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RELATIONSHIPS BETWEEN THE PHYSICO-CHEMICAL VARIABLES AND GROUNDWATER BIODIVERSITY: A CASE STUDY FROM MEKNES AREA, MOROCCO

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Abstract

The relationship has been established between the physico-chemical variables and the distribution of groundwater fauna in Meknes area, Morocco that is being subjected to anthropogenic pollution. This study aimed at showing the possible relationships between the physico-chemical variables of the water quality of wells and springs and the Groundwater biodiversity. To this end, the water quality and the fauna were regularly investigated in several stations (8 wells and 2 springs) selected in the region. The stations were chosen considering visible differences related to both their fauna and also some evident characteristics i.e. water table depth, nature of geological substratum, protection and human use. Groundwater crustaceans and especially its stygobiont fraction (species developing their entire life cycle exclusively in groundwater) living in this compartment are good predictors for the water quality. They are highly sensitive to any disturbance in their environment (both quality and quantity) and consequently their risks to be threatened are higher that turn to greater chances of extinction.

Keywords: *Wells; Stygobiont fauna; Water quality; Indicators*

Introduction

Biodiversity simply refers to the variety and variability of life forms (plants, animals and mico-organisms) on earth [1]. The need for an in-depth understanding of biological diversity with respect to groundwater is very important for an integrative assessment of abiotic and biotic indicators. This is crucial in the assessment of the environmental status, in monitoring trends ove time, in providing early warning of ecosystem deterioration, and in diagnosing the cause of an existing impact [2].

Groundwater accounts for over 97% of all freshwaters available on earth (excluding glaciers and ice caps) being the largest drinking freshwater reservoir in the world (almost 75% EU inhabitants depends on groundwater for their water supply) [3]. It represents also a significant resource for industry and agriculture and an important component of the global hydrological cycle [4, 5]. But groundwater can be recognized also as complex ecosystems varying in structure, dimension, and connectivity, and harbor a vast and almost unrecognized diversity of groundwater fauna [5]. Globally, it is only in the last years that the groundwater

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biodiversity has been acknowledged [3, 6, 7]. The groundwater fauna have been shown to be in some areas as diverse as those of the associated surface ecosystems, and especially in karst terrains [3]. The groundwater biodiversity has attracted much consideration in the last years due to the distinct assemblages when compared to surface water ecosystems. The groundwater lacks or have reduced diversification of insects, allowing the development of crustaceans. Consequently this makes groundwater to be more similar to marine waters than to freshwaters [7]. Furthermore, the endemism in groundwater is very common, and species are narrowly distributed on small areas, sometimes reduced to one single aquifer or even to a single site location [7, 8].

The role of groundwater ecosystems in hydrogeochemical cycling and enhancing groundwater quality, and the functional ecological significance of the biodiversity of groundwater recosystems is still poorly understood [9]. However it is thought that feeding, movement and excretion by groundwater fauna (stygobites and stygophiles) can enhance water purification, bioremediation and water infiltration [9, 10]. Found bacteria in the digestive tract of two stygobite crustacean species in Morocco and concluded that bacteria may be a nutritional resource for stygobites. The groundwater fauna is a living component that highly illustrates the quality of the subterranean waters. A number of studies have demonstrated the applicability of groundwater fauna for monitoring purposes related to any kind of disturbance (i.e. water pollution or drought) [4, 11-14].

The Moroccan groundwater fauna was still poorly known until the beginning of the eighties [15-18]. More systematic stygobiological investigations were recently performed, first in the Marrakesh region [19-21] then in other parts of Morocco: Goulmima [22, 23], Guelmim [24], Fez [25, 26], El Jadida [27], and the Rifian region. These last sampling were performed with the aim of both making more complete the inventory of known stygobiontic taxa from Morocco and testing once more the possible relationships between the biodiversity of the subterranean aquatic fauna and groundwater quality. This paper finally presents the first data on the stygobiontic fauna of Meknès area, as well as the relationships between the physico-chemical variables and stygofauna.

Materials and methods

Study area

The study area is the aquifer of Saiss basin of Meknes,The shallow aquifer Saïss Basin is located in the centre of Sebou watershed (Fig. 1), and corresponds geographically to the plain of Fez - Meknes. This aquifer is bordered by the valleys of Sebou and Beht respectively from the East and the West. The Saïss basin which is the study area, is one of the sub basins of Sebou, it extends over a length of 100km and a width of 30km between the Lambert coordinates: $465 < X < 545$ km and $335 < Y < 385$ km. It is bounded on the north by the Pre-rif, east through the valley of Wadi Sebu, west by the tributaries of the wadi Beht and south by the Middle Atlas Causse. This basin includes two structural units, the Saïss plain to the east and the plateau to the west of Meknes [28].

The circulation of this aquifer occurs primarily in the sands, sandstones, conglomerates and Sahelian Pliocene lacustrine limestones and locally in the travertine. Tortonian deposits of marl are the nature impermeable bedrock of the aquifer. Cuts derived from lithological columns stratigraphic drilling Plateau Meknes (Fig. 2) indicates that the Plio-Quaternary deposits show a wide variation facies of a well to another [29].

A Hydrogeological point of view, the watershed is the subject of several studies saw its water potential and its major activity, it contains two layers of uneven interest and are counted among the major aquifer systems in Morocco:

- Groundwater: flowing through the sands, conglomerates and limestones in parts of the lacustrine Plio-Villafranchian. On the hydrodynamics of the food web is through rainwater infiltration, the drainage of the deep aquifer and the return of irrigation water. And it is the most accessible reservoir region of Fez-Meknes.

- The deep aquifer: circulating in the dolomitic limestones of the Lias and starts to charge under the thick series of Miocene marls raincoats. This aquifer has an area of artesian important, but its overuse causes a decline in its area of artesian. These two aquifers are separated by a thick series of marls of Miocene [30].

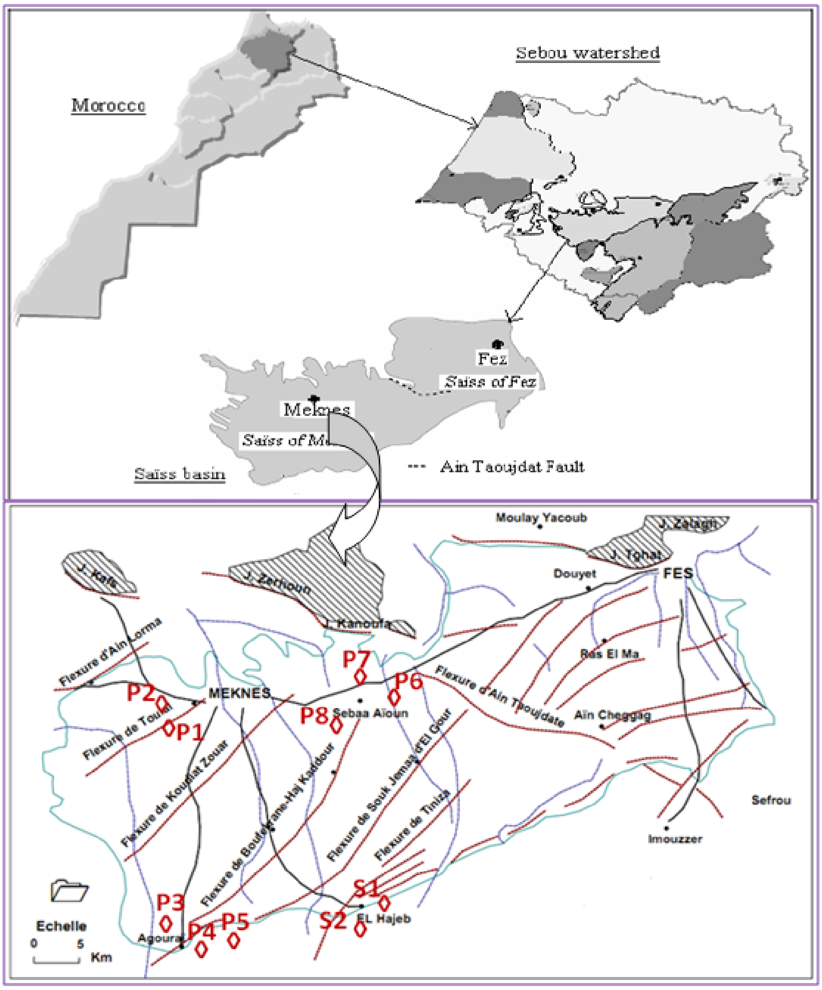

Fig 1. The study area (P = wells; S = springs)

The piezometric map (Fig. 3) of the shallow aquifer shows that the dominant flow is generally from south to north with the individualization of both flow directions. The first is South-east to north-west towards the plateau of Meknes and the second southwest to north-east. These two directions of flow are governed by the flexure of Ain Taoujdate, and are partly governed by a call for water to the north where the main irrigation schemes [31].

Most of the 8 study wells and 2 prings are used for agricultural or domestic purposes, and are located near a landfill (P1 and P2). Six wells (P3, P4, P5, P6, P7, P8) and 2 springs (S1, S2) are located near a man-made pollution. The characteristics of the wells are summarized in Table 1.

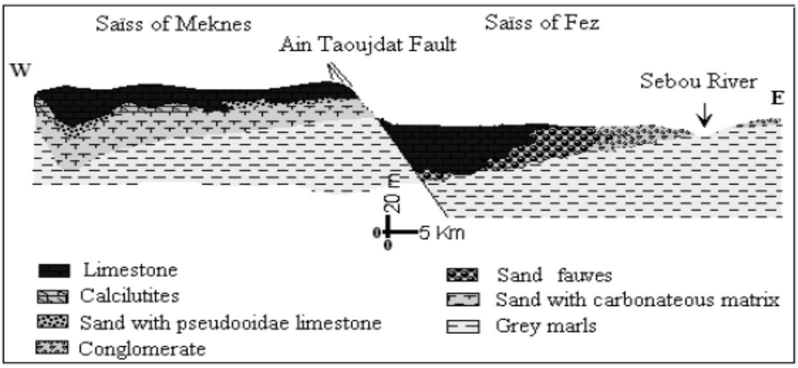

Fig. 2. Lithology of Saïss basin

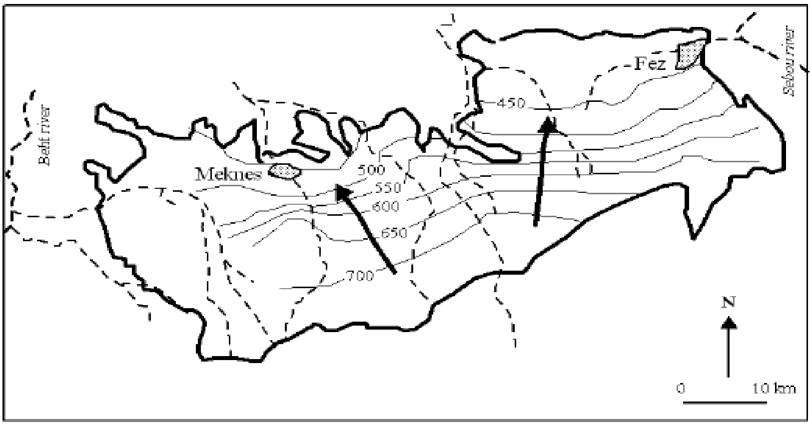

Fig. 3. Piezometric map of Saïss basin

Table 1. Characteristics of the 10 studied stations (P = wells; S = springs)

Stations	Diameter (m)	Mean water level below the soil (m)	Piezometric level	Protection	Usage	Environment
P1	1,6	14	9	Unprotected	Livestock watering	Waste and leachate
P2	1,3	25	2	Unprotected	domestic purposes	Waste and leachate
P3	1,7	25	16	protected	agricultural or domestic purposes	Wastewater discharge
P4	1,2	18	4	Unprotected	agricultural or domestic purposes	Manure and wastes
P5	1,2	24	8	protected	Drinking water	dig within a garden
P6	1,5	26	3	Unprotected	Drinking water	dig in a house
P7	1,6	27	4	Unprotected	agricultural or domestic purposes	Manure and wastes
P8	1,4	30	12	Unprotected	Drinking water	Manure and wastes
S1	-	-	-	Unprotected	Drinking water	wastes
S2	-	-	-	Unprotected	Drinking water	wastes

Sampling methods

Temperature, pH, conductivity, salinity and dissolved oxygen were measured *in situ* with a WTW multi-parameter probe. The other physico-chemical parameters (Chemical Oxygen Demand, Total Hardness, Alcalimétriques Complete Title, Nitrates, Nitrites, Ammonium, Orthophosphate, Sulphates, Calcium, Magnesium and Chloride) were measured in laboratory to assess the groundwater quality. Fauna was collected in each well four times from February to July 2013 with two types of sampling equipment: a phreatobiological net sampler [32, 33], 20cm in diameter at the opening, composed of a cone filter with a 150μm mesh, drawn up 10 times in each well through the entire water column, which was of different depths in the various wells; a nasse-type baited trap developed by [34] (Fig. 4). The traps were set in contact with the bottom for 24 hours. The same number of traps was placed in each well throughout the sampling period, with the same time of immersion. The samples were fixed in 5% formalin in the field. After the sorting, individuals were preserved in the field in 70% ethanol before being identified. All animals were identified to the lowest taxonomical level possible using published and informal keys.

Results and discussion

Physico-chemical variables

Adverse or positive impacts on stygofauna are influenced by some Physico-chemical variables such as Electrical Conductivity, Dissolved oxygen, Temperature and pH , as all these can change the habitat is available and influence stygofaunal communities in the study area are discussed below (Fig 5).

The mean temperatures recorded in the wells and springs varied from16,2°C to 18,1°C, with the minimum (16,2°C) measured in springs S1 and the maximum measured in the wills P6. [35] Suggests that groundwater organisms may not be sensitive to changes in water temperature. The pH ranged from 7.3 to 11.27, with the lowest mean value (6.8) measured in well P1. This low pH could contribute to the high EC of the well waters as low pH waters have been reported to increase the tendency of water to dissolve minerals and metal, thereby increasing EC [36]. Based on this data, the optimal pH range for stygofauna presence appears to be between pH = 6,95 and pH = 7,21. This is consistent with results from the other Australian studies by [37]. Additionally, many of the aquifer with these pH levels did not contain stygofauna, indicating that pH is not the sole determinant of stygofauna presence or absence. Then, water is highly mineralized in all the area with conductivities and salinity respectively above 507µS/cm and 280 mg/L. This mineralization is greater in the water of wells compared to the springs. The conductivity reaches maximum values of 13840µS/cm in the wells P1. This high mineralization may be influenced by anthropogenic sources, especially the landfill such as wells P1. Our results indicate that analysis of subterranean stands related to the water quality shown in the event of local pollution of the wells or ground water, the richness of the stygofauna in the wells decreases, and that the stygocénose first decreased and disappears completely when strong pollution as is the case of wells P1 located in landfill area. Although Electrical Conductivity is a primary determinant for the presence of stygofauna, it the water quality is unsuitable, and then the likelihood of detection decreases proportionately. The available data indicated that, if the EC is > 10000µS/cm, the likelihood of detecting stygofauna during is significantly reduced [37]. In several environmental variables, such as in specific conductivity, this varied from 507 to 13840µS/cm. More generally, our results reveal notable spatial variability in groundwater quality within the region (Fig. 5). Groundwater was generally under-saturated with dissolved oxygen, the DO concentrations ranging from 2,88mg/L at P1 to 9,05mg/L at S2; the highest values occurred in the springs S2. The presence of DO is vital for stygofauna survival, there was little available information regarding the optimal level of DO that is required for sustaining stygofauna populations. DO concentrations in groundwater can be very heterogeneous and influenced by factors such as sediment composition, formation structure, hydraulic exchange, organic matter content and the abundance of microorganisms in the aquifer [38]. It is difficult to correlate DO readings with the presence of stygofauna as habitat variability is so great between sampling locations [39], and other factors may be determining the presence or absence of stygofauna [38]. Also note that stygofauna are specifically adapted to highly dynamic DO environments [40], and this was confirmed by the Australian literature with no clear correlation between DO and stygofauna presence found. Low influence of DO concentrations in groundwater has also been observed by [38] found that many stygofauna are resistant to low levels of DO, with some populations located only in oxygen deficient goundwaters. The endemic characteristics of some stygofauna communities may be linked to the DO available in each aquifer type [40].

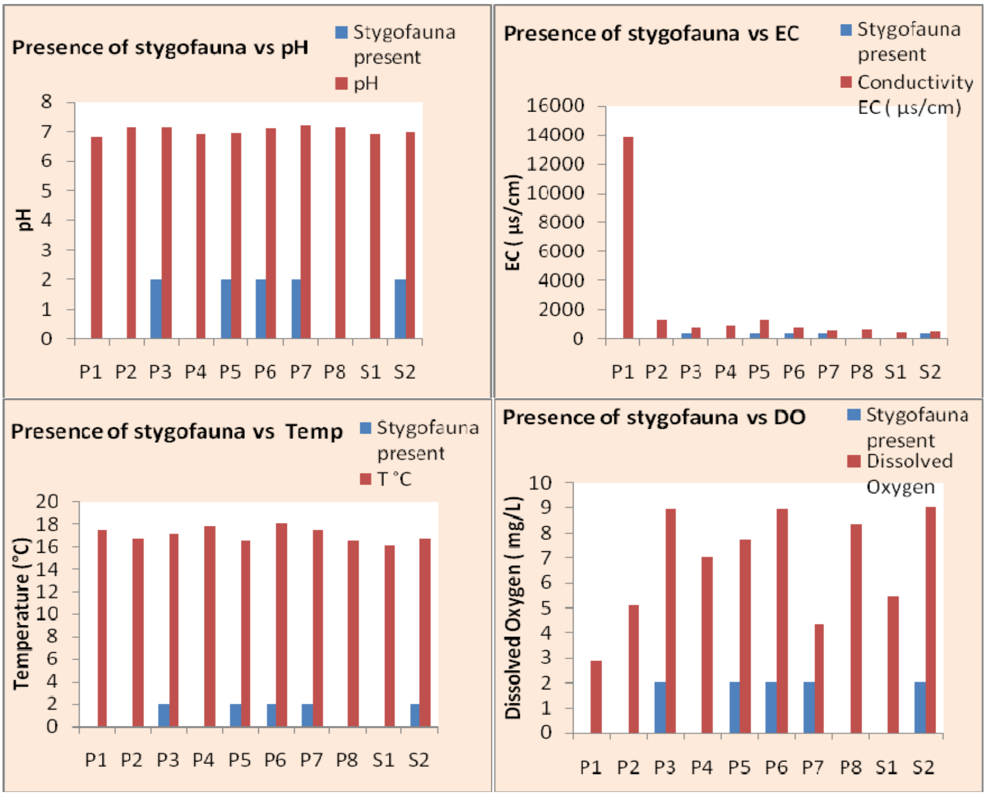

Fig. 5. Mean value of the main groundwater physico-chemical variables in the Meknes aquifer (presence of stygofauna compared to EC, pH, DO and temperature)

Other water quality parameters

The spatial variations of the physico-chemical parameters in the wells and springs water such as Chemical Oxygen Demand, Total Hardness, Alcalimétriques Complete Title, Nitrates, Nitrites, Ammonium, Orthophosphate, sulphate, Calcium, Magnesium and chloride of Meknès area are discussed below (Table 2).

The literature review failed to provide sufficient information from which to draw any conclusions about other water quality parameters, such as sulphate and nitrate, which may influence the presence of stygofauna.

Table 2. Mean values of the physical-chemical parameters of water from the 10 studied stations (P = wells; S = springs).

Stations	pH	O_2 mg/L	T °C	TH °F	Ca^{2+} mg/L	Mg^{2+} mg/L	Salinity mg/L	EC µS/cm
P1	6,8	2,88	17,5	23,5	215	20	7670	13840
P2	7,16	5,12	16,75	7,5	45	30	7,08	1324
P3	7,15	8,96	17,2	34	175	165	398	747
P4	6,92	7,03	17,8	39	295	95	485	906
P5	6,95	7,75	16,5	52,25	335	187,5	679	1277
P6	7,12	8,96	18,1	30,5	180	125	355	785
P7	7,21	4,36	17,5	27,5	230	45	350	654
P8	7,14	8,36	16,5	24,25	195	47,5	352	663
S1	6,91	5,46	16,2	32	170	150	262	507
S2	6,99	9,06	16,7	29,4	155	139	280	531

Stations	ACT °F	Cl^- mg/L	COD mg/L	SO_4^{2-} mg/L	NO_2^- mg/L	NO_3^- mg/L	PO_4^{3-} mg/L	NH_4^+ mg/L
P1	13	4082,5	40	187,26	0,013	12,73	0,231	0,872
P2	15,5	124,25	16	37,19	0,523	13,16	0,185	1,901
P3	22	53,25	10	63,21	0,004	17,47	0,32	0,133
P4	28	71	20	38,7	0,009	32,55	0,231	0,121
P5	28,75	124,25	25,2	66,98	0,013	10,44	0,092	0,109
P6	22	53,25	30	3,43	0,115	30,83	0,203	0,303
P7	21	35,5	20	5,15	0,138	37,49	0,097	0,024
P8	19	39,05	35,5	28,8	0,105	34,7	0,0021	0,012
S1	25,5	17,75	18,55	27,77	0,073	1,13	0,002	0,291
S2	22,5	26,98	23,54	60,19	0,001	2,01	0,157	0,157

T° = Temperature; EC = Electrical Conductivity; O_2 = Dissolved Oxygen; COD = Chemical Oxygen Demand; TH = Total Hardness; ACT = Alcalimétriques Complete Title; NO_3^- = Nitrates; NO_2^- = Nitrites; NH_4^+ = Ammonium; PO_4^{3-}= Pyrophosphate; SO_4^{2-} = sulphates; Ca^{2+} = Calcium; Mg^{2+} = Magnesium; Cl^- = Chloride.

The role of nutrient concentrations in determining groundwater ecosystems is not well understood [41]. Discussed the environmental variables that were important in determining groundwater species found at the Italian PASCLAIS sites and suggested that phosphate was not important, but that there was a weak relationship between nitrate and stygobiont species suggesting that groundwater pollution by nutrients might play a minor role in defining groundwater communities.

Also report a study by [42, 43] in which cyclopoids in a French aquifer were not affected by high nitrate concentrations. Groundwater animals are indicated in the literature to be especially sensitive to pollution, suggesting that groundwater fauna can be used as sensitive indicators of aquifer contamination [44-46]. However, sensitivity is rarely studied with a view to understand reasons for habitat preferences of species [47].

Faunal data

According to the results during this year 2013, preliminary results from the six month from February to July 2013 of sampling indicate that stygofauna is not very abundant and widely distributed across the region, and occurs in several different aquifer types area are discussed below (Fig. 6 and Table 3).

The invertebrate fauna collected in the wells and springs consisted of a combination of epigean and hypogean taxa, the latter represented mainly by crustaceans. Among the seven crustacean taxa, five were stygobiont. The most diverse groups were Amphipoda (3 taxa), followed by Ostracoda (1 taxa) and Copepoda Cyclopidae. The last taxon might be a stygobiont species. [48] Note that copepoda are particularly sensitive to microhabitat characteristics and therefore are good indicators of anthropogenically induced changes in water quality and hydrological regime. Groundwater is characterized in the study area by 20 aquatic biodiversity taxa (Table 3). Some taxa are stygobiont species, it is essentially amphipod: Metacrangonyctidae, Pseudoniphargidae and *Echinogammarus sp*; copepods: Cyclopidae. Other species are sometimes aquatic forms stygophiles as ostracods: *Eucypris virens sp* Ilyocypris or forms stygoxènes represented mainly by insect larvae and young imagos.

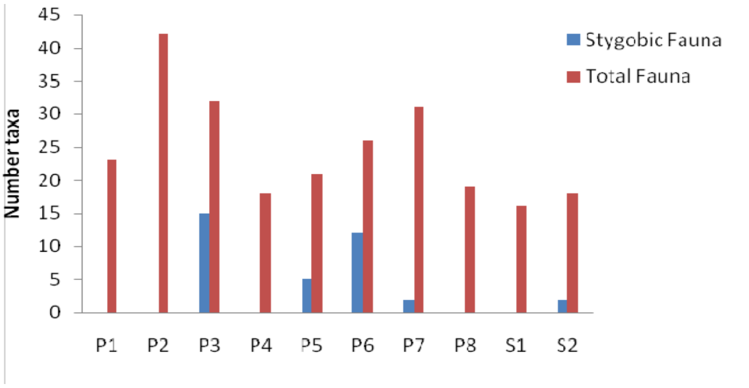

Fig. 6. Total number of taxa (epigean + stygobitic) and of stygobitic taxa collected in the wells and springs.

Table 3. Faunal list of the taxa in the water of the 10 studied stations (P= wells; S= springs)

Taxa		**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**S1**	**S2**
Plathelminthe	Dugesia gonocephala						11	22	14		
Oligochaeta	Lumbriculidae						3				
	Tubificidae					4					
	Naididae			2							
Gastropoda	Planorbidae			2						3	2
	Physa sp									7	5
Copepoda	** Cyclopidae						12	2			
Ostracoda	*Eucypris virens*									4	
	Ilyocypris sp.					3					2
	** *Ostracoda Indt*			15							
Amphipoda	***Echinogammarus* sp.										2
	** *Pseudoniphargidae*					3					
	***Metacrangonyctidae*					2					
Collembola	Collembola			2	1	4		2	3		
Heteroptera	Mesovellidae		1		1	2					
Diptera	Culicidae	23	36		2			2			
	Chironomidae		2	11	13				2		3
Coleoptera	Dytiscidae										1
	Elmidae		3		1	3					
	Larvae ind.	4						3		2	3
Total Taxonomic Richness		**23**	**42**	**32**	**18**	**21**	**26**	**31**	**19**	**16**	**18**

(** - Stygobiont).

A strong dominance of a few taxa was generally observed, with one dominant taxon per station, often representing over 70% of the total fauna. This was particularly true for Cyclopidae in P6 (85%), for the *Ostracoda Indt.* in P3 (74%), for the Gammaridae, *Echinogammarus sp.* in S2 (64%) and for Diptera, Culicidae in P1 (90%). In well P6, Cyclopidae represented 74% of the total fauna and the *Ostracoda Ilyocypris sp.* 63.16%. Similarly, stygobitic crustaceans were dominated specially by the species and family such as Pseudoniphargidae, Metacrangonyctidae, *Echinogammarus sp.*, *Ostracoda Indt.*, and Cyclopidae which represented 73-98% of the total abundance in wells P3, P5, P6, P7 and Springs S2. In P3, P4, P8 and Springrs S1, the invertebrate community was dominated by two epigean taxa: Physidae (Mollusca, Gastropoda), Plathelminthe, Oligochaeta and Culicidae, Collembola and Diptera (Arthropoda, Insecta). The remaining taxa were only present in 1 to 3 wells with very low abundance (< 3%), except for Chironomidae (Arthropoda, insecta) which were present in most wells with low abundance.

The mean taxonomic richness in the 8 wells and 2 springs is lower than that observed in other region in Morocco, e.g. by [49] at Marrakech (a mean of 12 species in 11 wells), by [23] in Tiznit region in the northern Anti-atlas (a mean of 14 species in 10 wells) and by [50] in the southern Anti-atlas (a mean of 10.8 species in 7 wells). Moreover, the subterranean aquatic fauna collected in this study is characterized by relatively low taxonomic richness: 11 and 18 stygobitic species were reported in previous studies of wells in other region of Morocco [21, 23]. Accordingly, groundwater fauna is characterized by low local diversity in relation to regional diversity.

In the references [51] is noted that studies have concluded that surveys of groundwater fauna can be used as indicators of environmental health in aquifers, and that stygofauna should be incorporated into groundwater management and protection programs.

Conclusion

In conclusion, the present paper has shown that the main determinants of stygobiotic biodiversity are linked to water chemistry, especially are factors related to conductivity electric, which has strong implications for the dissolved oxygen in the groundwater; it clearly visible for the case of wells P1 and P2 ; the analysis of the subterranean stands related to the water quality shows in particular some physico-chemical parameters that in case of local pollution of the wells or the ground water, the richness of the zoocénose of the wells decreases, and that the stygocénose in the first decreases and disappears completely in the case of strong pollution as was the case of wells P1 and P2 located in the discharge area household waste. This relationship between the physico-chemical parametres and the richness stygobic confirmed the sensitivity of the stygofauna the deterioration of the water quality, mainly the high electrical conductivity. However, other factors not considered here may also be important. These include availability of food resources, seasonal and other influences (including water extraction) on aquifer levels, physical habitat fragmentation and biological interactions, the additional parametres that could potentially influence the presence of stygofauna.

Groundwater is an extremely heterogeneous biotope and at the same time characterized by scarcity. Different spatial scales, especially the site specific local scale, have to be considered for an ecologically based assessment of groundwater. With drying climate, salinisation of surface waters and increasing population, groundwater is becoming an increasingly important resource, one already over utilized in places. Stygofauna could be used in both monitoring and maintaining aquifer condition.

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