3) and allows discernment of four groups:

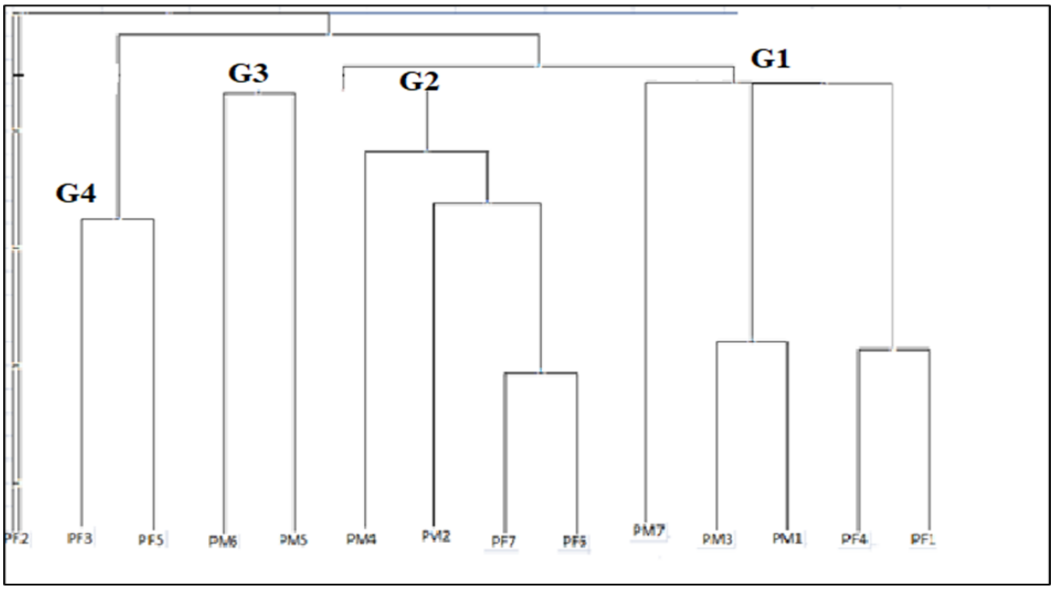

Figure 3: Dendrogram showing the hierarchical classification of the 14 wells obtained from the mean values of water characteristics.

- **Group 1**: included PM1, PM3, PM7, PF1 and PF4 wells, which had a fairly good water quality, characterized by a low mineralization, low concentration of ammonium ions, phosphate, nitrate and organic pollution indicator ions. On the other hand, these wells were generally distinguished from the others by their great depth (greater than 20 m) and good protection against wind inflows.
- **Group 2:** consisted of PF6, PF7, PM2 and PM4 wells which were on the contrary, shallow with poor to low-quality water, mineralized with high values of ammonia and phosphate ions.
- **Group 3:** consisted of wells PM5 and PM6 characterized by chemical and organic pollution with highly mineralized waters, highly concentrated in ammonia ions and high BOD_5 values.
- **Group 4:** consisted of PF2, PF3 and PF5 wells with hard, poor quality, coloured water with high TSS values, although normally oxygenated.

Abiotic Source Variables

The main physico-chemical characteristics of spring water are summarized in Table 2. The average temperature varied between 24.5 °C and 25.8 °C. The spring water in both basins always remained acidic (with average pH values between 5 and 5.7). The Electrical conductivity measured in the sources of the Sigus Basin was approximately double of that measured in the sources of the Rahmounia Basin. In the Sigus springs, the average conductivity of the water ranged from 440 to 708 $\mu S.cm^{-1}$ while in the Rahmounia springs it was always less than 300 $\mu S.\ cm^{-1}$ (Table 2). The mean TSS concentration did not exceed 7 $mg.L^{-1}$ in sources SM1, SM2 and SM3, but was much higher than this value in the sources of the Rahmounia watershed (17 to 91 $mg.L^{-1}$). Similarly, oxygen saturation percentages remained high (always above 50%) in the Sigus catchment area (56% on average) and always well below this value in the Rahmounia catchment area (37% on average).

Calcium hardness values in the Rahmounia springs remained below 12 $mg.L^{-1}$ on average and were often higher than this value in the Rahmounia lower-slope. The nitrite ion content was low in the springs of both watersheds (less than 0.15 $mg.L^{-1}$of NO_2^-) and was even below the detection limit in the SF1 and SM3 sources. Similarly, the concentration of nitrate ions was below 0.15 $mg.L^{-1}$ everywhere, except for the SF3 source where it reached an average value of 1.3 $mg.L^{-1}$. The concentration of ammonium ions was less than 1 $mg.L^{-1}$ in the wells of Sigus watershed (PF2 and PF7) and wells in the Rahmounia. The concentration of orthophosphate ions averaged 0.4 to 0.5 mg/L of PO_4^{3-} in the Sigus springs, while it was less than 0.2 $mg.L^{-1}$ in the Rahmounia springs.

Table 2: Main physicochemical characteristics of the water from the 6 studied springs. Each data is the mean value of all measured values during the study.

	Sigus Watershed			El Rahmounia Watershed		
	SF1	**SF2**	**SF3**	**SM1**	**SM2**	**SM3**
Temperature (°C)	24.7	24.5	25.8	24.8	25.2	25.3
pH (en U.C.)	5.7	5.4	5.6	5	5.1	5.6
Electric Conductivity (µS.cm^{-1})	708	514	440	295	256	238
Suspended Matter (mg. L^{-1})	17	18	91	3	7	6
Colour (UPl. Col.)	10.7	17.3	605.3	17.3	40	43.7
Dissolved O_2 (% of saturation)	54	52	62	30	48	32
Hardness Cal (mg. L^{-1} $CaCO_3$)	55.3	20.7	8	6.7	11.3	8
Nitrite NO_2^- (mg. L^{-1})	0	0.13	0.12	0.01	0.06	0
Nitrate NO_3^- (mg. L^{-1})	0.02	0.05	1.31	0.06	0.13	0.04
Ammonium (NH_4^+ mg. L^{-1})	1.35	1.13	3.29	0.11	0.74	0.25
Phosphates (PO_4^{3-} mg. L^{-1})	0.36	0.5	0.5	0.17	0.03	0.23
BOD_5	70	60	62	47	40	43

The dendrogram based on the mean values of the physico-chemical variables measured in the spring water is presented in Figure 4. It clearly shows the differences between the source waters of the two watersheds and classifies these sources into two groups:

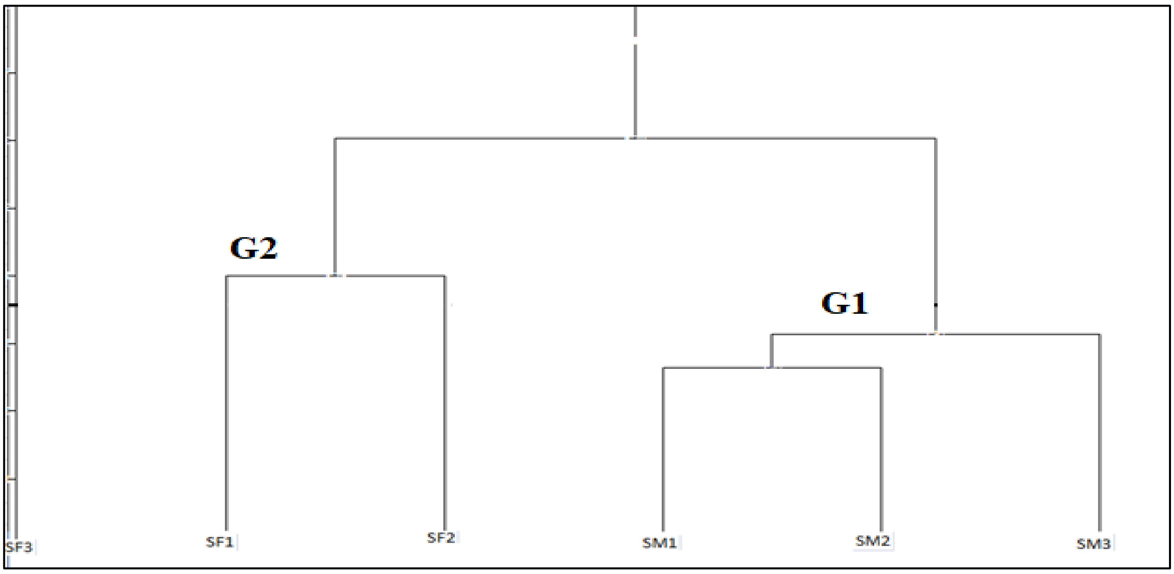

Figure 4: Dendrogram showing the hierarchical classification of the 6 springs obtained from the mean values of their water characteristics.

- **Group 1:** consisted of 3 springs located in the Rahmounia Basin, whose water is characterized by low chemical and organic pollution, with low values of electrical conductivity and equally low contents of nitrite, nitrate and orthophosphate ions, as well as BOD_5.
- **Groups 2:** consisted of 3 springs located in the Sigus Basin (Figure 4). All three contained water of relatively poor quality compared to that of Group 1. In the Sigus Basin, the spring water was polluted everywhere to varying degrees and was characterized by relatively high concentrations of ammonium and phosphate ions, as well as high BOD_5 values. However, source SF3 differed not only from the previous Rahmounia stations by the cited components but also from sources SF1 and SF2 by considerably higher values of nitrates and ammonia, as well as by its colouration, so that it was isolated from the 5 other sources and alone formed the third group which isolates the 2 source SF1 and SF2 in group 2.

Diversity of Wells Fauna

In the total aquatic fauna collected in the wells of the two watersheds, it was possible to distinguish 29 taxa (Table 3) belonging to 3 phyla (Annelids, Molluscs and Arthropods) and 25 families. The families Naididae, Cyclopidae, Haliplidae were each represented by two species belonging to two different genera and that of the Stenasellidae by two species of the same genus. The taxonomic richness of the fauna collected in the wells most often varied from 7 to 12 species, although at one station in the Rahmounia Basin (PM5) it was greater than 12 species and at two other stations (PF4 and PF7) in the Sigus watershed, it was less than 4 species. In the Sigus Basin, the richest samples were taken in the PF5 well with 12 species while in the Rahmounia watershed, the PM5 well provided 14 species. The poorest wells were PF4 and PF7 in the Sigus Basin with 3 aquatic species each, and the PM2 well in the Rahmounia watershed with 4 species.

In all the 14 wells and 6 sources studied, stygoby species were only collected in 2 wells in the Sigus Basin (PF1 and PF7) which yielded a total of 10 individuals, but in 4 of the 7 wells (PM1, PM3, PM5 and PM7) in the Rahmounia Basin, 34 individuals were captured. In the study area, the family Stenasellidae was represented by two species of isopod crustaceans belonging to the genus Metastenasellus, provisionally designated in this study as Metastenasellus sp. 1 and Metastenasellus sp. 2.

The *Culex culex* species, represented by its larvae, was by far the most abundant and most frequent in the 14 wells of the two basins, reaching 584 individuals in well PF1 of the Sigus Basin and 53 individuals in well PM6 of the Rahmounia watershed. Dero sp. was also very abundant with 110 individuals collected in well PF1 and 46 in well PM3. Dero sp. was present in the 5 wells PF1, PF2, PF3, PF5, PF6 of the Sigus watershed and in the 3 wells PM1, PM3, PM4 of the Rahmounia watershed.

Table 3: List of main taxa collected from the faunal sampling of the 14 studied wells. Each data is the total number of individuals got during the whole study.

				Sigus Watershed							**El Rahmounia Watershed**						
Phylum	**Class**	**Family**	**Genus or species**	**PF1**	**PF2**	**PF3**	**PF4**	**PF5**	**PF6**	**PF7**	**PM1**	**PM2**	**PM3**	**PM4**	**PM5**	**PM6**	**PM7**
Annelida	**Oligochaeta**	Naididae	*Dero sp.*	110	5	4		2	3		14		46	4			
			Chaetogaster sp.	52									6				
		Tubificidae	*Potamothrix moldaviensis*	1		6					4	4	1		6	2	1
Molluscs	**Gastropoda**	Hydrobiidae	*Lithoglyphus sp.*	4											4		
		Lymnaeidae	*Potamopyrgus antipodarum*		3												
Arthropoda	**Crustacea**	Cypridae	*Herpetocypris sp.*	2													
		Cyclopidae	*Tropocyclops confinis*										4		1		
			Mesocyclops sp.								4				2		
		Stenasellidae	*Metastenasellus sp.1*	6							2						
			Metastenasellus sp. 2							4	11		7		9		5
	Insecta	Entomobryidae	*Entomobryomorpha sp.*	7	3	2			5				8	1	3		17
		Ephemeridae	*Gen. sp.*					1									
		Gomphidae	*Onychogomphus sp.*												9		
		Aeschnidae	*Anaciaeschna sp.*		3								1	3			5
		Cordulidae	*Epitheca bimaculata*											3			
		Libellulidae	*Libellula sp.*														3
		Perlodidae	cf *Arcynopteryx sp.*													6	
		Plecoptera	*Gen. sp.*		1	1			1						2		
		Dytiscidae	*Gen. sp.*							1							
		Haliplidae	*Haliplus sp.*												52		
			Peltodytes sp.								2						
		Coléoptères	*Gen. sp.*		3	1									2	1	
		Rhyacophilidae	*Hyporhyacophila sp.*													1	
		Glossosomatidae	*Glossosoma sp.*												3		
		Tipulidae	*Gen. sp.*		1										2		
		Culicidae	*Culex culex*	584	25	17	4	9	15	4		14	19	29	2	53	2
		Chironomidae	*Chironomus sp.*	57	2	21	2	109	156		10	22		28	32	22	
		Ceratopogonidae	*Dasyhelea sp.*	3	1	1	1	4	3			2	2	3	1	6	1
		Simuliidae	*Gen. sp.*		1			3									

The projection of taxa on the factorial plane of the first two axes of the Principal Component Analysis (PCA) (Figure 5) shows three groups of taxa quite clearly. The first axis of the plane separates, on the negative coordinate side, the most common taxa that are known to be resistant to water pollution (such as Culicides and Chironomides and other aquatic insect larvae), which oppose stygobial (such as the Crustacea Metastenasellus) or stygophilic (such as the Copepods and Annelids) taxa, all of which are on the positive coordinate side, and which are also separated on axis 2 of the PCA.

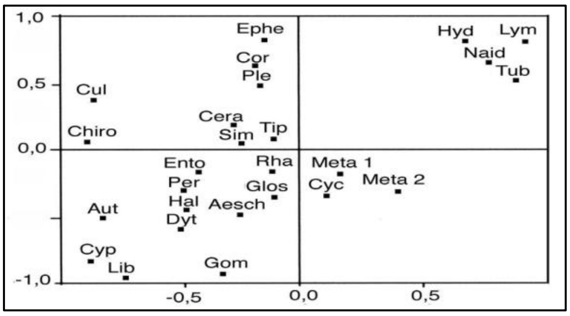

Figure 5: Projections of the main taxa of the well water fauna on the plan of the two first axes of a PCA.

Springs Fauna

As in the well fauna, 21 taxa, belonging to the 3 branches of the Annelids, Molluscs and Arthropods, could be counted in the harvests obtained by filtering spring water in the two watersheds (Table. 4). No stygobic species were harvested from the springs in the two watersheds.

In the springs of Sigus all repertory families are represented by a single species; on the other hand, in the Rahmounia Basin, the Cyclopid copepod crustaceans include two species: *Tropocyclops confinis* and *Mesocy-clops sp*. In this basin the arthropods belong to 9 families of insects, Crustaceans being absent, and the Gastropod Molluscs represented by 2 taxa, as well as the Oligochaete Annelids. In the Rahmounia watershed, on the other hand, Arthropods are represented by 13 families (including 3 Crustaceans and 10 Insects), Annelids by 2 families and molluscs by only one.

The Oligochaete Naïdidae Dero sp. was the most abundant and most frequent species in the springs of the Sigus catchment area followed by Chironomus sp. In the lower Rahmounia catchment area Chironomus sp. and *Culex culex* species was the most abundant and most frequent in all spring.

In the springs, some species appeared only once in all the crops during the whole study (Gasteropoda *Potamo-pyrgus antipodarum*, the insects Anaciaeschna and *Libellula sp.* in the springs SF2, SF3 and SF1). In the Rahmounia watershed, *Mesocyclops sp*. and *Oniscus sp.* appeared only once in source SM1.

Table 4: List of main taxa collected from the faunal sampling of the 6 studied springs. Each data is the total number of individuals got during the whole study.

				Sigus Water shed			**Rahmounia Watershed**		
Phylum	**Class**	**Family**	**Genus or species**	**SF1**	**SF2**	**SF3**	**SM1**	**SM2**	**SM3**
		Naididae	*Dero sp.*	5	150	13	7		
annelides	**Oligochaeta**		*Chaetogaster sp.*		62				
		Tubificidae	*Potamothrix moldaviensis*		7		2		
Molluscs	**Gastropoda**	Hydrobiidae	*Lithoglyphus sp.*	1		4		7	
		Lymnaeidae	*Potamopyrgus antipodarum*		1				
		Cypridae	*Herpetocypris sp.*				3		
	Crustacea	Cyclopidae	*Tropocyclops confinis*				2	3	
			Mesocyclops sp.				1		
		Entomobryidae	*Entomobryomorpha sp.*	1	1			2	
		Ephemeroidea	*Gen. sp.* 1						11
			Gen. sp. 2					1	2
		Aeschnidae	*Anaciaeschna sp.*			1		2	4
		Libellulidae	*Libellula sp.*	1					
Arthropods		Gerridae	*Gerris sp.*				3		
	Insecta	Dytiscidae	*Dytiscus sp.*			5			
		Glossosomatidae	*Glossosoma sp.*	1	2			2	
		Ptychopteridae	*Gen. sp.*					6	
		Culicidae	*Culex culex*	4	18		1	31	3
		Chironomidae	*Chironomus sp.*	18	11	9	23	46	20
		Ceratopogonidae	*Dasyhelea sp.*		10	2		2	7
		Simuliidae (Simuliini)	*Gen. sp.*	1		1			2

The projection of taxa on the factorial plane of the first two axes of the PCA (Figure 6) does not show a very clear and easily interpretable structure. On the contrary, there is a significant dispersion of taxa, which are distributed in the four quadrants into several small groups. However, it can be observed that the first factorial axis shows, on the side with negative coordinates, the most common taxa that are known to be resistant to water pollution (Culicidae, Ceratopogonidae and Chironomidae), unlike the stygophilic taxa (Copepods or Oligochaeta) that were present on the opposite side with positive coordinates.

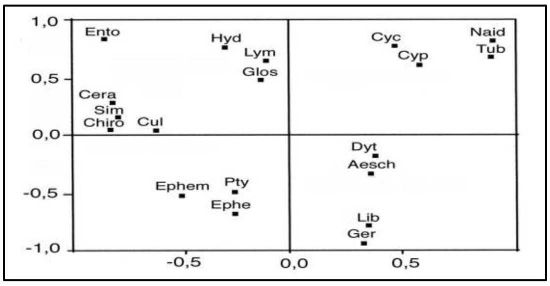

Figure 6: Projections of the main taxa of the fauna from the 6 springs, on the plan of the two first axes of a PCA.

DISCUSSION

Groundwater Quality

Throughout the study area, both well and spring water were characterized by significant mineralization (with high electrical conductivity) and a marked acidic character (with a pH generally below 6 in both wells and springs in the two basins. These two peculiarities can be considered to be related to the nature of the geological substratum where silico-feldspathic and ferralitic rocks dominate. This substratum is the same in both river basins and the Mediterranean climate, the temperature of the water table being generally between 23°C and 25°C, and erosion and dissolution of the rocks by infiltration water is very active. Strong mineralization and acidity of groundwater was often observed in siliceous regions (Oga et al., 2009; Hassoune et al., 2010). These authors point out that where waters with electrical conductivity higher than 500 µS.cm^{-1} can be considered as abnormal in Europe; it is different in Africa. Gagneur and Yadi (2000) observed electrical conductivity values higher than 1000 µS.cm^{-1} in the springs of Algeria. This characteristic was also observed in Morocco, near Marrakech (Boulanouar, 1986; Boulanouar, 1995) and in South-West Morocco (Boulal, 2002). Previous studies have also reported electrical conductivity values well above 1000 µS.cm^{-1} in some wells and springs in eastern Algeria (Merzoug et al., 2008; Khammar et al., 2019). The high values observed throughout the study area are therefore not exceptional.

However, while the average temperature and pH values did not differ significantly in all the wells in the two basins, the electrical conductivity, although high everywhere, was much higher in the wells in the Sigus Basin (average 1004 µS. cm^{-1}) than in Rahmounia Basin (barely 715 µS.cm^{-1}). Similarly, average conductivity measurements in spring water were around 554 µS.cm^{-1} in the Sigus Basin, whereas it was only about 263 µS.cm^{-1} in the springs of Rahmounia Basin. Knowing that the geological and pedological substratum of the aquifers are the same, as well as the climatic conditions in the two basins, the importance of urbanization and the anthropogenic impact that characterize only the Sigus Basin (the studied area corresponding to the urban agglomeration of Sigus) must be taken into account to explain such differences. If this is indeed the case, water from wells and springs in the study area should also show measurable signs of higher pollution in the Sigus Basin than in the Rahmounia Basin.

This is precisely what has been observed. Indeed, even if the concentration of nitrate ions in water is everywhere rather low, compared to what is often observed in Europe (Paran et al., 2005) or the Maghreb in anthropised regions, it should be noted that in all the wells of Rahmounia Basin the average value of nitrate ion concentrations observed was close to 0.04 $mg.L^{-1}$, this same average concentration reached 0.25 $mg.L^{-1}$ in the Sigus Basin. Similarly, in the springs, these values were 0.08 $mg.L^{-1}$ and 0.46 $mg.L^{-1}$ respectively. The nitrate content of the water was thus 6 times lower in the Sigus Basin than in the Rahmounia Basin, both in wells and springs.

The average nitrite concentration was 0.10 $mg.L^{-1}$ in the water of the Sigus wells and only 0.04 $mg.L^{-1}$ in the water of well in the Rahmounia Basin. In springs, these values were 0.08 $mg.L^{-1}$ (Sigus) and 0.02 $mg.L^{-1}$ (Rahmounia) respectively. Thus, if we compare the groundwater of the two basins, we find significant differences in nitrite concentration, since the dissolved nitrite contents were 2.5 to 4 times higher in the anthropized basin.

Similarly, on average, the concentration of ammonium ions was 4.83 $mg.L^{-1}$ in the wells of the Sigus and 0.93 $mg.L^{-1}$ in the wells of the Rahmounia Basin, and 1.92 $mg.L^{-1}$ and 0.14 $mg.L^{-1}$ in the spring water of the two basins, respectively.

Finally, the average orthophosphate ion content was 1.54 $mg.L^{-1}$ and 0.36 $mg.L^{-1}$ in the wells of both basins; whereas in the spring water, it was 1.54 $mg.L^{-1}$ in the Sigus Basin and only 0.36 $mg.L^{-1}$ in the Rahmounia Basin.

Phosphates, which most often come from detergents or the chemical industry, or even faecal pollution (outside areas of intensive agriculture using phosphate fertilizers), are most often indicators of anthropogenic pollution in or near urbanized areas (Herguez, 1965; Brémond and Perrodon, 1979; Atteia, 2005). The same is true for the 3 types of nitrogen ions considered above, which very rarely originate in the subsoil (Nisbet and Verneaux, 1970). Although, they can sometimes result from the more or less complete bacterial decomposition (depending on whether the medium is more or less oxidizing) of plant organic matter that may naturally enter well or spring water. It may be inferred, from the overall differences in concentrations of the various nitrogen ions and phosphates in the well and spring water of the two catchment areas, evidence of significant groundwater pollution in the Sigus catchment area which corresponds precisely to the Sigus agglomeration.

However, it should be noted that in both wells and springs in the two watersheds, BOD_5, which is an indicator of the organic load in the water, does not differ significantly from the different nitrogen and phosphate ions. It is therefore, very likely that these nitrogen ions, which are more abundant in the water of the wells and springs of the Sigus Basin, do not come, for the most part, from the natural decomposition of leaves or various plant debris brought by the wind to stations more or less protected from these external inputs in the two sectors. They can more likely be considered as indicator ions of pollution - brought by water infiltrating from the surface to the water table - which characterize the urban area of Sigus and which are much less abundant west of this area (Figure 1) in the Rahmounia catchment area which has retained a rural character with a lower density of settlements and polluting economic activities.

These results therefore, largely corroborate with those obtained in the Bir Amar (Merzoug et al., 2011) and Ksar Sbahi region (Hadjab et al., 2018), which had already highlighted the vulnerability and pollution of the groundwater of Oum-El-Bouaghi. By comparison, in the Rahmounia catchment area, water from wells and springs appears to be of relatively good quality, taking into account the physico-chemical values observed in this catchment area, and with reference to the WHO (2004) and JORA (2011) standards for drinking water.

Fauna of Wells and Springs

The fauna harvested in the 20 stations studied was first characterized by the dominance of epigean aquatic species, i.e. of external origin, compared to the very small number of stygoby species, underground species whose life cycle is always and entirely carried out in the water table. Not surprisingly, this result illustrates the fact that, as Vandel (1964) and Dalmas (1972, 1973) had already shown, wells and springs are ecotones where two communities cohabit epigean and endogenous species. Wells and springs are well fed by groundwater but are much less protected from external inputs than the water table itself.

A richer, more diverse fauna in the wells than in the springs was observed in this study, with the number of taxa collected varying from 7 to 10 per source, compared to 18 to 56 in 6 sources in Algeria studied by Gagneur and Yadi (2000). However, the study in Algeria had gathered results of many harvests carried out over a much longer period (6 to 7 years) and many of their determinations had been made at the species level, as the work was oriented towards a faunistic study, and particularly towards a study of the entomofauna. However, the number of species during the present study (7 to 10) was slightly lower than that obtained by Merzoug et al. (2002; 2007; 2008; 2011) and slightly higher than that obtained by Hadjab et al. (2018) (2 to 8 aquatic species) in springs also located in the Sigus watershed.

Similarly, the number of aquatic taxa collected in well water from the Rahmounia Basin (5 to 11, with an average number of 6.6) was higher than that of well water taxa from the Sigus Basin (only 2 to 9 taxa, with an average of 5.6 per station). These results, therefore, suggest that the overall taxonomic diversity of well and spring zoocenoses may be higher at stations located in areas where the water table provides better quality water. Biodiversity, evaluated most simply, in terms of taxonomic richness, seemed to vary just as much as the quality of groundwater.

It should be noted that the most varied biodiversity and density was observed in Rahmoinia Basin (Table 2), especially the larvae of Diptera Chironomides and Culicides, and to a lesser extent the Oligochaete Naïdidae of the genus Dero. All these species are known to be particularly resistant to pollution. Moreover, Dipteran larvae come from the eggs of adult insects outside the aquatic ecosystem itself and provide more information on the local microclimate and especially on the effectiveness of the protection of water points than on the physico-chemical characteristics of the water.

In 6 of the 14 wells studied, the harvested fauna contained representatives of the Stygoby community. These were two species of Isopod crustaceans belonging to the family Stenasellidae and the genus Metastenasellus, which have been previously reported (Merzoug et al., 2011; Khaldoun et al., 2013; Hadjab et al., 2018). This genus of isopods is present in many parts of tropical and equatorial Africa including Nigeria (Lincoln, 1972; Magniez, 1979) and even north of the Sahara (Magniez, 1986). A taxonomic study of the Metastenasellus of north-eastern Algeria was undertaken, and it may be stated that we are indeed in the presence of species that are new to science and will be described later. Four of the stations that delivered Metastenasellus during this study (PM1, PM3, PM5 and PM7) are located in the Rahmounia watershed, which is the least polluted, and only two stations (PF1 and PF7) in the Sigus watershed, thus in the Oum-El-Bouaghi agglomeration.

While some authors have sometimes written that "spatial variations in the physical chemistry of groundwater" do not appear to be "the primary factor controlling the distribution of fauna" in groundwater (Paran et al. 2005), for this conclusion to make sense it is essential to clarify the scale at which the diversity and distribution of stygoby organisms are considered. Indeed, it is generally agreed that: on a very large scale (that of a group of countries, or even an entire continent or the entire planet), the entire geological and paleographic history of the earth, over tens and sometimes hundreds of millions of years, with its climatic and geographical consequences, as well as large-scale phenomena such as continental drift, is the only way to explain the significant differences between flora and fauna, including that of the subterranean fauna on the various continents.

On a medium scale (that of a country, or a geographical region of a country) it is the nature and characteristics of the different terrains that form the aquifers in which groundwater flows that are decisive. As the rocks are more or less porous or fractured, and therefore more or less permeable, the slope of the land is more or less steep and as a result, the water will circulate more or less easily, and this water will consequently be more or less oxygenated. Finally, the permeability and especially the granulometry of the loose sediments facilitate more or less not only the movement of water but also that of the stygoby organisms that live in the interstices and can remain there.

On a smaller scale (in kilometres or at most a few tens of km), when the same water table extends in a plain, or the alluvium of a valley or a hydrographic basin, then the faunistic differences which are observed (presence of such or such stygoby species in certain stations whereas they are absent in certain others) can most often be explained by local variations in the physico-chemical quality of the water, and be most often related to the sources of surface pollution and infiltration that locally affect the water table, and therefore to the impact of the various anthropogenic activities on the surface.

The prospecting area for this study extends over less than 20 km from North to South and much less from West to East. Majority of stations, especially all the wells, are less than 10 km apart; a hydrographic basin was deliberately chosen for this study, where anthropogenic effects were evident since it included the Sigus agglomeration to compare it, with stations in a second, very close hydrographic basin with the same geomorphological and hydrogeological characteristics. These conditions were necessary to show a possible correlation between the Stygobian fauna and water quality or pollution due to anthropogenic activities. This was clearly observed in this study, confirming the interest of the Stygoby species and, to a lesser degree, the overall species richness, as indicators of well water quality.

It is possible that the relatively small number of stygoby organisms harvested at stations in the Sigus Basin, compared to the number of those harvested in the Rahmounia basin during this study, is not related to groundwater pollution due to anthropogenic pressure, since other important abiotic characteristics of aquifers, such as the nature and granulometry of the aquifer sediments, or the speed of water flow, do not differ significantly from one basin to another. This result is also in line with some previous studies (Boutin, 1984; Fakher et al., 1998), which experimentally showed the sensitivity of Stygobian crustaceans to water pollution, and had proposed to use these species as indicators (by their presence) of the relative quality of the water in a well or a groundwater table, or on the contrary (by their absence) of the pollution of the water in this table (Boutin 1984; Boutin and Dias 1987).

These results are also in agreement with the hypothesis put forward by Zébazé Togouet (2004) of a positive relationship between the presence of stygobionts and taxonomic richness since the latter is on average 8 in the Rahmounia basin where stygobionts are present in more than half of the stations and less than 7 (6.71 to be exact) in the Sigus Basin.

Finally, given the much higher number (32) of individuals of

Metastenasellus sp. 2, the large species, caught in the Rahmounia watershed, which is less polluted than the Sigus, which yielded only 4, we must finally consider the hypothesis that this species may be more sensitive to pollution than *Metastenasellus sp. 1* , since it is frequent (4 stations out of 7) in the Rahmounia basin with little anthropisation, and much rarer (only one station out of 7) in the Sigus basin where the water quality is lower. *Metastenasellus sp. 1* (the smaller species) on the contrary is rare in both basins (only one station); this apparent relative poverty must, therefore, be explained by causes other than the physico-chemical quality of the water, at least in the region studied. *Metastenasellus sp. 2,* would, therefore, be a better marker of water quality. However, this conclusion, however plausible it may be, is still uncertain and impossible to test experimentally in the laboratory because of the lack of the ability to capture a sufficient number of individuals of the two species alive, which is essential to implement a reliable experimental protocol allowing experiments comparable to those carried out by Boutin et al. (1997) or by Fakher et al. (1998). It cannot, therefore, be excluded that the respective distribution of the two crustacean species may also depend on factors other than water quality, such as the granulometric characteristics of aquifer sediments, for example. New research will, therefore, need to be undertaken in other river basins located in other regions of Algeria, with the aim both of knowing the diversity of the Algerian Stygobian fauna and of providing elements to answer these questions when the biogeographical characteristics of the two species are better known.

CONCLUSION

The water physico-chemical quality and sygobic fauna varied in the wells and springs. This variation is related to mineralization and especially to nitrogen pollution which sometimes exceeds the World Health Organization guideline levels in some wells. The causes for such situations need to be examined in the future and solved, as they concern a public health problem when the polluted wells are still used as a drinkable water source.

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