Hydrobiological Research 4(1), 1-13 (2026) https://www.doi.org/10.5281/zenodo.18380739

Research Article

Ecological health status of some watercourses in the Mfoundi Watershed, Yaoundé (Central Cameroon): Structure of the benthic macroinvertebrate community and water quality

Nathaniel Larry Lactio[a]*, Samuel Foto Menbohan[a], Désire François Edoa Owona[a], Jean Dzavi[a, b], Bertrand Gabriel Zambo[a], Marie Anita Zemo Temgoua[a], Ghislain Ulric Tchouta[a]

[a] *University of Yaoundé I, Faculty of science, Department of Animal Biology and Physiology, Hydrobiology and Environment Laboratory, P.O. BOX 812, Yaoundé Cameroon*
[b] *Institute of Geological and Mining Research, Research Centre for Water and Climate Change, P.O. BOX 4110, Yaoundé Cameroon*

Abstract: In Cameroon, as in many developing countries, urban aquatic environments are subject to increasing degradation of their quality. This phenomenon results from a multitude of extrinsic factors, stemming from rapid population growth coupled with anarchic urban sprawl. In this context, watercourses serve as final receptacles for domestic and industrial waste, as well as latrine drainage channels, significantly contributing to water pollution. The Mfoundi basin and its tributaries perfectly illustrate this situation, currently acting as dumping grounds and ultimate receptacles for various wastes. These discharges directly affect water quality and the biodiversity of these ecosystems. The present study aims to assess the impact of anthropogenic pressures on the biodiversity of benthic macroinvertebrates in three rivers of the Mfoundi basin (Odza, Akeu, and Olézoa), as well as in the upstream part of the Mfoundi River, in order to determine their current ecological status. To achieve this, hydro-morphometric parameters were measured using standardized methods, and benthic macroinvertebrates were collected following a multi-habitat approach. Hydro-morphometric analyses revealed that the structure of the banks of the different watercourses is, in places, marked by a loss of natural sinuosity in favour of channel reconfiguration. This phenomenon affects the natural transport of solid and liquid flows, as well as riparian vegetation, which has been replaced by crops and constructions, thereby increasing the vulnerability of the watercourses. On the biological level, a total of 3,467 benthic macroinvertebrate specimens were recorded, distributed across three phyla, twelve orders, and more than thirty families. The community is dominated by insects and characterised by low diversity, with a predominance of pollution-tolerant organisms such as Chironomidae, Belostomatidae, and Anthomyiidae, which are saprobionts and saprophiles. A canonical correspondence analysis indicated that the main groups of benthic macroinvertebrates identified were associated with the poor hydro-morphometric conditions observed. The Shannon-Weaver diversity and Piélou's evenness indices confirmed the low diversity of organisms within the studied aquatic ecosystems, as well as their poor evenness. This situation is primarily explained by the dominance of saprobiont and saprophile groups. Finally, the weakening, and in some cases complete destruction, of natural riparian vegetation observed along the watercourses of Yaoundé, combined with their role as dumping grounds, constitutes a key factor in the degradation of water quality and the loss of ecological stability. Benthic macroinvertebrates, an essential link in water quality monitoring due to their diversity and variable sensitivity to pollution, thus reflect the extent of disturbances experienced by these ecosystems.

Keywords: Benthic macroinvertebrates, Hydro-morphometric, Aquatic ecosystems, Water quality

Nathaniel Larry Lactio ORCID ID: 0009-0008-1940-7456
Samuel Foto Menbohan ORCID ID: 0000-0002-4113-0982
Désire François Edoa Owona ORCID ID: 0009-0000-5375-8745
Jean Dzavi ORCID ID: 0000-0001-8532-2516
Bertrand Gabriel Zambo ORCID ID: 0009-0000-8821-9637
Marie Anita Zemo Temgoua ORCID ID: 0000-0002-1311-3093
Ghislain Ulric Tchouta ORCID ID: 0009-0007-7156-2528

*Corresponding author: karimlarry86@gmail.com
(Received: 26.08.2025, Accepted: 19.11.2025, Online Publication: 28.01.2026)

1. INTRODUCTION

Freshwater aquatic environments are complex and dynamic, representing one of the most important reservoirs of biodiversity in the world (Astruch et al., 2023). Beyond their intrinsic value as refuges for biodiversity, they provide multiple ecosystem services and are involved in a multitude of human activities (AbdelHady et al., 2017; Ajeagah, 2017). However, these ecosystems are among the most degraded worldwide (Docile et al., 2016; Allan et al., 2021; Arenas-Sánchez et al., 2021).

Despite their very low representativeness (less than 1% globally) and uneven distribution, available freshwater faces numerous challenges, ranging from rapid population growth coupled with anthropogenic activities to the challenges of climate change, which threaten this resource (UNEP, 2024). Yet, it is involved in almost all human activities, making it a resource of socio-economic interest and of vital importance to preserve (Ajeagah, 2017; Iyiola et al., 2019). This preservation requires continuous knowledge of the ecological health status of ecosystems.
The ecological status of a watercourse refers to the quality of its structure and functioning (WFD, 2019). Thus, a good ecological status is crucial for maintaining aquatic biodiversity and ensuring the proper functioning of ecosystems. Conversely, a poor status can lead to the disappearance of sensitive species, the appearance or multiplication of other species, and harm the water quality for human uses. Its assessment relies on several aspects, including the biological, physico-chemical, and hydro-morphometric aspects. Regarding the biological aspect, benthic macroinvertebrates stand out as excellent bioindicators of the ecological health status of aquatic ecosystems, due to their response to environmental disturbances favoured by their very low dispersal capacity (Camargo et al., 2004; Sinche et al., 2022; Ispir & Özcan 2023). Their great taxonomic diversity also allows them to offer a wide range of responses, enabling the detection of various forms of pollution and river degradation (Chessman, 1995). In aquatic ecosystems, they inhabit a variety of microhabitats, and their diversity increases in ecologically stable areas that provide the necessary resources for their development (Andersen et al., 2004). Changes in the structure of benthic macroinvertebrates can occur following habitat alteration, environmental conditions, and seasonality (Taylor & Doran., 2001; Al-shami et al. 2011). Furthermore, anthropogenic activities coupled with urbanisation have negative effects on the diversity and structure of benthic macroinvertebrate communities. All these changes affect the physical and chemical characteristics of rivers, causing ecological disturbances, notably a decrease in biodiversity and degradation of ecosystem services (Stepenuck et al., 2002; Zemo et al., 2023; Zemo et al., 2024). It is therefore imperative to assess the ecological health status of these environments in order to act effectively against these ever-growing threats.
Yaoundé, the administrative and political centre of Cameroon, like many African cities, faces rapid population growth and impressive urban sprawl, increasing from 58,000 inhabitants in 1958 to 3,570,810 in 2023, with an average annual growth rate of 4.97% (Danielle & Miguel, 2025). At the same time, the urban area expanded from 84.67 km² to 468.28 km² between 1984 and 2024, particularly affecting the peripheral zones (Danielle & Miguel, 2025). However, these significant changes within the population pose dangers to the environment in general and aquatic environments in particular if appropriate measures are not taken to preserve them. This study was conducted to determine, using benthic macroinvertebrates, the ecological health status of four watercourses in the city of Yaoundé, namely the Olézoa, Akeu, Odza, and upper Mfoundi. Thus, after measuring the hydro-morphometric characteristics, benthic macroinvertebrates were identified and counted, and the influence of hydro-morphometric parameters on the benthic macroinvertebrate community was determined.

2. MATERIAL AND METHOD

2.1. Study site

This study was conducted in the Mfoundi division, Central Region of Cameroon, at the geographical coordinates 3°51'28'' North latitude and 11°31'05'' East longitude. The study area is characterised by a Guinean-type equatorial climate with four seasons, an average temperature of approximately 23 °C, ferrallitic soils, and intertropical vegetation dominated by humid forest (Abossolo et al., 2015). A total of four watercourses were selected: the upper part of the Mfoundi, Olézoa and Akeu located in the urban area, and Odza situated in the peri-urban area. The urban zone is characterised by a very high population density and intense economic activity, while the peri-urban zone features scattered dwellings and more prevalent agricultural activities. A total of 15 sampling stations were selected based on their accessibility and proximity to pollution sources: 3 on the Mfoundi (Mfo1, Mfo2, and Mfo3), 4 on the Olézoa (Ole1, Ole2, Ole2', and Ole3), 4 on the Akeu (Ake1, Ake1', Ake2, and Ake3), and 4 on the Odza (Odz1, Odz1', Odz2, and Odz3) (Figure 1). Table 1 presents the summary characteristics of the sampling stations. Sampling was carried out during a single campaign across all sites from 10 to 18 June 2024.

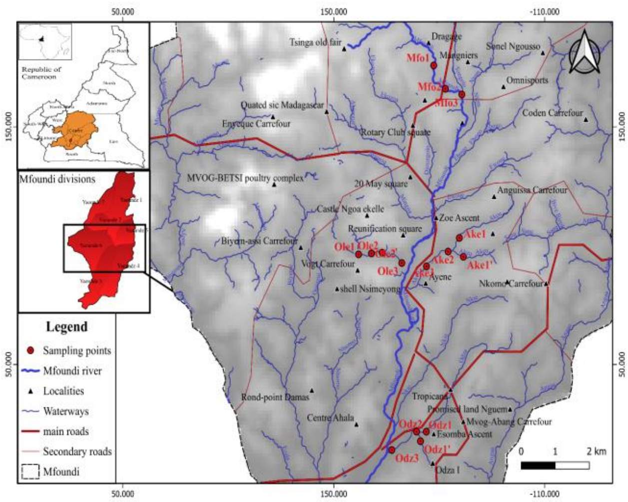


Figure 1. Map showing the location of the various river study stations.

Table 1. Summary of the characteristics of the various sampling stations

Watercourses	Stations and codes	Geographical coordinates	Altitude (m)	Substrate	Surrounding activities	Source of pollution
Mfoundi	Mfoundi 1 (Mfo1)	03°53'32.0"N, 11°31'17.4"E	735	Sandy and muddy	Nkol-Eton market, Housing	Miscellaneous waste, wastewater, faecal matter
	Mfoundi 2 (Mfo2)	03°53'12.3"N, 11°31'28.5"E	722	Sandy and muddy	Growing maize	Wastewater, plant debris
	Mfoundi 3 (Mfo3)	03°53'07.5"N, 11°31'44.2"E	727	Muddy	Laundries, Garages, Housing	Waste water and faecal matter
Olézoa	Olézoa 1 (Ole1)	03°50'52.4"N, 11°30'05.9"E	716	Muddy	Garage, accommodation	Faecal matter and plastic, wastewater and sewage
	Olézoa 2 (Ole2)	03°50'53.8"N, 11°30'16.5"E	712	Muddy	Waste accumulation, maize cultivation	Leachate
	Olézoa 2' (Ole2')	03°50'56.0"N, 11°30'20.1"E	706	Muddy	Market gardening	Fertilizers and pesticides
	Olézoa 3 (Ole3)	03°50'45.12"N, 11°30'46.99"E	692	Sandy and muddy	Laundry, fishing and maize growing	Wastewater, detergents
Akueu	Akueu 1 (Ake1)	03°51'06.3"N, 11°31'41.8"E	726	Muddy	Waste dump on the right bank, housing	Wastewater
	Akueu 1' (Ake1')	03°50'50.4"N, 11°31'45.6"E	711	Muddy	Fishing and market gardening	Run-off water
	Akueu 2 (Ake2)	03°50'54.8"N, 11°31'31.1"E	723	Muddy	Market gardening, reforestation area	Fertilizers, Run-off water
	Akueu 3 (Ake3)	03°50'42.3"N, 11°31'10.5"E	710	Sandy and muddy	Siantou complex	Wastewater
Odiza	Odiza 1 (Odiz1)	03°48'22.7"N, 11°31'10.3"E	719	Sandy and muddy	Garage, car wash, plastic bottle washing	Wastewater and drainage
	Odiza 1' (Odz1')	03°48'16.6"N, 11°31'04.8"E	684	Rocky and sandy	Fishpond, Housing	Wastewater
	Odiza 2 (Odz2)	03°48'22.7"N, 11°31'01.1"E	682	Sandy and muddy	Coal mining, swimming	Run-off water
	Odiza 3 (Odz3)	03°48'07.2"N, 11°30'37.5"E	696	Muddy	Garage, heavy machinery parking	Run-off water

2.2. Measuring environmental parameters

Geographical coordinates and altitude were recorded in the field using a Garmin 60 S GPS device. To better understand the influence of environmental factors governing the distribution of benthic organism taxa, certain hydro-morphometric parameters of the 15 sampling stations were measured (Current velocity, Depth, Minor bed, Major bed, and Riparian zone). These parameters were measured in situ using appropriate tools and equipment:

- **Current velocity (m/s):** It determines the availability of oxygen and the type of habitat available for aquatic organisms SIGNA (2015). Calculated using the formula **V = d/t (m/s)**, where **d** = distance (**m**) and **t** = time (**s**), its value is obtained by measuring the distance travelled by a polystyrene block over a given time.
- **Depth (m):** It creates refuge, feeding, and breeding zones for different species SDAGE (2015). Its measurement is obtained by using a graduated ruler to measure the water depth at the sampling site.
- **Minor bed (m):** This is the space occupied by the water current during low flow periods. In its normal state, it contains various habitats such as alluvial banks, pools, and riffles, which support biodiversity SDAGE (2015). Its measurement was taken using a tape measure.
- **Major bed (m):** This is the floodplain adjacent to the minor bed, essential for dissipating the energy of the watercourse during floods and maintaining lateral continuity SDAGE (2015). Its measurement was taken using a tape measure.
- **Riparian zone (m):** Located on both sides of a watercourse's banks, this zone stabilises the banks through its root system, regulates water temperature by shading, and reduces runoff of contaminants into the environment. Its measurement was taken using a tape measure from one bank to the other one, the distance from the bank to the point of cultivation, bare soil, or any other human activities SDAGE (2015).
- **Riparian Buffer Quality Index (IQBR):** The Riparian Buffer Quality Index (IQBR) is a tool developed to assess the ecological condition of riparian buffers, which is the vegetation zone located between an aquatic environment (such as a river or lake) and the terrestrial environment, generally over a minimum width of 10 to 15 metres. The IQBR allows for mapping and monitoring the condition of riparian buffers within a given territory, identifying areas in need of restoration, and guiding conservation or environmental management efforts (Saint-Jacques & Richard, 1998; Feld, 2013).
- **Interpretation of the Index:** The IQBR score generally ranges from 17 to 100 and is classified into five quality categories:
    - Very low : 17 to 39
    - Low : 40 to 59
    - Medium : 60 to 74
    - Good : 75 to 89
    - Excellent : 90 to 100

The higher the score, the better the ecological quality of the riparian buffer, meaning it effectively fulfils its role in protecting and supporting the aquatic ecosystem.

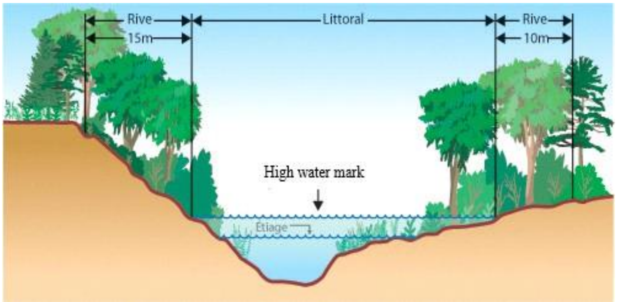


Figure 2. Riparian zone illustration (MDDEP).

2.3. Sampling of Benthic Macroinvertebrates

Benthic macroinvertebrates were collected using a square Surber net measuring 30 cm by 30 cm, equipped with a conical net with a 500 µm mesh size and 50 cm depth, following the multi-habitat approach Stark et al. (2001). At each station, approximately 20 net sweeps were performed over a length about 10 times the width of the waterbody, equivalent to an area of approximately 3 m², in different habitats characterised by substrate/velocity pairs. Organisms retained in the net were collected using fine forceps and fixed in a 10% formalin solution. The specimens were then rinsed with tap water to remove the formalin and preserved in 50 ml bottles with 70% ethanol. The organisms were subsequently placed in Petri dishes, grouped according to size and morphology, and identified at least to the family level under a Bresser HG878513 binocular loupe, using appropriate identification keys (Durand & Lévêque, 1981; Day & Moor, 2002; Tachet et al., 2010).

2.4. Data analysis

Kruskal-Wallis and Mann-Whitney tests, performed using R software (version 4.4.1), were used to determine whether results varied significantly between the different sampling stations. The Shannon-Weaver index was used to show variation in taxonomic diversity, and Pielou's evenness index was employed to assess the even distribution of individuals within communities. To evaluate the level of disturbance from extrinsic factors on diversity and ecological quality, the Riparian Buffer Quality Index (IQBR) was calculated according to the protocol described by Moisan & Pelletier (2008).

The Hilsenhoff Biotic Index (FBI) (1988), which considers tolerance ranges assigned to each organism, was used to determine pollution levels at the different sampling stations (Hilsenhoff, 1988; Bode, et al., 1991).

$$\mathrm{FBI} = \frac{\sum(x_i \cdot t_i)}{n}$$

Where: $\mathbf{x_i}$=number of individuals of the i[th] taxon, $\mathbf{t_i}$=tolerance value of the i[th] taxon, **n**=total number of individuals in the sample.

Table 2. Evaluation of water quality using the Family-level biotic index (FBI) Hilsenhoff (1988)

Family biotic index	Water quality	Degree of organic pollution
0.00-3.75	Excellent	Organic pollution unlikely
3.76-4.25	Very good	Possible slight organic pollution
4.26-5.00	Good	Some organic pollution is probable
5.01-5.75	Fair	Fairly substantial pollution is likely
5.76-6.50	Fairly poor	Substantial pollution likely
6.51-7.25	Poor	Very substantial pollution
7.26-10.00	Very poor	Severe organic pollution is likely

Spearman rank correlations were obtained using R software version 4.4.1, and a canonical correspondence analysis was performed with the same software to determine the associations between hydro-morphometric parameters and benthic macroinvertebrate communities.

3. RESULTS

3.1. Typological profile of catchment areas

The watersheds (Mfoundi, Olézoa, and Akeu) are characterised by a close proximity of dwellings, with activities generating intense and diverse aquatic disturbances, and a predominance of saprobic groups (Diptera, Oligochaetes, and Molluscs). Conversely, in the Odza watershed located on the outskirts of the metropolis, although urbanisation and anthropogenic activities are present and growing, the benthic macrofauna remains diverse, with a significant presence of pollution-sensitive organisms, such as Blaberidea (Biram, 2019).

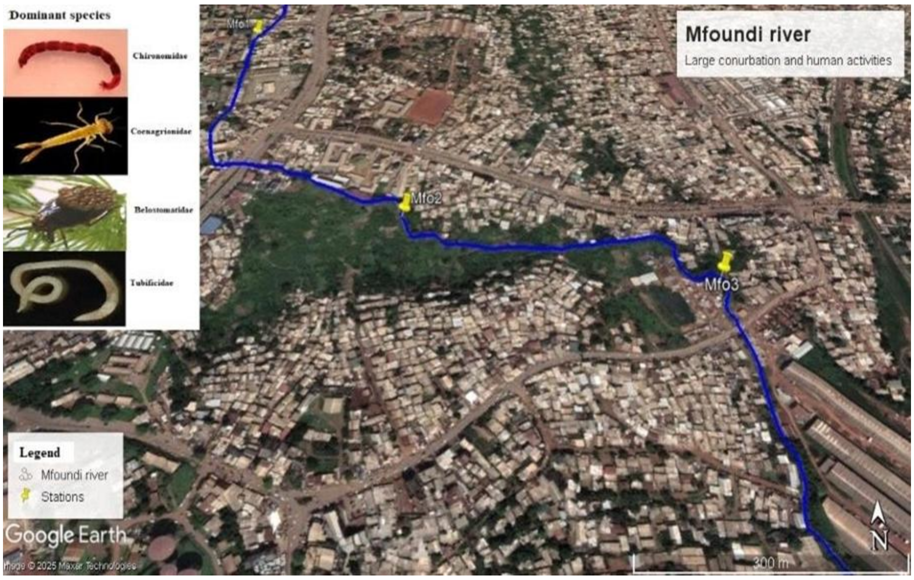


Figure 3. Mfoundi catchment area

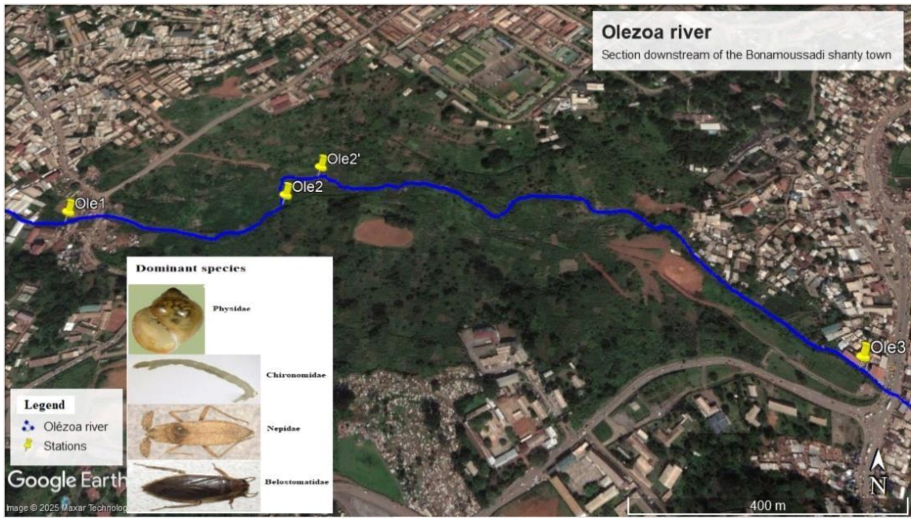


Figure 4. Olézoa catchment area

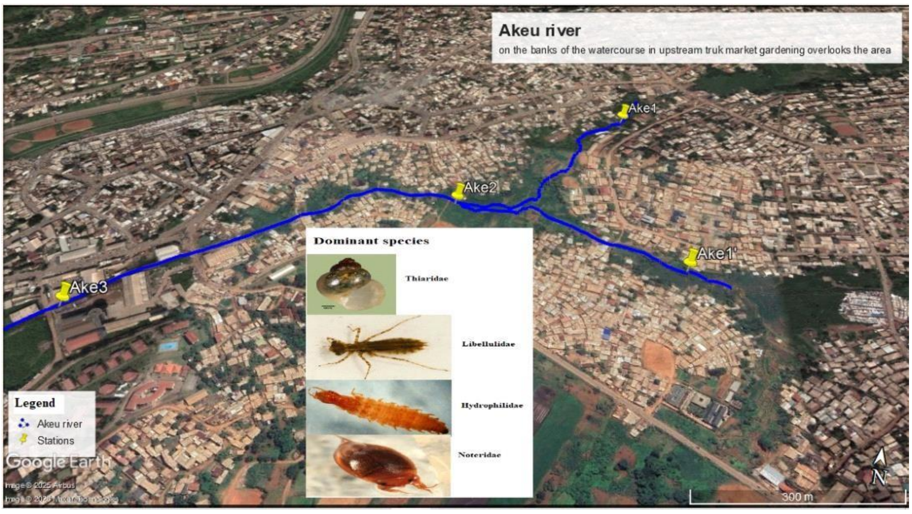


Figure 5. Akeu catchment area

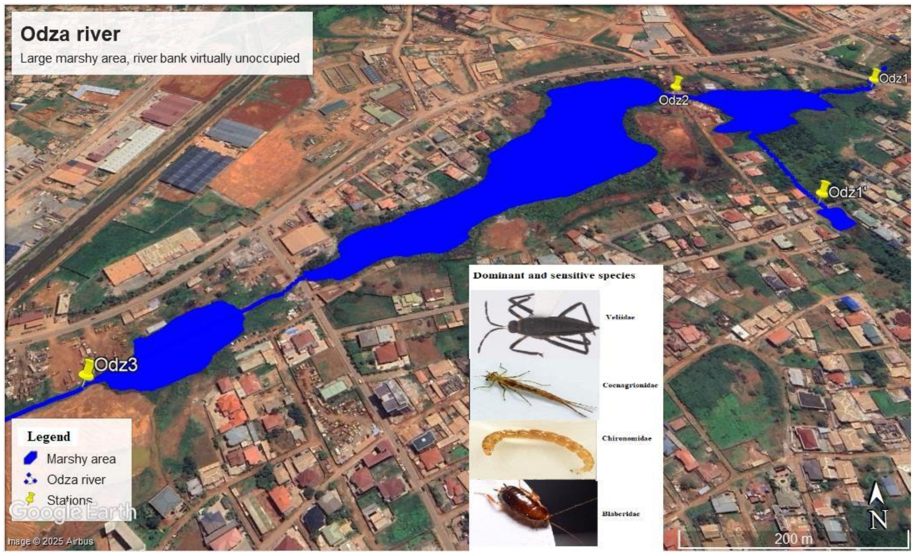


Figure 6. Odza catchment area

3.2. Hydro-morphometric variables

During the study period, the water current velocity varied in the Mfoundi from 0.3 m/s (Mfo1) to 0.6 m/s (Mfo2) with a mean of 0.47 ± 0.15 m/s; in the Olézoa from 0.01 m/s (Ole1) to 0.45 m/s (Ole2') with a mean of 0.22 ± 0.2 m/s; in the Akeu from 0.3 m/s (Ake1) to 0.74 m/s (Ake2) with a mean of 0.49 ± 0.22 m/s; and finally in the Odza from 0.13 m/s (Odz1') to 0.37 m/s (Odz3) with a mean of 0.26 ± 0.12 m/s (Figure 7A). Depth, meanwhile, varied in the Mfoundi from 0.4 m (Mfo1) to 0.6 m (Mfo3) with a mean of 0.47 ± 0.11 m; in the Olézoa from 0.02 m (Ole2) to 0.52 m (Ole3) with a mean of 0.33 ± 0.22 m; in the Akeu from 0.24 m (Ake1') to 1.1 m (Ake3) with a mean of 0.55 ± 0.39 m; and finally in the Odza from 0.25 m (Odz1') to 1.08 m (Odz2) with a mean of 0.62 ± 0.37 m (Figure 7B). Regarding the width of the water column, it varied in the Mfoundi from 4 m (Mfo1) to 4.71 m (Mfo3) with a mean of 4.44 ± 0.38 m; in the Olézoa from 1.95 m (Ole2) to 3.83 m (Ole3) with a mean of 2.9 ± 0.79 m; in the Akeu from 1.62 m (Ake1') to 3.52 m (Ake1) with a mean of 2.53 ± 0.81 m; and finally in the Odza from 1.53 m (Odz1') to 4.47 m (Odz3) with a mean of 2.88 ± 1.28 m (Figure 7C). The riparian zone fluctuated on both sides of the different banks. Regarding the right bank, it varied from 0 m (Ole1, Ole2, Ole2' and Odz3) to 5 m (Ake1'), and from 0 m (Ole1, Ole2, Ole2' and Odz1') to 15 m (Odz3) for the left bank (Figure 7D).

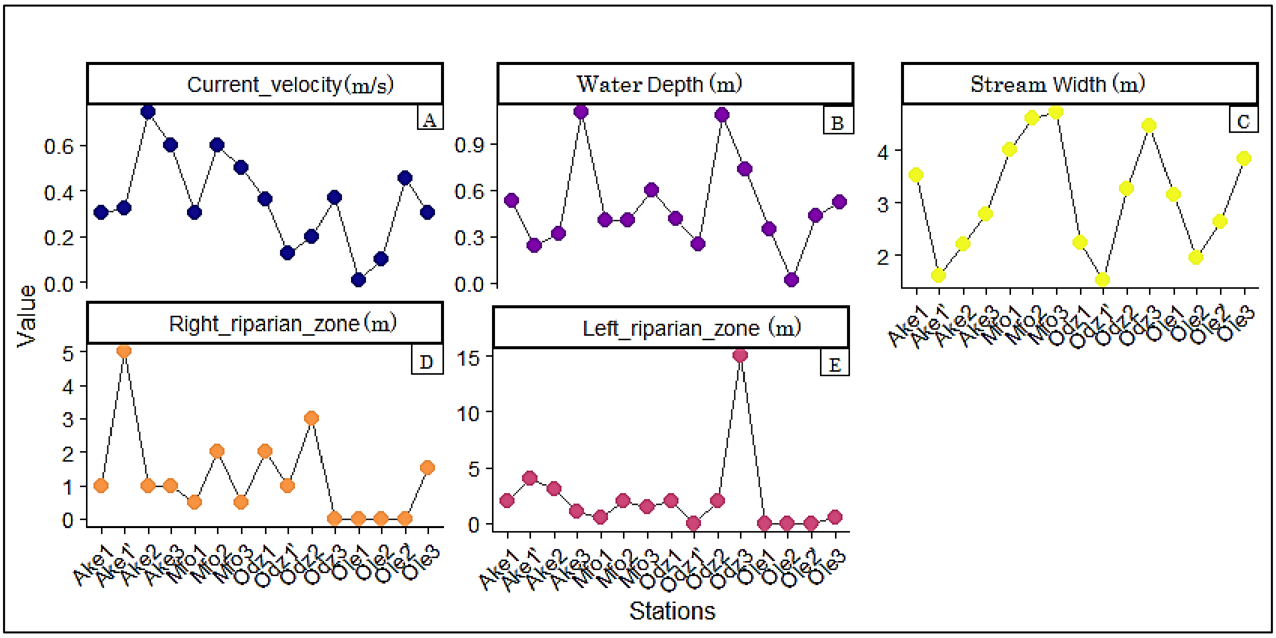


Figure 7. Spatial variations in hydro-morphometric parameters.

The values of the Riparian Buffer Quality Index (IQBR) on both sides of the banks at the various stations within the study basins range from very low (Mfo1, Mfo2, Mfo3, Ole1, Ole2, Ole2', Ole3, Ake2, and Ake3), low (Ake1, Ake1', Odz1', Odz2 [right bank] and Odz3) to medium (Odz1 and Odz2 [left bank]), thus indicating a degradation of the riparian buffer with a reduction in its capacity to perform its functions (Table 3). Across all study environments, only the Odza watercourse has a riparian buffer quality ranging from poor to medium, followed by the Akeu watercourse with a riparian buffer quality ranging from poor to very poor, and finally the Mfoundi and Olézoa watercourses where the overall quality of the riparian buffers is very poor (Figure 8).

Table 3. Variation in the riparian quality index (RBQI) according to study stations. (RG: left bank; RD: right bank)

RBQI					
Rivers	Stations	RG	Quality	RD	Quality
Mfoundi	Mfo1	25	Very low	26	Very low
	Mfo2	27	Very low	29	Very low
	Mfo3	31	Very low	34	Very low
Olezoa	Ole1	38	Very low	32	Very low
	Ole2	35	Very low	35	Very low
	Ole2'	27	Very low	27	Very low
	Ole3	32	Very low	33	Very low
Akeu	Ake1	41	Low	43	Low
	Ake1'	41	Low	49	Low
	Ake2	33	Very low	28	Very low
	Ake3	22	Very low	25	Very low
Odza	Odz1	60	Medium	60	Medium
	Odz1'	43	Low	53	Low
	Odz2	54	Low	60	Medium
	Odz3	54	Low	40	Low

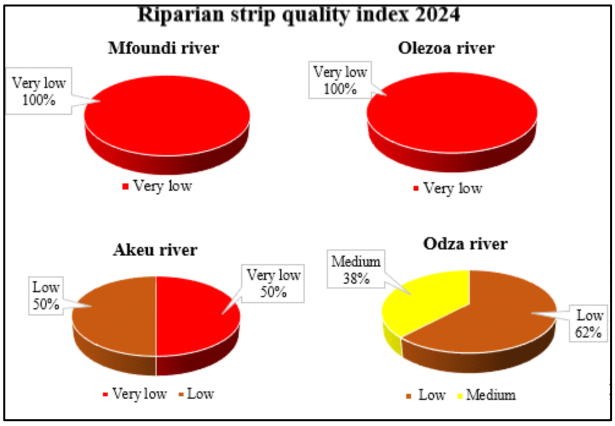


Figure 8. Variation in the quality of the riparian strip in all the watercourses during the study period

3.3. Benthic macroinvertebrates

A total of 3,467 organisms were collected, belonging to 3 phyla, 5 classes, 12 orders, 36 families, and more than 57 taxa. The phylum Arthropoda dominated, with a relative abundance of 80.13%, representing 25 families, followed by the phylum Mollusca with a relative abundance of 15.26%, representing 6 families, and finally the phylum Annelida with a relative abundance of 4.61%, representing 5 families (Figure 9A). However, among all the benthic macroinvertebrates obtained, Arthropods were the most representative of the community (Figure 9B). The orders Diptera (1,863 individuals, or 53.74% abundance) and Hemiptera (388 individuals, or 11.19% abundance) were the most represented, each comprising 7 families (Figure 9C). The families Chironomidae (50.53% relative abundance), Belostomatidae (8.08%), and Anthomyiidae (2.28%) were present at all stations. Across all study sites, abundance varied from one site to another, with the highest values recorded at stations Odz1', Odz1, and Ole3, with 655, 462, and 353 organisms respectively (Figure 10A). Regarding species richness, stations Odz1, Odz2, and Ake2 were the most diverse (Figure 10B). The total taxonomic richness (TTR) recorded in the different environments was highest in the Odza watercourse, while the taxonomic richness of insects (TRI) and Diptera (DTR) was higher in the Odza and Akeu watercourses. Concerning the percentage of Chironomidae, the highest value was recorded in the Mfoundi and the lowest in the Odza watercourse (Table 4).

Table 4. Variation in metrics describing benthic macroinvertebrate structure over the study period.

Metrics	Mfoundi	Olezoa	Akeu	Odza
TTR	22	18	21	45
TRI	13	11	16	33
DTR	5	6	7	7
%chiro	73.24	35.75	48.93	31.33
H'	0.97	1.06	1.62	1.73
E	0.44	0.58	0.76	0.69
FBI	6.75	6.4	5.27	4.92

TTR- Total Taxonomic Richness; TRI- Taxonomic Richness of Insects; DTR- Dipterian Taxonomic Richness; %chiro- Percentage of Chironomidae; H'- Shannon diversity index; E- Pielou index; FBI- Hillsenhoff index.

Across all the rivers studied, the Shannon-Weaver diversity index and Piélou's evenness index remain relatively constant from upstream to downstream. Depending on the different stations and the watercourses, the respective variation in the Shannon-Weaver and evenness indices ranges from 0.29 (Mfo2) to 1.9 (Mfo1) and from 0.21 (Mfo2) to 0.74 (Mfo1), with mean values of 0.97±0.84 bits/ind (H') and 0.44±0.27 bits/ind (E) in the Mfoundi; then from 0 (Ole1) to 1.68 (Ole2') and from 0 (Ole1) to 0.94 (Ole2'), with mean values of 1.06±0.75 bits/ind (H') and 0.58±0.44 bits/ind (E) in the Olezoa; next from 1.27 (Ake3) to 1.99 (Ake2) and from 0.61 (Ake3) to 0.81 (Ake1'), with mean values of 1.62±0.31 bits/ind (H') and 0.76±0.11 bits/ind (E) in the Akeu; finally from 1.31 (Odz3) to 2.49 (Odz2) and from 0.56 (Odz1') to 0.88 (Odz2), with mean values of 1.73±0.53 bits/ind (H') and 0.69±0.15 bits/ind (E) in the Odza watercourse (Figure 11).

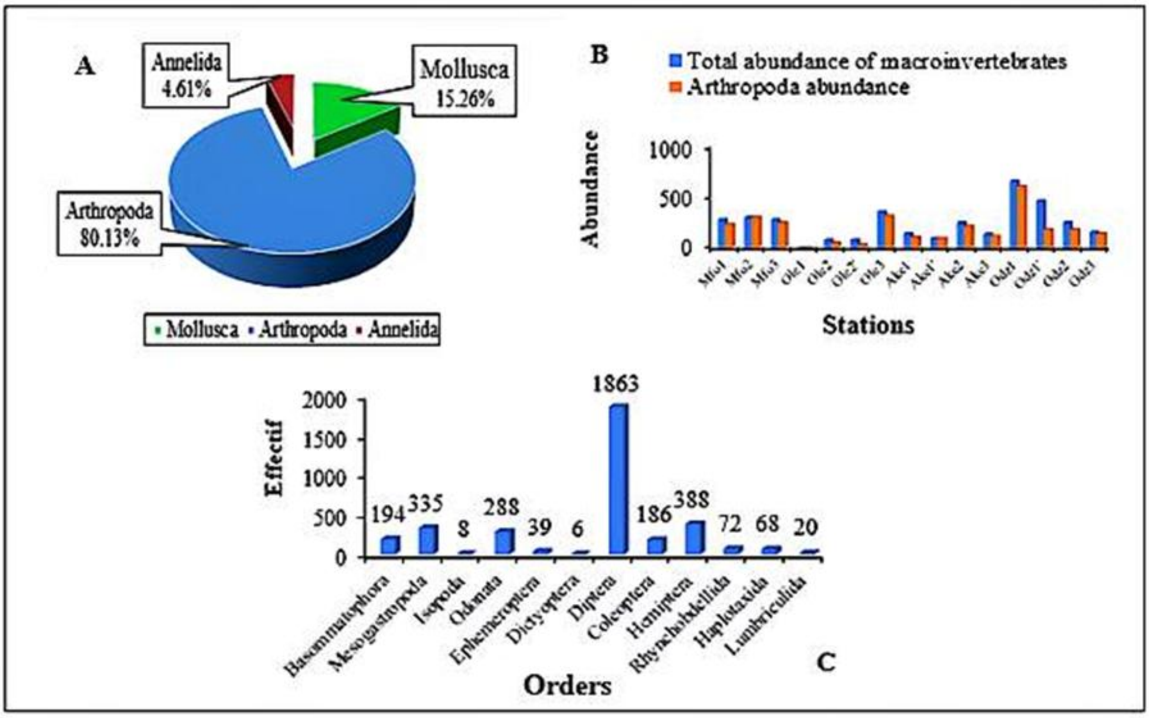


Figure 9. Relative abundance of benthic macroinvertebrate phyla (A); Abundance of arthropods relative to total abundance (B) and number of different orders (C).

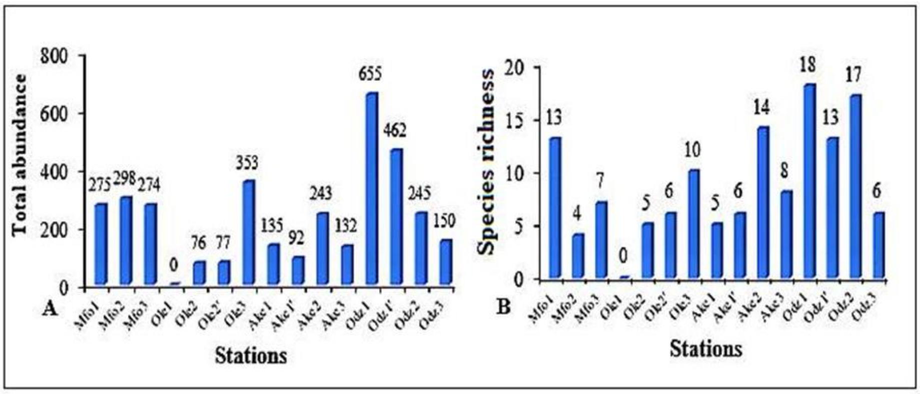


Figure 10. Variation in total abundance and species richness at the different study stations (A: Total abundance; B: Species richness).

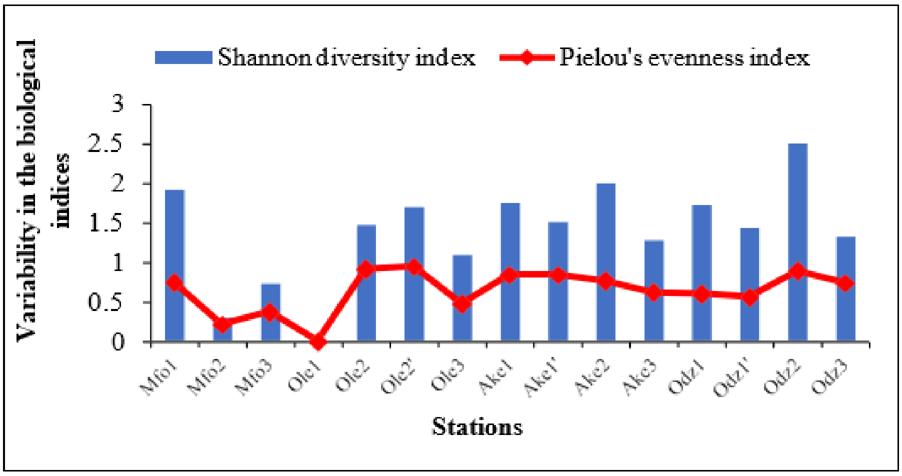


Figure 11. Variation in the Shannon-Weaver diversity index and Piélou equitability index at the different study stations

Overall, the Hilsenhoff index ranged from 4.92 (Odza) to 6.75 (Mfoundi), thus indicating a level of organic pollution in the watercourses ranging from low to very high.

Spearman's rank correlation (Table 5) was used to relate the affinities between the descriptive metrics of the collected benthic macroinvertebrate communities and the hydro-morphometric parameters.

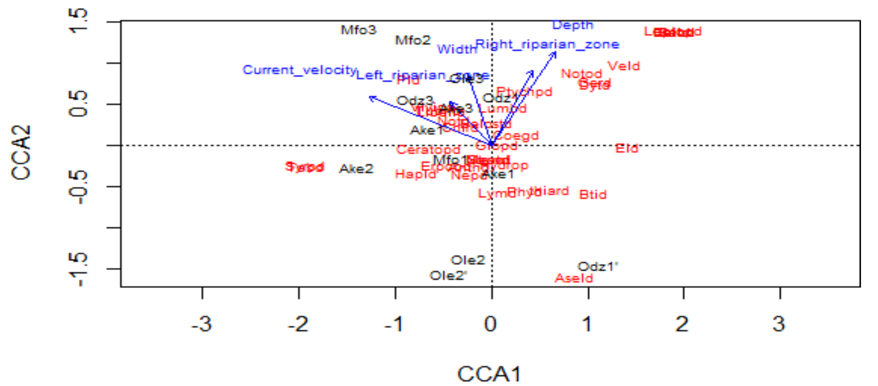
Table 5. Spearman rank coefficient values between hydro-morphometric parameters and benthic macroinvertebrate measurements.

	Current Velocity	Depth	IQBR
RTT	0.200	0.800	0.400
RTI	0.400	1.000**	0.800
RTD	0.211	0.738	- 0.949*
%chiro	0.600	- 0.400	- 0.800
H'	0.000	0.800	1.000**
E	0.400	0.600	0.800
FBI	0.000	- 0.800	- 1.000**

** significant at 0.01; *significant at 0.05

The relationship between the structure of the benthic macroinvertebrate community and the hydro-morphometric variables.

A Canonical Correspondence Analysis (CCA) (Figure 12) conducted between the hydro-morphometric variables and the abundances of benthic macroinvertebrate groups shows a clustering of different variables on the negative side of the CCA1 axis (36% of the explained information), which includes most of the organisms collected with affinities for hydro-morphometric parameters such as low water flow velocity, a degraded left riparian zone, and low sinuosity of the water column. The organisms frequently encountered in waters with these characteristics are Chironomidae, Lumbriculidae, Syrphidae, Ceratopogonidae, Belostomatidae, Viviparidae, Noteridae, Pleidae, and Tubificidae. Stations correlated with these conditions include, among others, Mfo3, Mfo1, Ole3, Odz3, Ake1', and Ake3. The CCA2 axis (24% of the explained information) groups on its positive side organisms having affinities with water depth and the relatively good quality of the right riparian zone. Organisms frequently found here include Dytiscidae, Gerridae, Notonectidae, Veliidae, and Coenagrionidae, among others. Only station Odz1 is correlated with these conditions.



Odz1-Odza1; Odz1'-Odza1'; Ole3-Olézoa3; Mfo1-Mfoundi1; Mfo2-Mfoundi2; Mfo3-Mfoundi3; Ake1-Akeu1; Ake2- Akeu2; Ake3-Akeu3 ; Belostd-Belostomatidae ; Hydrop-Hydrophilidae ; Glopd-Glossiphoniidae ; thiard-thiaridae ; Nepd-Nepidae ; Anthd-Anthomyiidae ; Lymd-Lymneaidae; Phyd-Physidae; Hapld-Haplotaxidae; Chird- Chironomidae; Eld-Elmidae; Aseld-Aselidae; Btid-Beatidae; Hapld-Haplotaxidae ; Pld-Pleidae; Ceratopd-Ceratopogoniidae; Notod-Notonectidae; Dytd-Dytiscidae; Nepd-Nepidae; Veld-Veliidae; Coegd-Coenagrioniidae.

Figure 12. Canonical Correspondence Analysis (CCA) of the main benthic macroinvertebrate taxa and hydro-morphometric variables.

4. DISCUSSION AND CONCLUSION

Hydro-morphometric parameters strongly contribute to the ongoing reshaping of watercourses to varying degrees depending on the energy transported by the water, thereby diversifying habitats and species (Chaussis & Suaudeau, 2010). Thus, stations with low flow velocities (< 0.5 m/s) were in some places found to be the most diverse and abundant (Odza1 and Odza1'). These results corroborate those of several authors studying the influence of flow on aquatic organisms (Bätz et al., 2023; Nathalie et al., 2024). Regarding the depth of the sampled environments, high diversity and abundance were recorded both at certain shallow and deep stations, which can be explained by the abiotic conditions prevailing in these habitats. In this respect, MDDEFP (2013) states that the depth of rivers and water bodies modulates the distribution and diversity of benthic macroinvertebrates by creating distinct ecological niches, with specific adaptations to the physico-chemical conditions of each zone. The riparian zone strongly influences the diversity of benthic macroinvertebrates. Thus, the Odza and Akeu watercourses, which have moderately stable riparian zones in some areas, possess the most diverse faunas. This is confirmed by the results of the riparian buffer quality index, which shows that only the Odza watercourse has relatively natural banks (low to medium), and to a lesser extent the Akeu watercourse (very low to low). On this matter, the Syndicat Mixte des Bassins Versants du Réart (SMBVR) (2022) states that the riparian zone exerts a structuring influence on benthic macroinvertebrate communities through complex ecological mechanisms, acting both as a resource and as a regulator of biotic and abiotic conditions.

The specific richness and low diversity of benthic macroinvertebrates recorded at the various stations are somewhat similar to values obtained by Zemo et al. (2023) in the same ecological zone. This is partly due to the increasing and anarchic urbanisation observed in most of the catchments of the sampled watercourses, coupled with the use of aquatic environments as dumping grounds for domestic wastewaters from latrine evacuation channels and industrial effluents, resulting in intense pollution whose direct consequence is a marked reduction in biodiversity. These results are similar to those of Idrissa et al. (2023) obtained in urban aquatic ecosystems in Burkina Faso, heavily polluted by industrial and domestic effluents, with a predominance of taxa resistant to pollutants. Consequently, the dominance of arthropods, particularly insects, is linked to the development of genetic plasticity and cosmopolitanism, which confer a great capacity to colonise different ecological niches while adapting to the environment (Tachet et al., 2010). The use of urban streams as final receptacles for domestic and industrial waste not only impairs aquatic biodiversity, as evidenced by the dominance of tolerant taxa like Chironomidae, but also poses significant public health risks. Studies conducted in sewage-contaminated regions further highlight this danger; for instance, investigations in Turkey have shown that freshwater turtles captured from sewage-discharged areas can harbor and serve as reservoirs for pathogens such as *Salmonella spp*., posing a threat to both fish and human health (Özcan & Sarıeyyüpoğlu, 2009). Consequently, effective waste management and the protection of riparian buffer zones in the Mfoundi Watershed are imperative not only for ecological restoration but also for mitigating the potential for pathogen transmission to human populations. The wide dominance of dipterans, and to a lesser extent hemipterans and mesogastropods, in the different stations results from their physiological resistance, trophic plasticity, and ability to exploit niches vacated by sensitive species (Pazira et al., 2018; Djene et al., 2021). Indeed, the ecosystem imbalance marked by heavy organic pollution is partly responsible for the simplification of environmental diversity in favour of pollution-resistant taxa such as Chironomidae, Physidae, Belostomatidae, and Thiaridae. These findings align with those obtained by Zemo et al. (2023) in other tributaries of the Mfoundi watershed, where pollution-resistant taxa, primarily Chironomidae and Physidae, dominate. The proliferation of dipteran organisms, particularly the family Chironomidae and to a lesser extent Anthomyidae and Ceratopogonidae, in the watercourses indicates organic pollution partly of faecal origin. However, it should be noted that Chironomidae colonise all types of substrates such as mud, sand, gravel, aquatic vegetation, or hard surfaces like rocks and concrete in aquatic environments and can tolerate extreme temperatures, acidic or basic pH, fluctuating salinity, great depths, very low flow velocities, and even dehydration and ultraviolet and gamma radiation. They dominate fauna in polluted watercourse areas, whereas in unpolluted sections, they form only a minor part of the fauna (Thorat & Nath, 2015; Doric et al., 2023). This is confirmed by observations across all collected samples, where Chironomidae supplant the benthic macroinvertebrate fauna in polluted stations (all stations except Odz1' and, to a lesser extent, Odz2).

The relatively high abundance of organisms collected at stations Odz1 and Odz1' is likely due to a dual effect: on the one hand, a low and constant flow velocity and runoff waters supplying organic matter favourable to the proliferation of Chironomidae (an abundant taxon); on the other hand, specific conditions at the station (fairly good riparian vegetation and habitat diversity) that promote the emergence of other organisms. Similar results were obtained by Dingtoumda et al. (2022) in aquatic environments receiving wastewater from the city of Ouagadougou in Burkina Faso, where Chironomidae (47.26%) were the most abundant species, albeit with a diversity of 20 families.

Variations in Shannon-Weaver diversity index values from one station to another within the different watercourses are linked to the presence within the watershed of numerous anthropogenic activities generating waste, but also in the immediate environment of the station, which contributes to increased organic pollution essential for the proliferation of pollution-tolerant dipteran organisms, particularly the Chironomidae family. Likewise, Piélou's evenness index is very low for the Mfoundi and Olezoa watercourses and moderate in the Akeu and Odza, indicating the dominance of one group over others. In this regard, according to Dajoz (2000), low diversity index values reflect poorly diversified and poorly organised communities.

The Hilsenhoff index (FBI) showed a gradient of increasing organic pollution from the city centre towards the peripheries. Thus, the Mfoundi and Olezoa watercourses, located in the urban core and characterised by very high human density coupled with numerous anthropogenic activities, had the highest index values, followed by the Akeu watercourse, and finally the Odza on the periphery with a low value. Similar results were obtained by Djene (2020) in urban aquatic ecosystems of Daloa (central-west Côte d'Ivoire), where aquatic environments in areas of low population density were the most diverse and least degraded. These findings are indicative of the structural and environmental degradation prevalent in urban aquatic ecosystems. A similar study conducted in Turkey also demonstrates that the efficiency of structural interventions (e.g., fish passages on the Ceyhan River) and their profound impact on the migration of aquatic species must be carefully examined (Alp et al., 2020). This underscores the idea that proposed restoration efforts in the Yaoundé River systems should encompass not only pollution control but also the improvement of structural ecological integrity.

The Canonical Correspondence Analysis shows that low water flow velocities, a degraded riparian zone, and low sinuosity of the water column strongly influence the quality and diversity of organisms present in the environment, leading to a proliferation of pollution-tolerant organisms at the expense of pollution-sensitive ones. These results corroborate those of Sinave & Grégoire Taillefer (2018) on habitat characterisation and protection of fish in the Beaudette River in Quebec, where the Beaudette River has greater species richness in the presence of good-quality riparian buffers and very low richness otherwise.

The waters of the various watercourses studied in the Mfoundi watershed are characterised by degradation of riparian buffer quality, low flow velocities, and low sinuosity of the water column, thus reflecting heavy organic pollution. The organisms collected are mainly represented by the insect class, with dominance of the order Diptera, notably the Chironomidae family, present at all stations and containing saprobiont organisms that testify to anthropisation of the various catchments. Thus, urbanisation linked to demography and coupled with increased anthropogenic activities leads to a decline in benthic habitat diversity and quality. This favours the development of tolerant species and the reduction of sensitive species. The diversity index and Spearman rank correlations between hydro-morphometric parameters and macroinvertebrate metrics reveal a community essentially dominated by Diptera, Hemiptera, and Mesogastropods. The riparian buffer quality index (RBQI) reflects a very high vulnerability of the different watercourses, while the Hilsenhoff index confirms this vulnerability by indicating organic pollution ranging from low to very high. In view of this, it is important to note that the growing and anarchic urban sprawl of a metropolis such as Yaoundé leads to increased vulnerability of surrounding aquatic ecosystems. The poor functioning or near absence of an effective solid and liquid waste collection system in such a city contributes to increasing pollution of watercourses. Consequently, drastic and imperative restoration measures for these ecosystems would involve better waste management as well as the preservation of buffer zones of watercourses in urban areas.

Acknowledgments
The authors thank RAINBOW Environment Consult for their logistical support, as well as the authorities of the Laboratory of Hydrobiology and Environment (LHE) of the Department of Animal Biology and Physiology, Faculty of Science, University of Yaoundé I, for providing the equipment made available to us.

Authors' Contributions
NLL: Manuscript design, Field sampling, Laboratory experiments, Draft checking, Writing, Reading, Editing, Statistical analyses.
SFM: Manuscript design, Laboratory experiments, Draft checking, Reading, Editing.
DFEO: Field sampling, Laboratory experiments, Draft checking, Reading, Editing.
JD: Manuscript design, Laboratory experiments, Draft checking, Reading, Editing.
BGZ: Laboratory experiments, Draft checking, Reading, Editing.
MAZT: Laboratory experiments, Draft checking, Reading, Editing.
GUT: Laboratory experiments, Draft checking, Reading, Editing.
All authors read and approved the final manuscript.

Conflict of Interest
The authors declare that there is no conflict of interest.

Statement on the Welfare of Animals
Ethical approval: For this type of study, formal consent is not required.

Data Availability Statements
The authors confirm that the data supporting the findings of this study are available within the article.

REFERENCES

AbdelHady, R. S., Fahmy, H. S., & Pacini, N. (2017). Valuing of Wadi El-Rayan ecosystem through a water-food-energy nexus approach. *Ecohydrology & Hydrobiology* 17, 247-253. https://doi.org/10.1016/j.ecohyd.2017.07.001

Abossolo Samuel A., Romain Armand S. B., Joseph Armathé A., & Mesmin T. (2015). Relationship between antarctic stratospheric ozone concentration and annual rainfall variability in Yaoundé, Cameroon. *Rev. Ivoir. Sci. Technol. 26,* 139-155.

Ajeagah, G.A. (2017). Water as a weapon of international confrontations, *L'Harmattan*.

Allan JD, Castillo MM, Capps KA. (2021). Rivers in the Anthropocene. In: Allan JD, Castillo MM, Capps KA, eds. *Stream Ecology*: Structure and Function of Running Waters, *Springer International Publishing, Cham*, 1-17. https://doi.org/10.1016/j.biocon.2006.08.017

Alp, A., Akyüz, A., Özcan, M., & Yerli, S. (2020). Efficiency and suitability of the fish passages of River Ceyhan, Turkey. *Journal of Limnology and Freshwater Fisheries Research, 6*(1), 1-13. https://doi.org/10.17216/limnofish.618924

Al-Shami, S.A.; Salmah, M.R.C.; Abu Hassan, A.; Azizah, M.N.S. (2011). Evaluation of mentum deformities of Chironomus spp. (Chironomidae: Diptera) larvae using a modified toxic score index (MTSI) to assess the environmental stress in Juru River Basin, Penang, Malaysia. *Environ. Monit. Assess.* 177, 233-244. https://doi.org/10.1007/s10661-010-1630-1

Andersen, A.N., Fisher, A., Hoffmann, B.D., Read, J.L., Richards, R. (2004). Use of terrestrial invertebrates for biodiversity monitoring in Australian rangelands, with particular reference to ants. *Austral Ecol.* 29, 87-92. https://doi.org/10.1111/j.14429993.2004.01362.x

Arenas-Sánchez A, Dolédec S, Vighi M, Rico A. (2021). Effects of anthropogenic pollution and hydrological variation on macroinvertebrates in Mediterranean rivers: A case study in the upper Tagus River basin (Spain). *Science of The Total Environment* 766: 144044. https://doi.org/10.1016/j.scitotenv.2020.14404

Astruch P, Orts A., Schohn, T., Belloni, B., Ballesteros, E., Bănaru, D., Bianchi CN., Boudouresque C-F, Changeux T., Chevaldonné P., Harmelin J-G, Michez N., Monnier B., Morri C., Thibaut T., Verlaque M and Daniel B. (2023). Ecosystem-based assessment of a widespread Mediterranean marine habitat: The Coastal Detrital Bottoms, with a special focus on epibenthic assemblages. Front. Mar. Sci. 10:1130540. https://doi.org/10.1016/j.ecohyd.2017.07.001

Bätz, N., Judes, C., & Weber, C. (2023). Nervous habitat patches: The effect of hydropeaking on habitat dynamics. *River Research and Applications*, 39(3),349-363. https://doi.org/10.1002/rra.4021BÄTZ ET AL. 363

Biram A Ngon E. (2019). *Étude bioécologique des dictyoptères aquatiques dans le bassin versant de la Mefou,* PhD Thesis, University of Yaoundé I, Cameroon, 162 p.

Bode, R.W., M.A. Novak, & Abele, L.E. (1991). Methods for rapid biological assessment of streams. *Stream Biomonitoring Unit*, Division of Water, New York State Department of Environmental Conservation, Albany, NY. 57 pp.

Camargo J. A, Alonso A, De la Puente M. (2004). Multimetric assessment of nutrient enrichment in impounded rivers based on benthic macroinvertebrates. *Environmental Monitoring and Publishers,* 96: 233-249. https://doi.org/10.1023/B:EMAS.0000031730.78630.75

Chaussis R., & Suaudeau R. (2010). Morphologie des cours d'eau. *France Nature Environnement publication*. 37 p.

Chessman, B.C. (1995). Rapid assessment of rivers using macroinvertebrates: A procedure based on habitat-specific sampling, family level identification and a biotic index. *Aust. J. Ecol.* 20, 122-129. https://doi.org/10.1111/j.1442-9993.1995.tb00526.x

Dajoz, R. 2000. Précis D'écologie, 7th ed*; Dunod*: Paris, France; p. 615.

Danielle Laure M., & Miguel Benoit A.O. (2025). Urbanisation et déforestation à Yaoundé: analyse des dynamiques spatiales et des enjeux écologiques. Éditions *Francophones Universitaires d'Afrique*. 84-124. https://edition-efua.acaref.net/wp-content/uploads/sites/6/2025/06/3-Danielle-Laure-MATATEYOU.pdf

Day, J.A., & De Moor, I.J. (2002). Guides to the Freshwater Invertebrates of Southern Africa. In Volume 6: Arachnida and Mollusca (Araneae, Water Mites and Mollusca); WRC Report No. TT 182/02; *Water Research Commission*: Pretoria, South Africa.

Dingtoumda Oswald G., Ilboudo Edith M., Kam Wenceslas K., Ilboudo Zakaria., Sanon Antoine. (2022). Inventory of the entomofauna associated with wastewater drainage channels in the city of Ouagadougou, Burkina Faso. *Natural and Applied Sciences.* Vol. 41, No. 2 (2), 77-95.

WFD, (2019). Monitoring the annual status of Martinique's watercourses. ODE972-Rapport-DCE-2019-VF.pdf

Djene, K.R., Bony, K. Y, Allouko, J.R, Kressou, A., N'guessan, A.S. (2021). "Diversity of Diptera and Their Contribution in the Assessment of the Ecological Quality of Daloa's Urban Aquatic Ecosystems (West-Central Cote d'Ivoire)." *International Journal of Zoology and Applied Biosciences*, 6 (4), 212-217.

Djene, K.R. (2020). *Diversité des macro-invertébrés et leur utilisation dans l'évaluation de la qualité écologique des écosystèmes aquatiques urbains de Daloa (centre-Ouest, Côte d'Ivoire).* PhD Thesis, Université Jean Lorougnon Guede, Côte d'Ivoire, 177p.

Docile TN, Figueiró R, Portela C, Nessimian JL. (2016). Macroinvertebrate diversity loss in urban streams from tropical forests. *Environ Monit Assess* 188: 237.

Doric, V., Ivkovic, M., Baranov, V., Pozojevic, I. & Mihaljevic, Z. (2023). Extreme freshwater discharge events exacerbated by climate change influence the structure and functional response of the chironomid community in a biodiversity hotspot. - *Science of the Total Environment* 879: 163110. https://doi.org/10.1016/j.scito tenv.2023.163110

Durand, J. R., & Lévêque, C. (Eds.). (1981). Flore et faune aquatiques de l'Afrique Sahélo-soudanienne: tome 2. *Insectes et vertébrés*. Paris: ORSTOM, p. 390-873 (Initiations-Documentations Techniques; 45). ISBN 2-7099-0585-X.

Feld, C.K, (2013). Response of three lotic assemblages to riparian and catchment-scale land use: Implications for designing catchment monitoring programmes. *Freshw. Biol*. 58, 715-729.

Hilsenhoff, W.L, (1988). Rapid field assessment of organic pollution with a family-level biotic index. *J. N. Am. Benthol. Soc*. 7, 65-68.

Idrissa, K., Victor, B., Rebecca, Z. T. D., & Adama, O. (2023). Influence of municipal discharges on the physico-chemical and biological quality of urban aquatic ecosystems: Case of the Massili River (Burkina Faso, West Africa). *International Journal of Innovation and Applied Studies*, 40(4), 1281-1291.

Iyiola, A.O., Asiedu, B., Kolawole, A.S., Failler, P. (2019). Assessment of water quality and bacteriological levels in Nile tilapia (Oreochromis niloticus) of Aiba Reservoir, Nigeria, west Africa. *Tropicultura*, 37, 3.

Ministère Du Développement Durable, De L'envıronnement, De La Faune Et Des Parcs (MDDEFP), (2013). Guide de surveillance biologique basée sur les macroinvertébrés benthiques d'eau douce du Québec. Cours D'eau Peu Profonds À Substrat Grossier. Direction du suivi de l'état de l'environnement, Ministère Dév. Durable L'Environnement Parcs. ISBN : 978-2-550-69169-3, 98 p.

Moısan, J. & L. Pelletıer, (2008). Guide de surveillance biologique basée sur les macroinvertébrés benthiques d'eau douce du Québec - Cours d'eau peu profonds à substrat coier. Direction du suivi de l'état de l'environnement, Ministère du Développement durable, de l'Environnement et des Parcs, ISBN: 978-2-550-53591-1 (printed version), 86 p.

Nathalie Friese, Diego Tonolla, Christine Weber, Kate Mathers, Nico Bätz, (2024). Experimental field study on macroinvertebrate drift at locks: Influence of hydraulic constraints and habitat type. *Water energy and air*, CH-5401 Baden, 31-39.

Özcan, M., & Sarıeyyüpoğlu, M. (2009). Investigation of Salmonella in fresh water turtle (Mauremys caspica caspica, Gmelin, 1774) from sewage discharged region into Keban Dam Lake, Elazığ. *Kafkas Üniversitesi Veteriner Fakültesi Dergisi*, *15*(5).

Pazira, A.R., Salehi, H. &, Obeidi, R., (2018). Identification and investigation of species diversity and richness of the Gastropoda in the intertidal zone of Bushehr Port coastal area (the Persian Gulf waters). *Iranian Journal of Fisheries Sciences*, 18(2), 355-370.

Saint-Jacques, N., & Richard, Y. (1998). Développement d'un indice de qualité de la bande riveraine : application à la rivière Chaudière et mise en relation avec l'intégrité biotique du milieu aquatique. Le Bassin de La Rivière Chaudière : L'état de L'écosystème Aquatique 1996.

SDAGE, (2015). Schéma directeur d'aménagement et de gestion des eaux 2016-2021. Loire- Bretagne water agency. Imprim'vert on PEFC™ paper under licence 10-31-1316.

Sinave, E., & Grégoire Taillefer, A. (2018). Characterization and protection of fish habitat in the Beaudette River (Quebec). *The Canadian Naturalist*, 142(3), 73-87. https://doi.org/10.7202/1051000ar

Sinche, F., Cabrera, M., Vaca, L., Segura, E., Carrera, P. (2022). Determination of the ecological water quality in the Orienco stream using benthic macroinvertebrates in the Northern Ecuadorian Amazon. Integr. *Environ. Assess. Manag*. 19, 615-625. https://doi.org/10.1002/ieam.4666

Stark JD., Boothroyd IKG., Harding JS., Maxted JR., Scarsbrook MR. (2001). Protocols for sampling macroinvertebrates in wadeable streams. New Zealand Macroinvertebrate Working Group Report No. 1. Prepared for the Ministry for the Environment. Sustainable Management Fund Project No. 5103. 57 p.

Stepenuck, K.F., Crunkilton, R.L., Wang, L. (2002). Impacts Of Urban Landuse On Macroinvertebrate Communities In Southeastern Wisconsin Streams. *JAWRA J. Am. Water Resour. Assoc.* 38, 1041-1051. https://doi.org/10.1111/j.1752-1688.2002.tb05544

SMBVR, (2022). River maintenance - The role of riparian vegetation. 3 rue des Fenouillèdes Parc d'activités Sud-Roussillon 66280 Saleılles.

Tachet, H., Richoux, P., Bournaud, M., Usseglio-Polatera, P. (2010). Invertébrés D'eau Douce :Systématique, Biologie, Écologie ; *CNRS Editions*: Paris, France ; Volume 15.

Taylor, R.J. & Doran, N. (2001). Use of Terrestrial Invertebrates as Indicators of the Ecological Sustainability of Forest Management under the Montreal Process. *J. Insect Conserv*. 5, 221- 231. https://doi.org/10.1023/A:1013397410297

UNEP (United Nations Environment Programme), (2024). Annual report UNEP-Annual-Report-2024_EN.pdf

Zemo, M.A.T., Menbohan, S.F., Atchrimi, B.T., Betsi, W.C.N., Nwaha, M., Dzavi, J., Mavunda, C.A., Lactio, N., (2023). Effect of Anthropogenic Pressure on the Biodiversity of Benthic Macroinvertebrates in Some Urban Rivers (Yaoundé). *Water,* 15, 2383. https://doi.org/10.3390/ w15132383

Zemo M.A.T., Menbohan S.F., Atchrimi B.T., Assou D. Biram à Ngon BE, Betsi NCW, Gwos Nhiomock S., Harissou., Lactio N.L, Far Ndourwe B., Nwaha M., Mbia D l'or N., Tchouapi L.Y., Tchouta G.U., Mboye B.R., Dzavi J. (2024). Distribution Profile of Benthic Macroinvertebrates in Some Rivers of Yaoundé City and Its Surroundings Using Self Organizing Map and Indicator Value Methods. *Diversity* 16: 385. https://doi.org/10.3390/d16070385.

Thorat L., Nath B. B. (2015). Tolerance to desiccation stress in Chironomus ramosus through plasticity in homeostatic control. *Eur. J. Environ. Sci.* 5 86-91.