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Groundwater Quality in Two Semi-Arid Areas of Algeria: Impact of Water Pollution on Biodiversity

GROUNDWATER QUALITY IN TWO SEMI-ARID AREAS OF ALGERIA: IMPACT OF WATER POLLUTION ON BIODIVERSITY

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ABSTRACT

The biodiversity and quality of subterranean waters were comparatively studied in the Tarf plain near Oum-El-Bouaghi and in the Ksar S'bahi in Oum-El-Bouaghi, in North-eastern Algeria. For this purpose, physicochemical and faunistic analyses were carried out on the water of ten stations located in the area of Tarf, and thirteen in the area of S'bahi. In the wells of Tarf, the average stygobiologic diversity was relatively high in the wells located upstream the dumping site from the city where the groundwater presented low contents of nitrates and orthophosphates. In contrast, the wells located in the spreading zone of Tarf wastewaters were characterized by the scarcity or the absence of stygobic species; in these latter wells, the water was highly polluted. It was rich in nitrates, nitrites, ammonium, and the conductivity was rather high. In the area of S'bahi, the faunistic inventory recorded ten species, some of which were living in hot springs. The subterranean water was highly mineralized. In the two studied areas, biodiversity decreased when well water was locally polluted.

Keywords: Biodiversity, stygobic fauna, groundwater, water pollution, Oum El Bouaghi.

INTRODUCTION

Groundwater accounts for 97% of liquid continental freshwater (Bosca, 2002) and in several regions of the world, humans depend on the existence and quality of this limited and fragile resource: 75-90% of the world's population uses groundwater (Taouil et al., 2013). This underlines the importance of studying groundwater in all its components to gain a better understanding of these ecosystems and to introduce new scientific concepts for management, development, monitoring, protection, and conservation (Danielopol et al., 2004). In the eastern regions of Algeria, groundwater, which plays an important role in the stability of the population, is a key factor in the development of the country's economy and is dependent on a combination of natural and anthropogenic factors. It is threatened by climate aridity, overexploitation and various local pollutants (Khammar et al., 2019).

An assessment of groundwater quality is needed to detect and limit pollution, a need that is now widely recognized. The aquatic groundwater ecosystem is a biological system containing an entire zoocenosis, the diversity of which is an important characteristic that can provide information on the quality or pollution level of the aquifer (Merzoug et al., 2008; Merzoug et al., 2011). It is in this context that we present a comparative study of the biodiversity and quality of groundwater in two regions of north-eastern Algeria, located respectively in the vicinity of the region of El Tarf (South-East Oum-El-Bouaghi Algeria) and of the city of Oum-El-Bouaghi (KsarS'bahi).

This study was undertaken to conduct a stygobiological research of two regions, i.e. El Tarf and Ksar S'bahi in the wilaya of Oum El Bouaghi. The physico-chemical quality of the water from the selected stations was evaluated in order to highlight the sensitivity of the invertebrates to pollutant infiltrations.

MATERIAL AND METHOD

Study Area

The study was carried out in the region of Oum-El-Bouaghi in the Tarf shott region in north-eastern Algeria. About ten stations, represented by wells, springs, and streams underflow were selected. Monthly sampling campaigns were conducted in the wells of both regions during a period from September 2018 to June 2019. In the El Tarf region, from the selected stations, three wells were located within an agricultural zone (P4, P5, and P6), two others were located downstream of the Djebel Tarf, (P1 and P2), located inside the douar next to the household waste dump and the other wells were distributed in the plain of the Mechta (Ouled Abdelouhabab) south of the city of Oum-El-Bouaghi (Figure 1).

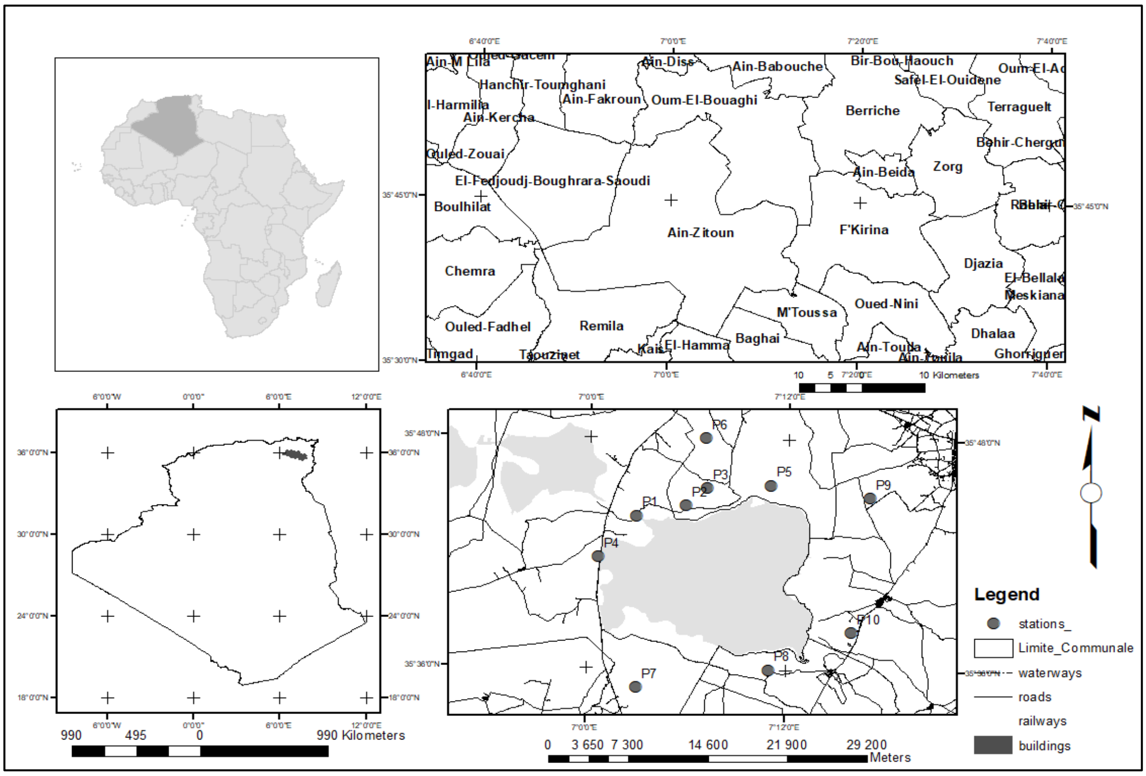

Figure 1. Geographical location of the El Tarf region

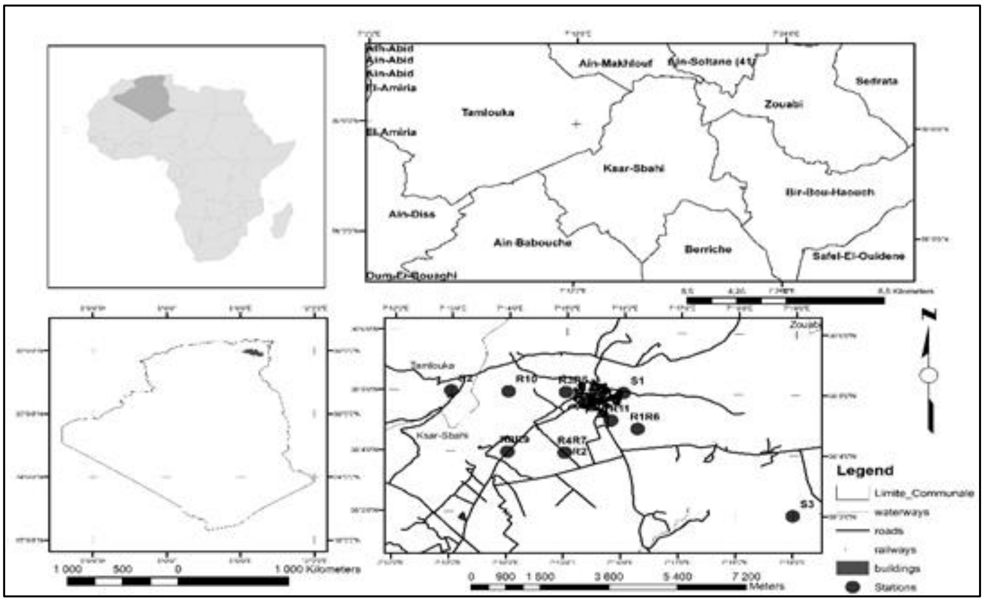

Figure 2. Geographical location of Ksar S'bahi region.

In the region of Ksar S'bahi 14 stations were selected (Figure 2). These stations were distributed as follows: two wells (R1 and R2) were upstream of the town of Ksar S'bahi, three wells were inside the town (R3, R4, and R5). The other wells were located downstream of the town (R6, R7, R8, R9, R10, and R11). Three other stations were selected: a station in the underflow of the Dhimine stream (S2) and two springs; the Hamel spring (S1) and the Zerdani spring (S3) (Figure 2). The climate is of semi-arid type in the region of Oum-El-Bouaghi. Rainfall does not exceed 300 mm per year (Anon, 2019). Daily and seasonal evaporation and temperature differences are high.

Sampling and Water Analysis Techniques

Stygofauna and water samples were taken from the wells on a monthly basis using a phreatobiological net, designed according to the model developed by Cvetkov (1968). The effectiveness of this method of sampling has been demonstrated (Boutin and Boulanouar, 1983). This technique was complemented by the use of baited traps, which are more efficient for the harvesting of crawling fauna, especially Isopods (Boutin and Boulanouar, 1983). Stygofauna in the underflow and stream sources was sampled using filtration techniques (Bou and Rouch, 1967). The stand harvested at each sampling was sorted, counted and determined to a specific level for the underground stand. The original epigenetic stand, usually formed by immature larvae, was determined at the family level (Tachet et al., 1980; Pinkster, 1993; Tachet et al., 2000). Oligochaetes and the Crustaceous Copepods and Ostracods have not yet been determined.

The Physico-chemical parameters of water, temperature, pH, conductivity and dissolved oxygen were measured in the field using portable WTW (345i) (Xylem, Germany) measuring devices. Ions indicating organic pollution, calcium and magnesium hardness, as well as the contents of sodium, potassium, sulfate, and chloride ions are measured in the laboratory, following the AFNOR standards (1983), the methods recommended by Rodier (2009) and Aminot et al. (1983, 2007).

Statistical Analysis

A Principal Component Analysis (PCA) was carried out on the Physico-chemical (mean values of monthly measurements) and biological data obtained in the two regions. Data processing was performed using SPSS 23.

RESULTS

Physical Chemistry of Water

Principal Component Analyses (PCA) performed on the physico-chemical data (Table 1 & 2), showed that the F1 axis, which represents 31.8 % of the inertia in El Tarf stations (Figure 3), opposes the PO_4^{3-}, SO_4^{2-} and Ca^{2+} ions with positive coordinates to the conductivity, $CaCO_3$, Cl^- and Mg^{2+}, having a strong contribution on the negative side. Axis 2, with 19.9 % inertia, opposed the nitrogen ions (NH_4^+, NO_3^- and NO_2^-) to alkalinity and to Na^+ and K^+ ions, which contributed negatively to the expression of this axis. The PCA results on the physico-chemical water data from the S'bahi (Figure 4) were very similar. The typology of the stations resulting from the PCA allowed three groups of stations to be distinguished, according to the physico-chemical quality of their water.

Table 1: Mean values and standard deviations (±) of physico-chemical water variables of stations in the Great El Tarf (Oum-El-Bouaghi) region.

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
O_2 mg. l^{-1}	6.2 ± 0.3	6.5 ± 0.2	6.9 ± 0.5	6.7 ± 0.35	6.5 ± 0.4	5.4 ± 0.7	5.9 ± 0.34	6.6 ± 0.4	6.0 ± 0.9	5.0 ± 0.7
pH	7.5 ± 0.1	7.5 ± 0.6	7.97 ± 0.21	7.97± 0.24	7.70 ± 0.12	7.30 ± 0.15	7.60 ± 0.15	7.90 ±0.14	7.3 ±0.06	7.4 ±0.33
CE mS.cm^{-1}	3.8 ±0.5	3.6 ±0.7	6.5 ±0.7	1.6 ±0.08	2.3 ±0.1	2.4 ±0.4	2.6 ±0.5	3±0.3	2.4 ±0.06	1.7 ±0.24
NO_3^- mg.l^{-1}	6.80 ±5.4	12.40 ±10.2	26.96 ±15.3	31.55 ±13.3	6.80 ±5.14	17.10 ±10.11	11.30 ±12.5	8.70 ±4.3	13.80 ±4.1	6.20 ±3.2
NO_2^- mg. l^{-1}	1.3 ±0.05	1.9 ±0.06	3.5 ±0.02	4.6 ±0.12	1.4 ±0.01	2.0 ±0.18	1.9 ±0.1	2.7 ±0.11	1.2 ±0.3	2.0 ±0.13
NH_4^+ mg. l^{-1}	0.5 ±0.02	0.00 ±0.03	0.06 ±0.05	0.05 ±0.01	0.10 ±0.08	0.10 ±0.06	0.10 ±0.01	0.10 ±0.03	0.00 ±0.01	0.00 ±0.06
PO_4^{3-} mg. l^{-1}	0.2 ±0.01	0.10±0.09	0.12 ±0.03	0.10 ±0.05	0.10 ±0.02	0.10 ±0.06	0.10 ±0.01	0.20 ±0.03	0.00 ±0.06	0.00 ±0.07
$CaCO_3$ mg. l^{-1}	402 ±20	558 ±80	504 ±29.4	680 ±.68.1	558 ±49.2	650 ±92	692 ±68	720 ±130	520 ±66.6	732± 113.3
K^+ mg. l^{-1}	3.3 ±0.7	3.3 ±0.35	3.1 ±0.40	2.6 ±0.61	3.2 ±0.50	4.1 ±0.20	2.9 ±0.22	3.4 ±0.29	4.0 ±0.70	3.4 ±0.45
Na^+ mg. l^{-1}	71 ±5.4	72.7 ±9.2	35.3 ±7.6	32.1 ±9.3	78 ±10.1	94.5 ±6.5	70.3 ±3.9	71.6 ±4.7	140 ±10	120 ±11.2
SO_4^{2-} mg. l^{-1}	1209 ±334	237.9 ±50.2	159.4 ±51.4	269.9 ±27.9	208.1 ±17.2	208.8 ±55	255.1 ±43.2	254.1 ±60.1	171.7 ±50.3	241.1 ±63
TAC mg. l^{-1} (CO_3^{2-})	2746 ±2.7	235.0 ±30.3	414.8 ±50.1	200.1 ±25	397.7 ±19.2	473.4 ±29.4	383.5 ±27.1	190.4 ±19.2	395.3 ±32.1	195.2 ±34.5
Ca^{2+} mg. l^{-1}	1099 ±252	123.4 ±40.6	169.9 ±32.9	142.7 ±19.3	121.0 ±36.9	152.3 ±36.9	153.1 ±36.7	124.0 ±14.4	104.2 ±17.4	184.4 ±36.8
$Mg.^{2+}$ mg. l^{-1}	2344 ±484	117.8 ±12.2	485.10 ±89.9	155.10 ±150.5	138.3 ±1788	127.6 ±234.7	214.6 ±36.5	249.1 ±36.6	154.9 ±35.3	94.2 ±22.3
Cl^- mg. l^{-1}	7241 ±913	894.6 ±86.1	1820.5 ±48.2	750.6 ±54.3	365.6 ±84.4	337.3 ±28.4	487.5 ±93.1	459.1 ±84.7	426 ±60.7	244.9 ±31.6

Table 2: Mean values and standard deviations (±) of physico-chemical water variables of stations in the Ksar S'bahi region (Oum-El-Bouaghi).

	S1	S2	S3	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11
O_2 mg. l^{-1}	6.90±1.2	40.1±0.9	7.35±0.8	4.30±0.2	6.1±0.4	6.50±0.3	6.90±0.2	6.70±0.3	6.45±0.1	6.60±0.5	5.35±0.3	5.85±0.3	2.40 ±0.2	5.10 ±0.1
pH	8.00±0.5	7.52±0.3	7.46±0.3	7.52±0.1	7.52±0.6	7.51±0.2	7.97±0.3	7.97±0.4	7.65±0.2	7.85±0.2	7.34±0.1	7.63±0.3	7.12 ±0.4	6.53 ±0.2
CE mS.cm^{-1}	0.39±0.02	2.53±0.01	2.13±0.08	0.99±0.04	1.63±0.02	1.62±0.01	1.70±0.01	1.87±0.04	1.36±0.01	2.88±0.01	2.23±0.18	1.84±0.01	2.47 ±0.01	10.83 ±1.1
NO_3^- mg.l^{-1}	31.1±18.2	14.21±4.5	10.51±2.3	9.20±5.1	6.76±2.9	32.39±14.3	52.96±12.3	41.55±14.3	6.79±1.4	8.73±2.1	37.13±3.1	11.26±6.2	23.45 ±2.1	23.13 ±1.2
NO_2^- mg.l^{-1}	2.49±0.01	0.68±0.1	0.40±0.03	0.71±0.1	1.34±0.6	1.86±0.31	3.47±0.21	4.59±0.11	1.39±0.17	2.73±0.16	2.05±0.09	1.89±0.2	0.75 ±0.04	9.60 ±0.12
NH_4^+ mg.l^{-1}	0.79±0.02	0.41±0.01	0.48±0.05	0.85±0.02	0.52±0.01	0.03±0.02	0.06±0.07	0.05±0.05	0.10±0.07	0.09±0.02	0.08±0.04	0.12±0.03	1.26 ±0.01	09.0 ±0.05
PO_4^{3-} mg.l^{-1}	0.00±0.01	0.00±0.01	0.00±0.04	0.00±0.05	0.16±0.03	0.06±0.03	0.06±0.01	0.12±0.08	0.10±0.06	0.08±0.04	0.09±0.05	0.15±0.07	0.00 ±0.02	0.00 ±0.00
$CaCO_3$ mg.l^{-1}	360±21.8	636±33.2	744±51.2	640±35	402±41.2	558±52.1	504±19.3	680±45.3	558±65.2	720±28.7	650±34.8	692±60.5	1760 ±35.2	6200 ±28.9
K^+ mg.l^{-1}	3.45±0.9	3.40±0.14	4.00±0.2	3.75±0.08	3.29±0.24	3.29±0.32	3.14±0.15	2.55±0.15	3.16±0.31	3.43±0.13	4.06±0.15	2.85±0.21	3.14 ±0.31	2.84 ±0.15
Na^+ mg.l^{-1}	88.64±12.5	120±21.3	140±6.5	98.75±14.2	71.03±9.8	72.65±14.2	35.30±13.1	32.06±12.8	77.97±14.3	71.58±14.3	94.49±17.2	70.34±15.4	98.14 ±12.2	112 ±19
SO_4^{2-} mg.l^{-1}	82.32±7.5	155.1±18.9	140.1±6.5	107.7±7.4	120.8±14.2	237.9±17.8	159.3±20.1	269.8±34.5	208.0±17.2	254.0±24.1	208.8±20.6	255.1±19.9	68.47 ±14.8	106.2 ±15.4
TAC mg.l^{-1} (CO_3^{2-})	273.2±25.6	195.0±14.8	395.3±23	265.4±19.2	274.6±25.5	235.0±36.4	414.8±45.1	200.0±15.4	397.7±16.8	190.4±24.5	473.3±45.1	383.5±15.3	287.2 ±35.1	316.8 ±46.3
Ca^{2+} mg.l^{-1}	55.93±14.5	95.11±17.8	55.34±17.3	63.04±15.1	72.14±16.3	123.4±18.9	120.2±14.5	142.6±17.4	121.0±18.4	124.0±21.3	152.3±25.4	153.1±21.1	8.93 ±12.4	6.39 ±3.15
Mg^{2+} mg.l^{-1}	304.0±41.5	540.8±23.5	480.7±14.6	576.9±47.5	329.8±16.1	434.5±14.2	384±28.5	537.3±17.6	436.9±42.1	596.0±41.4	497.7±25.5	538.8±46.3	1751 ±47.8	6193 ±66.4
Cl^- mg.l^{-1}	794.1±31.1	487.0±25.8	602.1±19.2	857.2±27.8	504.1±35.6	227.2±17.5	383.4±40.5	340.8±31.2	198.8±15.4	752.6±29.5	312.4±24.7	411.8±47.5	1267 ±47.5	907.7 ±35.5

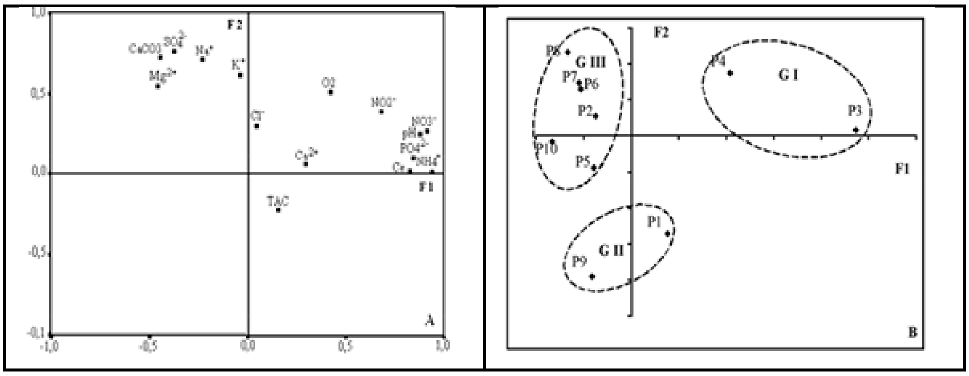

Figure 3: Projection of the physicochemical factors of the water (A) and the stations studied in the El Tarf region (B), in terms of the first two axes of the principal component analysis. CE: electrical conductivity; O2: dissolved oxygen, NO_3^-: nitrates; NO_2^-: nitrites; NH_4^+: ammonium; PO_4^{3-}: orthophosphates; K^+: potassium; Na^+: sodium; SO_4^{2-}: sulfates; TAC: total alkalinity, Ca^{2+}: calcium; Mg^{2+}: magnesium, Cl^-: chloride, $CaCO_3$: total hardness.

- ***Group G I:***

Included stations located in the spreading area (P3 and P4): they presented waters highly contaminated by the wastewater of the city of Oum El Bouaghi. It contained oxygenated water with a relatively high amount of nitrogen ions. The P3 well located in the urban area receives the inflow of wastewater from the public dump leachate. The waters of this well were characterized by their strong mineralization and conductivity higher than 6 $mS.cm^{-1}$, the contents of nitrite (3.5 mg. l^{-1}) and nitrate ions (26.96 mg. l^{-1}) was quite high.

- ***Group G II:***

Consisted of station P1 and P9, located far from any source of pollution. The waters were of good physico-chemical quality with relatively high mineralization, linked to the schistose nature of the land. The average electrical conductivity was 3.8 $mS.cm^{-1}$ in P1 and 2.4 $mS.cm^{-1}$ in P9. The water in these wells was well-oxygenated, with dissolved oxygen levels exceeding 6 mg. l^{-1} throughout the study period.

- ***Group G III:***

Included all the stations located outside the wastewater spreading area of El Tarf region (P2, P5, P6, P7, P8, and P10). They were characterized by fairly low organic ion content (Table 1). These wells are well protected and are located far from surface pollution sources. Their overall mineralization expressed by electrical conductivity varied between 1.7 $mS.cm^{-1}$ in P10 and 3.6 $mS.cm^{-1}$ in P2. Nitrogen ion content was generally low. The highest value of nitrates was recorded in well water P6 (17.1 mg. l^{-1}).

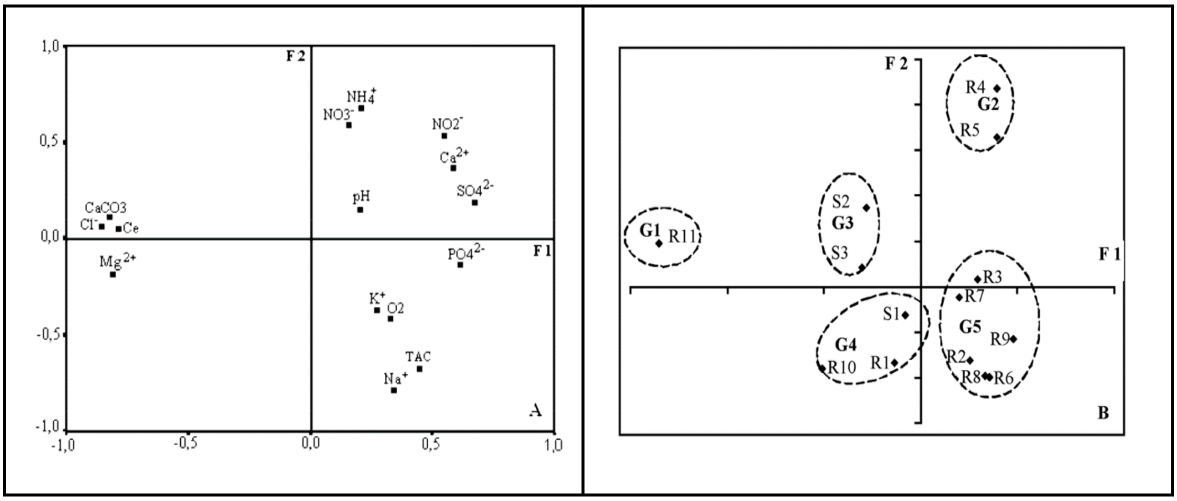

Figure 4: Projection of the physicochemical factors of water (A) and the stations studied in the Ksar S'bahi region (B), in terms of the first two axes of the principal component analysis. CE: electrical conductivity; 2: dissolved oxygen; NO_3^-: nitrates; NO_2^-: nitrites; NH_4^+: ammonium; PO_4^{3-}: orthophosphates; k+: potassium; Na+: sodium; SO_4^{2-}: sulphates; TAC: complemented alkalinity; Ca^{2+}: calcium; Cl^-: chlorides; Mg^{2+}: magnesium and $CaCO_3$: total hardness.

- **Group G I:**

Made up of the stations located in the spreading area (P3 and P4): they presented waters highly contaminated by the wastewater of the city of Oum El Bouaghi. It is still oxygenated water but with relatively high content of nitrogen ions. The P3 well located in the urban area receives the influx of wastewater from the public dump leachate. The waters of this well are characterized by their strong mineralization and conductivity higher than 6 $mS.cm^{-1}$, the contents of nitrate ions (3.5 $mg. l^{-1}$) and nitrates (26.96 mg l^{-1}) are quite high. (Table 2).

- ***Group G II:***

Consists of station P1 and P9, located far from any source of pollution, the waters were of good Physico-chemical quality with relatively high mineralization, linked to the schistose nature of the land. The average electrical conductivity values were 3.8 $mS. cm^{-1}$ in P1 and 2.4 $mS.cm^{-1}$ in P9. The water in these wells was well-oxygenated, with dissolved oxygen levels exceeding 6 $mg. l^{-1}$ throughout the study period.

- ***Group G III:***

Included all the stations located outside the wastewater spreading area of El Tarf region (P2, P5, P6, P7, P8, and P10). They were characterized by fairly low organic ion content. These wells were well-protected and were located far from surface pollution sources. Their overall mineralization expressed by electrical conductivity varied between 1.7 $mS.cm^{-1}$ in P10 and 3.6 $mS.cm^{-1}$ in P2. Nitrogen ion concentration was generally low. The highest value of nitrates was recorded in well water P6 (17.1 $mg. l^{-1}$). The hierarchical classification of the stations in the Ksar S'bahi region, the projections of which are shown in Figure 4, make it possible to distinguish five groups of stations:

- ***Group G1:***

Composed of borehole R11. The water was characterized by very high concentrations of $CaCO_3$ and chloride ions, reaching 907.75 $mg. l^{-1}$; as well as a very high electrical conductivity (10.83 $mS. cm^{-1}$). The poor water quality of this drilling is related to the nature of the water table, which is artesian, and to the geological nature of the aquifers. This station stands in contrast to all the others, particularly on axis 1 of the PCA.

- ***Group G2:***

Composed of the two wells R4 and R5, located respectively in the Ksar S'bahi town. The waters of these two stations were characterized by slightly high levels of nitrogenous elements, especially nitrate ions, which varied between 41.55 mg. l^{-1} in R5 and 52.96 mg. l^{-1} in R4 with standard deviations of 12 to 14 mg. l^{-1}. Thus, exceeding the potability threshold (50 mg. l^{-1}) set by the WHO (2004) and JORA (2011). The poor water quality in these plants is due not only to poor protection but also to the probable contamination of the water table by the wastewater from the town of Oum-El-Bouaghi.

- ***Group G3:***

It included the spring (S2) and spring (Blue Spring) (S3) which are characterized by hard waters with low nitrogen and phosphorus ion content. The average calcium and magnesium contents were very high (95.1 to 540.9 mg. l^{-1} in S2 and 55.34 to 480.76 mg. l^{-1} in S3).

- ***Group G4:***

Composed of S1, R1 and R10, which projected at the median of the first two factorial axes, with small negative coordinates. These three stations were located far from the Douar, away from any source of pollution and had good water quality.

- ***Group G5:***

Composed of stations R2, R3, R6, R7, R8 and R9, located in the Douar of Ksar S'bahi town and the 'downstream' zone of the hydraulic basin. This group is negatively correlated to axis 2. The waters of this group are characterized by very high alkalinity (720 mg. l^{-1}) and fairly high sodium (94.49 mg. l^{-1}) and potassium (4.06 mg. l^{-1}) contents. Wastewater infiltration from the city, more than the nature of the geological terrains is probably responsible for this degradation of quality. The age of the wastewater system and its very limited capacity to population growth is conducive to groundwater contamination. The R9 well is a special case where, despite the location of the well which is far downstream from the town, the water quality is again good. This well is located far from any source of pollution.

Populations Diversity

In the El Tarf region, 13 aquatic taxa were collected and generally determined at a specific level. Eleven were stygoby species whose habitat is the water table; they are essentially representatives of the Amphipod and Isopod Crustaceans (Table 3), with a new species of Isopods: *Microcharon sp.* which had just been collected for the first time. Two other species were aquatic epigenetic, benthic or nectonic forms, represented mainly by larval stages of insects and copepods. The stygobiological richness was nil in well P5, while 5 species were observed in well P1 located far from the sewage disposal area of this region.

In Ksar S'bahi, among the 25 taxa identified, 14 were stygoby species (Table 3). This diversity was nil in the majority of wells located within the urban perimeter of the town (R3, R4, R5, R6, and R7); it was 9 in well R9. Several species of Stygobian crustaceans were captured, namely the Amphipods (*Metacrangonyx longicaudatus*, *Metacrangonyx sp.*, *Metacrangonyx goulmimensis*, *Metacrangonyx panousei, Salentinella sp. and Maghrebidiella sp.)*, Isopods (*Typhlocirolana sp.*, *Microcerberus remyi*, *Magniezia gardei* and a new species of Isopods Microparasellidae *Microcharon oubrahimae)*, as well as species of Subterranean Gastropods *Hydrobiidae* (Table 3).

Table 3. List of taxa collected from wells in the Ksar S'bahi region and El Tarf

	Ksar S'bahi region														El Tarf region									
Stations	**S1**	**S2**	**S3**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
Oligochaete Class																								
Nadidae																				+			+	
Oligochète ind	+	+	+	+	+					+		+												
Pulmonary gastropods Class																								
Physa acuta	+		+	+		+					+							+						
Limacidae		+																						
Crustacean class																								
Cyclopoid copepods	+	+	+	+	+										+	+		+	+	+	+	+	+	+
Copepods		+		+		+									+		+		+	+	+	+	+	+
Harpacticoids																								
Ostracods				+								+												
Oniscudae sp(T)								+		+					+								+	
Arachnid class																								
Acariens (Gamasida) (T)				+							+	+	+							+		+		
Arrhenuridae					+				+															
Acarien oribate																				+	+			
Pseudoscorpion																					+			
Insect class																								
Collemboles(T)				+					+		+													
Psocoptères ind						+				+	+													
Culex sp															+	+	+	+		+	+	+	+	
Tabanidae																		+	+			+	+	+
Ind. Hymenoptera																					+			
sF Culicinae	+																							
Machlonyx sp	+																							
Machlonyx sp		+	+																					
Diamensinae					+																			

Caenis sp		+	+					+																
Ephemerilla ignita		+																+						
Psocoptère (T)													+											
sF Tanyponidae																								
Psychodidae																								
sF Chironomida	+							+				+												
Limoniidae											+	+												
Ceratopogonidae						+																		
Coléoptères sp											+													
Datiscidae				+								+												
Caenis sp				+								+												
Potamonthidae						+					+											+		
Total 33 taxons	**6**	**6**	**5**	**9**	**4**	**5**	**0**	**3**	**2**	**3**	**7**	**7**	**2**	**0**	**4**	**2**	**2**	**5**	**3**	**5**	**6**	**5**	**7**	**3**

DISCUSSION

Physical and Chemical Quality of Water and Relationship with Biodiversity

The set of Physico-chemical data shows that the groundwater in the El Tarf and Ksar S'bahi regions is generally mineralized, hard and slightly alkaline. No critical pollution zones in the sense of Nisbet and Verneaux (1970) have been identified, but fairly high levels of nitrite, nitrate, and ammonium characterize the stations located near the town of Ksar S'bahi or in the town's wastewater treatment area, thus reflecting a fairly high input of organic matter. Groundwater temperature, which is not included in Tables 1 and 2, is not very discriminating and is close to 20°C in all the stations in El Tarf region and 21°C in all the stations in Ksar S'bahi region.

Water quality in these areas depends on the nature of the bedrock, which provides the water table with fairly high and increasing mineralization from upstream to downstream. Anthropogenic activities such as open sewage dumping and the presence of septic tanks have a local impact on the quality of the water table in the El Tarf plain and downstream of the city.

The comparison of the results of the recent analyses of the water coming from the city of Ksar S'bahi with that reported two years ago by Hadjab (2018) and by Merzoug (2008) shows a slight improvement of the water quality, probably due to the suppression of one of the wastewater inflows that used to arrive in this area. Concerning the animal population, this work complements the work already carried out on the surface waters in Algeria (Pesce et al.,1981; Coineau and Boutin, 1992; Ayati et al., 2019) and on the groundwater (Merzoug et al., 2008; Hadjab et al., 2018; Khammar et al., 2019). It draws up a contribution to inventory of the underground aquatic population of the El Tarf region, which is still poorly known from a stygobiological point of view, and verifies the future of the underground aquatic biodiversity in the KsarS'bahi region after the developments carried out in the city's wastewater spreading area. This study also highlights the impact of anthropogenic activities on the biotopes and stygoby fauna of the two regions.

The analysis of the diversity of the underground aquatic population of Ksar S'bahi and El Tarf showed that this population is more diversified in comparison with the groundwater populations of the other Maghreb countries (Fakher El Abiari, 1999), it is as diversified as the population of western Algeria (Belaidi et al., 2004; Lakhdari, 2014), and that of the region of Khenchela near Oum El Bouaghi city (Khaldoun et al., 2016). The relatively low diversity of the stygofauna known from the other Maghreb countries and the Mediterranean basin is certainly largely the result of the lack of attention paid to stygofauna in these countries.

Stygoby settlement in the two study regions is relatively diverse, at least in areas outside the areas subject to the impact of human activity. This variation in specific wealth is comparable to that of the other regions of Morocco (Mohati, 1985; El Abiari et al., 1998; Coineau et al., 1999).

Several abiotic factors explain this richness, notably water quality. The joint analysis of biodiversity and water quality shows that several stygoby species of Peracarid crustaceans require good quality water with low levels of nitrite, nitrate, ammonium, and orthophosphates (Plenet, 1993). Experiments carried out in the laboratory on peracarid stygobia crustaceans confirm these findings (Boutin, 1993). High levels of nitrite appear to be limiting for the Amphipods *Metacrangonyx spinicaudatus*, *Metacrangonyx paurosexualis* and Isopode *Typhlocirolana haouzensis* (Boutin, 1993; Messouli, 1994).

The detailed analysis of the composition of underground invertebrate populations inside and outside the polluted areas revealed a modification of underground aquatic biodiversity about the relative deterioration of the Physico-chemical quality of the water. Several groups of taxa characteristic of good quality water, notably the Stygoby crustaceans, disappeared in the stations R3, R4, R5, R6, R7, R8, R10 and R11 in Ksar S'bahi and the wells P2, P3, P4, P5 and P6 in El Tarf region (Table 4), whereas these taxa were present in the corresponding area and occur as long as water pollution was not too high. These modifications were accompanied by variations in the population numbers, mainly in stations P2, P3, P4, and P6 of El Tarf and station S2 of Ksar S'bahi.

The disappearance of several species more sensitive to pollution in the P2, P3, P4, P5 and P6 stations in the El Tarf region is a change that seems to be linked to the impact of wastewater rich insoluble, organic or mineral elements. This is mainly the case for the amphipod crustaceans *Metacrangonyx spinicaudatus*, *Metacrangonyx paurosexualis*, which have a wider regional distribution (Bouzidi, 1989), and are sensitive to very high levels of ammonium, nitrate, nitrite and orthophosphate ions. Their absence in stations located in the area of application, where water quality is degraded, is certainly not due to any other cause. The high levels of ammonium ions and nitrates probably also explain the absence in this area of the Isopod crustaceans *Typhlocirolana*.

These observations are confirmed by the analysis of the distribution of crustaceans in Morocco, where this species is present from the Rifain domain to the Saharan regions (Bouzidi, 1989), via the coastal Mesa and the Atlas. Finally, the new species *Microcharon sp.* (Isopoda, Microparasellidae) was only collected in station P1 located in the Djebel Tarf aquifer, where the water quality is good. The fact that this species was collected for the first time during this study when numerous surveys had been carried out since 2010 all-around Oum-El-Bouaghi, is certainly because, for the most part, the research carried out in Algeria until then had been occasionally carried out, i.e. to the south of the water table of Oum-El-Bouaghi. While, station P1 which recently delivered the new Microcharon is located on the right bank of the Oued Dhimine and is therefore fed by the water table flowing from the hills of the Ksar S'bahi and Ain babouche plains (Figure 2).

In the El Tarf region, domestic discharges, laden with organic matter, lead to a degradation of water quality and thus, limit the installation of a diversified underground aquatic population. The presence of the use of groundwater is limited to wells with relatively good water quality. Well R9, located in the Ksar S'bahi site, had the highest fauna richness.

The unpublished species (*Microcharon oubrahimae*) (Aït Boughrous et al., 2007) was captured as well as several species of amphipods, isopods, and gastropods (Table 3). In wells R3, R4, R5 and R6, where stygobiological richness was nil, the levels of nitrates, nitrites, ammonium, and orthophosphates were relatively high, with the infiltration of wastewater from the city of Ksar S'bahi and the overuse of fertilizers and pesticides. These observations again confirm the sensitivity of the Stygobian fauna to high levels of organic elements. Stenasellid isopods were represented in our crops by *Magniezia gardei*, which had never been found since their description almost 40 years ago, in the typical station of the Kef Aziza cave, near Boudnib. This species was recently caught in R2 a few kilometers north of the Oum-El-Bouaghi region and then in the waters of the R9 well 40 km away in the Khenchela region south of El Tarf, dug in soft alluvium (Khaldoun et al.2016). We now have evidence that this species, although relatively robust, is not necessarily dependent on karst cave habitats.

In Ksar S'bahi, the wells best protected by coping stones (R1, R7, R8, R9 and R10) also had the highest stygobiological richness. These are wells located outside the sewage spreading area, whose water is of good Physico-chemical quality. On the other hand, the other wells (R4, R5 and R6) located in the spreading zone or in the perimeter used for some years for the public dumping of household waste (R2), which are poorly protected and exposed to various types of sources of surface pollution, appeared particularly poor in stygoby fauna (Table 3).

A comparison of the current aquatic biodiversity underground in the KsarS'bahi region with that observed in the past by Merzoug (2008; 2011), shows overall faunistic stability of the water table over decades, thus illustrating relative stability of the underground domain despite climatic and environmental hazards.

In the El Tarf region, our observations confirmed those made at Oum-El-Bouaghi and Khenchela, concerning the stygobiological richness which is relatively high in well-protected wells located outside the areas affected by human activities. The further one moves away from pollution sources (sewage and septic tanks), the greater the relative abundance and biodiversity underground. This correlation, which has already been observed in other regions of Morocco

(Boulanouar, 1995; El Abiari, 1999), appears to be general since it leads to the same conclusions for the groundwater in the Algerian region.

One can thus distinguish species that are very sensitive to pollution such as the *Metacrangonyx* amphipods or sensitive but less so as the *Typhlocirolana* isopods (Coineau et al., 1999). This sensitivity is less marked in certain groups of Stygobian crustaceans such as the *Thermosbaenaceae* (Monodella). Conversely, the epigean stygophilic and stygoxene fauna that inhabits groundwater is often indicative of poor water quality, as is the case for ostracods, copepods and larvae of Diptera Chironomidae and Diptera Culicidae, usually found in waters rich in organic matter and poor in oxygen. This was particularly observed in unprotected wells in the sewage disposal area of the two study areas.

Table 4. Grouping of Tarf (3 groups) and Ksar S'bahi (5 groups) stations as obtained by a hierarchic classification based on PCAs taking into account water quality and the richness in stygobic and epigean species.

Study area	Station Group	Stations	Richness		Species characteristic of the group		Water Quality
			Stygobiological	Total	Stygoby Fauna	Stygoxen and Stygophile Fauna	
El Tarf	G I	P3	1	3	*Heideilla andreae boulanouari*	Copepods	Bad
		P4	1	6	*Guistia gofasi*	*Ephemerella igniita*	
						Tanyponidae	
	G II	P1	6	10	*Maghrebidiella maroccana*	*Naididae sp*	Good
		P9	5	13	*Marocolana delamarei*	Copepods	
					Typhlocirolana haouzensis	*Culex sp*	
					Typhlocirolana leptura	Tabanidae	
					Microcharon sp		
					Monodella atlantomaroccana		
		P2	1	3	*Guistia gofasi*		
	G III	P5	0	3	*Heideilla andreae boulanouari*	Copepods	Very Good
		P6	1	6	*Metacrangonyx spinicaudatus*	Tanyponidae (larves)	
		P7	4	10	*Metacrangonyx paurosexualis*	Culicidae (larves)	
		P8	4	9	*Maghrebidiella maroccana*	Naididae sp	
		P10	4	7	*Marocolana delamarei*		
					Typhlocirolana haouzensis		
Ksar S'bahi	G1	R11	0	0	Total absence	Total absence	Very Bad
	G2	R4	0	0	Total absence	*Ephemerella ignita*	Very Bad
		R5	0	5		Chironomidae (larvae)	
	G3	S2	1	7	*Salentinella sp*	Oligochaete ind	Good
		S3	6	11	*Microcerberus remyi*	*Phytsa acuta*	
					Typhlocirolana cf haouzensis	Copepods	
					Guistia meskiensis	Caenis	
	G4	S1	4	10	*Typhlocirolana cf haouzensis*	ind Ostracoda	Very Good
		R1	5	14	*Metacrangonyx longicaudatus*	Oligochaete ind	
		R10	0	2	*Guistia meskiensis*	*Phytsa acuta*	
					Monodella cf atlantomaroccana	Copepods	
						Chironomidae (larvae)	
	G5	R2	4	8	*Typhlocirolana cf haouzensis*	ind Ostracoda	Medium
		R3	0	3	*Magnezia garrdei*	Oligochaete ind	
		R6	0	2	*Metacrangonyx longicaudatus*	Chironomidae	
		R7	0	3	*Guistia sp*	Psychodidae (larvae)	
		R8	0	7	*Monodella cf atlantomaroccana*	Caenis sp (larvae)	
		R9	9	16	*Microcharon oubrahimae*		
					Microcharon oubrahimae		
					Metacrangonyx goulmimensi		
					Salentinella sp		

It appears that well water quality is certainly a determining factor in the distribution of phreatic species, although this important biotope characteristic is probably not the only factor that can explain the observed distributions. Biological descriptors are good indicators of the quality of an aquatic subsurface environment. Their integration in water quality assessment would be an additional tool for assessing the state of the ecosystem to ensure monitoring and protection of the aquatic subsurface environment.

The overall composition of the Stygoby community showed some similarity in the two study regions, which are not too far apart (about 40 km) and have been separated since the end of the Lutetian stage, about 40 million years ago, during the first orogenic movements that initiated the South Atlasic formation. Since that time, the atlasic chain has formed an impassable barrier for the aquatic subterranean fauna inhabiting the water tables, which are definitively separated, to the south and north of the chain (Ayati et al.2019).

It is however remarkable that in each of the two study areas, 3 species of Gastropod Molluscs: Hydrobiidae have been collected (although they belong to a single genus in Ksar S'bahi whereas two quite distinct genera are present in Tarf), as well as 10 species of stygobian crustaceans which include in each region a representative of the Order Thermosbaenaceae, 4 representatives of the Order Isopods and 4 species of Amphipods belonging to two genera.

Among Isopods, the Cirolanidae of the genus *Typhlocirolanais* were represented in both regions by closely related species. The Microcerberidae, *Microcerberus remyi* was only collected in Ksar S'bahi during this work, but we know that a very close species has also been described in Marrakech (Magniez, 1978). Similarly, a morphologically close population of Stenasellidae *Magniezia gardei*, whose prototype comes from the Kef Aziza cave near Boudenib (Yacoubi et al., 2004), has been collected in Ksar S'bahi region but another very close population also exists in the North Atlas, in the Zat valley and near Marrakech (Boutin et al., 2002). All these Stygobian crustaceans, which are thalassoid species (Boulanouar,1995; Bouzidi, 1989) and which are represented by sister species on both sides of the High Atlas, strongly suggest that the establishment in the groundwater of these two populations of Stenasellidae, strongly suggest that the establishment in the groundwater of these two populations in regions of their ancestral marine populations is very old, older than the Atlas itself and that the Eocene sea did not reach the Ksar S'bahi region. This colonization thus, dates back to the late Cretaceous, presumably to the Turonian when the same regressive shores passed through the two regions studied some 90 million years ago (Messouli, 1994).

The genus *Marocolana* on the other hand, which only appears in the harvests of El Tarf, where these two currently known species meet, and which has never been harvested elsewhere, has been considered as a thalassoid species which would have passed from the interstitial space of the coastal marine environments to the continental underground waters only at a more recent time, during the Eocene (40 million years ago). Its absence in the harvests made at Ksar S'bahi is in perfect agreement with the evolutionary scenario already proposed (Pesce, 1985; Magniez, 1978) since the Gulf of the Eocene Sea, coming from the Atlantic, did not reach the El Tarf region, which is very far from the Atlantic. Finally, the Microparasellidae of the genus *Microcharon* were certainly present on both sides of the Djebel Sidi R'hgiss, but the population of the Tarf plain (*Microcharon oubrahimae*) has more affinity with the populations of the Eastern Mediterranean group (*Microcharon orghidani*-*M. bureschi*-*M. phlegetonis* group from Romania and Bulgaria) than with the species of the Moroccan High Atlas (Coineau et al., 1999).

Finally, the subterranean zoonosis of the two regions studied appears, if we consider it as a whole, quite comparable since the same large groups and genera occur on both sides of the Atlas, where they are represented by different species that are often closely related, which illustrates the endemic character of subterranean species in general, and the role of vicariance in the origin of the diversity of these species.

However, two exceptions can be noted: the genus *Marocolana* (Isopoda: Cirolanidae) which is absent in El Tarf, probably for the paleogeographical reasons indicated above, as well as the genus *Heideella* (Gasteropode:

Hydrobiidae) which is also absent from our crops in El Tarf and which may also not exist in the southern part of the plain. As this genus is only known in the northern region of Oum-El-Bouaghi (where the sea last returned in the Eocene), the species of the *Heideella* genus may have an identical distribution and origin to those of the Cirolanides, *Marocolana*. If our subsequent research confirms that the genus is indeed absent in south-eastern Algeria, this paleobiogeographic hypothesis will then be strongly supported.

As for the epigeous aquatic fauna present in our crops, the list presented in Table 5 should be considered preliminary only. The diversity of epigenetic organisms appears to be lower in harvests from Tarf (13 taxa) than in harvests from Ksar S'bahi (25 taxa).

CONCLUSION

The results obtained on the relationships between water quality and biodiversity reflect and confirm the possibility of assessing local or temporal variations in water quality from groundwater fauna sampling. It is remarkable to note the similarity of the settlements in the two regions studied, in relation to the palaeogeographic history of each region and the separation of the water tables on either side of the High Atlas Mountains in two very remote areas. The biological results showed that in the case of local pollution of wells or groundwater, the specific richness of zoocenosis in the wells decreases, and that it is stygocenosis that is reduced first and disappears completely in the case of excessive pollution.

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