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Influence of a dam and tributaries on macrobenthos communities and ecological water quality in the Kebir–Rhumel wadi (Northeast Algeria)

by

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Abstract

The water-quality biomonitoring programs based on macroinvertebrates of the Kebir–Rhumel wadi remain limited. We assessed macroinvertebrate assemblage structure and biological water quality to explore the impact of two discontinuities (a dam and a tributary) on biotic conditions. We sampled site communities above and below the Beni Haroun dam and in two tributaries in April, July, and November 2017. Sites above the dam had lower macroinvertebrate richness compared to reaches below the dam, while the tributaries had a relatively negligible effect on the confluence and mainstem communities. Ephemeroptera, Plecoptera, and Trichoptera (EPT) taxa richness; Hilsenhoff Biotic Index (BI); Iberian Biological Monitoring Working Party (BMWP') index; and Average Score Per Taxon (ASPT) demonstrate a fairly poor quality above the dam and a fair quality below it. One-way analysis of similarity (ANOSIM) and similarity percentage procedure (SIMPER) analyses revealed dissimilar community structures, with pollution-tolerant and pollution-sensitive species most contributing to the dissimilarity between studied reaches. This study has suggested only small changes in macroinvertebrate structure downstream of the dam and no significant impact of tributaries on the mainstem community composition.

Key words: Macroinvertebrates, biotic index, water quality, Kebir–Rhumel

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1. Introduction

In lotic systems, dams and tributary confluences are two major types of discontinuities that constitute a longitudinal continuum at a small scale (Stanford & Ward, 2001). Dams generate an adverse impact on riverine systems, mostly related to the alteration of the natural flow regime, physical habitat structure, and water physicochemical composition (Baxter, 1977; Morgan et al., 1991; Poff & Hart, 2002; Vinson, 2001). Tributaries can play a significant role in stream rehabilitation by delivering water, sediment, and nutrients to the main channel (Gomi et al., 2002). Tributaries can enhance habitat heterogeneity, river connectivity, and community diversity (Gomi et al., 2002; Rice et al., 2006; Svendsen et al., 2008).

Benthic macroinvertebrates are widespread and sensitive to most of the changes in water quality and habitat conditions. Their abundance, distribution, and functions are controlled by interactive conditions inherent to each microhabitat in the substratum (Thonney et al., 1987). Consequently, macroinvertebrates can serve as good indicators of river health through variations in their occurrence or abundance related to anthropogenic perturbations (Kevan, 1999). The use of macroinvertebrates in water quality monitoring is based on the different biotic indices. These indices are often based on the taxonomic diversity of invertebrates and their sensitivity to environmental changes. Several studies have reported changes in either the abundance or diversity of taxa downstream of dams (Sharma et al., 2005; Xiaocheng et al., 2008). Aquatic macroinvertebrate communities are principally affected by alterations of habitat caused by dams (Armitage, 1984).

In this framework, the objectives of this research are (1) to study macroinvertebrate assemblages above and below a dam to quantify the influence of this dam on the macroinvertebrate biodiversity, (2) to study the influence of a tributary on upstream and downstream aquatic assemblages in the mainstem, (3) to study the relationships between the composition of macroinvertebrate assemblages and water quality, and (4) to use several metrics for evaluating the ecological status of the studied stations.

2. Materials and methods

2.1. Study area

The study was conducted in the Kebir–Rhumel watershed (catchment area c. 8800 km^2), upstream and downstream of the Beni Haroun Dam, Northeast Algeria (lat 36°32′36.9″N, long 6°16′07.5″E) (Fig. 1). Beni Haroun, the largest dam in the country (40 km^2), originates at the confluence of the Rhumel and Enndja wadi. Below the dam, the Kebir wadi flows northwards for 56 km until it mouths into the Mediterranean Sea.

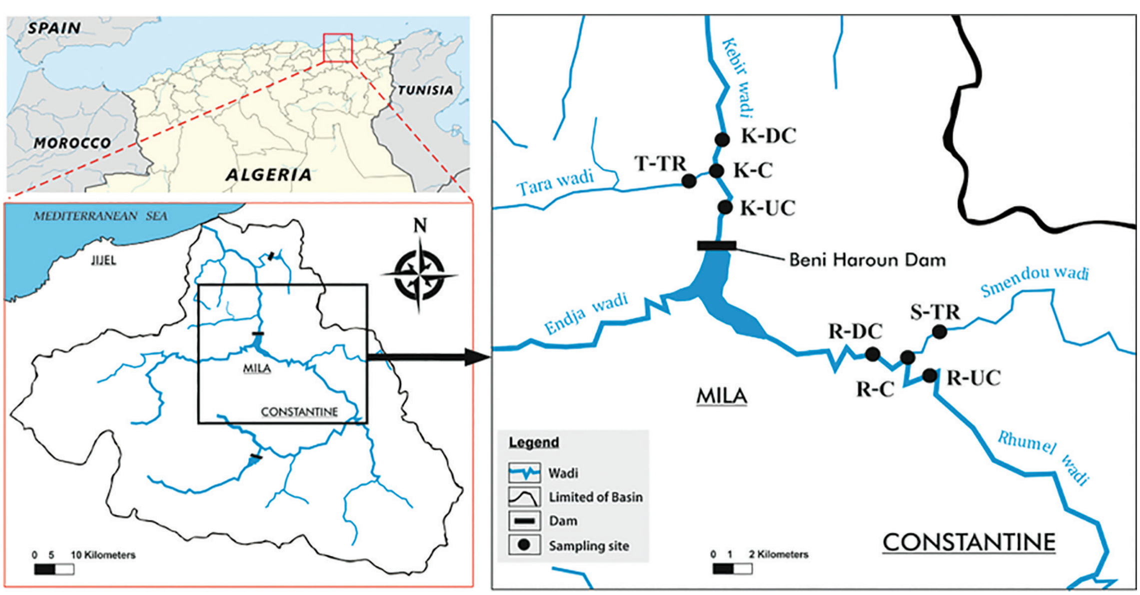

Figure 1

Locations of the sampling sites upstream and downstream of the Beni Haroun dam in the Kebir–Rhumel catchment (-UC, -DC: upstream and downstream of the confluence; -TR: tributary).

The climatic conditions of the basin are typical of a Mediterranean climate type and are characterized by moderate annual average temperature (18°C) and high rates of precipitation from December to March/April (Mébarki, 1982, 1984). The Rhumel wadi catchment exhibits areas highly disturbed by human activities, while the Kebir wadi drains a basin with relatively few anthropogenic impacts and has a largely natural, undammed watershed.

Eight sites were sampled in April, July, and November 2017. Four sites were upstream of the Beni Haroun dam, in the Rhumel wadi: (i) in the Smendou tributary (S-TR), (ii) in the confluence of the Rhumel and the Smendou wadi (R-C), and (iii) upstream and downstream of the tributary confluence (R-UC and R-DC, respectively). This river section was surrounded by a large agricultural area. The river substrate in this section consists mainly of stones and a few boulders, while the water is murky with a foul odor along the mainstem. The other four stations were located 4 km below the dam, on the Kebir wadi: (i) in the Tara tributary (T-TR), (ii) in the Kebir and Tara wadi confluence (K-C), and (iii) upstream and downstream of the confluence (K-UC and K-DC, respectively) (Fig. 1). These stations were surrounded by mountainous areas, and the effect of the anthropogenic disturbances was assumed to be low. The riverbanks in this section were less vegetated, and the substrate was stony except in the confluence (K-C) where the substrate consisted mainly of sand, gravel, stone and few large boulders.

2.2. Benthic macroinvertebrate and water sampling

Benthic macroinvertebrates were collected using a Surber sampler (30 cm × 30 cm; 500 μm mesh). We established eight haphazardly sampling locations along a ~35 m reach of the stream, including all possible microhabitats within each site for benthic macroinvertebrate sampling. At each site, the organisms were pooled. In total, the benthic fauna samples covered a 0.72 m^2 area at each site. Samples were fixed in 70% ethanol in the field and returned to the laboratory, where macroinvertebrates were sorted, counted, and identified to the lowest practical taxonomic level (usually family, genus, or species) using a binocular loupe (40× magnification; OPTIKA), a stereomicroscope (400× magnification; Motic), and taxonomic keys (Dommanget, 1994; Himmi et al., 1995; Poisson, 1957; Tachet et al., 2010).

On each sampling occasion, punctual measures of water temperature (°C), dissolved oxygen (DO, mg l^{-1}), electrical conductivity (EC, μS cm^{-1}), salinity (Sal, Practical Salinity Unit [PSU]), and pH were collected with a WTW™ 305i Multi-Parameter and a Mettler Toledo pH meter. We also estimated current velocity (cm s^{-1}) via the time taken for a flutter to travel a measured distance downstream. In parallel with macroinvertebrate sampling, water samples were collected in plastic bottles and taken to the laboratory for the determination of the following parameters: ammonium (NH_4^+, mg l^{-1}), nitrites (NO_2^-, mg l^{-1}), nitrates (NO_3^-, mg l^{-1}), and orthophosphates (PO_4^{3-}, mg l^{-1}). These parameters were analyzed according to standardized methods presented by AFNOR (Association Française de NORmalisation).

2.3. Data analyses

The normality of data and homogeneity of variances were tested using the Shapiro–Wilk and Levene's tests, respectively. One-way analysis of variance (ANOVA) and Kruskal–Wallis tests were conducted to test the significance of among-site differences in environmental variables and biological metrics. Principal component analysis (PCA) was applied to ordinate sites according to physicochemical parameters using XLSTAT software.

To explore taxonomical changes in the macroinvertebrate community, taxonomic richness (*S* = number of taxa), Shannon–Wiener diversity index (*H'*), Ephemeroptera, Plecoptera, and Trichoptera (EPT), and the ratio EPT/(EPT + Chironomidae) were calculated. In addition, we estimated the ecological water quality at all sampling sites using the Hilsenhoff Biotic Index (BI), the Biological Monitoring Working Party (BMWP) index, and the Average Score Per Taxon (ASPT).

The Shannon–Wiener diversity index is commonly used in the type calculation and the percentage of each species within the benthic community. This index was calculated as:

$$H' = -\sum_{i=1}^{s} Pi \; ln \; Pi$$

Where '*Pi*' is the relative abundance of i^{th} taxon of the community and '*S*' is the total number of species in the sample (Jørgensen et al., 2005).

The EPT family richness is equal to the total number of families belonging to three orders of aquatic insects considered as very sensitive to pollution: EPT; thus, their richness increases when water quality increases and vice versa (Table 1).

The metric EPT/(EPT + Chironomidae) is calculated by dividing the total abundance of EPT by EPT plus the total abundance of Chironomidae. This ratio expresses the relationship between the generally pollution-intolerant EPT organisms and the generally pollution-tolerant Chironomidae organisms. A value close to 0 indicates poor biotic condition, whereas a higher ratio (values 0.75 or greater) indicates a low number of Chironomids, denoting a fairly even distribution among these four groups (James, 2002).

The Hilsenhoff Biotic Index (BI) was developed to detect organic pollution and is based on the genus and species-level tolerance values (Bode et al., 2002). The formula for calculating the BI is:

$$BI = \frac{\sum(X_i t_i)}{n}$$

Where 'X_i' is the number of individuals in the 'i^{th}'taxon, 't_i' is the pollution tolerance score of the 'i^{th}' taxon, and '*n*' is the total number of organisms in the sample.

BI values range from 0 to 10 and are classified into seven quality categories (Table 2).

The BMWP' (Alba-Tercedor & Sanchez-Ortega, 1988) is a Spanish adaptation of the British Biological Monitoring Working Party (BMWP) score system (Armitage et al., 1983). The BMWP' index considers the sensitivity of invertebrates to pollution. A score between 1 and 10 is assigned to each family along an increasing gradient of pollution sensitivity. It is calculated by adding the tolerance scores of all the macroinvertebrate families (and Oligochaeta) in the sample (Alba-Tercedor & Pujante, 2000). The five classes of quality and their boundaries used in the quality mapping are shown in Table 3.

Furthermore, the has been calculated as the ratio between the BMWP' score and the number of taxa in the sample:

$$ASPT = \frac{\text{BMWP' score}}{\text{Total number of families}}$$

ASPT is suitable for assessing the impact of organic pollution based on five quality classes (Table 3) (Mandaville, 2002).

The correlations between macroinvertebrate metrics and physicochemical values were determined using a Pearson's correlation analysis. All statistical analyses were carried out using the statistical software package SPSS 26 (IBM Corp, 2019). We used a one-way analysis of similarity (ANOSIM) (Chapman & Underwood, 1999) to identify significant differences in community structure among sites. In addition, the similarity percentage procedure (SIMPER) analysis (Clarke & Warwick, 2001) was also applied to determine the species that best contributed to dissimilarity among sections. ANOSIM and SIMPER were conducted using PAST 4.08 software (Hammer et al., 2001). The relationship between macroinvertebrate assemblage

Table 1

Value of EPT richness according to corresponding water quality bioclassification categories (Bode et al., 1996).

EPT richness index	<2	2–5	6–10	>10
Water quality	Poor	Clean	Good	Excellent

EPT, Ephemeroptera, Plecoptera, and Trichoptera.

Table 2

Water quality classification system based on the BI values (Hilsenhoff, 1987).

Biotic index	Water quality	Degree of organic pollution
0.00–3.50	Excellent	Organic pollution unlikely
3.51–4.50	Very good	Possible slight organic pollution
4.51–5.50	Good	Some organic pollution probable
5.51–6.50	Fair	Fairly substantial pollution likely
6.51–7.50	Fairly poor	Substantial pollution likely
7.51–8.50	Poor	Very substantial pollution likely
8.51–10.00	Very poor	Severe organic pollution likely

BI, Hilsenhoff Biotic Index.

Table 3

Value of BMWP' (Alba-Tercedor & Pujante, 2000) and ASPT biotic indices (Hynes, 1998) and color codes according to corresponding water quality classes.

Bioclassification of water quality					
BMWP' score	≤15	16–35	36–60	61–100	101–150 >150
Color codes	Very critical	Critical	Dubious	Passable	Good
ASPT values	<3.9	4–4.9	5–5.9	6–6.9	>7
Color codes	Very poor	Poor	Moderate	Good	Very good

ASPT, Average Score Per Taxon.

structure and physicochemical parameters was analyzed by canonical correspondence analysis (CCA) in CANOCO 4.5 software (ter Braak & Šmilauer, 2002). Only taxa representing at least 0.15% of the total abundance were included in the CCA to minimize the effects of rare taxa. To stabilize the variances and improve normality, the abundance (x) of each taxon and the environmental variables data were log10(x + 1)-transformed (Sokal & Rohlf, 1995).

3. Results and discussion

3.1. Benthic macroinvertebrates

In this study, a total of 11 720 individuals in 91 taxa of benthic macroinvertebrates were recorded and identified during the three sampling seasons, above and below the Beni Haroun dam in Kebir–Rhumel wadi (Table 4).

Above the dam, the benthic macroinvertebrate communities were dominated by Diptera, Ephemeroptera, Oligochaeta, and Heteroptera with 36.92%, 25.03%, 15.01%, and 12.52%, respectively. Below the dam, Diptera, Ephemeroptera, and Trichoptera were abundant with 42.97%, 32.52%, and 13.45%, respectively (Fig. 2). Chironomidae, *Simulium (S.) pseudequinum*, *Baetis pavidus, Caenis luctuosa,* and *Hydropsyche lobata* were the most abundant taxa above and below the dam. Also, *Tubifex* sp. and *Micronecta* sp. were only dominant in stations above the dam. In terms of diversity, the Kebir wadi (Kr) segment and the tributary T-TR were the richest sites with 54 and 46 taxa, respectively. Diptera and Ephemeroptera were highly diversified in the station T-TR (11 taxa each), followed by Trichoptera with 7 taxa. In the S-TR station, Diptera, Coleoptera, and Odonata showed the highest richness with 10, 8, and 5 taxa, respectively (Table 4).

Macroinvertebrate densities and taxon richness were relatively higher below the dam than above and also higher in tributaries compared to the stations in the mainstem. Plecoptera have been observed only below the dam. Generally, this taxon is known to be sensitive to external influence (Cuffney et al., 2010; Evans-White et al., 2009; Villalobos-Jimenez et al., 2016). On the other hand, Oligochaeta and Hirudinea have been observed only above the Beni Haroun dam. These taxa are usually considered moderately tolerant or tolerant to organic enrichment and pollution (Cortelezzi et al., 2018; Lenat, 1993; Wang et al., 2012).

One-way ANOSIM yielded a significant difference between benthic community structure in the sampling stations (global test$R$ = 0.7, p = 0.0001). Pairwise ANOSIM test indicated that the following sites were significantly different except between R-DC and two stations, R-UC and R-C, and between K-DC and two stations, K-UC and K-C (Table 5). The SIMPER analysis (Table 6) recorded the highest average dissimilarity (70.58%) between the tributaries S-TR and T-TR. The dissimilarity between the Rhumel segment (Rh) and S-TR (59.84%) was mainly caused by *Caenis luctuosa*, *Micronecta* sp., Naididae, *Simulium. (W.) pseudequinum*, and *Baetis pavidus*.

The assemblage composition differed most across the dam (between above and below the dam) and between the tributaries (S-TR and T-TR) and mainstem segments (Rh and Kr). The low dissimilarities between R-UC and R-C and between K-UC and T-TR show slight effects of the tributaries on the assemblage structure in confluence stations. Faster-flowing tributaries have effects on the physical channel, such as increased channel depth and width, which would have influenced habitats (Wallis et al., 2008). In our study, the similarity of assemblages at the mainstem stations confirms the negligible effects of the tributaries (generally of low flow) in modifying the physicochemical characteristics of the channel to observe detectable effects on macroinvertebrate assemblages. The main differences in macrobenthos assemblages between the mainstem and the tributaries might be due to differences in habitat, including water depth, velocity, and substrate. On the other hand, the appearance of sensitive taxa and change in assemblage structure below the dam compared to above the dam sites likely reflected the change in environmental variables caused by the dam.

3.2. Physicochemical parameters and biological metrics indices

The results of the analyzed physical and chemical parameters of water in eight sampling stations are shown in Table 7.

The ANOVA demonstrated that almost all physicochemical parameters of water in this study, except temperature and pH, showed a significant difference between above and below the dam. The average water temperature ranged between 12.33 ± 4.93 and 18 ± 7°C. Water pH has shown very small variation, with average values ranging from 8.10 ± 0.53 to 9.33 ± 0.35, meaning that in all sites the water is alkaline. The highest average of DO was recorded in the T-TR with 7.93 ± 0.40 mg l^{-1}, and the lowest amount was 4.83 ± 0.99 mg l^{-1} at the station R-DC. The R-DC station presented the highest average values in EC and salinity, with 1728.33 ± 358.34 μS cm^{-1} and 0.92 ± 0.34 PSU, respectively; the lowest

Table 4

Taxa richness and mean abundance of benthic macroinvertebrates collected above and below the Beni Haroun dam in the Kebir–Rhumel wadi.

		Above the dam		Below the dam	
Taxon	**Code**	**Rhumel wadi (Rh)**	**S-TR**	**Kebir wadi (Kr)**	**T-TR**
TRICLADIDA					
Dugesia gonocephala	*D.gon*	1	4	7	1
Polycelis felina		-	1	2	2
OLIGOCHAETA					
Lumbriculidae		1.67	1	-	-
Tubifex sp.	*Tub*	270	-	-	-
Naididae	*Nai*	16.67	92	3	-
HIRUDINEA					
Dina lineata	*D.lin*	29.33	22	-	-
Erpobdella octoculata		0.67	-	-	-
Helobdella stagnalis	*H.sta*	2.67	3	-	-
Placobdella costata		0.67	-	-	-
GASTROPODA					
Physa acuta	*P.acu*	29.33	42	12	2
Ancylus fluviatilis	*A.flu*	-	4	-	13
Lithoglyphus naticoides		1	-	-	-
ARACHNIDA					
Unionicola sp.	*Uni*	-	-	28.33	60
DECAPODA					
Atyaephyra desmarestii	*A.des*	1.33	28	5.33	-
AMPHIPODA					
Gammarus sp.		-	-	0.67	4
DIPTERA					
Chironomidae	*Chi*	475	253	241.33	440
Limnophora riparia	*L.rip*	-	3	-	16
Simulium hispaniola	*S.his*	-	-	0.67	52
S. (S.) ornatum	*S.orn*	-	10	76.33	-
S. (W.) pseudequinum	*S.pse*	196.67	25	116.67	116
S. (E.) aureum	*S.aur*	-	-	32.33	120
Ceratopogonidae	*Cer*	-	11	6.67	57
Tabanus sp.			4	2.33	-
Culex sp.		-	2	-	-
Tipulidae	*Tip*	0.33	4	2.33	5
Empididae		0.67	2	1.33	-
Syrphidae		2.33	-	-	-
Hexatoma sp.	*Hex*	3.67	4	7	7
Dicranota sp.		-	-	-	3
Stratiomyidae		-	-	1.67	2
Atherix sp.	*Ath*	-	-	1.67	5

(*Continued*)

Table 4

Continued.

Taxon	Code	Above the dam		Below the dam	
		Rhumel wadi (Rh)	S-TR	Kebir wadi (Kr)	T-TR
PLECOPTERA					
Capnia nigra		-	-	1.67	1
Isoperla sp.	*Iso*	-	-	-	11
Leuctra sp.		-	-	-	9
EPHEMEROPTERA					
Acentrella sinaica	*A.sin*	-	-	19.33	26
Baetis pavidus	*B.pav*	401.67	41	177	448
Baetis rhodani	*B.rho*	-	-	2	85
Cloeon dipterum	*C.dip*	1.67	7	-	23
Cloeon saharense		-	-	-	5
Procloeon stagnicola	*P.sta*	-	-	3.33	6
Caenis luctuosa	*C.lus*	1	310	89	77
Caenis pusilla	*C.pus*	-	-	3.33	67
Ecdyonurus rothschildi	*E.rot*	-	-	1.33	41
Choroterpes atlas	*C.atl*	-	-	-	62
Choroterpes lindrothi	*C.lin*	-	-	-	13
COLEOPTERA					
Laccophilus hyalinus		1	3	0.67	-
Aulonogyrus striatus	*A.str*	-	-	6.67	-
Gyrinus dejeani		-	2	1	-
Limnius intermedius	*L.int*	0.33	11	0.67	37
Esolus filum	*E.fil*	7	-	1.67	20
Stenelmis consobrina	*S.con*	-	-	-	41
Dryops sp.	*Dry*	0.33	6	6.33	-
Hydraena sp.		3	-	1	-
Ochthebius		-	1	-	-
Hydrobius sp.		0.67	7	-	-
Laccobius gracilis	*L.gra*	3.33	-	2	-
Crenitis sp.		-	8	-	-
Coelostoma sp.		-	1	-	-
Helochares obscurus		2.67	-	-	-
Hydrochus sp.		2	-	-	-
Hydrocyphon sp.		-	-	-	7
TRICHOPTERA					
Hydropsyche lobata	*H.lob*	51.33	48	91.33	193
Hydropsyche maroccana	*H.mar*	2.33	27	23	49
Cheumatopsyche lepida	*C.lep*	-	-	6	24
Rhyacophila munda		-	-	-	2
Pararhyacophila sp.	*Par*	-	-	1	15
Chimarra marginata	*C.mar*	-	-	-	64
Psychomyia pusilla		-	-	2	1

(*Continued*)

Table 4

Continued.

Taxon	Code	Above the dam		Below the dam	
		Rhumel wadi (Rh)	S-TR	Kebir wadi (Kr)	T-TR
ODONATA					
Gomphus lucasii	*G.luc*	-	-	6.67	-
Praragomphus genei		-	-	-	2
Onychogomphus costae		-	-	1.33	-
O. unguiculatus		-	-	1.67	2
Boyeria irene		-	-	-	3
Orthetrum chrysostigma		-	2	0.67	-
Sympetrum fonscolombii		0.67	-	1	-
Sympetrum striolatum		0.33	-	0.67	-
Brachythemis impartita		1.67	4	2.33	-
Coenagrion sp.	*Coe*	2.33	3	1	-
Erythromma lindenii		-	5	-	-
Ischnura graellsii		0.67	3	-	-
Platycnemis subdilatata		-	-	0.33	-
HETEROPTERA					
Nepa sp.		0.67	-	0.67	1
Micronecta sp.	*Mic*	110.33	420	20.67	-
Corixa punctata		2	-	-	-
Paracorixa concinna		2.67	-	-	-
Microvelia pygmaea		-	6	-	-
Gerris lacustris	*G.lac*	1.67	4	3.33	-
Naucoris maculatus		-	4	2.67	-
Naucoris cimicoides		-	-	0.67	-
Notonecta obliqua	*N.obl*	3.33	-	-	-
Anisops sardea		1	-	-	-
Abundance		1634.35	1438	1032.68	2240
Number of taxa		43	41	54	46

S-TR, Smendou tributary; T-TR, Tara tributary.

values were recorded at the station T-TR, with 718.33 ± 163.58 μS cm^{-1} and 0.29 ± 0.08 PSU, respectively. As for the nutrient concentrations (ammonium, nitrite, nitrate, and phosphate), they have shown significant differences observed between the tributaries and mainstem, and they were higher immediately above the dam than below the dam.

The Rhumel wadi is greatly affected by anthropogenic activities such as land use activities, discharge of household sewage, and industrial wastes. The Beni Haroun dam has constituted a barrier, which can disrupt the continuity of the fluvial environment by the accumulation of sediment, nutrients, and organic matter supplied by the Rhumel wadi. This was confirmed by Kondolf (1997) and Takao et al. (2008). Wiatkowski (2011) emphasized the contribution of the sedimentation process in reservoirs to decrease the pollution in rivers flowing through them.

Results of PCA indicated that PC1 and PC2 accounted for 75.57% and 15.66% of the total variance of environmental variables, respectively (Fig. 3). The distribution of the stations in the first factorial plane shows a clear differentiation of the sampling sectors based on the physical and chemical variables. The PCA ordination plot has suggested that stations above the dam were positively influenced by temperature, salinity, conductivity, and nutrient loads. The dam here clearly had a remarkable effect on the physicochemical characteristics of the river.

A summary description of the calculated biotic indices and the community structure indices of the sampling stations is provided in Table 8. According

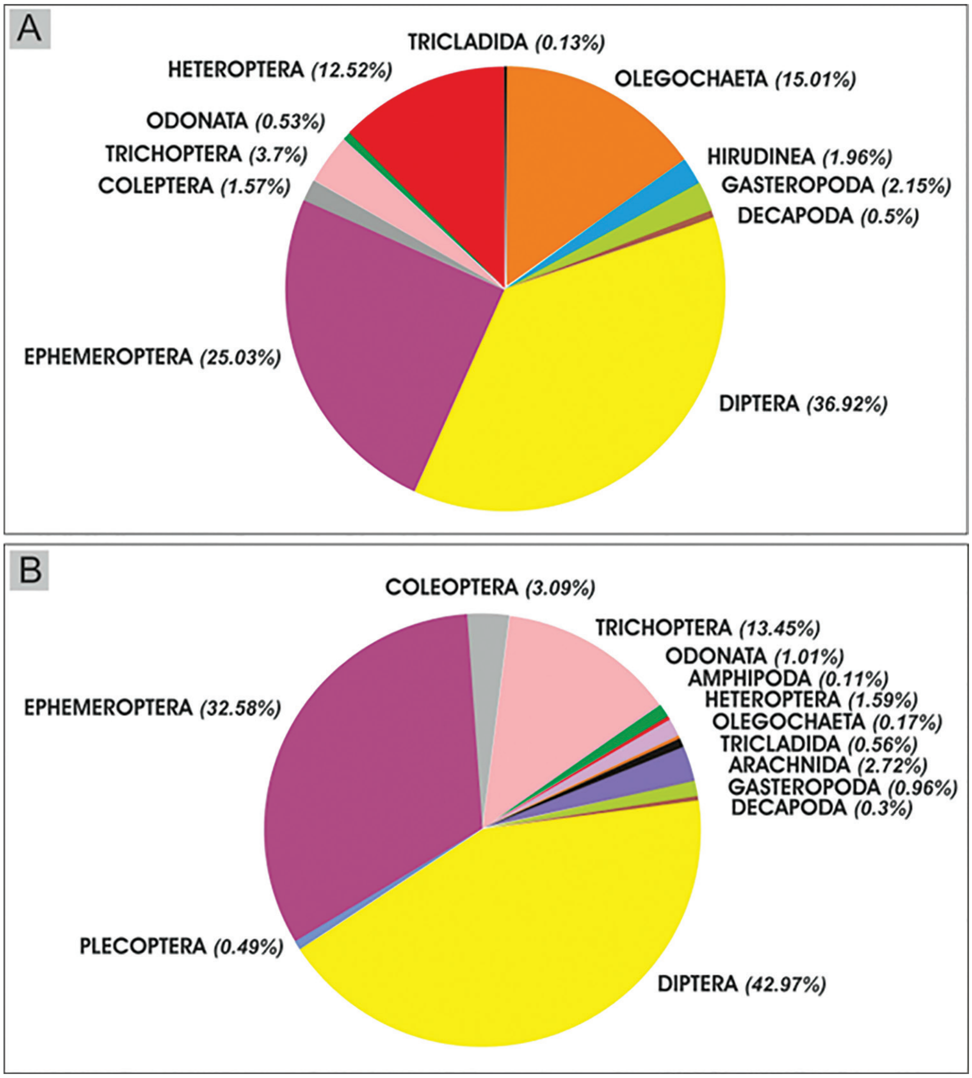

Figure 2

Relative composition in macroinvertebrate orders in stations above (A) and below (B) the Beni Haroun dam.

Table 5

SIMPER and one-way ANOSIM on pairwise comparisons of sites using Bray–Curtis dissimilarities. Upper triangular matrix shows the overall average dissimilarity (%) and lower triangular matrix shows the R-statistic. *Ns*: not significant difference ($p > 0.05$).

Above the dam					Below the dam				
	R-UC	R-C	R-DC	S-TR		K-UC	K-C	K-DC	T-TR
R-UC		45.56	40.77	61.68	**K-UC**		45.57	42.99	62.75
R-C	0.35		39.48	56.5	**K-C**	0.24		48.99	61.10
R-DC	0.05^{Ns}	0.20^{Ns}		61.33	**K-DC**	0.19^{Ns}	0.20^{Ns}		60.41
S-TR	0.97	0.97	1.00		**T-TR**	0.99	1.00	0.79	

ANOSIM, one-way analysis of similarity; DC, downstream of the confluence; SIMPER, similarity percentage procedure; S-TR, Smendou tributary; T-TR, Tara tributary; UC, upstream of the confluence.

Table 6

Output from SIMPER analysis of macroinvertebrates, showing the most influential taxa to total dissimilarity among segments (Rh, S-TR, Kr, and T-TR). List of taxa, which cumulatively account for 50% of the dissimilarity between sample groups. Av.%. dissim: average% dissimilarity,%. Cont. dissim: % Contribution to the dissimilarity.

Pairwise comparison	*R*-statistic	Av.%. dissim	Most discriminating taxa	%. Cont. dissim	Most discriminating taxa	%. Cont. dissim
Rh *vs.* S-TR	0.95	59.84	*Caenis luctuosa*	7.72	*Tubifex* sp.	4.28
			Micronecta sp.	6.17	*Hydropsyche maroccana*	3.35
			Naididae	5.97	*Limnius intermedius*	2.83
			Simulium. (W.) pseudequinum	5.59	*Dina lineata*	2.52
			Baetis pavidus	5.49	*Esolus filum*	2.26
			Atyaephyra desmarestii	4.3		
Rh *vs.* Kr	0.87	59.09	*Simulium. (S.) ornatum*	5.77	*Physa acuta*	3.71
			Caenis luctuosa	5.47	*Hydropsyche maroccana*	3.56
			Tubifex sp.	4.84	*Simulium. (W.) pseudequinum*	3.42
			Micronecta sp.	4.5	*Acentrella sinaica*	2.94
			Dina lineata	4.29	*Baetis pavidus*	2.61
			Chironomidae	4.1	*Gomphus lucasii*	2.40
			Simulium. (E.) aureum	3.98		
Kr *vs.* T-TR	0.9	61.42	*Baetis rhodani*	4.44	*Caenis pusilla*	3.06
			Chimarra marginata	4.18	Chironomidae	2.79
			Choroterpes atlas	3.99	*Caenis luctuosa*	2.71
			Simulium. (S.) ornatum	3.83	*Simulium. (E.) aureum*	2.7
			Limnius intermedius	3.53	*Cloeon dipterum*	2.69
			Simulium hispaniola	3.52	*Stenelmis consobrina*	2.56
			Ecdyonurus rothschildi	3.49	*Unionicola* sp.	2.39
			Simulium. (W.) pseudequinum	3.18		
S-TR *vs.* T-TR	1	70.58	*Micronecta* sp.	5.78	*Simulium hispaniola*	2.99
			Naididae	3.97	*Caenis luctuosa*	2.97
			Baetis rhodani	3.85	*Atyaephyra desmarestii*	2.80
			Baetis pavidus	3.67	*Physa acuta*	2.58
			Chimarra marginata	3.36	*Caenis pusilla*	2.57
			Choroterpes atlas	3.21	*Simulium. (W.) pseudequinum*	2.49
			Simulium. (E.) aureum	3.05	*Acentrella sinaica*	2.17
			Ecdyonurus rothschildi	3	*Stenelmis consobrina*	2.06

Kr, Kebir wadi; Rh, Rhumel wadi; SIMPER, similarity percentage procedure; S-TR, Smendou tributary; T-TR, Tara tributary.

to Mason (2002), Shannon–Wiener index values in this study (ranging from 1.46 and 2.57) were in the range indicating moderate-polluted environment, with relatively high index values below the dam. It is obvious from the observation during the sampling process that the mainstem above the dam was more polluted than the section below the dam.

The EPT, EPT/(EPT + Chironomidae), and BI index values classified the majority of the stations in the same quality class, with the highest values recorded in the stations below the dam.

The high values of EPT (8.33), BMWP' (108.66), and ASPT (6.05) collectively indicate that the water quality at T-TR is good. The biological indices, except ASPT, allocated to the majority of the stations passable and clear water quality. Based on ASPT, the mean water quality in all sampling stations, except T-TR, was poor to very poor.

In our research, there are differences in water quality classification with different indices, whereas the application of EPT and BMWP' index seems to be more reliable and to better reflect the

Table 7

Mean ± SD values of physicochemical variables at the sampling stations above and below the Beni Haroun dam in the Kebir–Rhumel wadi. Values in bold indicate significant differences based on ANOVA.

Variable	Above the dam				Below the dam				p-value
	R-UC	R-C	R-DC	S-TR	K-UC	K-C	K-DC	T-TR	
T (°C)	18.00 ± 6.08	18.00 ± 6.24	18.00 ± 7.00	14.67 ± 5.51	16.33 ± 6.66	15.67 ± 6.35	15.33 ± 6.66	12.33 ± 4.93	0.526
pH	8.23 ± 0.47	8.17 ± 0.35	8.10 ± 0.53	8.90 ± 0.35	8.80 ± 0.46	8.53 ± 0.38	8.67 ± 0.25	9.33 ± 0.35	0.062
DO (mg l^{-1})	5.17 ± 0.85	5.23 ± 1.08	4.83 ± 0.99	6.40 ± 0.61	6.53 ± 0.70	6.73 ± 0.83	6.67 ± 0.65	7.93 ± 0.40	**0.003**
EC (µS cm^{-1})	1701 ± 290.11	1693.33 ± 344.29	1728.33 ± 358.34	1370 ± 329.7	986.67 ± 100.66	1048.33 ± 101.15	1050.67 ± 115.52	718.33 ± 163.58	**0.0001**
Salinity	0.87 ± 0.25	0.89 ± 0.30	0.92 ± 0.34	0.62 ± 0.13	0.51 ± 0.14	0.51 ± 0.13	0.52 ± 0.13	0.29 ± 0.08	**0.034**
NH_4^+ (mg l^{-1})	1.90 ± 0.79	3.68 ± 1.83	3.98 ± 1.69	1.85 ± 2.82	0.14 ± 0.04	0.13 ± 0.03	0.12 ± 0.03	0.08 ± 0.03	**0.009**
NO_2^- (mg l^{-1})	2.58 ± 2.46	1.94 ± 1.69	2.26 ± 2.06	0.36 ± 0.33	0.07 ± 0.05	0.06 ± 0.04	0.06 ± 0.05	0.02 ± 0.02	**0.028**
NO_3^- (mg l^{-1})	2.75 ± 2.37	2.40 ± 1.71	3.23 ± 3.02	3.56 ± 1.09	0.67 ± 0.29	0.89 ± 0.27	0.98 ± 0.30	0.32 ± 0.16	**0.023**
PO_4^{3-} (mg l^{-1})	2.37 ± 0.59	2.52 ± 1.00	2.51 ± 0.87	1.56 ± 0.46	0.46 ± 0.12	0.44 ± 0.17	0.45 ± 0.16	0.31 ± 0.17	**0.0001**

ANOVA, analysis of variance; DC, downstream of the confluence; DO, dissolved oxygen; EC, electrical conductivity; NH4<qsisup>+, ammonium; NO2<qsisup>−, nitrite; NO3<qsisup>−, nitrate; PO4<qsisup>3−, phosphate; S-TR, Smendou tributary; T, water temperature; UC, upstream of the confluence; T-TR, Tara tributary.

environmental condition since they are both based on the presence of sensitive species to disturbances. Logically, the section below the dam had a relatively higher water quality than the ASPT category, as indicated by the classification of other biotic indices and physicochemical evaluation of water quality. The differences in quality class allocation among indices may be due to different values limiting the quality class levels and the systems of categorization.

Pearson correlation analyses between biological indices and physicochemical parameters show that temperature and DO had a significant correlation with all the biological indices (Table 9). pH and salinity had significant correlation with the majority of biological indices, except EPT/(EPT + Chironomidae). NO_3^- exhibited significant negative correlation with only ASPT. Nutrients had no significant correlation with taxonomic richness (*S*), EPT, and BMWP'. The Shannon–Wiener index (*H'*) has a strong correlation ($p < 0.01$) with all physicochemical parameters, except NO_3^-. Also, ASPT was significantly correlated to all the physicochemical parameters (Table 9).

The results of Pearson's correlation approach have shown the major influence of water physicochemical variables on the taxonomic richness and the diversity of macroinvertebrates in the study area. Similar studies have documented the negative effects of chemical variables on the richness and diversity of benthic macrofauna (Lewin et al., 2013; Zhushi Etemi et al., 2020). Chen et al. (2015) found that the diversity of macrobenthic assemblages was negatively correlated with the nutrient enrichment in the water body. The BI index is inversely related to the quality of water and increases with river pollution. Although biotic indices are intensely influenced by anthropogenic activities, it should be clear that they can also respond relatively to a range of potential physicochemical parameters (Sharifinia et al., 2016).

3.3. Relationships between physicochemical parameters and benthic macroinvertebrate assemblages

A multivariate CCA was applied to summarize the relationships between macroinvertebrate assemblages and water physicochemical parameters above and below the dam (Fig. 4). The parameters that have negligible variance were omitted from the ordination. Above the dam, the results of CCA analysis showed that *Simulium ornatum*, Ceratopogenidae, *Limnius intermedius,* and *Caenis luctuosa* abundances were closely and positively related to DO concentration and

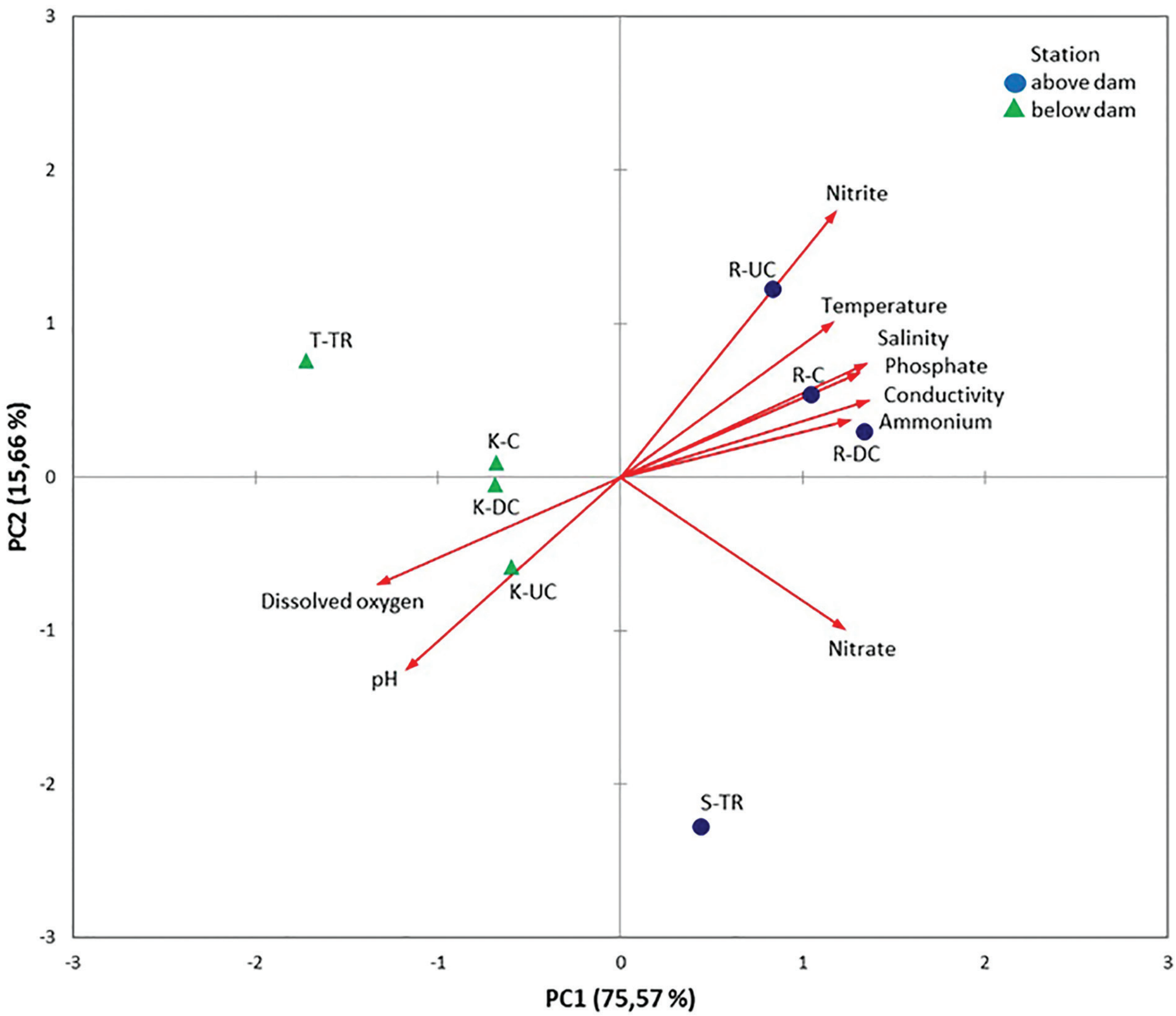

Figure 3

PCA ordination plot explaining the variation of physicochemical parameters among sampling sites. DC: downstream of the confluence; PCA, principal component analysis; T-TR, Tara tributary; UC, upstream of the confluence.

pH. *Helobdella stagnalis*, *Cloeon dipterum,* and Naididae showed preferences for high nitrate concentrations. Temperature, conductivity, and nitrite were positively related to the abundance of *Tubifex* sp. and *Esolus filum* (Fig. 4). Below the dam, *Choroterpes lindrothi*, *Choroterpes atlas, Caenis pusilla, Ecdyonurus rothschildi* and *Cloeon dipterum* (Ephemeroptera), *Simulium hispaniola*, *Limnophora riparia* (Diptera), *Isoperla* sp. (Plecoptera), *Stenelmis consobrina, Limnius intermedius* (Coleoptera), *Chimarra marginata* (Trichoptera), and *Ancylus fluviatilis* (Gastropoda) showed preferences for well-oxygenated waters and a great sensitivity to temperature, conductivity, salinity, and nitrate. These last parameters were positively related to the abundance of *Gomphus lucasi* (Odonata), *Simulium ornatum* (Diptera), *Dugesia gonocephala* (Turbellaria), and *Aulonogyrus striatus* (Coleoptera) (Fig. 4).

According to the results of CCAs applied to the data above and below the Beni Haroun dam, water temperature, conductivity, and DO concentration were the most important factors that affected the macrobenthic assemblage. The CCA ordination plots obviously divided tolerant macroinvertebrate species affected by temperature, conductivity, and nutrients from sensitive species to decrease in DO concentration. Similarly, De Jonge et al. (2009), Sharifinia et al. (2012), and Raphahlelo et al. (2022) reported that nutrients, water temperature, conductivity, and DO directly affect the composition, life cycle, and distribution of macrobenthic communities.

Table 8

Mean ± SD values of biological indices and classification of water quality at the sampling stations above and below the Beni Haroun dam in the Kebir–Rhumel wadi. Values in bold indicate significant differences based on ANOVA.

Biological index	Above the dam				Below the dam				*p*-value
	R-UC	R-C	R-DC	S-TR	K-UC	K-C	K-DC	T-TR	
Taxonomic richness (*S*)	14.00 ± 1.00	18.00 ± 1.73	13.33 ± 2.31	24.33 ± 5.13	20.33 ± 2.08	14.00 ± 1.73	23.33 ± 4.16	27.67 ± 1.53	**0.006**
Shannon-Wiener index (*H'*)	1.57 ± 0.25	1.82 ± 0.02	1.46 ± 0.43	2.19 ± 0.43	2.13 ± 0.39	2.16 ± 0.12	2.25 ± 0.21	2.57 ± 0.10	**0.003**
EPT index	2	2.66 ± 0.58	2.33 ± 0.58	2.66 ± 0.58	3.66 ± 0.58	2.66 ± 0.58	4	8.33 ± 1.53	**0.009**
Water-quality-evaluation rating	Clean	Clean	Clean	Clean	Clean	Clean	Clean	Good	
EPT/(EPT + Chironomidae)	0.37 ± 0.04	0.64 ± 0.22	0.51 ± 0.16	0.65 ± 0.15	0.53 ± 0.25	0.71 ± 0.21	0.71 ± 0.31	0.76 ± 0.27	0.30
Hilsenhoff biotic index (BI)	6.41 ± 1.94	6.38 ± 1.11	7.07 ± 0.64	5.85 ± 0.09	6.29 ± 0.49	5.79 ± 0.50	5.90 ± 0.56	5.54 ± 0.57	0.34
Water-quality-evaluation rating	Fair	Fair	Poor	Fair	Fair	Fair	Fair	Fair	
BMWP' index	47.00 ± 20	64.66 ± 7.57	42.00 ± 7.21	83.33 ± 14.29	70.00 ± 16.64	47.66 ± 2.08	86.00 ± 15.62	108.66 ± 12.42	**0.001**
Water-quality-evaluation rating	Dubious	Passable	Dubious	Passable	Passable	Dubious	Passable	Good	
ASPT index	3.52 ± 0.21	4.22 ± 0.20	3.42 ± 0.23	3.96 ± 0.24	4.74 ± 0.40	4.62 ± 0.41	4.99 ± 0.25	6.05 ± 0.28	**0.0001**
Water-quality-evaluation rating	Very poor	Poor	Very poor	Very poor	Poor	Poor	Poor	Good	

ANOVA, analysis of variance; ASPT, Average Score Per Taxon; BMWP', Iberian Biological Monitoring Working Party index; DC, downstream of the confluence; EPT, Ephemeroptera, Plecoptera, Trichoptera; S-TR, Smendou tributary; T-TR, Tara tributary; UC, upstream of the confluence.

Table 9

Pearson's correlation between diversity and biotic indices with water physicochemical parameters.

	S	*H'*	EPT	EPT/(EPT + Chironomidae)	BI	BMWP'	ASPT
T°C	−0.83*	−0.93**	−0.83*	−0.74*	0.86**	−0.85**	−0.82*
pH	0.87**	0.92**	0.81*	0.60	−0.81*	0.87**	0.81*
DO	0.76*	0.97**	0.81*	0.74*	−0.89*	0.79**	0.91*
EC	−0.65	−0.92**	−0.76*	−0.66	0.78*	−0.69	−0.91**
Salinity	−0.71*	−0.95**	−0.77*	−0.69	0.84**	−0.74*	−0.90**
NH_4^+	−0.47	−0.79*	−0.52	−0.43	0.77*	−0.50	−0.73*
NO_2^-	−0.66	−0.92**	−0.53	−0.74*	0.79*	−0.64	−0.76*
NO_3^-	−0.36	−0.69	−0.66	−0.50	0.57	−0.44	−0.87**
PO_4^{3-}	−0.55	−0.87**	−0.61	−0.62	0.75*	−0.57	−0.83*

*Correlation is significant at the 0.05 level (2–tailed).
**Correlation is significant at the 0.01 level (2–tailed).
ASPT, Average Score Per Taxon; DO, dissolved oxygen; EC, electrical conductivity; EPT, Ephemeroptera, Plecoptera, and Trichoptera.

As illustrated by the CCA analysis, the stations above the dam had the most moderately pollution-tolerant species, such as the Chironomidae, *Tubifex* sp., *Micronecta* sp., and *Physa acuta*. The total absence of Plecoptera and the presence of *Tubifex* sp. only at Rhumel wadi confirm its very degraded state.

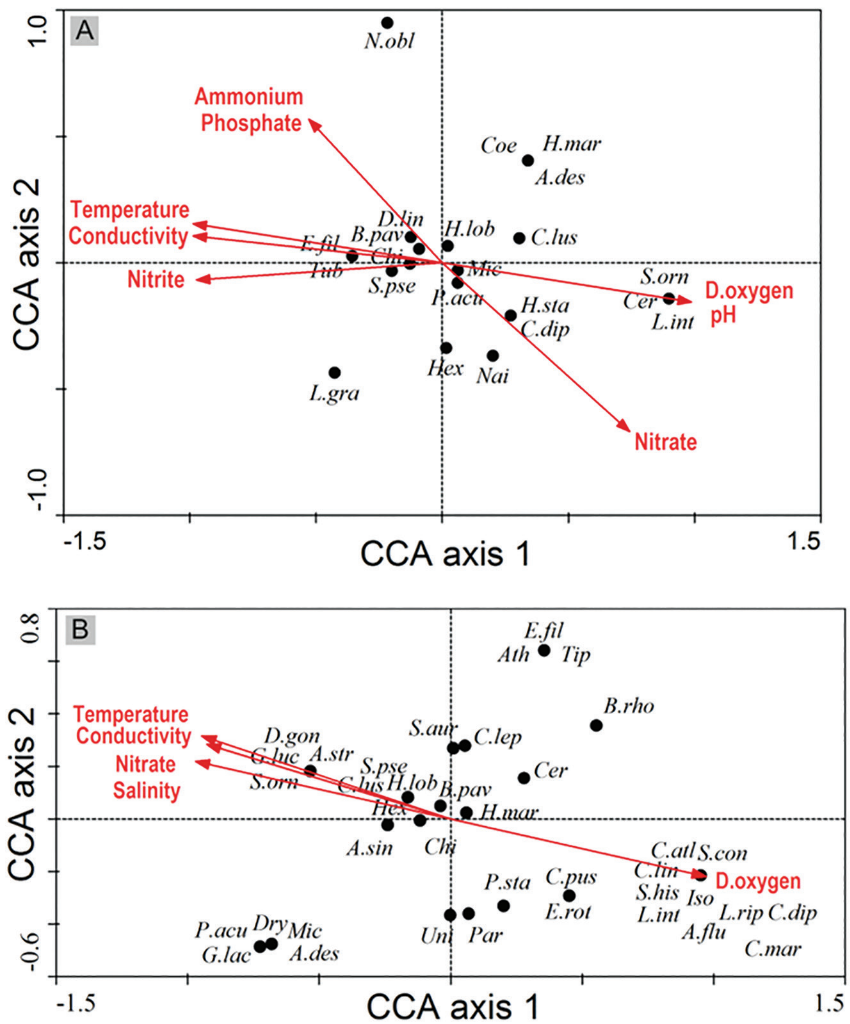

Figure 4

CCA ordination diagram illustrating the relationships between macroinvertebrate taxa and physicochemical parameters in sites above (A) and below (B) the Beni Haroun dam. The codes of taxa are provided in Table 4. CCA, canonical correspondence analysis.

On the other hand, the CCA ordination plot showed a strong relationship between sensitive taxa and good oxygenation below the dam.

4. Conclusion

The Beni Haroun dam has constituted a barrier reducing the downstream transport of nutrient pollution by accumulating sediments supplied by the Rhumel wadi. Thus, the dam alters the natural flow regime and water depth downstream, the most important factors affecting habitat and substratum. This seems to have impacted the physicochemical characteristics and the macrobenthos community structure below the dam. We conclude that the dam has caused a discontinuity in the upstream–downstream gradient of the stream. Thus, the Beni Haroun dam separates two distinctly different environments in terms of morphodynamics and physicochemical aspects. On the other hand, despite their high taxonomic richness and abundance, tributaries did not show any significant effect on macroinvertebrate diversity and abundance in the stations of the mainstem.

To strengthen the local knowledge in terms of dam impact on the macrobenthos community, future investigations should include additional environmental factors, notably riparian vegetation and the distribution of local precipitation, which are integrated with the type of climax community occupying this area.

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