Taxa richness and community structure of macroinvertebrates in rivers of different bioclimatic regions of Algeria

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Taxa richness and community structure of macroinvertebrates in rivers of different bioclimatic regions of Algeria

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Abstract

There is still little knowledge about macroinvertebrate communities in Algerian rivers. In this study, we investigated variation in taxa richness and community structure of benthic macroinvertebrates in three rivers located in different bioclimatic regions of Algeria: the Wadi Sahel (Bouira), the Wadi Djedir (Djelfa) and the Wadi M'zi (Laghouat). Macroinvertebrates were sampled using a kick-net sampler in 14 sites (4-5 sites in each river) representing characteristic habitats along the upstream-downstream longitudinal gradient. We tested the hypothesis that spatial variation among rivers in macroinvertebrate communities will be more important than within river, across the longitudinal gradient, due to important environmental changes between bioclimatic regions. A total of 51 taxa (family level) were reported across the studied rivers. The highest taxa diversity was found in the Wadi Sahel (40 taxa) and the Wadi Djedir (30 taxa) located in the mountainous semi-arid temperate regions and the smallest (21 taxa) in the Wadi M'zi located in the arid and cold Saharan plateau. Clustering analysis showed that taxa composition greatly varied among rivers with different climates while there was little variation along the upstream-downstream gradient within each river. Higher abundances of sensitive insect larvae were found in the two rivers (Wadis Sahel and Djedir) located in semi-arid temperate regions than in the river M'zi located in arid region which support tolerant insect larvae and worms. Biotic indices based on macroinvertebrates diversity and community structure also indicated that rivers with temperate climate (Wadi Sahel and Djedir) had high ecological integrity than the river (Wadi M'zi) with arid climate.

1. Introduction

Benthic macroinvertebrates play a key role in river food webs as primary resources for fish and waterbirds [1-2]. They are recognized as suitable bioindicators of ecological integrity of lakes and rivers [3-4]. However, more of the current knowledge on distribution patterns of freshwater macroinvertebrate community and their regulating processes came from studies conducted in Europe and North America. In Europe, macroinvertebrates have been recognized as good indicators of ecological integrity and anthropogenic impacts in ponds [5 -6] and rivers [7-8-9]. In North America, they served for assessing the ecological integrity of coastal wetlands of the Great Lakes [10], fluvial lakes in large rivers as the St. Lawrence River [11-12-13-14] and the River Fraser [15-16], and streams [17-18-19]. In contrast, community structure of macroinvertebrates in Mediterranean rivers has received less attention. Despites that several thesis and papers described the taxonomy and biogeography of freshwater macroinvertebrates in North-African countries [20-21-22-23-24-25-26-27-28-29-30-31-32-33-34], most of the studies were carried out on rivers of mountainous northern regions of Morocco and Algeria whereas no study documented rivers of southern arid and sub-arid regions. Moreover, any study evaluated how macroinvertebrate communities varied across bioclimatic regions and most of the studies were restricted to the insect fauna.

Algeria is the largest country in North Africa covering more than 2 million km^2 of land between the Mediterranean Sea and the Africa. Its geography is very diverse and characterized by different bioclimatic regions: the mountainous and coastal temperate regions in the north spreading from west to east, and the sub-arid and arid southern regions of the Sahara Atlas. This climatic gradient creates contrasted environmental conditions in hydrological basins, such as extreme high temperature and drought during summer or heavily rain and important floods during spring and winter, which can affect river habitats and biota. Consequently, Mediterranean rivers are subjected to abrupt variations in water level and current. Annual variations in water discharge are characterized by high water level at spring and fall and very low water level during summer [35]. As macroinvertebrates respond to a variety of disturbances in hydrology and river habitats, they offer a good potential to assess changes in ecosystem-level processes such as erosion and habitat degradation during flooding, or sediment organic enrichment and contamination due to human activities [17]. In Algeria, effective bioassessment of ecological integrity of rivers is still too limited to give a comprehensive knowledge of spatial variation within and among rivers in benthic macroinvertebrates along bioclimatic and disturbance environmental gradients.

This study investigated the variation in community structure of benthic macroinvertebrates in three major rivers of Algeria across a large biogeographical and climatic gradient in altitude, temperature, geomorphology and hydrology. We selected univariate and multivariate metrics based on taxa richness and abundances, and biotic indices to compare and contrast macroinvertebrate communities within and among rivers using cluster analysis. We evaluated the variation in macroinvertebrate taxa richness and community structure along the upstream-downstream longitudinal gradient within each river and among rivers across different bioclimatic regions. We tested the hypothesis than due to contrasted bioclimatic features, most of the spatial variation in macroinvertebrate communities will be accounted by environmental differences among rivers whereas within-river variation along the longitudinal gradient will be weak.

2. Material and methods

2.1. *Study area and environmental features*

The study area ranges over 400 km from north to south in Algeria between the mountains of the Djurdjura region to the high plateaus of the Sahara Atlas. We selected three river basins (Wadis) varying by their bioclimatic and edaphic features in the regions of Bouira, Djelfa and Laghouat (Figure 1). Main characteristics of environmental and climatic features of each river are presented in Table 1a and table 1b.

Wadi Sahel (36° 23'N; 3°54'E) is located in the northern region of Bouira in the Sahel valley between the Djurdjura and the Babors mountains, at 120 km south of the city of Algiers and an altitude of 370 m (Figure 1, Table 1a and Table 1b). The river flows from the Soumman valley in the municipalities (wilaya) of Bouira and Béjaia over 40 km from d'El-Adjiba till Akbou. The basin catchment of the Wadi Sahel and its tributaries extends over an area of 3815 km^2 from Akbou to El-Ghozlane in lowlands (slope < 1%) covered by Mediterranean xeric forest (Holm oak, olive trees, and silver poplar). Wadi Sahel is shallow (max depth of 1.2 m) and small (river bed width of 100 m). Sediments are composed of coarse materials as rocks, gravels and pebbles. Current is moderate and water is circumneutral and polluted. Mean annual temperatures of air and water are respectively 17.8 and 16°C, ranging from a maximum of 34°C to a minimum of 3.8°C. Annual precipitation is of 478 mm. Based on three important climatic variables (precipitation, temperature, and evaporation) [36], the Emberger pluviometric quotient is of 52.8 (Table 1a and Table 1b), indicating temperate and semi-arid climatic conditions in the region.

Wadi Djedir (33-35°N; 2-5°E) is situated at the altitude of 1085 m in the Djelfa region on the high plateau of the Tell Atlas in the central northern part of Algeria at 300 km south of the city of Algiers (Figure 1). It is an effluent of the river Mellah located 20 km north from the municipality of Djelfa. Wadi Djedir is narrow (river bed width: 25m) and moderately deep (max. depth: 1.4 m). Sediments are composed of rocks and sands. Current is slow and water is circumneutral and non-polluted. Its basin covers a small area of 150 km^2 on calcareous soils composed of marls, clay and schist. Its catchment is forested with conifers (Aleppo pines). Mean annual temperatures of air and water are respectively 14 and 19°C, ranging from a maximum of 34°C to a minimum of -0.5°C with freezing conditions during winter. Annual precipitation is of 335 mm. Based on the Emberger's pluviometric quotient of 33,29 , climatic conditions are cold and semi-arid.

Wadi M'zi (33°54'N; 30°77'E) is located in the central region Laghouat, 400 km south of the city of Algiers, at 909 m of altitude in the high plateaus of the Sahara Atlas. It is formed by the confluence of the rivers M'Said and M'zi surging from the Djebel Amour Mountain which reaches an altitude of 2000 m. Wadi M'zi is a large (width: 1200 m) but very shallow (max. depth: 0.45 m) river. Sediments are composed of fine materials (sands and clays). Current is slow and water is circumneutral and moderately polluted. Its basin covers a large area of 1618 km^2 on calcareous soils composed of marls. Its catchment is covered by semi-arid and shrub vegetation (salt cedar, wormwood, Alfalfa). Mean annual temperatures of air and water are respectively 20.8 and 19.8°C, with important variation from maximum of 43.7°C to a minimum of 2.4°C. Annual precipitation is low reaching only 178 mm. Based on the Emberger's pluviometric quotient of fifteen (15), the moderately cold and arid climatic conditions are the most extreme of the study area.

Table 1a : Typology and Environmental features of the studied rivers.

Environmental Features	Wadi Sahel (Bouira)	Wadi Djedir (Djelfa)	Wadi M'zi (Laghouat)
Altitude (m)	370	1085	909
Mean air temperature (°C)	17.8	14	20.8
Mean water temperature (°C)	16	18.9	19.8
Catchment slope (%)	0.3	5	3
Nature of soil	Depression	Marl, Schist, Clay	Marl
River bed width (m)	100	25	1200
Vegetation	*Olea europea* *Querqus ilex, Populus alba*	*Pinus halepensis*	*Tamarix sp* *Artemisia* sp. *Stipa tenacissima*
Sediment substrat	Rocks, Gravel, Pebble	Rocks Sands	Sands, Clay
Water current	Moderate	Slow	Slow
Max. depth (cm)	120	140	45
Water pH	7.9	7.4	7.5

Table 1b : Climatic features of the studied rivers.

Climatic Features	Wadi Sahel (Bouira)	Wadi Djedir (Djelfa)	Wadi M'zi (Laghouat)
Precipitation (mm)*	478	335	178
Max. air temperature (°C)*	34	34.1	43.7
Min. air temperature (°C)*	3.8	- 0.5	2.4
Emberger quotient	52.8	33.29	15
Bioclimatic stage*	Semi-arid Mild temperate	Semi-arid Cold	Arid Moderately cold

***from A.N.R.H (2012) and O.N.M. (2012**).

2.2. *Macroinvertebrate sampling and analysis*

Macroinvertebrate sampling survey was carrying out on 14 sites equally distributed in the Wadis Sahel (5 sites: B1-B5), Djedir (5 sites: D1-D5), and M'zi (4 sites: L1-L4) (Figure 1). Site selection was based on several criteria: distribution along the upstream-downstream longitudinal gradient, permanent water, diversity of river habitats and accessibility. Eighteen (18) field samplings were made between January and October 2012. Samples were collected at frequency of twice a season (spring, summer, autumn) in each river. Macroinvertebrates were collected in sediments and aquatic vegetation using a kick-net sampler (area of 0.05 m^2, 275-μm mesh size). Collected organisms were transferred to clean contents and preserved with 10% formaldehyde solution. In the laboratory, all macroinvertebrates were rinsed and sorted on a series of metallic sieves of decreasing mesh sizes (500-, 275- and 75-μm) and stored in 70% ethanol solution. Taxonomic analysis was performed in square-patterned Petri disks under a stereomicroscope model discovery V8, Zeiss. All macroinvertebrates in each size fraction were counted and identified at the family level using taxonomic keys [37-38-39-40- 41].

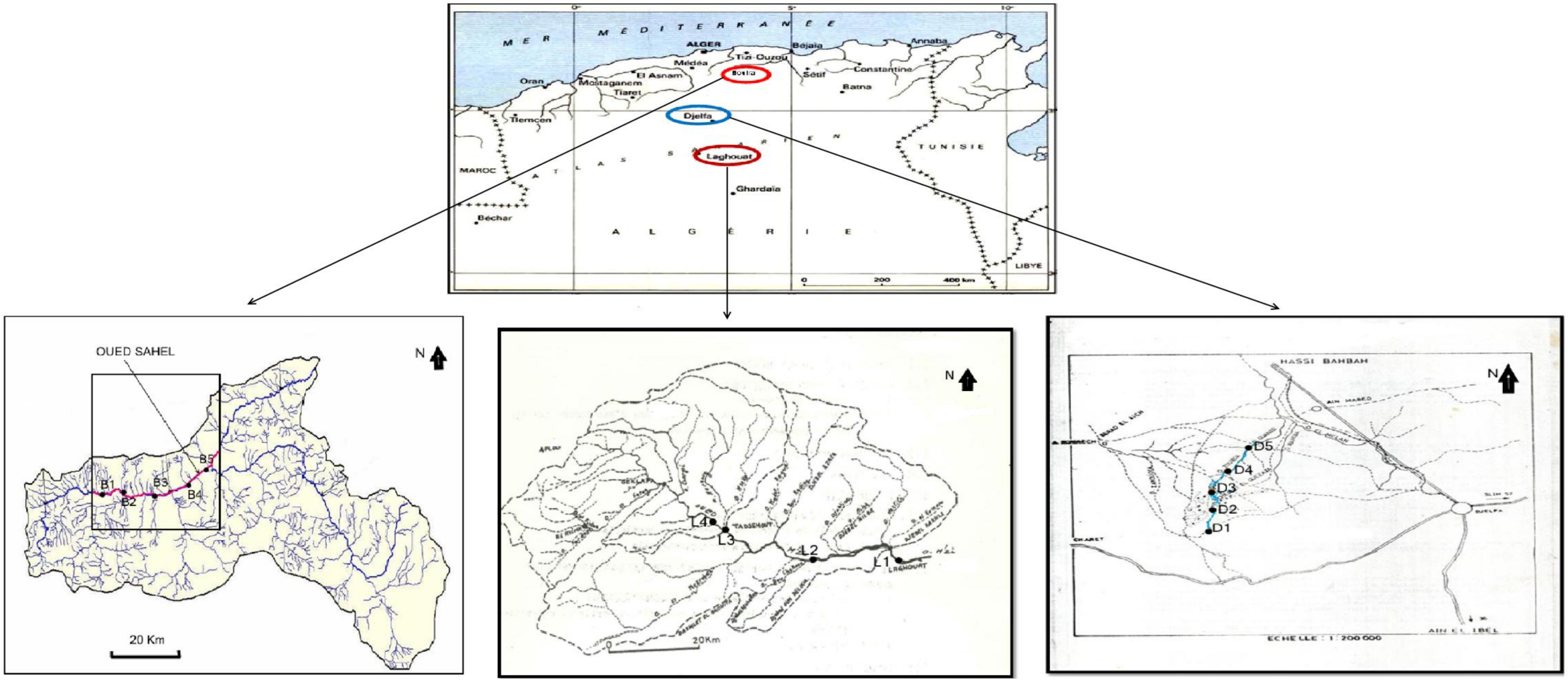


Figure 1 : Map of Algeria and location of the hydrographic basins and sampling stations in the studied rivers.

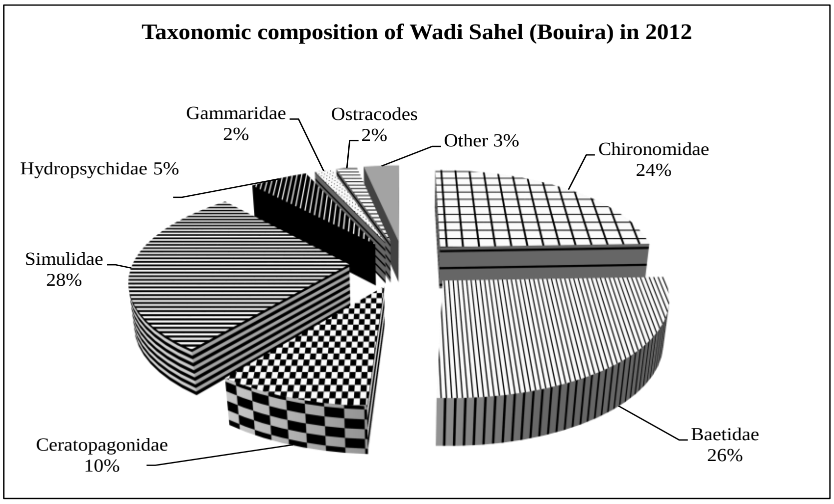
2.3. *Data analysis*
We calculated multiple metrics based on family taxa richness and abundances to assess spatial variation in macroinvertebrate diversity and community composition among rivers, using taxa composition at each sampling site as replicates. For the present study, biodiversity was expressed in terms of taxa richness, which has become the common currency of biodiversity assessment [42]. We made a descriptive analysis of the macroinvertebrate taxa occurrence (presence/absence) and abundance (mean number of individuals of each family per unit sampling effort) within each river. We also calculated biotic indices based on various metrics related to ecological integrity of rivers . [43]. Some metrics as total taxa richness and number of taxa and relative abundance of sensitive groups (Ephemeroptera, Trichoptera and Odonata) decreased with habitat disturbances while the abundance of tolerant groups (Diptera Chironomidae, Oligochaeta, and Hirudinea) increased with habitat disturbances. These biotic indices have already been used as suitable indicators of water quality and ecological integrity of rivers and lakes in Europe [44-45-46-47-37-4].
To compare macroinvertebrate assemblages between rivers, we performed a K-means clustering analysis [48] on the taxa abundance data tables (14 sites x 51 family taxa) (Table 2a,b,c). Prior to analysis, taxa data were transformed using the Hellinger method [49]. This cluster analysis consisted of dividing the dataset into k groups using the Calinski-Harabasz criterion [50] which produced the most parsimonious community dendogram in relation to river types. K-means clustering was run for 10 000 iterations. We compared macroinvertebrate dominance patterns and community composition among cluster groups.
As principal component analysis (PCA) is currently performed to determine spatial patterns of similarity in ecological data among regions or habitats [51], we performed a PCA on the taxa abundance matrix to show affinities of dominant taxa with river habitats. As Euclidian distances are not efficient to compare taxa assemblages among sites, we applied the Hellinger distances as recommended [49]. All statistical analyses were performed in R version 2.1.2.2 [52].

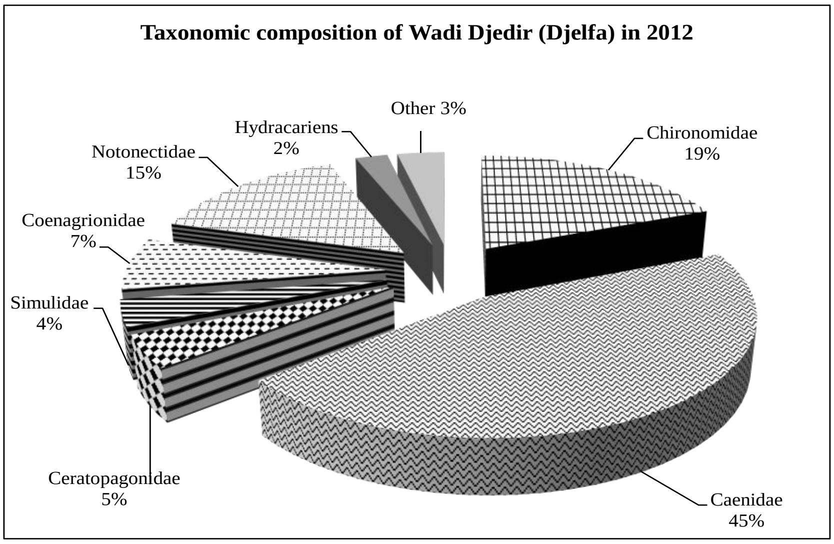
3. Results and discussion

3.1. Taxa richness and dominance patterns
A total of 51 taxa, represented by 25700 individuals distributed in 13 major taxonomic groups, were collected in the three studied rivers (Table 2a,b,c). Macroinvertebrate taxa richness varied among rivers. Wadi Sahel had the highest richness with 40 family/order taxa; Wadi Djedir was intermediate with 30 family/order taxa and Wadi M'zi was the less diverse river with only 21 family/order taxa (Tables 2a,b,c and 3). Macroinvertebrate assemblages in all rivers were dominated by aquatic insects which accounted for 96% of the total community in the Wadi Sahel, 82% in Wadi Djedir, and 86% in Wadi M'zi.
Dominance patterns clearly contrasted among rivers (Figure 2, Table 2a,b,c). In Wadi Sahel, macroinvertebrates were dominated by three groups of Diptera (Simuliidae, Chironomidae, and Ceratopogonidae) representing respectively 28, 24 and 10% of the community. The Ephemeroptera Baetidae and the Trichoptera Hydropsychidae were also frequent in Wadi Sahel accounting for 26 and 5% of the community. In Wadi Djedir, most of the community is composed of Ephemeroptera Caenidae (45%) whereas Diptera dominant taxa (mainly Chironomidae, Ceratopogonidae and Simuliidae) were less frequent (4 to 19%). This river distinguished from the others by the relative dominance of the Heteroptera Notonectidae (15%), and the Odonata Coenagrionidae (7%). In Wadi M'zi, macroinvertebrates were in majority represented by Diptera groups (Chironomidae, Limoniidae) forming 80% of the total community, and the Oligochaeta Tubificidae (12%).

3.2. Biotic indices
Biotic indices based on the number and abundance of intolerant (with tolerance values < 4) and tolerant (with tolerance values > 6) taxa varied among rivers (Table 3). Wadi Sahel hosted the highest number and percentage of EPT (6 taxa representing 33%) and the highest numbers of POET (8). In this river, macroinvertebrate community was rich in intolerant taxa (9 taxa with tolerance values ≤ 4, representing 34%), as the Ephemeroptera Baetidae and the Trichoptera Hydropsychidae. The percentage of tolerant taxa (with tolerance values ≥ 6) was the lowest (64%) and the Oligochaeta Tubificidae was very rare. Finally, Wadi Sahel showed the lowest value (5.09) for the FSi tolerance Index and a ratio ETO/CO > 1. In Wadi Djedir, the numbers of EPT (1) and POET (4) taxa were lower than in Wadi Sahel. However the abundance of the unique taxa of Ephemeroptera (Caenidae) was very high, representing 45% of all macroinvertebrates. This results in the highest value (2.8) for the ETO/CO ratio. As the Caenidae are tolerant insect taxa (tolerance value > 6), the percentage of intolerant taxa was very low (<1) and this of tolerant taxa high (80%). Consequently, the FSi

tolerance index was the highest (6.51). Wadi M'zi showed the worst conditions based on its macroinvertebrate community. The number and abundance of EPT taxa was low (2 taxa, representing only 1.3 %). The percentage of intolerant taxa (mainly the Diptera Chironomidae and Limoniidae, and the Oligochaeta Tubificidae) was the highest (98%) as reflected by the low value of the ETO/CO ratio (0.02). In Wadi M'zi, the tolerance index was also high (6.34).





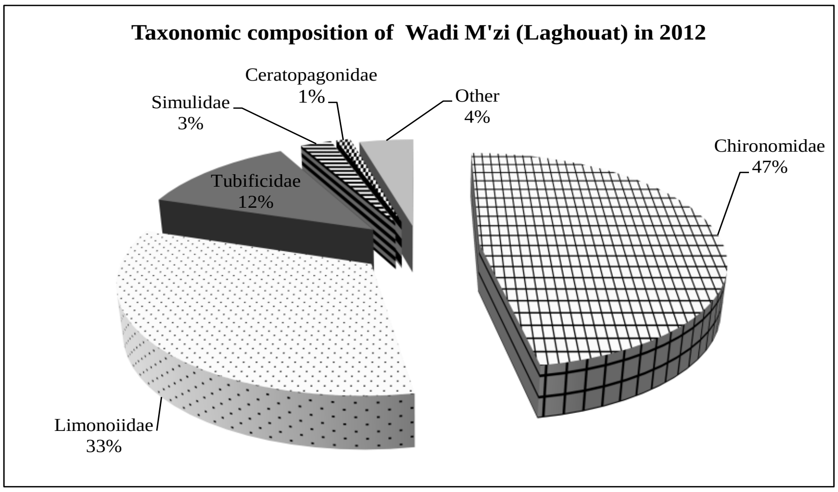


Figure 2 : Taxonomic composition of macroinvertebrate communities in three rivers of the north Algeria.

Table 2a : Taxa composition of macroinvertebrate communities at each station in the studied rivers. T: Taxa abundance; %: Taxa percentage. Numbers in parentheses : Tolerance value of each taxa [44].

Taxa	Family (tolerance value)	Laghouat (Wadi M'zi)						Djelfa (Wadi Djedir)							Bouira (Wadi Sahel)						
		L1	L2	L3	L4	T	%	D1	D2	D3	D4	D5	T	%	B1	B2	B3	B4	B5	T	%
	Baetidae (3)	41	36	7	0	84	0.88								694	871	24	285	432	2306	26.36
Ephemeroptera	Caenidae (7)	3 0	14	0	0	44	0.46	1061	929	438	490	444	3362	45.21	0	14	5	0	24	43	0.49
	Heptageniidae (4)														0	0	0	20	0	20	0.23
	Chironomidae (6)	2329	1093	971	98	4491	47.20	393	317	180	309	207	1406	18.91	478	391	200	426	636	2131	24.36
	Limoniidae (6)	1731	297	1060	37	3125	32.84	4	0	0	0	0	4	0.05	0	0	0	0	6	6	0.07
	Tabanidae (5)	0	30	52	0	82	0.86	9	0	2	1	0	12	0.16	2	0	1	0	6	9	0.10
	Ceratopogonidae (6)	45	29	23	0	97	1.02	118	107	32	28	53	338	4.54	214	344	0	237	44	839	9.59
	Simuliidae (6)	101	19	111	0	231	2.43	86	63	34	52	38	273	3.67	949	363	50	346	745	2453	28.04
	Dixidae (5)	0	13	0	0	13	0.14								0	1	0	0	0	1	0.01
Diptera	Thaumaleidae (5)	0	0	3	0	3	0.03								1	0	0	0	0	1	0.01
	Tipulidae (3)	0	0	0	0			0	0	0	0	0			3	1	0	0	0	4	0.05
	Empididae (5)	0	0	0	0			0	0	0	0	0			0	0	0	0	1	1	0.01
	Ephydridae (5)	0	0	0	0			0	0	0	0	0			5	0	11	0	0	16	0.18
	Ptychopteridae (6)	0	0	0	0			0	0	0	0	0			0	0	1	0	0	1	0.01
	Chaoboridae (8)	0	0	0	0			0	0	0	0	0			3	0	0	0	8	11	0.13
	Hydrophilidae (5)	2	0	0	0	2	0.02	0	14	0	0	3	17	0.23	0	0	2	1	0	3	0.03
	Dryopidae (5)							0	2	1	0	0	3	0.04	2	0	0	0	2	4	0.05
Coleoptera	Dytiscidae (5)	26	8	0	0	34	0.36	18	19	0	11	0	48	0.65	5	1	18	1	1	26	0.30
	Elmidae (4)							0	0	0	2	0	2	0.03	1	0	4	0	0	5	0.06
	Heteroceridae (5)	6	1	4	0	11	0.12	0	0	0	0	15	15	0.20							
	Gyrinidae (4)	3	0	0	0	3	0.03	0	4	5	1	0	10	0.13	0	0	0	2	0	2	0.02

Table 2b : Taxa composition of macroinvertebrate communities at each station in the studied rivers. T: Taxa abundance; %: Taxa percentage. Numbers in parentheses : Tolerance value of each taxa [44] (following table 2a).

Taxa	Family (tolerance value)	Laghouat (Wadi M'zi)						Djelfa (Wadi Djedir)							Bouira (Wadi Sahel)						
		L1	L2	L3	L4	**T**	**%**	D1	D2	D3	D4	D5	T	**%**	B1	B2	B3	B4	B5	**T**	**%**
								0	0	0	8	0	8	0.11							
	Helophoridae (5)							4	0	0	0	2	6	0.08							
Coleoptera	Haliplidae (5)							0	0	0	1	0	1	0.01	0	0	4	0	0	4	0.05
	Hydraenidae (5)							0	4	0	0	0	4	0.05	0	0	7	0	0	7	0.08
	Chrysomelidae (5)							4	0	2	15	12	33	0.44							
	Hydropsychidae (4)														111	300	4	0	80	495	5.66
Trichoptera	Hydroptilidae (4)														5	0	0	1	8	14	0.16
	Polycentropodidae (4)														1	0	0	0	0	1	0.01
Oligochaeta	Tubificidae (9)	120	835	212	0	1167	12.26								9	0	2	0	0	11	0.13
Hirudinea	Hirudinae (8)	5	0	3	0	8	0.08	1	1	0	2	7	11	0.15	12	0	0	0	0	12	0.14
	Glossiphoniidae (8)							1	0	0	0	0	1	0.01	2	0	0	0	1	3	0.03
Nematoda	Nematoda (5)	5	2	3	0	10	0.10														0.00
	Coenagrionidae (9)	0	0	0	0			159	217	53	24	85	538	7.23							0.00
	Libellulidae (9)	0	0	0	0			1	4	18	3	7	33	0.44							0.00
Odonata	Platycnemididae (7)	0	0	0	0		0	0	0	0	0	1	1	0.01							0.00
	Gomphidae (1)														0	0	1	0	2	3	0.03
	Lestidae (9)														0	0	0	0	1	1	0.01
	Ostracoda (8)	12	48	12	0	72	0.76	0	1	2	1	0	4	0.05	11	10	0	138	0	159	1.81
	Cyclopidae (8)														0	0	7	0	0	7	0.08
Crustacea	Gammaridae (4)														125	0	0	8	0	133	1.52
	Cladocera (8)														0	0	1	0	0	1	0.01

Table 2c : Taxa composition of macroinvertebrate communities at each station in the studied rivers. T: Taxa abundance; %: Taxa percentage. Numbers in parentheses: Tolerance value of each taxa [44] (following table 2b).

Taxa	**Family (tolerance value)**	**Laghouat (Wadi M'zi)**						**Djelfa (Wadi Djedir)**							**Bouira (Wadi Sahel)**						
		L1	L2	L3	L4	**T**	**%**	D1	D2	D3	D4	D5	T	**%**	B1	B2	B3	B4	B5	**T**	**%**
	Planorbidae (6)	10	0	0	0	10	0.10	4	1	2	1	0	8	0.11	2	0	0	0	0	2	0.02
Gastropoda	Physidae (8)							0	0	3	2	6	11	0.15	0	0	0	1	0	1	0.01
	Lymnaeidae (6)														0	0	0	0	1	1	0.01
	Corixidae (5)	1	17	0	0	18	0.19								0	0	10	1	0	11	0.13
	Notonectidae (5)	6	0	1	0	7	0.07	309	260	183	100	238	1090	14.66	0	0	0	0	1	1	0.01
Heteroptera	Nepidae (5)	0	0	0	0			0	13	0	1	0	14	0.19							0.00
	Hydrometridae (5)	0	0	0	0			0	0	0	1	0	1	0.01							0.00
Hydracarina	Hydracarina (6)						0	57	0	41	21	55	174	2.34	0	1	2	0	0	3	0.03
Araneae	Araneidae	1	2	0	0	3	0.03	2	1	0	2	3	8	0.11							0.00
Total						9515	100						7436	100						8749	100

Table 3 : Values of biotic indices based on taxa richness and community structure of macroinvertebrates of each river.

Biotic Indices	Wadi Sahel	Wadi Djedir	Wadi M'zi
NTAXTOT	40	30	21
NTAXEPT	6	1	2
NTAXPOET	8	4	2
PINSE	96	82	86
PEPT	33	45	1.3
POLICHO	< 1	0	12
ETO/CO	1.34	2.80	0,02
NTAXINTO	9	2	1
PTAXINTO	34	< 1	< 1
PTAXTOL	64	80	98
FSi	5.09	6.51	6.34

NTAXTOT : total number of taxa ; NTAXEPT : Total number of taxa of Ephemeroptera, Plecoptera and Trichoptera; NTAXPOET: Total number of taxa of Plecoptera, Odonata, Ephemeroptera and Trichoptera; PINSE: percentage of insects; PEPT: percentage of Ephemeroptera, Plecoptera and Trichoptera; POLICHO: percentage of Oligochaeta; ETO/CO : ratio of numbers (density) of Ephemeroptera, Trichoptera and Odonata on numbers of Chironomidae and Oligochaeta; FSi: Tolerance Index of Hilsenhoff (1987); NTAXINTO: number of intolerant taxa tolerance ≤ 4); PTAXINTO: percentage of intolerant taxa (tolerance ≤ 4); PTAXTOL: percentage of tolerant taxa (tolerance ≥ 6).

3.3. Macroinvertebrate community structure

Cluster analysis clearly illustrated the strong differences in community composition among rivers (Figure 3) and enabled us to distinguish two main clusters. Group 1 included all sites of Wadi Djedir (D1-D5), which formed a distinct community. Group 2 is composed by two subgroups corresponding to Wadi M'zi (Group 2A: L1-L4), and to Wadi Sahel (Group 2B: B1-B5). Each group is composed by all sites of the same river, indicating low spatial variation in macroinvertebrate composition along the longitudinal gradient of each river, and strong regional variation among rivers. However, we observed more local variation in macroinvertebrate communities among sites in Wadis M'zi and Sahel than in Wadi Djedir.

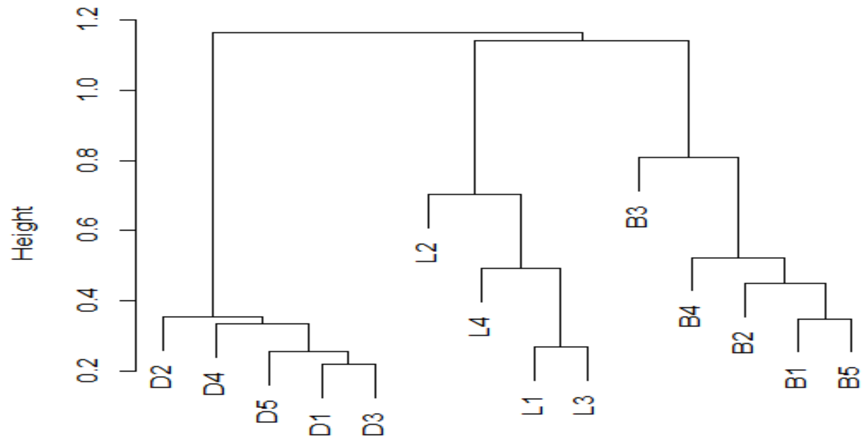


Figure. 3. Cluster analysis of macroinvertebrate abundance taxa matrix.

PCA analysis (Figure 4) illustrated more clearly the regional differences in macroinvertebrate communities among rivers and the distinct patterns of dominance as showed in figures 2 and 3. Axis 1 accounted for 48.86% of the total variance and opposed Wadi Djedir (right side) to Wadis Sahel and M'zi. Axis 2 accounted for 31.54% of the total variance and opposed Wadi Sahel (Bottom side) to Wadi M'zi (top side). The most tolerant groups, including the Diptera Chironomidae and Limoniidae with the Oligochaeta Tubificidae, reflected the disturbed conditions in sites (L1-L4) of the Wadi M'zi. Although the Chironomidae were frequently found in each river, the family Limoniidae was restricted to Wadi M'zi. The Ephemeroptera, Trichoptera and Odonata insects were characteristic of the other two rivers. However, macroinvertebrate assemblages differed between Wadi Sahel and Wadi Djedir. Tolerant taxa as the Ephemeroptera Caenidae and the Odonata Coenagrionidae, and the Hydracarina were characteristic of Wadi Djedir and associated to a more sensitive group, the Heteroptera Notonectidae. Sensitive taxa of Ephemeroptera (Baetidae) and Trichoptera (Hydropsychidae) as well as the Diptera Simuliidae and Ceratopogonidae were characteristic of Wadi Sahel.

4. Discussion

4.1. Regional changes in macroinvertebrate taxa richness

Overall, macroinvertebrate taxa richness observed (21-40 taxa) in the three studied rivers located in semi-arid and arid climatic regions with relatively low annual precipitation (178-478 mm) was lower than this reported in other rivers of the Kabylie [32]: 88 taxa, and Soumman [33]: 55 taxa regions in more humid climate with higher annual precipitation (respectively 876 and 757 mm). At the scale of the studied area, there was also a decreasing trend of taxa richness in rivers located in higher altitude (Djedir and M'zi) and in a more arid climate (lower precipitation). This altitudinal decreasing gradient in macroinvertebrate diversity was also observed in the other rivers of Algeria, as Wadi Sébaou [26]. Macroinvertebrate taxa richness was the highest (40 taxa) in Wadi Sahel, a river located at low altitude in northern mountainous piedmont region covered by Mediterranean xeric forest. This river benefits from a temperate and semi–arid climate with annual precipitation reaching 478 mm. It also offers more habitat heterogeneity because its bed is composed of coarse sediments (rocks, gravel, pebble) offering refuge from predatory fish. Taxa richness was intermediate in Wadi Djedir (30 taxa) located in a less humid region with annual precipitation of 335 mm, and the lowest in Wadi M'zi (21 taxa) located in an arid region with only 178 mm of precipitation per year. These two rivers located at higher altitude in the high plateaus of the Tell and Sahara Atlas also offered less heterogeneous habitats due to the small catchment and size of Wadi Djedir, and the more polluted conditions and fine sediment substrate in Wadi M'zi.

4.2. Community structure and dominance patterns

Our results support the hypothesis that spatial variation in macroinvertebrate community structure arose from regional differences among rivers, whereas within-river differences were low. The PCA analysis clearly distinguished 3 macroinvertebrate assemblages, each of them characteristic of a specific river. Wadi Sahel presented the most diverse communities of macroinvertebrates in relation to its higher environmental heterogeneity; Wadi Djedir also showed good conditions favoring sensitive taxa as Ephemeroptera and Odonata; Wadi M'zi presented the worst conditions hosting very tolerant taxa as Diptera and Oligochaeta. Our study indicates that the upstream-downstream species replacement currently observed in temperate and alpine rivers in Europe [53] and North America [54-55], characteristic of the river continuum model, did not occurred in the studied rivers of Algeria.

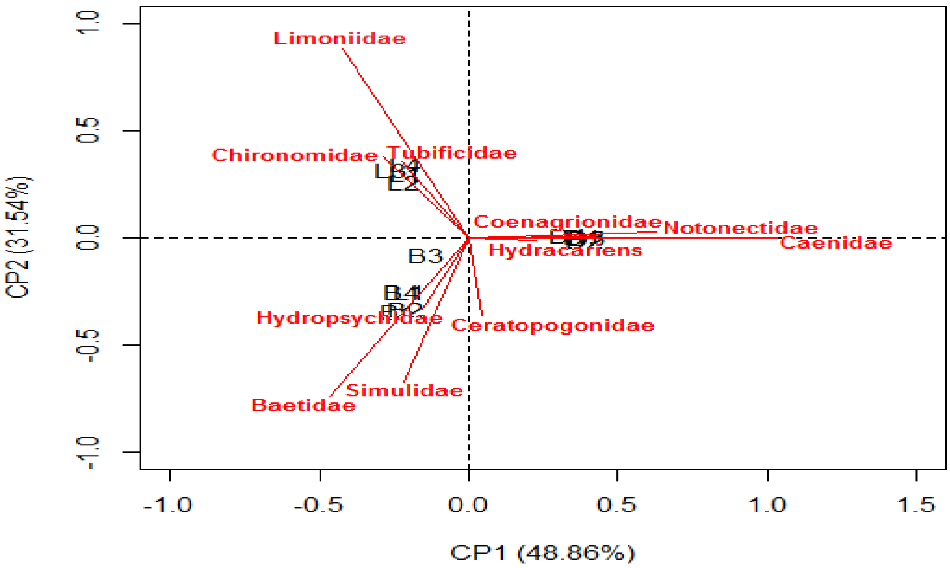


Figure 4 : Principal component analysis based on taxa abundances in each site of each river.

Macroinvertebrates in Wadi Sahel were the most diverse and composed of thermophilic taxa found in the potamic sections of rivers of France [56] and northern regions in Algeria [26]. The Ephemeroptera (Baetidae) and the Diptera (Chironomidae and Ceratopogonidae) are eurytopic and tolerant taxa currently found in high abundances in lowland and piedmont rivers of northern regions of Algeria. Respiring with external gills, Ephemeroptera are especially sensitive to anoxia and organic pollution. The Diptera Simuliidae are the most abundant in habitats exposed to current and rich in organic matter, which sustain the development of insect aquatic larvae [32-33]. Trichoptera (mainly Hydropsychidae) occurred only in Wadi Sahel. They are thermophilic taxa only found in warm waters in Mediterranean rivers located at low altitude [20]. They require coarse and heterogeneous substrate to build their cases and find refuge from predators and current. Epi- and endobenthic fauna such as the Amphipoda Gammaridae and the Ostracoda also were encountered in low abundance in the Wadi Sahel, indicating habitats offering detritus resources to these crustaceans. Worms as the Oligochaeta, an indicator of organic or polluted habitats, were not found in Wadi Sahel.
Wadi Djedir, a small river (width: 25 m) located at high altitude (1000 m) supported abundant populations of the Ephemeroptera Caenidae (45%) and Odonata Coenagrionidae (7%), two groups of insect larvae recognized as sensitive to pollution [57]. The Diptera (Chironomidae, Ceratopogonidae, and Simuliidae) were less abundant in this river than in the two others. Caenidae are frequent and abundant in North-African rivers. They are thermophilic species with large ecological preferences adapted to low current conditions [21- 24-32-58-28] reported that *Caenis* genera were mainly found in lowland and piedmont rivers, but more rarely in rivers at high altitude except in warm waters and fine sediment habitats. In Lebanon, abundant and diverse populations of Odonata were found in rivers with a large cover of macrophytes, moderate current and coarse to fine sediments [59], as observed in Wadi Djedir. The importance of the Notonectidae (15%) in Wadi Djedir is also an indicator of habitats of good quality The Heteroptera are good swimmers found only in stagnant waters of river shores [60-25]; they are moderately tolerant to disturbance and pollution.
Wadi M'zi presented the worst conditions. Macroinvertebrate communities were mostly composed of Diptera (Chironomidae, Limoniidae) and Oligochaeta (Tubificidae). These taxa are endobenthic and tolerant to organic pollution, low oxygen conditions and sediment disturbance [61-62-63]. Some taxa produce hemoglobin for sustaining anoxia in sediments. In temperate lakes, they are associated to lakeshore disturbances due to

residential development, eutrophication by nutrient input and fine and organic sediments [64]. The abundance of the Oligochaeta Tubificidae in Wadi M'zi can be associated to anthropogenic disturbance due to the proximity of the municipality of Laghouat, and pasture and agriculture activities in the catchment.
Macroinvertebrate communities encountered in our studied rivers were devoted of Plecoptera, as observed in other Mediterranean rivers in North Africa [20-35-32]. Plecoptera insects are cold stenotherm species very sensitive to disturbance. They are found in pristine and cold rivers located at high altitude, in habitats characterized by a steep longitudinal gradient, high current, coarse sediment, and well oxygenated waters. They are generally absent in Mediterranean rivers due to too high temperature during summer [27] as observed in our rivers (max air temperature 34-44°C).

4.3. Macroinvertebrate-environment relationships
Macroinvertebrate taxa richness and community structure are known to be strongly influenced by spatial heterogeneity in river habitats, and environmental features dynamics [65]. The nature of sediment substrate, the current and water level fluctuations are considered as the most important factors driving spatial variation in river macroinvertebrates in Europe [66-67-68]. Our study gives strong evidence that spatial variations in macroinvertebrate taxa richness and community composition in Algerian rivers are related to regional changes in climate and river habitats. Decline in annual precipitation with altitudinal gradient is related to decreasing taxa richness and changes in community structure. Rain and snow precipitations are the major source of water renewal in aquatic ecosystems, and determine the quantity of water input in river basins [69-70]. Several studies have shown that macroinvertebrate taxa richness in rivers is influenced by the amount and frequency of precipitations which control water discharge and current [75-29]. In Mediterranean rivers, dry drought during summer causes a strong limitation to colonization and development of abundant and diverse macroinvertebrate communities. Higher evaporation and drought in the Wadi M'zi subjected to arid climate can explain its low diversity and the dominance of tolerant endobenthic taxa (Diptera, Oligochaeta) which can survive in dry sediments and colonise new flooded habitats. Similarly, permanent ponds support higher diverse macroinvertebrate communities than temporary ponds [71].
The nature of sediment substrate and the speed of current also seem to influence macroinvertebrate community structure in Algerian rivers. Coarse sediments and moderate current favor more diverse and abundant macroinvertebrate assemblages as observed in Wadi Sahel. In contrary, fine and organic sediments and low current as in Wadi M'zi favor the development of less diverse community dominated by endobenthic and tolerant taxa as the Diptera Chironomidae and the Oligochaeta Tubificidae. A similar tolerant community was found in fine and organic sediments in temperate lakes subjected to accelerated eutrophication due to residential development in shores and catchments [64].
Other environmental variables such as water level and temperature as well as riparian vegetation can also explain spatial patterns of macroinvertebrate communities in rivers [32]. For instance, the environmental characteristics of Wadi M'zi, such as a very low water level (< 0.5 m), a very high water temperature (> 40°C) during summer, and the absence of riparian vegetation in the river shores can strongly limit its support capacity for macroinvertebrates. In contrast, Wadis Sahel and Djedir offered a better support capacity due to higher water depth (> 1m), lower maxima of temperature during summer, and the presence of coniferous or mixed forest and the river shores. In these rivers, macroinvertebrate communities were characterized by abundant populations of Ephemeroptera insect larvae (Baetidae, Caenidae). Trichoptera were only found in Wadi Sahel. The less diverse community of macroinvertebrates in Wadi Djedir compared to Wadi Sahel might be due to the reduced in river bed size in Wadi Djedir
Macroinvertebrate community composition and taxa richness can also be influenced by biotic factors as competition and predation [72] which were not directly evaluated in our study. Finally, stochastic changes in environmental factors as water quality (conductivity, nutrient, dissolved oxygen) over space and time, and interactions among abiotic and biotic factors are also sources of variations in macroinvertebrate communities of river ecosystems.

Conclusion

This study showed that the macroinvertebrates distribution in the three study areas is different, where every river is markedly different from the others. This study allowed us to distinguish three groups, the first belongs to the stations of the Oued Sahel, which includes taxa that have a wide ecological valence and are thermophilic; the Baetidae the Hydropsychidae and Simuliidae. The second group features the stations of the Wadi M'zi consists of Diptera Chironomidae and Limoniidae and oligochaetes Tubificidae. The third group characterizes the stations of the wadi where Djedir Caenidae mayflies, dragonflies and heteroptera Notonectidae are well represented. Within the limits of the study, our results support the hypothesis of regional control of macroinvertebrates communities in Algerian rivers and does not indicate important longitudinal gradient in macroinvertebrate assemblages. Each river supported a specific community distinct from each other by taxa richness and composition. Our study showed lower taxa richness and ecological integrity in rivers located at higher altitude and with semi-arid to arid climate (low annual precipitation). Wadis Sahel and Djedir in temperate and semi-arid climate offer better habitats for benthic macroinvertebrates than Wadi M'zi in arid climate.

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