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BENTHIC MACROINVERTEBRATE ASSEMBLAGES IN THE MAIN CONFLUENCES OF THE KEBIR-RHUMEL WADI (NORTHEAST ALGERIA)

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KEBIR-RHUMEL WADI
BENTHIC MACROINVERTEBRATES
BIODIVERSITY
PHYSICOCHEMICAL
POLLUO-RESISTANT

ABSTRACT. – Macroinvertebrate assemblages in Kebi-Rhumel, one of the largest watersheds in Algeria, are insufficiently documented. During spring, summer and autumn 2018, macro-benthos and water samples were collected and treated out at 16 stations located in the main confluence area along the Kebir-Rhumel wadi. One of the main objectives of the present work was to investigate diversity and distribution of benthic macroinvertebrates species according to environmental characteristics in this catchment area. The pH, conductivity, dissolved oxygen, ammonia, nitrite and phosphate were significantly different (P value < 0.05) between the sampling sites. The conductivity and nutrient concentrations were higher in the upstream part of the Kebir-Rhumel catchment, while dissolved oxygen decreased, indicating that Rhumel wadi is more polluted. A total of 16,069 individuals and 129 taxa, belonging to 77 families in 15 orders, were identified. Mean values of taxon richness, Shannon-Wiener (1949), Pielou's (1966) evenness, Margalef (1958) and Simpson (1949) indices indicate that Kebir wadi and their tributaries supported a more macro-benthos diversity than Rhumel wadi. The species composition and the EPT index (Ephemeroptera, Plecoptera, Trichoptera) showed the occurrence of pollution-sensitive macro-benthos groups in Kebir wadi, while the Rhumel wadi was mainly characterized by pollution-tolerant taxa, indicating anthropogenic disturbance and habitat degradation, which is evident by the diagnosis of the physicochemical water quality at Kebir-Rhumel wadi. Canonical correspondence analysis (CCA) revealed that altitude, conductivity, dissolved oxygen and nitrate were found to be the primary factors affecting the communities structure of benthic macroinvertebrates in the study area.

INTRODUCTION

Benthic macroinvertebrates are quite small aquatic organisms without backbones, that can generally be seen in moderate detail with the naked eye, or at most with a hand lens, which live a part of their lives in freshwater biotopes. You can find them on or inside the deposit at the bottom of running water and still water, but these can be broken up into different freshwater environments (Mackay & Eastburn 1990, Idowu & Ugwumba 2005).

Macroinvertebrates play an important ecologic role in aquatic communities, which includes fragmentation and decomposition of organic matter, mineralization, mixing of sediments, and are directly involved in energy flow and perform an effective role in biogeochemical cycles (Ismael *et al*. 1999, George *et al*. 2009). Many studies have reported that activities such as agriculture, silviculture, urban development, and mining produce contaminated runoffs that deteriorate the overall ecological integrity and affect the assemblages of freshwater macrobenthos (Barbour *et al*. 1996, Wahizatul *et al*. 2011).

Recently, the measurement of physicochemical parameters is known to be insufficient to characterize the state of health of a stream or reliably detect sources of pollution (Mandaville 2002); while these physicochemical analyzes must be supported by surveillance studies of the macroinvertebrate community structure that has been commonly used as bioindicator of stream biological quality (Rosenberg & Resh 1993, Jonasson 1996, Pace *et al*. 2013, Barros *et al*. 2016).

Benthic fauna composition in freshwater ecosystems, occupying a very tiny fraction of the Earth's, responds mainly to factors such as substratum physical composition, water trophic status, and hydro-period (Merz & Ochikubo Chan 2005). Some studies have showed that temperature, dissolved oxygen, pH and nutrients have considerable effects on the distribution, composition, and diversity of aquatic organisms (Danes & Hynes 1980, Vought *et al*. 1998, Buss *et al*. 2002).

The Kebir-Rhumel is one of the big Algerian wadis and is the subject of numerous studies on the water quality, sediments, and border soils, based on the use of physicochemical measurements (*e.g.*, Afri-Mehennaoui 1998, Djeddi & Laouar 2001, Sahli 2002, Afri-Mehennaoui 2006, Sahli *et al*. 2011, Benrabah *et al*. 2013, Azzouz *et al*. 2014, Melghit *et al*. 2015, Keddari *et al*. 2019). To the best of our knowledge, this study provides the first insight into spatial and temporal variation of the benthic macroinvertebrate assemblage in Kebir-Rhumel wadi, while research on communities and ecology of benthic macroinvertebrates was much more limited in time and space. The aim of this research was to determine the benthic macroinvertebrate diversity and distribution in the main confluences of Kebir-Rhumel watershed with particular emphasis on the relationship between the macroinvertebrate community structure and the environmental variables.

MATERIALS AND METHODS

Study area: The Kebir-Rhumel is one of the largest watersheds in Algeria with an entire area of approximately 8815 km^2. It is drained by the Kebir-Rhumel wadi along 208 km, through several different geological and hydrogeological domains. It originates from the northwestern Bellaa in Setif. In upper basin, the Rhumel wadi crosses the high plains of Constantine up to its confluence with Boumerzoug wadi, upstream of Constantine city. Then, it flows towards the northwest, it confluences with the Endja wadi and forms the largest dam in the country, Beni-Haroune. Below the dam, the Kebir wadi and its tributaries form the lower basin. The Kebir wadi, almost 56 km long, traverses the heavily watered massifs of the small Kabylia of El Milia and finally flows into the Mediterranean Sea. The study area has a continental climate; it is semi-arid in the southern high plains and sub-humid in the middle basin. Further north, the Kebir wadi drains a well-watered sub-basin belonging to the humid Mediterranean bioclimatic stage (Mébarki 1982).

The upper part of the watershed is affected mainly by sewage urban, industrial wastewater and intensive agriculture. In contrast, the lower part drained by Kebir wadi has little anthropogenic disturbance.

Fig. 1. – Study area and location of sampling stations in the Kebir-Rhumel catchment area.

The sampling stations selected for this study are distributed over four confluences all along the Kebir-Rhumel wadi (Fig. 1). The confluence areas have been chosen taking into account criteria such as the accessibility of the stations, the heterogeneity and the ecological diversity of the environment, the sources of pollution (discharges of urban areas and industry), the altitude, and the importance of the area drained by the tributary. To study the benthic macroinvertebrate assemblage structure in the Kebir-Rhumel wadi, we sampled at each confluence, above and below the confluence and at it tributary (Fig. 1) (Table I).

Sampling: Measurement of environmental parameters and macroinvertebrate sampling have been carried out on three separate occasions (spring, summer and autumn in 2018) in 16 sampling stations along the river basin. In this way, 48 sampling occasions were available. Hydrological, physical, and chemical factors were measured on each sampling occasion before sampling of benthic macroinvertebrates. Water temperature (°C), water conductivity (EC, µS/cm), dissolved oxygen (DO, mg/l) and water pH were measured in the field using a WTW 305i Multi-Parameter and Metteler Toledo pH-meter. Water depth (cm) was measured with a wading rod. Current velocity (cm/s) is the amount of time a flotter takes to move a distance of 10 m. Substrate composition was measured via visual assessment over a 2 m^2-area. Water samples were also taken from each station and carried to the laboratory in an insulated box. Ammonium ion concentration (NH_4^+, mg/l) was evaluated according to ISO 7150/1 (1984), nitrate (NO_3^-, mg/l) and nitrites (NO_2^-, mg/l) according to AFNOR T90-012 (1952) and AFNOR T90-013 (1956), respectively. Phosphate (PO_4^{3-}, mg/l) was measured according to ISO 6878/1 (1998). Benthic macroinvertebrate communities were collected on each sampling occasion using a Surber net sampler, a 500 µm-mesh sized and a 30 cm diameter. At each sampling station, we collected and pooled 8 samples allowing prospecting of 0.72 m^2 of substrate in order to include all possible microhabitats along a ~35 m reach of the stream at each station. The sampling was done by embedding the net into the substrate against the current, and disturbing the sand and gravel within the sampler quadrate by hand to a depth of 5-10 cm so that the invertebrates are carried along into the net. The pebbles, rocks and woody debris present in some of the habitats were brushed and washed into the net. We also used for-

Table I. – Description of sampling stations.

Code	Wadis	Altitude (m)	GPS coordinates	Substratum	Aquatic vegetation
R1	W. Rhumel	655	36°13.700'N 6°23.149'E	silt, clay, gravel, pebble	*Typha* sp., *phragmites* sp.
SE	W. Seguen (tributary)	657	36°12.809'N 6°24.423'E	silt, clay, gravel, pebble	none
R2	W. Rhumel	646	36°13.744'N 6°24.656'E	silt, gravel, cobble	Filamentous algae in summer
R3	W. Rhumel	642	36°14.059'N 6°24.992'E	sand, gravel, pebble	none
R4	W. Rhumel	211	36°29.111'N 6°27.181'E	gravel, pebble, cobble	none
SM	W. Smendou (tributary)	213	36°29.853'N 6°27.590'E	silt, pebble, cobble	*Potamogeton* sp., *Typha* sp., *Scirpus* sp., Filamentous algae
R5	W. Rhumel	208	36°29.369'N 6°26.905'E	silt, pebble, cobble, boulders	*Phragmites* sp., *Scirpus* sp., *Juncus* sp.
R6	W. Rhumel	207	36°28.736'N 6°26.613'E	slit, pebble, cobble, boulders	none
K1	W. Kebir	78	36°36.933'N 6°16.698'E	pebble, cobble, boulders	*Typha* sp., *Scirpus* sp., Filamentous algae in summer
TA	W. Tara (tributary)	94	36°37.178'N 6°15.502'E	pebble, cobble, boulders	Filamentous algae in summer
K2	W. Kebir	64	36°37.373'N 6°16.396'E	sand, gravel, pebble, cobble, boulders	none
K3	W. Kebir	60	36°38.312'N 6°16.668'E	pebble, cobble	Filamentous algae in summer
K4	W. Kebir	9	36°48.354'N 6°10.190'E	gravel, pebble, cobble	*Juncus sp.,* Filamentous algae in summer
IR	W. Irdjana (tributary)	21	36°47.367'N 6°9.164'E	pebble, cobble	Filamentous algae in summer
K5	W. Kebir	8	36°48.307'N 6°9.320'E	pebble, cobble	none
K6	W. Kebir	7	36°48.773'N 6°8.749'E	sand, gravel, pebble, cobble	Filamentous algae in summer

ceps to collect the invertebrates attached to the substrate. The collected benthic macroinvertebrates were immediately fixed in 70 % ethanol solution on the site. In the laboratory, the fauna was sorted, identified to the lowest possible taxon, mostly to the genus and species level, using various taxonomic keys (Poisson 1957, Dommanget 1994, Himmi *et al*. 1995, Tachet *et al*. 2000, 2010), and counted by handpicking with the aid of stereomicroscope.

Data analysis: Benthic macroinvertebrate assemblage structures were analyzed using the calculation taxon richness (*S*), abundance and diversity indices including Shannon-Wiener diversity index (*H'*), Pielou evenness index (*E*), Simpson diversity index (*D*), and Margalef richness index (*M*) (Table II). The EPT family richness index is equal to the total number of families classified as Ephemeroptera, Plecoptera, and Trichoptera in the sample.

One-way analysis of variance (ANOVA) with Tukey's multiple-comparisons was conducted to test the significance of differences of environmental variables (depth, current, temperature, pH, dissolved oxygen, conductivity, ammonium, nitrite, nitrate and phosphate), abundance, taxon richness (*S*) and biological indices (Shannon-Wiener index, Pielou evenness index, Simpson index, and Margalef index and EPT index) between stations. Relations between sampling stations and environmental variables were examined by normalized Principal Component Analysis (PCA) (ter Braak & Šmilauer 2002) using XLSTAT software. Relationship of the benthic macroinvertebrate assemblages with environmental variables and altitude was explored using canonical correspondence analysis (CCA) as recommended by Jongman *et al*. (1995). This ordination analysis was performed in the CANOCO program (Version 4.5) (ter Braak & Šmilauer 2002). For the CCA analysis, only species constituting more or equal than 0.2 % to total abundance were included to minimize the effects of rare taxa. To reduce the influence of abundant taxa (*e.g*., Chironomidae), aquatic macroinvertebrate abundances values were log(x+1)-transformed prior to analysis (Zar 1998). Similarly, all environmental variables except pH were log-transformed to improve the normality.

Table II. – The different diversity indices. *Pi*: proportional abundance of (i)th species, *S*: total number of species, *N*: total number of individuals.

Index	Equation	Reference
Shannon-Wiener	$H' = -\sum_{i=1}^{s} Pi \log_2 Pi$	Shannon and Weaver (1949)
Pielou	$E = \frac{H'}{\log_2 S}$	Pielou (1966)
Margalef	$M = \frac{(S-1)}{\ln N}$	Margalef (1958)
Simpson	$\widetilde{D} = 1 - \sum Pi^2$	Simpson (1949)

Table III. – Mean (± SD) values of environmental variables in sampling stations and the results of variance analysis. * $P < 0.05$, ** $P < 0.01$, *** $P < 0.0001$, *NS*: not significant.

Station	Depth (cm)	Current (cm/s)	T (°C)	pH	Dissolved oxygen (mg/L)	Conductivity (µS/cm)	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)
R1	24.3 ± 4	21.7 ± 10.4	19.3 ± 4	6.8 ± 0.8	5.4 ± 0.7	1196.7 ± 15.3	0.47 ± 0.6	0.03 ± 0.04	6.15 ± 2.9	1.45 ± 1
SE	18.3 ± 5	25 ± 13.2	20 ± 3.6	8.4 ± 0.5	4.3 ± 0.6	1449 ± 166.7	2.26 ± 1.3	3.89 ± 2.02	2.87 ± 3	2.83 ± 0.7
R2	28.3 ± 7	26.3 ± 9	19 ± 3.6	7.93 ± 0.3	5.1 ± 0.8	1236.7 ± 111	2.12 ± 0.6	0.13 ± 0.1	3.58 ± 2.7	1.36 ± 0.4
R3	23.3 ± 6	29 ± 11.5	19.7 ± 4.2	7.84 ± 0.2	5.3 ± 0.8	1199.7 ± 110	1.64 ± 1.2	0.15 ± 0.1	3.12 ± 2.2	1.28 ± 0.4
R4	17.7 ± 2	33.3 ± 12.6	19.3 ± 2.5	7.77 ± 0.9	4.8 ± 0.4	1377.3 ± 307.4	2.13 ± 1.6	1.19 ± 1.7	5.31 ± 7.7	2.23 ± 0.9
SM	21.7 ± 3	22.3 ± 6.4	17.7 ± 2.5	7.5 ± 0.5	5.1 ± 0.9	1276.7 ± 281.1	1.52 ± 2.4	0.27 ± 0.4	6.87 ± 2.6	1.49 ± 0.4
R5	28.7 ± 6	30 ± 10	19 ± 2	8 ± 0.2	5.1 ± 0.5	1449.7 ± 482.3	2.96 ± 1.8	1.08 ± 1.6	5.75 ± 8	1.99 ± 0.8
R6	25 ± 5	35 ± 10	20 ± 2	8.42 ± 0.2	5 ± 0.5	1536 ± 610.6	3.44 ± 1.8	1.78 ± 3	5.66 ± 7.7	2.09 ± 0.6
K1	26.3 ± 4	19 ± 5.3	19.3 ± 3.5	6.87 ± 0.5	6.2 ± 0.2	725.7 ± 56.4	0.13 ± 0.02	0.06 ± 0.06	0.81 ± 0.3	0.5 ± 0.2
TA	22.3 ± 6	28.3 ± 5.8	16.7 ± 3.5	7.2 ± 0.3	6.9 ± 0.4	483.7 ± 26.5	0.10 ± 0.03	0.03 ± 0.04	0.5 ± 0.3	0.45 ± 0.2
K2	31.7 ± 6	33.3 ± 10.4	18.7 ± 3.5	7.03 ± 0.8	6.4 ± 0.5	731 ± 29.5	0.13 ± 0.01	0.06 ± 0.06	1.14 ± 0.3	0.5 ± 0.2
K3	24.3 ± 6	25 ± 5	18.3 ± 3.8	7.27 ± 0.6	6.4 ± 0.3	734.7 ± 34.6	0.12 ± 0.01	0.07 ± 0.06	0.71 ± 0.1	0.49 ± 0.2
K4	30 ± 5	24 ± 9.6	19.7 ± 2.5	6.5 ± 1	5.9 ± 0.5	807.3 ± 89.2	0.11 ± 0.1	0.04 ± 0.06	1.81 ± 1	0.49 ± 0.3
IR	21.7 ± 6	26.7 ± 5.8	16 ± 3.5	7.22 ± 0.1	7.2 ± 0.4	439 ± 19.7	0.06 ± 0.06	0.07 ± 0.05	0.34 ± 0.3	0.19 ± 0.1
K5	31.7 ± 3	35 ± 10	18.7 ± 2.3	7.05 ± 1	5.6 ± 0.5	843 ± 108.3	0.07 ± 0.06	0.01 ± 0.01	2.26 ± 0.4	0.45 ± 0.3
K6	29 ± 2	26.7 ± 7.6	19 ± 3	6.93 ± 1.4	5.4 ± 0.5	893.3 ± 67.1	0.11 ± 0.05	0.25 ± 0.4	3.56 ± 1.1	0.48 ± 0.3
F ratio	2.21*	0.81^{NS}	0.37^{NS}	2.44**	6.44***	7.08***	3.52**	2.69*	1.06^{NS}	7.20***

RESULTS

Environmental variables

On average, the conductivity, pH and concentrations of ammonium, nitrite, nitrate and phosphorus were generally higher in Rhumel wadi than those in the other stations of the Kebir wadi. Higher dissolved oxygen concentrations were recorded in the sampling stations of Kebir wadi. However, depth and dissolved oxygen showed significant variation ($p < 0.05$) in both space and time. Water temperature, nitrate and current did not vary significantly ($p > 0.05$) among the sampling stations but it varied significantly between the sampling seasons. In contrast, the variation of pH, Conductivity, ammonium, nitrite and phosphate were not significant between the three studied seasons but they vary significantly between the sampling stations. Current and depth of all stations were generally higher in spring than in summer and autumn (Table III).

The temperature values varied from 12 °C in IR station in spring, to 24 °C in SE station in summer. On average, the water of the Kebir-Rhumel watershed is moderate to alkaline, it ranged from 5.8 at K6 station, up to 8.9 at SE station, in the summer. The lowest values of dissolved oxygen are recorded at SE (Segune tributary) during summer and autumn, with, respectively, 3.63 mg/l and 4.5 mg/l. In spring, the R6 station presents the highest values of conductivity and ammonium with 2240 µS/cm and 5.46 mg/l, respectively. The highest mean values of phosphate and nitrite are recorded in SE station with 2.83 ± 0.7 mg/l and 3.89 ± 2.02 mg/l, respectively. The nitrate level has shown very big variation, with minimum value 0.34 ± 0.3 mg/l in IR, and maximum value 15.04 mg/l at R5 station, during spring.

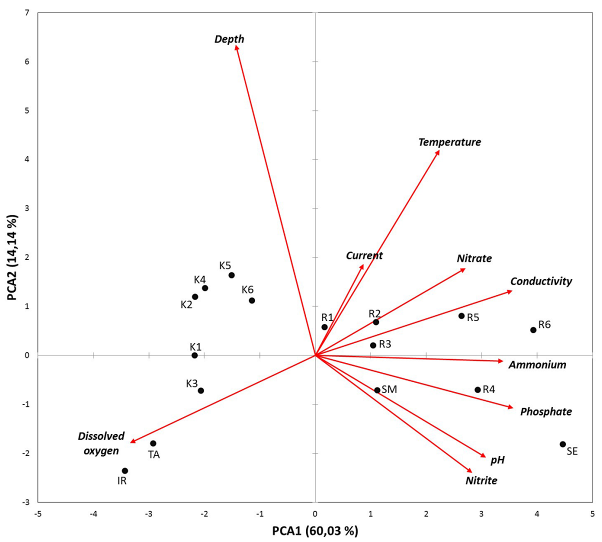

Fig. 2. – Principal component analysis (PCA) ordination plot of the sample scores and the environmental variables for the first two axes.

According to the results of PCA, the first axis explained 60.03 % of the total variance of environmental variables representing the importance of environmental parameters at all the stations (Fig. 2). Conductivity, temperature and concentrations of phosphorus, ammonium, nitrite and nitrate were all highly correlated with the PCA1 axis. Dissolved oxygen ($r = -0.911$) was related to the negative direction of the first axis. All environmental variable factors except for depth were in the opposite direction from dissolved oxygen. Moreover, the PCA2 axis, explaining 14.14 % of variance, was influenced by depth and temperature. Taken together, results of the PCA suggested that stations belonging to the Rhumel wadi were placed on the right of the figure, which exhibits higher conductivities and nutrient loads.

Benthic macroinvertebrate community structure

Across all sampling periods (48 samples total), 129 taxa and 16,069 individuals were collected and identified in this work. Most of these were aquatic insects (107 taxa) belonging to 7 orders: Coleoptera (28 taxa), Diptera (22 taxa), Odonata (20 taxa), Ephemeroptera (14 taxa), Heteroptera (10 taxa), Trichoptera (8 taxa), and Plecoptera (5 taxa). The other species were grouped as: Gasteropoda (7 taxa), 4 taxa for Oligochaeta and Hirudinea, 1 taxa for Bivalvia, Arachnida, Decapoda and Amphipoda (Table IV). Results on abundance of various macrobenthic invertebrate taxa collected during this study period are presented in Appendix.

In general, macroinvertebrate communities were dominated by the Chironomidae family with 23.32 % of the total abundance, followed by *Baetis pavidus* (16.02 %). Chironomidae and Simuliidae family, *Baetis pavidus*, *Caenis luctuosa* and *Micronecta* sp. were the most abundant groups in Rhumel and Kebir wadi. *Simulium (W.) pseudequinum* and *Tubifex* sp. were dominant only in Rhumel wadi. Also, Gasteropoda were mainly represented by *Physa acuta* and *Lithoglyphus naticoides* at Rhumel wadi. In the latter, Trichoptera were totally dominated by *Hydropsyche lobata*. *Caenis pusilla*, *Hydropsyche maroccana* and *Hydropsyche lobata* were dominant only at Kebir wadi (Figs 3, 4). Plecoptera was found only in stations IR, TA and K3 (in Kebir wadi) with 40, 32 and 7 individuals, respectively. In R6 station, Diptera and Oligochaeta showed the highest abundances with 623 and 312 individuals, respectively. The high abundances of Ephemeroptera are recorded in stations K4 and R6 with, respectively, 629 and 589 individuals. Trichoptera were abundant in TA, K6 and K3 stations with 178, 166 and 164 individuals, respectively. Also, the SM station presents the highest abundance of Heteroptera and Odonata. Only three Hirudinea were found only at the Kebir wadi (in K4 station).

Table IV. – Taxonomic list of benthic macroinvertebrates and the number of individuals collected from the Rhumel and Kebir wadi.

Taxon	Code	Rhumel wadi	Kebir wadi
Tricladida			
Dugesia gonocephala	D.gon	18	55
Polycelis felina		6	14
Oligochaeta			
Lumbriculidae		09	1
Tubifex sp.	Tub	1050	100
Naididae	Nai	260	107
Eiseniella tetraedra		5	0
Hirudinea			
Dina lineata	D.lin	125	0
Erpobdella octoculata		4	0
Helobdella stagnalis	H.sta	43	3
Placobdella costata		1	0
Gasteropoda			
Physa acuta	P.acu	186	136
Physella gyrina		12	0
Ancylus fluviatilis	A.flu	26	48
Gyraulus sp.		9	0
Lithoglyphus naticoides	L.nat	143	0
Bithynia sp.		6	0
Radix peregra		0	5
Bivalvia			
Anodonata sp.		3	2
Arachnida			
Unionicola sp.	Uni	70	89
Decapoda			
Atyaephyra desmarestii	A.des	49	138
Ostracoda	Ost	150	0
Amphipoda			
Gammarus sp.		0	8
Diptera			
Chironomidae	Chi	2158	1598
Limnophora riparia	L.rip	14	11
Simulim hispaniola	S.his	0	35
S. (S.) ornatum	S.orn	65	77
S. (W.) pseudequinum	S.pse	1000	107
S. (E.) aureum	S.aur	0	52
S. (E) velutunim	S.vel	49	0
Ceratopogonidae	Cer	12	50
Tabanus sp.	Tab	19	31
Lipneura sp.		0	2
Culex sp.		8	2
Tipulidae	Tip	12	17
Empididae		0	2
Syrphidae		6	0
Psychodidae		5	0
Hexatoma sp.	Hex	15	34
Dicranota sp.		0	2

Taxon	Code	Rhumel wadi	Kebir wadi
Habrophlebia fusca		0	3
Coleoptera			
Bidessus minutissimus		2	3
Laccophilus hyalinus		5	10
Laccophilus minitus		0	1
Nebrioporus clarkii		0	7
Agabus nebulosus		7	4
Aulonogyrus striatus	A.str	6	29
Gyrinus dejeani		2	1
Limnius intermedius	L.int	15	50
Oulimnius maurus		0	1
Esolus filum	E.fil	23	10
Stenelmis consobrina		0	5
Riolus villosocostatus		0	7
Dryops sp.	Dry	22	24
Ochthebius sp.		10	11
Hydraena sp.		8	9
Hydrobius sp.		8	3
Laccobius gracilis	L.gra	12	27
Crenitis sp.		2	0
Berosus affinis		5	0
Berosus signaticollis		2	0
Anacaena globulus		0	5
Helochares obscurus		4	0
Helochares lividus		6	2
Hydrochus sp.		9	0
Hydrocyphon sp.		0	4
Helophorus sp.		2	8
Peltodytes rotundatus		0	7
Haliplus lineaticollis		2	0
Trichoptera			
Hydropsyche lobata	H.lob	174	396
Hydropsyche maroccana	H.mar	20	439
Cheumatopsyche lepida		9	12
Rhyacophila munda		0	14
Pararhyacophila sp.		0	7
Chimarra marginata		0	8
Leptoceridae		0	1
Psychomyia pusilla		0	2
Odonata			
Gomphus lucasii	G.luc	0	29
Praragomphus genei		0	8
Onychogomphus costae		0	3
O. unguiculatus		0	15
Ophiogomphus		0	2
Boyeria irene		0	11
Aeshna mixta		0	5
Anax sp.		3	0

Table IV. – Continued.

Taxon	Code	Rhumel wadi	Kebir wadi
Stratiomyidae		0	2
Atrichops crassipes	A.cra	0	31
Rhagionidae		0	3
Dixa sp.		3	0
Atherix sp.		0	1
Plecoptera			
Capnioneura sp.	Cap	0	36
Capnia nigra		0	12
Isoperla sp.		0	9
Rhabdiopteryx sp.		0	2
Leuctra sp.		0	20
Ephemeroptera			
Acentrella sinaica	A.sin	0	60
Baetis pavidus	B.pav	1852	729
Baetis rhodani	B.rho	0	65
Cloeon dipterum	C.dip	33	14
Cloeon saharense		0	3
Caenis luctuosa	C.lus	488	1680
Caenis pusilla	C.pus	0	259
Rhithrogena sp.		0	1
Ecdyonurus rothschildi		0	15
Choroterpes atlas	C.atl	0	82
Choroterpes lindrothi		0	4
Orthetrum chrysostigma		8	10
Orthetrum nitidinerve		5	0
Sympetrum fonscolombii		2	4
Sympetrum striolatum		1	4
Brachythemis impartita		6	7
Crocothemis erythraea		6	0
Coenagrion sp.		13	6
Erythromma lindenii		1	1
Ischnura graellsii		8	4
Platycnemis subdilatata		1	5
Lestes barbarus		0	1
Chalcolestes viridis		3	0
Heteroptera			
Nepa sp.		4	4
Micronecta sp.	Mic	400	230
Corixa affinis		3	0
Corixa punctata		3	4
Paracorixa concinna		11	0
Microvelia pygmaea		10	2
Gerris lacustris	G.lac	24	19
Naucoris maculatus	N.mac	5	20
Notonecta obliqua		3	0
Anisops sardea		4	0

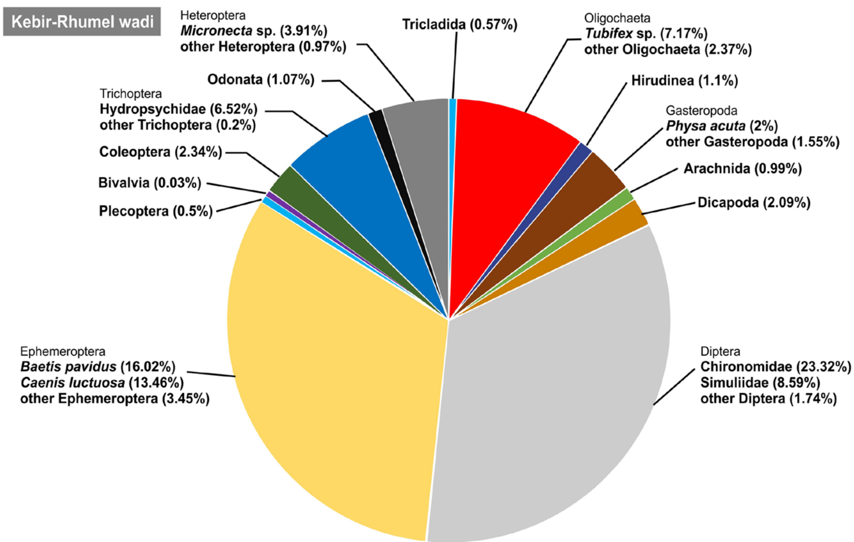

Fig. 3. – Relative abundances of the benthic macroinvertebrate groups collected in Kebir-Rhumel wadi.

Taxa abundance and communities diversity

According to the ANOVA, macroinvertebrates abundance was significantly different ($p < 0.05$) among the sampling stations. On average, highest abundance was recorded in station R6 with 561.67 (± 43.32) individuals per 0.72 m^2, while stations K2 and K5 showed lower abundance with 138.67 (± 122.81) ind./0.72 m^2 and 142.33 (± 64.69) ind./0.72 m^2, respectively (Table V). On the other hand, out of the 129 taxa identified, 54 taxa are common to the two streams Rhumel and Kebir, 47 taxa were collected only at the Kebir wadi and 28 taxa at the Rhumel wadi. The highest taxa richness was recorded during spring in SM (34 taxon) and IR (32 taxon), and

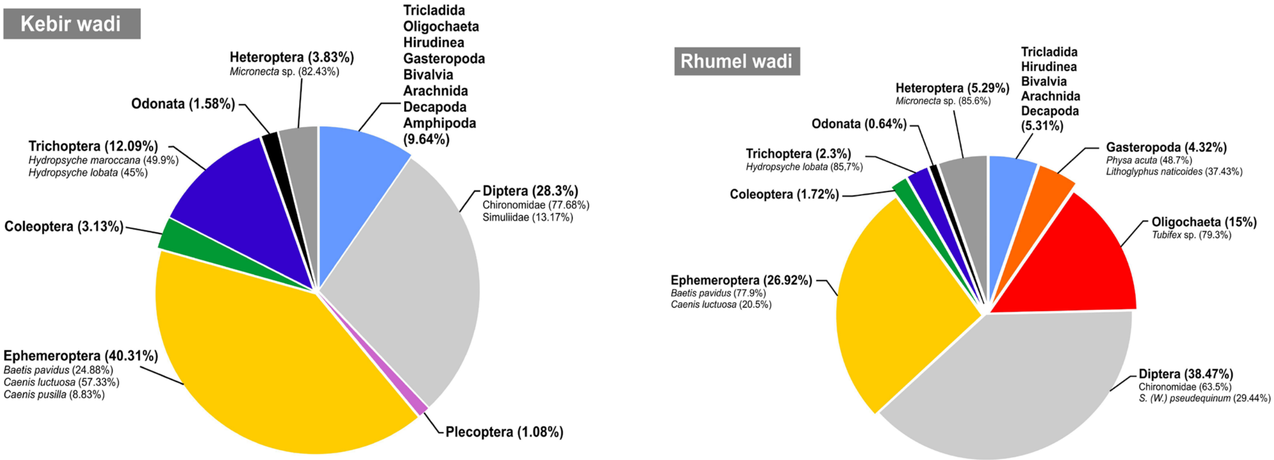

Fig. 4. – Relative abundances of the various taxonomic groups of benthic macroinvertebrates investigated in Rhumel and Kebir wadi.

Table V. – Mean values and SD of total taxon richness, abundance, and biological indices of benthic macroinvertebrate in the Kebir-Rhumel wadi. * $P < 0.05$, *** $P < 0.0001$, *NS*: not significant.

Station	Abundance (ind./0,72 m^2)	Taxon richness (*S*)	Shannon-Wiener index (*H'*)	Pielou index (*E*)	Margalef index (*M*)	Simpson index (*D*)	EPT family richness
R1	231 ± 165.42	15.67 ± 4.51	2.54 ± 0.42	0.92 ± 0.11	2.74 ± 0.62	0.72 ± 0.15	2 ± 1
SE	345.67 ± 191.4	9.33 ± 6.66	1.9 ± 0.52	0.91 ± 0.18	1.4 ± 0.99	0.65 ± 0.18	1.67 ± 1.53
R2	366.33 ± 82.71	21 ± 3.61	2.9 ± 0.32	0.95 ± 0.07	3.39 ± 0.48	0.8 ± 0.08	1.33 ± 0.58
R3	186 ± 88.02	19 ± 4.58	2.4 ± 0.39	0.84 ± 0.18	3.49 ± 0.78	0.8 ± 0.08	1.33 ± 0.58
R4	311 ± 35,37	12.33 ± 1.53	2.09 ± 0.05	0.84 ± 0.01	1.97 ± 0.24	0.68 ± 0.03	1.67 ± 0.58
SM	490.33 ± 110.8	29 ± 4.36	3.25 ± 0.03	0.97 ± 0.03	4.52 ± 0.55	0.83 ± 0.02	3
R5	440 ± 319	16.67 ± 3.51	2.44 ± 0.04	0.88 ± 0.06	2.64 ± 0.27	0.75 ± 0.04	2.67 ± 0.58
R6	561.67 ± 43.32	14 ± 4.36	2.35 ± 0.1	0.91 ± 0.08	2.05 ± 0.67	0.75 ± 0.04	2.67 ± 0.58
K1	231 ± 271.07	15.33 ± 3.51	3.04 ± 0.13	1.13 ± 0.09	2.92 ± 0.07	0.83 ± 0.02	2.33 ± 0.58
TA	388.67 ± 163.54	28.33 ± 5.51	3.52 ± 0.19	1.05 ± 0.02	4.61 ± 0.74	0.85 ± 0.03	8 ± 1
K2	138.67 ± 122.81	12 ± 1.73	2.54 ± 0.64	1.02 ± 0.23	2.42 ± 0.72	0.71 ± 0.22	3.33 ± 1.15
K3	295.33 ± 45.08	23 ± 3.61	2.97 ± 0.56	0.94 ± 0.15	3.88 ± 0.73	0.76 ± 0.15	4.67 ± 2.08
K4	519 ± 180.8	20.67 ± 3.51	2.51 ± 0.23	0.84 ± 0.07	3.16 ± 0.5	0.74 ± 0.06	2.67 ± 0.58
IR	406.67 ± 141.19	27 ± 4.36	2.93 ± 0.45	0.89 ± 0.12	4.34 ± 0.52	0.74 ± 0.14	4.67 ± 3.08
K5	142.33 ± 64.69	12.67 ± 4.04	2.27 ± 0.71	0.88 ± 0.21	2.37 ± 0.78	0.64 ± 0.28	3.33 ± 1.15
K6	302.67 ± 166.07	19.33 ± 2.52	2.96 ± 0.35	1.01 ± 0.15	3.28 ± 0.16	0.8 ± 0.1	3.33 ± 0.58
F ratio	2.03*	6.68***	1.85^{NS}	0.64^{NS}	7.3***	0.76^{NS}	5.72***

during summer in TA station with 32 taxa. The Shannon-Wiener diversity index was higher during spring and summer in station TA and K3, respectively. The lowest taxa richness and Shannon-Wiener index values were recorded in Station SE and K5 during summer and autumn, respectively (Fig. 5). One-way ANOVA analyses indicated that the sampling stations not differed significantly ($p > 0.05$) in three diversity indices, but not for Margalef index and taxon richness ($p < 0.0001$). On average, the taxa richness, Shannon-Wiener, Simpson and Margalef indices were higher values in the effluents SM and TA. Moreover, SE station showed the lowest taxa richness, Shannon-Wiener and Margalef indices. Furthermore, K5 station showed lowest Simpson value. The EPT family richness index showed significant differences ($p < 0.0001$) between the stations. The highest values for EPT index were recorded from Tara tributary (TA) during the three seasons, IR tributary (in spring), and K3 (in autumn). The lowest means of EPT index were obtained at stations SE, R2, R3 and R4 (Table V).

Relationships between macroinvertebrate assemblages and environmental variables

The results of canonical correspondence analysis (CCA) shows that 11 environmental variables were

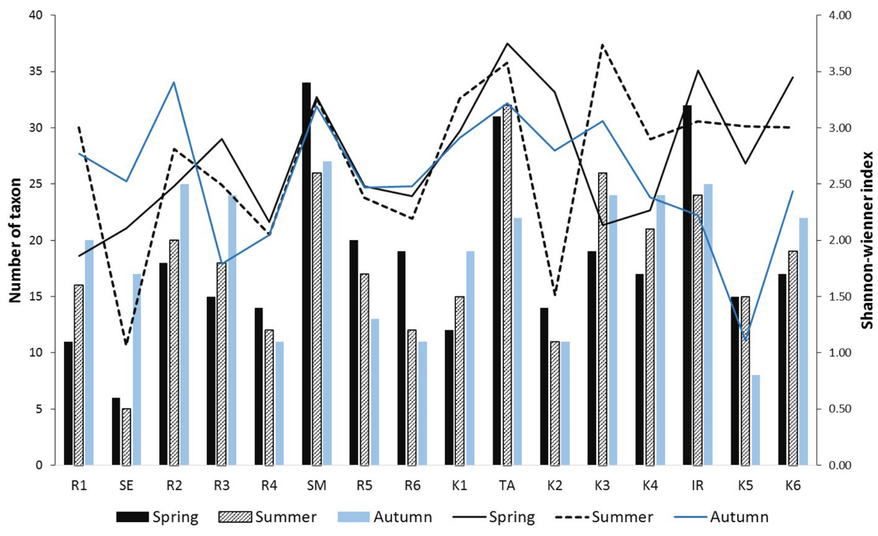

Fig. 5. – Taxon richness histograms and Shannon-Wiener index of benthic macroinvertebrate communities at each sampling station during the spring, summer and autumn in Kebir-Rhumel wadi.

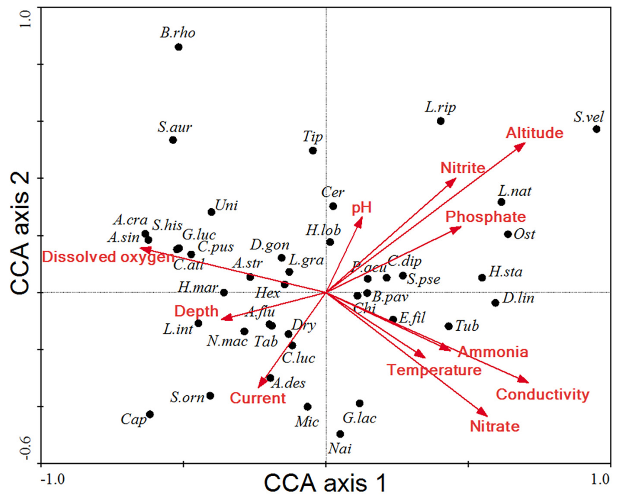

Fig. 6. – Canonical correspondence analysis ordination plot of macroinvertebrates taxa with environmental variables in Kebir-Rhumel wadi. The summary of ordination results is presented in Table VI and the codes for each taxon are shown in Table IV.

detected as significant factors explaining the assemblage of 42 macroinvertebrate taxa. The first two canonical axes explained 25,7 % (499 permutations under the reduced model-Eigenvalue: 0.325, F-ratio: 1.385, p-value: 0.006) and 13.77 % (Eigenvalue of 0.174) of the variation in the taxa data, respectively. Altitude, conductivity and nitrate had the biggest influence on CCA axis 1, in a positive direction, and dissolved oxygen had the greatest influence on axis 1 in a negative direction (Fig. 6; Table VI). Other environmental variables including phosphate, nitrite and ammonium also had an influence on CCA axis 1. Altitude and nitrite had the greatest influence on axis 2 in a positive direction, and nitrate had the greatest negative influence on axis 2. Taxa with high positive scores on the first CCA axis included *Simulium (E.) velutunim*, Hirudinea (*Dina lineata* and *Helobdella stagnalis*), Ostracoda, *Lithoglyphus naticoides* and *Tubifex* sp., indicating that these taxa were positively correlated with altitude, conductivity and nitrate. Taxa *Atrichops crassipes*, *Simulim hispaniola*, *Gomphus lucasii* and Ephemeroptera (*Acentrella sinaica*, *Caenis pusilla* and *Choroterpes atlas*) had high negative scores on axis 1, indicating a positive correlation with dissolved oxygen. The Chironomidae, Ephemeroptera (*Beatis pavidus*, *Cloeon dipterum*), *Physa acuta*, *S. (W.) pseudequinum* and *Esolus filum* were distributed in the centre of the axes in a positive direction along axis 1. The weak association between these taxa and environmental factors, and the fact that these species occurred in several sites, reflect that these taxa are tolerant to disturbance and resident of impacted environments. Taxa like *Capnioneura* sp., *Simulium (S.) ornatum*, *Micronecta* sp. and *Atyaephyra desmarestii* have been found to occur most dominant with current.

DISCUSSION

In the present investigation, higher values of physicochemical parameters (EC, pH and nutrient load) were reported at Rhumel wadi compared to Kebir wadi. The pH values are generally in a range of low alkalinity to alkaline; these results are in agreement with the results of Keddari *et al.* (2019). Electrical conductivity values show a spatial variation (Kruskal-Wallis, p value < 0.05), indicating a mineralization of the water of Rhumel wadi; this is mainly due to the carbonate nature of the area crossed by the latter and the increase in water chloride concentrations (Afri-Mehennaoui & Mehennaoui 2005, Ramdani & Laifa 2017).

However, an increase in ammonium, nitrite, nitrate and phosphorus concentrations registered in Rhumel wadi compared with Kebir wadi, especially in spring, could be associated with agricultural activities, industrial wastes (pharmaceutical industry), domestic sewage

Table VI. – Summarized results of CCA for the abundance of macroinvertebrate taxa and environmental variables. Intraset correlation coefficients between the environmental variables and the first 4 canonical axes. Significance of the axes by Monte Carlo test is given.

Variables	Axis 1	Axis 2	Axis 3	Axis 4	Total inertia
Axis summary statistics of CCA results					
Eigenvalue	0.325	0.174	0.124	0.092	1.263
Species-environment correlations	0.994	0.993	0.984	0.936	
Cumulative percentage variance					
of species data	25.7	39.5	49.3	56.5	
of species-environment relationship	33.9	52.0	65.0	74.5	
Sum of all unconstrained eigenvalues					1.263
Sum of all canonical eigenvalues					0.958
Correlation coefficients					
Altitude	**0.704**	**0.507**	0.110	0.060	
Depth	–0.371	–0.066	–0.269	0.097	
Current	–0.246	–0.312	–0.209	0.283	
Temperature	0.347	–0.261	0.362	0.598	
pH	0.136	0.239	–0.583	–0.315	
Dissolved oxygen	**–0.642**	0.161	–0.655	–0.101	
Conductivity	**0.699**	–0.325	0.329	0.190	
Ammonia	0.429	–0.210	0.137	0.300	
Nitrite	0.456	0.404	0.298	0.322	
Nitrate	**0.550**	–0.420	0.482	–0.157	
Phosphate	0.472	0.233	0.101	0.039	

and other effluents containing nitrogen which transports sediments and organic matter from the catchment into the river (Royer *et al.* 2004). These nutrient loads flow and are accumulated in Beni-Haroune dam and it could be a reason for drastic decrease in their concentrations below the dam along the Kebir wadi. Dissolved oxygen (DO) showed both spatial and temporal variation. It decreases during summer and autumn especially at Rhumel wadi, at higher water temperatures and lower water volume and velocity. The water of Kebir wadi remains the most oxygenated: this could be attributed to the high vegetation along the edges, relatively rocky substrates, low agricultural and other anthropogenic activities and therefore to a decrease in water temperature and significant mixing of the water mass. Our results show that the water of the Rhumel wadi is of average to poor quality, while the water of El Kebir wadi is of average to good quality, which has been confirmed by the Hydrographic Basin Agency/CSM (2009).

On the other hand, the relationships between sampling stations and environmental factors (water quality parameters) was highlighted by the PCA, the latter shows clearly the difference in water quality between Rhumel wadi and Kebir wadi, especially for nutrients and dissolved oxygen. According to Herrmann (1999), excess amounts of nutrient loads result in increased eutrophication and consequently oxygen depletion.

In the present study, aquatic macroinvertebrate assemblages in the basin were mainly dominated by Chinonomidae, Ephemeroptera (*e.g.*, *Baetis pavidus* and *Caenis luctuosa*), Simuliidae (*e.g.*, *Simulium (W.) pseudequinum*), Oligochaeta (*e.g.*, *Tubifex* sp.), Hydropsychidae (*e.g.*, *Hydropsyche lobata* and *Hydropsyche maroccana*), and Heteroptera (*e.g.*, *Micronecta* sp). Related studies conducted in different freshwater bodies in Algeria (*e.g.*, Zouggaghe & Moali 2009, Bebba *et al.* 2015, Hafiane 2016, Sellam *et al.* 2017, Benzina & Si Bachir 2018, Ghougali *et al.* 2019) have showed the abundance of these families in different arid, semi-arid and humid bioclimatic regions. Generally, the assemblage structure of macroinvertebrates between the Rhumel and Kebir wadi were different distinctively.

The upstream area of Kebir-Rhumel watershed contains major cities, with denser human population, anthropogenic and intensive agricultural activities, that could contribute to increase eutrophic processes and organic enrichment of the streams (Marouf & Remini 2016), which negatively impact benthic communities (Theodoropoulos *et al.* 2015). Headwater stations (Rhumel wadi) except SM (Smendou tributary) were dominated by Chironomidae, *Baetis pavidus*, *Tubifex* sp. and *Simulium (W.) pseudequinum*. These are characteristic species in stressing environments showing some degree of organic pollution as a result of high nutrient enrichment and sedimentation, resulting in the reduction of dissolved oxygen, which may become limited to the survival of some pollution-sensitive taxa (Buss *et al.* 2002, Wang *et al.* 2012). Also, according to Patrick & Drew (1994), Hooper *et al.*

(2003) and Saloom & Duncan (2005), Chironomidae, Oligochete and Hirudinea (*e.g.*, *Dina lineata* and *Helobdella stagnalis*) have been reported to be pollution-tolerant and able to inhabit low dissolved oxygen level water bodies. The dominance of this pollution-insensitive taxa and low taxon richness indicates moderate environmental pollution in Rhumel wadi especially at Seguen tributary (SE). Additionally, we found significantly distinct macroinvertebrate assemblages at Smendou tributary compared to other stations of the Rhumel wadi. This station had relatively equal family richness, in comparison to Kebir wadi with quite similar macroinvertebrate communities. This may be supported by the presence and/or abundance of some taxa characteristic of Kebir wadi in the SM station, among which *Ancylus fluviatilis*, *Simulium (S.) ornatum*, *Caenis luctuosa, Limnius intermedius, Dryops* sp., *Hydropsyche maroccana, Micronecta* sp. A possible explanation for this is that SM station is characterized by a presence of riparian vegetation cover and macrophytes (*i.e.*, filamentous algae) throughout the study period, which may offer habitat diversity to aquatic biota.

The Kebir stations were dominated by pollution-sensitive macroinvertebrates such as Ephemeroptera, Plecoptera and Trichoptera, which declined headwater. Additionally, we found that abundance of Caenidae, particularly *Caenis pusilla*, Odonata, and Trichoptera (*Hydropsyche maroccana,* Rhyacophilidae) can be regarded as a bioindicator for stations that were relatively free of pollution. The EPT taxa (Ephemeroptera, Plecoptera, and Trichoptera) are very sensitive to the water organic load and to reductions in dissolved oxygen (Leprieur *et al*. 2009). In Kebir wadi, stonefly (Plecoptera) representation was low, compared to that of Ephemeroptera and Trichoptera, with a total of 79 individuals sampled in Kebir-Rhumel catchment area. Their high presence in Tara and Irdjana tributaries during spring and autumn is a common feature of riffle habitats, stony substrates, habitat diversity, clear waters and cold or cool water bodies.

The taxa richness and evenness are two distinct aspects for synthetic measurement of biological structure of macrobenthos communities. The substrate and habitat heterogeneity are known to be determining factors of benthic assemblage structure (Zhang *et al*. 2014). In the Kebir-Rhumel basin, taxa composition was very heterogeneous, although abundance of macroinvertebrates varied slightly among different stations. The significant difference of macroinvertebrate richness among sampling stations perhaps explains the substrate characteristic variability, habitat complexity and water quality.

In our study, taxa richness and diversity indices, in particular Shannon-Wiener and Margalef indices, showed a pattern of high values in tributaries, except SE station, as compared to the mainstream stations. There have been a large number of studies documenting riparian vegetation (Angradi *et al*. 2001), stony beds, oxygenating fast-flowing water (Boyero & Bosch 2004), restoration of aquatic macrophytes, accumulation of dead leaves (allochthonous materials) and large woody debrisbecomes (Rice *et al*. 2001), provide heterogeneous habitats and microhabitat variability, and lead to increased diversity. Such hydraulic conditions can explain the high taxon richness at tributaries (SM, IR and TA), K3 and R2 stations. Additionally, the highest number of EPT taxa recorded in stations TA (22 taxa), IR (13 taxa), K3 (12 taxa) and K2 (11 taxa), reflects a slightly disturbed to good quality of stream. On the other hand, Toriman *et al*. (2009) noted that substrate characteristics are sensitive indicators of the human land use intensity, where increasing agricultural land use, including removal of the riparian vegetation, resulting in increased of silt, clay and sand in the streams, which negatively impact macro-benthos structure. This observation is supported by Jun *et al*. (2016) who stated that macroinvertebrate richness and abundance were lower in homogeneous substrate with fine particles despite good water quality condition of stream. This could be also a reason for relatively low richness or abundance at SE, R4, K2 and K5 stations.

Ephemeroptera, Plecoptera, and Trichoptera are considered to be more pollution sensitive species that enable to evaluate the water quality of an aquatic system (Myers *et al*. 2011). On average, our results show that the lowest values of EPT family richness index are obtained in upstream stations of Rhumel wadi, with a low representation of semi-tolerant taxa *Baetis pavidus* and *Hydropsyche lobata*. This can be linked to agricultural land-use intensification in the area around the stations. According to the Lenat's (1993) classification based on the EPT family richness index, the water biological quality in Tara tributary (TA) was in good condition (EPT = 6-10), while stations SE, R2, R3 and R4 indicated poor water quality (EPT < 2). Water in the other stations could be classified as fair quality (EPT = 2-5).

The taxa-environment relationships showed by the CCA suggested that some environmental variables recorded, such as altitude, dissolved oxygen, conductivity, and nitrate, had a noticeable effect on the distribution and community structure of benthic macroinvertebrates. Many authors consider velocity, water depth and dissolved oxygen to be major variables that change the benthic communities by directly influencing microhabitats (Nelson & Lieberman 2002, Oliveira & Nessimian 2010, Shearer *et al*. 2015). According to Ghougali *et al*. (2019), the substrate type and flow velocity were found to be important determinants of macroinvertebrate assemblages. On the other hand, Rouibi *et al*. (2021) found that dissolved oxygen and depth are the factors that strongly influence the distribution of benthic macroinvertebrates. Based on the CCA biplot, the Chironomidae and other taxa, on centre of axes, are positively related with the dissolved nutrients and negatively with dissolved oxygen, indicating that these taxa are tolerant to disturbance. In contrast, several taxa proposed as polluto-sensitive taxa of moderately to lightly polluted waters, showed a positive correlation with increasing dissolved oxygen, depth and current. Thus, negative correlations between the other environmental variables and some of these species, such as *Capnioneura* sp., Ephemeroptera (*Baetis rhodani*, *Acentrella sinaica*, *Choroterpes atlas* and *Ecdyonurus rothschildi*), may be explained by their sensitivity to water temperature and nutrient elements. CCA ordination clearly reflected the difference in taxa assemblage between Kebir and Rhumel wadi.

The relationship between taxon richness and altitude is generally assumed to be decreasing. According to Sellam *et al*. (2017), the macroinvertebrate composition indicates low spatial variation along the longitudinal gradient of same river and strong regional variation among rivers, due to important environmental changes between bioclimatic regions. Although aridity and human pressure tends to limit the diversity and abundance of benthic macroinvertebrate populations (Benzina *et al.,* 2018), distribution patterns of benthic communities in the Belezma National Park streams (arid area) clearly changed along the altitudinal gradient, and diversity increases and abundance decreases with altitude (Benzina *et al*. 2019). Macroinvertebrate richness, therefore, results from a combination of climatic and hydrological parameters, which screen geographic processes (Beauchard *et al*. 2003).

When considering the numerous studies carried out, benthic macroinvertebrate biodiversity and assemblage in Kebir-Rhumel watershed remain poorly documented. The present study primarily provides valuable information on the taxon richness and abundance of macroinvertebrate fauna in the main confluences along the Kebir-Rhumel wadi. The confluences and transitional habitats are often more heterogeneous and support greater biodiversity (Benda *et al*. 2004, Clarke *et al*. 2008). The evaluation of the physicochemical water quality showed a variation from moderate and poor quality class in sampling stations of Rhumel wadi, to moderate and good quality at Kebir wadi. Our results revealed that the Kebir wadi was richer in taxa composition than Rhumel wadi. Although the tributaries, except SE tributary, offered a higher biological diversity than the mainstream stations. Furthermore, the taxon richness, Shannon-Wiener and Margalef indices, and EPT family richness showed a significant difference between the two streams. The Rhumel wadi macrobenthic invertebrate assemblage was mainly characterized by pollution-tolerant taxa, indicating upstream disturbance caused by wastes from untreated sewage drains, industrial discharges and agricultural runoff. The downstream stations in the Kebir sub-basin, with relatively high forest cover and less anthropogenic impact, are less polluted and sheltered those taxa that are pollution-sensitive. Beni Haroun dam also appears to be an important factor in substantially decreased discharge, velocities and nutrient concentrations in Kebir stream. The differences in taxa richness and EPT biotic index confirm the physicochemical evaluation of water quality at Kebir-Rhumel wadi, which indicates the importance of macroinvertebrate assemblages as a biomonitoring tool to assess water quality and ecological status in stream ecosystems. The CCA results suggest that altitude, dissolved oxygen, conductivity and nutrient were the most important environmental factors influencing the macroinvertebrate communities structure in Kebir-Rhumel watershed.

Based on the initial dataset presented in this study, we propose that future studies focus on long-term monitoring of macroinvertebrate assemblages, with focus on sets of life-history traits of benthic macroinvertebrates because of their value in explaining distribution patterns observed in nature, quantifying trophic relationships and energetics, and analyzing factors structuring macroinvertebrate assemblages in this relatively unstudied catchment area. This work contributes to fill the current knowledge gap concerning the macroinvertebrate communities in the Kebir-Rhumel watershed, and to expand the investigation of spatial and temporal distribution patterns of these taxa identified in the north of Algeria.

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