Biotic and abiotic interactions between the superficial and interstitial water of a river to the Middle Atlas (Oued Tizguit).

Nezha Berrada [1], Khadija Essafi [1] & Nezha Aouad [2]

1 Laboratory of Hydrobiology and General Ecology. Faculty Science Dhar El Mehraz B.P: 1796 Atlas – Fez
2 University Hassan II, Faculty Science Aïn Choq - Casablanca.

Biotic and abiotic interactions between the superficial and interstitial waters have been analysed on the level of the interfacing zone between a river (Tizguit oued) and its underflow. The interactions were the results of water, mineral nutrients, organic matter and live beings transfers. Biotic interactions estimated by the taxonomic richness of invertebrate interstitial and superficial communities permitted to describe a zone of interfacing characterized by a dominance of epigean taxa and the scarcity of hypogean individus, represented here by the only stygobionte species Pseudoniphargus sp. The physico-chemistry of water permits to determines its quality and detect a certain natural or artificial pollution. It allows to determine its origin and explain the variations of the biological function. The interstitial waters of the Oued are relatively cold, slightly alkalised, mineralised, and relatively similar to the superficial waters from which they originate. The dynamic of exchanges at the level of interfacing zone between the river and its underflow is a direct vertical type. Exchanges take place from the surface to interstitial middle. They drag in depth epigean fauna, washed P.O.M (Particulate organic matter) and the physico-chemical features of the superficial water.

I. INTRODUCTION

The colonization of the deep sediments of the river flow by benthic organisms was studied by several authors (Bishop, 1973,; Williams and Hyneses, 1974,; Bretscho, 1981,; Standford and Ward, 1988). At the same time, phreatobiologists confirmed that the deep sediments of the river contain several stygobiont organisms coming from the underground environment and colonizing this biotope (Husman, 1975,; Danielopol, 1976,; Gibert and al., 1977; Dole, 1985). The biologic losses of the karst to the profit of the alluvial plain have been known for a long time (Gibert, 1984,; Rouch, 1984), the drifting animals can find shelter in the sediments (Mathieu and al., 1990). This double source of organisms colonizing the underground-superficial ecotone is the origin of its biodiversity.

The physico-chemical characteristic of the interstitial water of the different sites of sample permit to determine its origin and the evolution of its numbers (Essafi, 1990,; 1993). they also allow to quantify the interactions in the ecotone zone situated between two adjacent ecosystems (Gibert and al., 1990; Vervier and Gibert, 1991,; Vervier and al., 1992; Plenet and al., 1992; Plenet and al., 1995, Plenets and al., 1996).Thus, it seems possible to use these features to know the origin of water and to understand the faunal functioning.

The description of interactions between two adjacent ecosystems; superficial and underground, is made through the survey of the interface zone existing between them (Triska and al, 1989,; Gibert and al, 1990,; Vallet and al, 1990,; Pinay and al, 1990,; Vervier and Gibert, 1991,; Plenet and al, 1992,; Vervier and al, 1992). These interactions influence the cycle of the chemical elements and the invertebrates dynamics. The coupling of the hydraulic and biologic survey permits to value the degree of permeability of the interface zones.

The aim of this work is to collect and compare the first physico-chemical and faunistic results of the superficial and interstitial waters of the same river after an extensive prospecting that permitted the choice of characteristic sites. It also aims at establishing a relationship between the characteristic physico-chemical of the two types of waters and the fauna.

II. MATERIAL AND METHODS

II- 1. Study area

Oued Tizguit is part of the network of the basin of the Oued Sebou. It is a tributary of the Mikkes oued that is a direct tributary of the Oued Sebou. Its limited upstream by afaquefaque of the branching of the track of Dayet Hachlaf with the R.P: 20, and downstream by Zaouia Sidi Brahim. It has a total length of 20 km.

The regime of the Oued Tizguit is characteristic of karstic hydrology: winter discharge can to reach up to 10 times the discharge during low water conditions. This regime is ordered by springs spaced out throughout the coast 1700 to 1450. Eight points of sample have been chosen along the Oued Tizguit, from the Tizguit spring (1700m) until the downstream toward the Zaouia of Ifrane (1480m) on a course of about 20 km. Thus, the S1

site is situated a few more downstream the Tizguit spring, the S2 site is at 100 m of S1 to the exit of a griffon. The S3 site is located in the main channel at 1000 m from S2. The S4 site is at 1100 m of S3 after the loss of the oued. These four sites constitute an upstream transect characterized by a relatively weak width of the bed, and a less important surrounding vegetation in relation to the downstream transect that situated 7 km ahead. It starts with the S5 site that receives sewages of the city of Ifrane city. The S6 sites is placed at 800 m of S5. The S7 site is situated close to a griffon and at 900m from S6. Finally, the S8 station is situated to the downstream of the oued and at 4 km from S7. It receives an affluent of the Oued Zerrouka, it is almost stagnant given the important width of the bed. These downstream sites (S5, S6, S7, and S8) are subject to the human influence, they especially constitute a tourist site in the summer. (Fig.1).

II- 2. Sampling methods.

The parameters considered in the present work are: temperature, pH, the conductivity, alkalinity, calcium and magnesium concentrations.

The superficial water is sampled directly in the river. Interstitial water is sampled at 50 cm of depth in the river bed by the pumping method of BOU-ROUCH (1967).

Interstitial fauna has been sampled by the method of the artificial substrata of 50 cm of height, described by MATHIEU and al. in 1984. It consists in implanting some metallic tubes (50 cm of height and 10 cm of internal diameter) whose partition is pierced of holes of 8 mms of diameter in the river bed a few centimetres from the banks. The supports of the sediment forming the substratum itsself consist of five baskets made of galvanized metal grating (stitch of 5 mms) disposed the some above one another in tubes. The external diameter and the height of every basket are 10 cm.

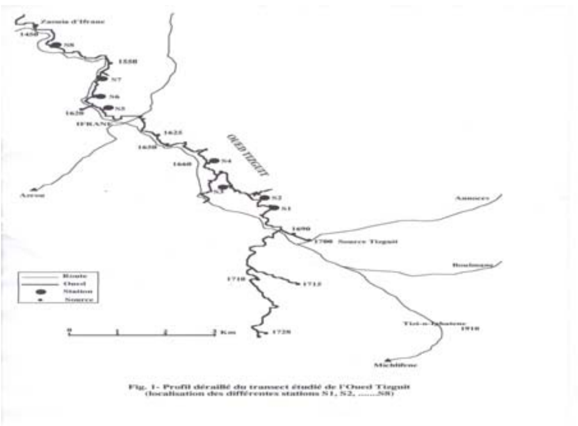


FIG 1 : Map of the study area showing the eight sampling sites

The sediment that fills them is sampled on the experimental site itself to reconstitute well the biotope, but it is cleaned beforehand and dried at the laboratory in order to eliminate all traces of organisms and pre-existing matters. Full baskets are left in place for about one month (necessary period to get a balance between contributions of organic matter and fauna in the substratum). The withdrawal of baskets must be done with care and the as quickly as possible in order to limit loss of organisms found in it, they are replaced then by other baskets.

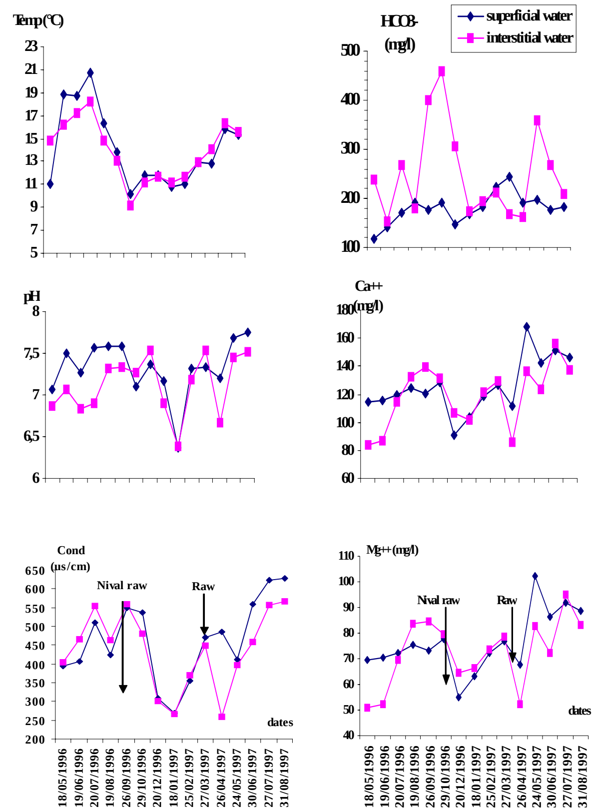
The content of every basket is rinsed at the laboratory on a sifter of 200 µms of diameter (Cleaning). filtered It (organisms + organic matter) is fixed to formol and stained by the Bengal pink.(colouring.)

The sample of the superficial fauna has been made by a Net surber close to every artificial substratum.

III – RESULTS AND ANALYSIS.

III.1-Physico-chemical characteristics.

The spatial and temporal evolution of the area values of the physico-chemical parameters is shown on Fig 2 and 3.



FIG, 2: Temporal evolution of the area values of the different physico-chemical parameters of the two types of waters

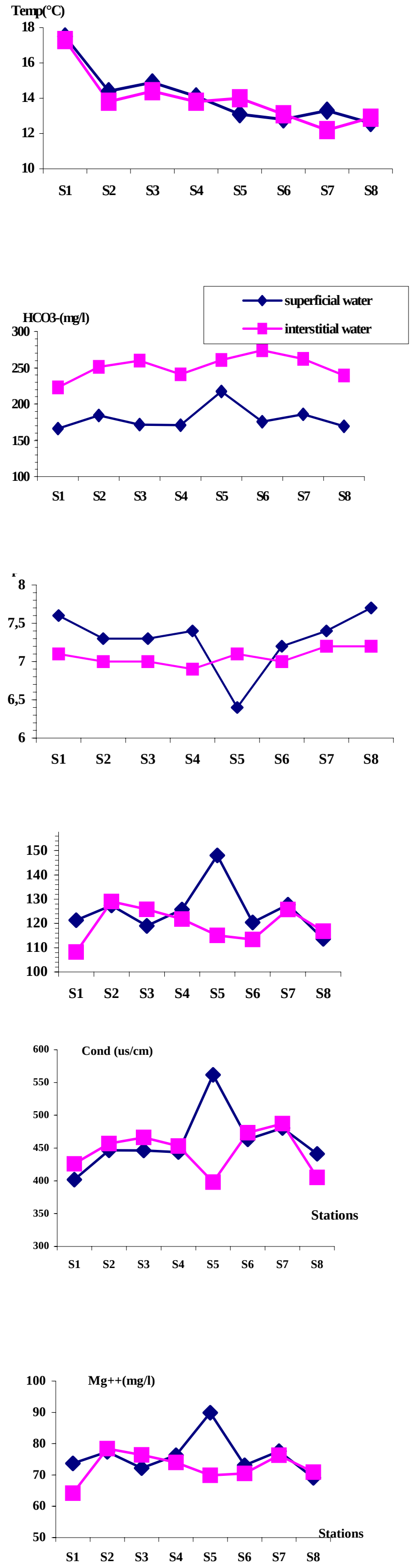


FIG 3, spatial Evolution of the middle values of the different physico-chemical parameters of the two types of waters.

The analysis retailed of thess parameters shows that:

The temperature of the two types of water shows a classic seasonal evolution well marked by a maximum in the summer (26°C) and of a minimum in the winter (8,5°C).

The spatial evolution of the temperature shows a decreasing gradient of the upstream toward the downstream, indeed, the downwelling stations are covered by the surrounding vegetation that reduces the sunshine.

The evolution of interstitial water temperature follows that of the superficial water, the tampon effect of the sediment is therefore not well marked.It is a case of a synchronous evolution of the temperature of the two types of water.

***The pH** doesn't show a marked seasonal evolution and it is close to neutrality (7 à8), except the samples made in March and July (1997) that show a light acidity that could be explained by the acid rains but not by the mineral manure contributions since the basins pouring of the Oued are not agricultural.

The spatial evolution of the middle values of the pH also shows a certain spatial homogeneity that could result from the feeding by the same type of water. The S5 station situated downstream the city of Ifrane and that receives the domestic sewages of the city shows a very acidic pH that can reach values of 5 in the superficial water (urban Pollution). The pH of the two types of water follows the same temporal evolution with more elevated amplitudes for the superficial water.

Conductivity (us/cm), shows a seasonal evolution marked with the maximal values during the low waters period that suddenly decreases during the high waters period (dilution). All stations present values ranging from 250 to 450 us/cm with the exception of the S5 station whose conductivity can reach some very elevated values up to until 550us/cm (domestic dismissals of Ifrane).

This strong minerality is essentially linked to the karstic structure of the pouring basin; indeed, contents in bicarbonates, Calcium and Magnesium are often high. Generally, interstitial water conductivity is higher than superficial water conductivity.

Alkalinity (mg/l of $HCO3^{-}$), it varies in all stations between 154 and 400.

The temporal evolution of contents in bicarbonates of interstitial water of all stations shows a cyclic aspect permitting to separate a high water period when the recorded values are minimal, from a low

water period when the recorded values are maximal.
The spatial evolution of the middle values of the alkalinity shows that the downstream stations are slightly richer in bicarbonates than upstream ones.

Calcium concentrations (mg/l of Ca++) varies between 83.8 and 156.5 mg/l; these strong contents can be explained by the chalky nature of terrains. It undergoes a light cyclic evolution in all stations. The maximal values are recorded during low water conditions then decrease during the high waters conditions (dilution).

The calcium concentration shows a very noticeable spatial variation. It increaces slightly in interstitial water than in the superficial water in the stations S2, S4, S7 and S8. In the other stationsS1, S3 and S6S calcium concentrations higher in interstitial water during the low water period and are raised in the superficial water during the high water period.

Magnesium concentrations (mg/l of Mg++) varies in interstitial water between 50.9 and 95 mg/l. These elevated values have a direct relation with the geological nature of the pouring basin that is linked to the dolomitic nature of the Lias.

The spatio-temporal evolution of contents in magnesium follows the one of calcium with weaker amplitudes that vary between 40 and 100 mg/l.

III. 2. Biocenotic characteristics.

Table1 – Total taxonomic richness of invertebrates recorded in the superficial and interstitial water of Oued Tizguit during the sampling period.

	Superficial water	Interstitial water
Nematoda	1	1
Plathelmida	1	0
Annelida	9	3
Mollusqua	26	13
Arachnida	6	2
Crustaceans	8	19
Pseudoniphargus sp	0	1
Ephémeroptera	17	6
Plécoptera	5	0
Odonates	6	1
Heteroptera	34	0
Lepidoptera	1	0
Homoptera	1	0
Collembola	1	1
Coleoptera	70	17
Trichoptera	10	1
Diptera	22	13
Total	218	78

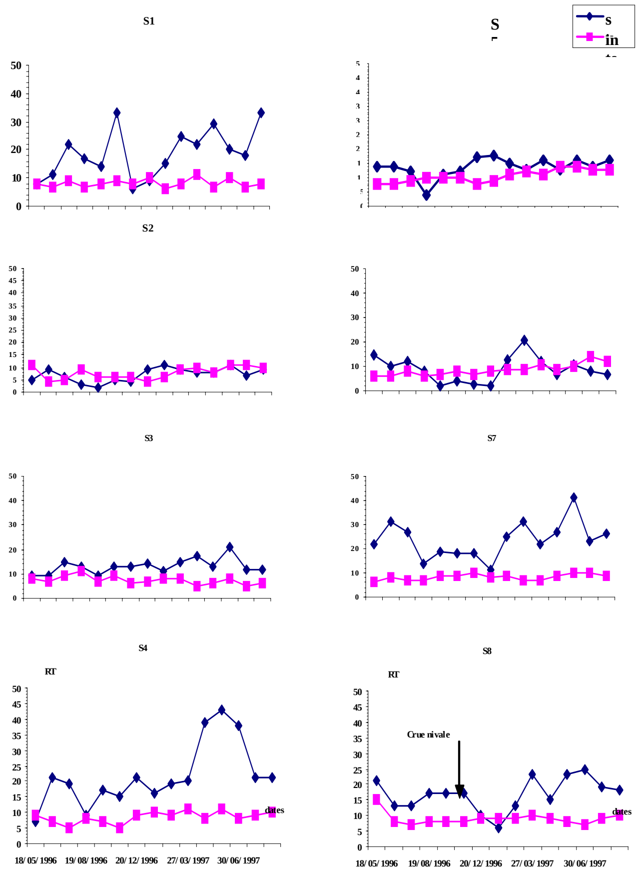
The analysis of this table shows that the survey site possesses a varied fauna with epigean dominance and containing only one stygobie species Pseudoniphargus sp represented by a weak total number in interstitial water**,** showing an underground water arrival in the under-flow of the oued. It underlines the heterogeneity of the population of this interface zone double hydrologic regime, superficial water infiltration conjugated to the arrival of lateral karstic water.

The superficial waters appear more varied by the presence of 218 taxa in comparisson to interstitial waters that shelter only 78 taxa**.** Indeed, sediments are coarse, formed of stones and gravels of large size. The infiltrations are then fast and make themselves most of the time in the direction of oued - aquifer preventing the installation of steady hypogean populations in this interface zone. This permits to show the importance of fauna and the granulometric characteristic indicating the direction of hydrologic flux.

The figure 4 illustrates the temporal variations of the taxonomic richness recorded in the 8 stations during the sampled period. It shows that the superficial waters are generally richer in taxa than interstitial waters. The temporal evolution of taxonomic richness shows that samples the high of December 1996 are poorer in taxa, this decrease of taxonomic richness is followed by a restoration in February 1997. Indeed; the high creates a disruption of the biotope and the installation of new steady populations. These results are more pronounced in the superficial waters directly affected by the seasonal variations, the tampon effect of the

sediment is more felt in interstitial waters. The difference between the two low water periods is well marked, the taxonomic richness recorded during low water period of the year 1996 is more much weaker than the one collected during low water conditions the of 1997.

Figure 5 illustrate the spatial variation of taxonomic richness recoded during the 15 months of sampling in every station. It confirms that the superficial waters are richer in taxa than interstitial waters, with the exception of the S2 station (griffin) whose interstitial waters appear more diversified by the presence of stygophiles species of ostracoda and copépoda. Maximal taxonomic richness were observed in the S2 (50 taxa) in interstitial waters and in the S7 (**90 taxa**) in the superficial waters.



FIG; 4 - temporal evolution of total taxonomic richness in the two water types

4- 1. Abiotic interactions between the superficial and interstitial ecosystems.

The majority of abiotic studied factors show some relatively similar values between the superficial and interstitial waters, especially during high waters period when the superficial water infiltration dominates on the arrival of karstic waters.

The classification of stations based on the chemistry of water showed a certain homogeneity and a weak spatial variability, since all stations are fed by infiltrations of superficial water with some arrivals of karstic water during low water periods.

These physico-chemical characteristics show that interstitial and superficial waters of Oued Tizguit are relatively cold, slightly alkalined and mineralised. All studied parameters present the marked seasonal variations; The superficial and interstitial waters are directly affected by fluxes of infiltration and sunstroke. The chemical quality of the oued influences directly the quality of interstitial water. The pH doesn't present any seasonal variations.

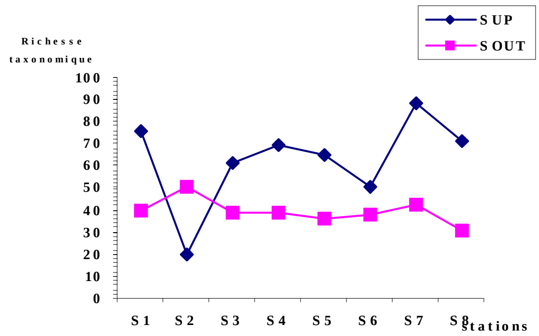


FIG: 5 - spatial evolution of taxonomic richness (RT) in the two types of water

The under –flow waters and those of the surface river have the "near"chemical features that evolve in a synchronous way with the passing of seasons. These results recall those found by ROUCH and al. (1989). the temperature of the surface water follows the same evolution that the one of subsurface (interstitial), but with more elevated amplitudes because it is directly affected by the seasonal variations. Sediment expositions can transfer the heat in the sun toward the lateral portion of hyporheïc zone by conduction. Thus, the temperature of interstitial water can increase quickly by the cumulative thermal effect of the land that nourishes it. The river influences the thermal regime of the interstitial aquifer by providing cold water during the winter and hot water during the summer. The large superficial aquifer, transmits greatly the thermal wave of the river.

The influence of the superficial or karstic contribution depends of the hydrologic cycle; During the high waters period, interstitial water is

of mainly superficial origin, and therefore the conductivity, bicarbonates, calcium and magnesium concentrations are weak. Whereas in low water period, the influence of the karstic water contribution begins to appear to the profit of that of the superficial water that decreases gradually. Thus, the conductivity, bicarbonates, calcium and magnesium concentrations become strong. During its displacement in storage zones, the quality of the water is modified by the contact between the biotic and abiotic components of the hydrosystem.

The increase of the mineralisation, alkalinity and contents in calcium and magnesium during the low waters conditions is explained by an increase of the stay of water in the aquifer and therefore a longer contact water- rock that is promoted by the weak speed of the current. During the low water period, the superficial river plays a role of drain, for the underground waters of the alluvial plain (GIBERT and al., 1977; REIHANI, 1980,; REYGROBELLEt, 1984). On the other hand, during the high waters period the fast contribution of the superficial water masses to the spring provokes a dilution of the chemical elements and therefore a reduction of the conductivity, alkalinity and contents in calcium and magnesium (ROUCH and al., 1989; MUDRY and a.l, 1979,; KIRALY and MULLER, 1979).

These results show that the localization of interactions between the surface and the underground system varies according to hydrologic conditions during the year; these interactions are strong during the high waters (the influence of the superficial water is more pronounced) then progressively decrease during the period of the low waters. These results join those found by VERVIER and GIBERT (1991). Therefore, the dynamics of the permeability of the ecotone is mainly controlled by the dynamics of the water flux, especially hydrologic cycle (high waters - low waters) and the speed of the flux. The temporal variability of the water quality is well marked, whereas the spatial variability is very attenuated, since in all stations, it is the superficial water infiltration that dominates the arrival of karstic water.

4- 2. Biotic interactions between superficial and interstitial environments.

A total of 218 **taxa** has been collected in the superficial waters, showing a strong density and diversity of the superficial population. In the interstitial area 78 taxa have been inventoried, and took out again all of epigean domain with the exception of pseudoniphargus sp.

Insects have been regularly captured, the presence of aquatic epigean larva is observed (diptera, chironomida, ephemeroptera, coleoptera, trichoptera, odonata), adults coleoptera, and endogeans collembola that are presumably driven by the water of infiltration.

This faunistic inventory permits to make some interesting remarks on the population of the Oued Tizguit:

*On the faunistic level, we note a big systematic unit diversity inventoried (nematoda, oligochaeta, mollusqua, crustaceans and insects).

*On the ecological level, this prospecting, although it is limited to 50 cm of depth, testifies a strong diversity and individuals abundance of the population of the under - out-flow. On the other hand, the presence of species at a same time in substrata to less 50 cm and in superficial water testifies some strong interaction between the two superficial and underground environments.

*The quantitative and qualitative variations observed in the population are in agreement with the hydrogeologic characteristics of different stations that are constantly nourished by the superficial water infiltration that dominates on the lateral karstic contribution. It results in a strong concentration of epigean populations and a weak percentage of hypogean population in all stations. In low water period, the contribution of interstitial water and lateral karstic water testified by the presence of Pseudoniphargus, prove the importance of the phenomenon on the drainage of the under - flow by the river at this period.

We analysed the results drawn considering the evolution of taxonomic richness. The number of taxa present in substrata increase highly during the high waters period, and stabilize during the wintry low water period, then decrease to the summery low water period. Individual abundance of macro invertebrates in substrata follow the same evolution as taxonomic richness but with stronger fluctuations. These results recall those of ESSAFI (1993) that revealed a discontinuity between the two hydrologic periods that corresponded to a quantitative difference of the sampled aquatic fauna. The number of collected taxa during the low waters period are reduced, while during the high waters period the aquatic fauna increases.

During the high waters period, the epigean species are essentially present in the deep layers (shelter) of substrata, and the hypogean fauna is found deeper in sediments. During the low waters period epigean fauna joins the superficial flow and hypogean fauna goes back up to the surface and easily colonizes the superficial layers of substrata, the deepest baskets seeming more revised by the contribution of underground water.

The homogeneity of the results remained remarkable, however. They prove the sensitivity of the method used. The observed differences come essentially from the time factor. The repetitivity of samples can be an improverishing factor of the population (MATHIEU and al, 1989).

V. CONCLUSION

We are dealing with waters quite of similar nature waters except in the periods of low water, and whose hydrologic parameters have a high temporal variability, with the exception of the pH that remains always less stable. The interstitial area of all stations undergoes the direct influence of the superficial river of which it constitutes the under-flow or the underground river, without undermining the karstic lateral contribution. This should be confirmed by a biocenotic study. Therefore, the quality of interstitial water to the interface superficial water - interstitial water depends on the relative proportions of karstic and superficial water arrivals linked to hydrologic cycles (low waters period – high waters period).

It is quite evident from this study that there is a certain homogeneity of the physico - chemical characteristic of interstitial water, since all stations are influenced by the same karstic aquifer and by a strong superficial infiltration. This homogeneity is the consequence of the similarity of the stations features (porosity, granulometrie,…..), permitting a fast transit of superficial water without change of its quality by the chemical processes (dissolution and adsorption of solutions) and biologic (consumption of the oxygen by the biofilm, production of the CO_2 with reduction of pH).

The site studied is a zone of exchange between benthic and underground areas where a varied and heterogeneous fauna settles. Thus, we find a mixture of stygoxenes organisms that penetrates in depth: it is about superficial crustaceans as gammarus sp. stygophile fauna or hyporheïque that can be permanent and accomplishes all its vital cycle under the river (oligochaeta, nematoda, cyclopoïda, ostracoda and harpacticoïda), or can be temporary, animals must leave the interstitieal area to finish their vital cycle (larvas of insects as chironomida, ceratopogonida, plecopteres, trichopteres, ephemeroptera). In short, stygobie fauna adapted to the underground environment, represented by the kind Pseuduniphargus sp. Given the good quality of the interstitieal waters of our site of study, which is not very different from that of surface waters, the zone of interface between superficial and underground waters of Oued Tizghit constitutes a relatively efficient filter in spite of the abundant surface waters. The speed of the infiltration seems to be slow allowing, thus, a natural purification of the infiltrated waters.

References.

BISHOP J.E. (1973) : Observations on the vertical distribution of the benthos in a Malaysian stream. *Freshwat. Biol.,3, 147-161*.

BOU C. & ROUCH R. (1967) : Un nouveau champ de recherche sur la faune aquatique souterraine. *C.R. Acad. Sc. Paris, 265, 369-370.*

BRETSCHKO G. (1981) : Vertical distribution of zoobenthos in a Alpine brook of the RITRODAT-LUNZ study area. *Verh. Internat. Verein. Limnol., 21, 873-876.*DANIELOPOL D.L. (1976) : The distribution of the fauna in the interstitial habitats of riverine sediments of the Danube and the piesting (Austria). Int. J. Speleol., 8, 23-51.

DOLE M.J. (1985) : Le domaine aquatique souterrain de la plaine alluviale du Rhône à l'est de Lyon. 2- Structure verticale des peuplements des niveaux supérieurs de la nappe. *Stygologia, 1, (3), 270-291.*ESSAFI K. (1990) : Structure et transfert des peuplements aquatiques souterrains à l'interface karst / plaine alluviale. *Th. Doc. Univ. Lyon I, 102p.*

ESSAFI K. (1993) : Etude de l'interface karst / milieu sédimentaire, sous climat tempéré et méditerranéen ., 91p Th. Doc. Etat. Univ. Mohamed premier, Oujda

GIBERT J., GINET R., MATHIEU J., REYGROBELLET J.R. & SEYED-REIHANI A. (1977) : Structure et fonctionnement des écosystèmes du Haut-Rhône français. IV- Le peuplement des eaux phréatiques, premiers résultats. *Annls. Limnol., 13 (1), 83-97.*

GIBERT J. (1984) : Répartition spatiale de l'Amphipode souterrain Niphargus rhenorhodanensis au sein d'un aquifer karstique.*Verh. Internat. Verein. Limnol., 22, 1739-1743.*GIBERT J., DOLE M.J., MARMONIER P. & VERVIER P. (1990) : Surface water / Groundwater ecotones ; Ecology and management of aquatic terrestrial ecotones, Naiman R.J. & Décamps H., *Partenon Publ, London, 199-225.*

HUSMANN S. (1975) : The boreoalpine distribution of groundwater organisms in Europe. *Verh. Internat. Verein. Limnol., 19, 2983-2988.*

KIRALLY L & MULLER I. (1979) : Hétérogénéité de la perméabilité et de l'alimentation dans le karst : effet sur la variation du chimisme des sources karstiques. *Bull. Centre Hydrogéol. Univ. Neuchâtel, 3, 237-285.*

MATHIEU J., MARTIN D. & HUISSOUD P. (1984) : Influence des conditions hydrologiques sur l'évolution de la structure spatiale et la démographie d'une population de l'Amphipode *Niphargus rhenorhodanensis*. Premiers résultats. *Mém. Biospéol., 11 27-36.*

MATHIEU J., DEBOUZIE D., RIABOFF H. & MARTIN D. (1989) : Démographie et répartition spatio-temporelle d'une population phréatique de *Niphargus rhenorhodanensis* (Amphipode souterrain). *Mémoires de Biospéléologie, Tome XVI, 215-224.*MATHIEU J.& ESSAFI – CHERGUI K. (1990) : Le peuplement aquatique interstitiel à l'interface karst / plaine alluviale. 1-

Cas d'une alimentation en eau essentiellement karstique. *Mém. Biospéol., 17, 113-122.*

MUDRY J., KIRALY L. & MILLER I. (1979) : Analyse multivariée du chimisme de quelques sources karstiques du jura suisse et franc-comtois. *Bull. Cent. d'Hydrogéol. n°3, 183-221.*

PLENET S., GIBERT J. & VERVIER P. (1992) : A floodplain spring : An ecotone between surface

water and groundwater. Regulated rivers : Research & Management, 7, 93-102.

REYGROBELLET J.L. (1984) : Premières données sur un milieu interstitiel original dans la plaine alluviale du Rhône : Le sous-écoulement du canal de Miribel. *Verh. Internat. Verein. Limnol., 22, 1744.*

ROUCH R. (1984) : Les structures de peuplement des Harpacticides dans l'écosystème karstique. Crustaceana sppl., 7, 359-368.

ROUCH R., BAKALOWICZ M., MANGIN A. & D'HULST D. (1989) : Sur les caractéristiques chimiques du sous-écoulement d'un ruisseau des Pyrénées. *Annls Limnol. 25 (1), 3-16.*

SEYED-REIHANI A. (1980) : Etude écologique du milieu aqutique interstitiel lié au fleuve Rhône en amont de Lyon. *Th. Doct. Univ. Lyon I. 70p.*
STANDFORD J.A. & WARD J.V. (1988) : The hyporeic habitat of river ecosystems. *Nature, 355, 64-66.*

VERVIER P. & GIBERT J (1991) : Dynamic of surface water / groundwater ecotones in a karstic system. *Freshwat. Biol., 26, 241-250.*
VERVIER P, GIBERT J., MARMONIER P. & DOLE M.J. (1992) : A perspective on the permeability of the surface fresh-water / groundwater ecotone. *J.N.Am. Benthol. Soc., 11, 93-102.*WILLIAMS D.D. & HYNES H.B.N. (1974) : The occurrence of benthos deep in the substratum of a stream. Freshwat. Biol. 4, 233-256.