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RESEARCH ARTICLE

IMPACT OF ANTHROPOGENIC DISTURBANCES ON THE STRUCTURE AND DIVERSITY OF BENTHIC MACROINVERTEBRATE COMMUNITIES IN THE CIRHANYOBOWA RIVER (SOUTH KIVU, DRC)

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ABSTRACT

This study assessed the impact of anthropogenic disturbances on the structure and diversity of benthic macroinvertebrate communities and on selected physicochemical parameters of the Cirhanyobowa River in South Kivu (DR Congo). Sampling was carried out monthly at three sites from January to December 2019. Biological surveys focused on abundance, species richness, and taxonomic composition of macroinvertebrates, considering spatial and temporal variations to evaluate ecological responses to human pressures. Eight physicochemical parameters were analyzed, including temperature, pH, dissolved oxygen, calcium, phosphate, nitrogen, depth, and current velocity. A total of 4,179 individuals representing 38 families and 57 taxa were recorded, with arthropods dominating the assemblages. Species diversity markedly declined downstream, coinciding with degraded water quality characterized by low dissolved oxygen, elevated temperatures, high nutrient concentrations, and a reduction of rheophilic groups such as Trichoptera and Ephemeroptera. These patterns are consistent with pollution inputs from agricultural runoff (notably pesticides), domestic effluents, and solid waste from riparian settlements. Further research integrating additional environmental variables and extending to other rivers of the region is recommended to better understand the ecological requirements of benthic macroinvertebrates. Strengthening land-use planning and watershed management policies that incorporate the conservation of aquatic communities is crucial for safeguarding the ecological integrity of river ecosystems.

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INTRODUCTION

Aquatic communities are among the first biological compartments to respond to physical, chemical, and microbiological disturbances in lotic ecosystems, making them highly sensitive indicators of environmental change (Allan & Castillo, 2007; Vörösmarty *et al*., 2020). Among these communities, benthic macroinvertebrates occupy a central ecological position due to their high taxonomic and functional diversity, their involvement in nutrient cycling and organic matter processing, and their strong responsiveness to habitat degradation and pollution. Widely distributed across freshwater environments—from small headwater streams to large river systems (Chessman, 1995) these organisms integrate environmental conditions over time owing to their relatively long and often multi-annual life cycles (Camargo *et al*., 2004; Rosenberg & Resh, 2020). Their heterogeneous tolerance to environmental stressors enables the detection of subtle or cumulative disturbances that would not be revealed by physico-chemical measurements alone (Bonada *et al*., 2006; Buss *et al*., 2023). As such, benthic macroinvertebrates constitute robust bioindicators of ecological integrity, providing an integrated assessment of the physical, chemical, and biological alterations that affect stream ecosystems (Barbour *et al*., 1999; Merritt *et al*., 2019). They are therefore widely implemented in biomonitoring frameworks and ecological assessment protocols worldwide, particularly through indices based on taxonomic composition, functional traits, and the presence of sensitive groups such as Ephemeroptera, Plecoptera, and Trichoptera (EPT), which decline markedly in response to eutrophication, sedimentation, metal contamination, temperature increases, and habitat simplification (Bonada *et al*., 2006; Haase *et al*., 2024). In tropical regions, especially in Central Africa, freshwater ecosystems are subject to increasing anthropogenic pressures driven by demographic growth, agricultural expansion, artisanal mining, land-use change, and poorly regulated urban development.

hese pressures contribute to habitat fragmentation, sediment loading, nutrient enrichment, and the introduction of chemical contaminants, profoundly modifying the composition and functioning of aquatic communities (Masilya *et al*., 2020; Nsengimana *et al*., 2022). In the South Kivu province of the Democratic Republic of Congo, rivers and streams are heavily impacted by soil erosion, untreated domestic wastewater, agricultural runoff rich in pesticides and organic matter, and the accumulation of solid waste (Zirirane *et al*., 2014; Bagalwa *et al*., 2013; Bagalwa *et al*., 2016). In the Katana region, where agricultural activity dominates, the intensification of land cultivation and deforestation exacerbates watershed degradation, promoting sedimentation processes and reducing riparian vegetation that ordinarily stabilizes banks and regulates water quality. The Cirhanyobowa River, located within this vulnerable landscape, is heavily exploited by riparian communities for agriculture, household use, and various informal activities, yet no environmental regulation or monitoring program ensures sustainable management of its resources. Despite these pressures, no study to date has documented how anthropogenic disturbances influence the structure and diversity of benthic macroinvertebrate communities in this river. Filling this knowledge gap is essential for understanding the ecological consequences of land-use practices and for guiding sustainable watershed management strategies in the region.

In this context, the present study aims to assess the impact of anthropogenic disturbances associated with riparian and agricultural activities on the structure of benthic macroinvertebrate communities in the Cirhanyobowa River. Specifically, it investigates the taxonomic composition, species richness, and abundance of these communities, and examines how these biological attributes relate to the physico-chemical characteristics of the water in order to provide an integrated evaluation of the river's ecological status.

MATERIALS AND METHODS

Description of the Study Environment: The Katana region is located between 2°15' and 2°30' South latitude and 28°45' and 28°55' East longitude. It lies at altitudes ranging from 1,463 to 2,200 m and is situated approximately 40 km north of Bukavu, the capital of South Kivu province in the Democratic Republic of Congo. The region has a humid tropical climate, characterized by a long rainy season lasting nine months (September–May) and a short dry season of about three months (June–August). The mean annual air temperature is around 19.5 °C, relative humidity ranges between 68–75%, and annual precipitation averages 1,500 mm (CRSN-Lwiro Climatological Service, 1973–2020). The natural vegetation, originally dominated by *Albizia grandibracteata* forests, has been largely replaced by cultivated savanna due to intense agricultural pressure (Baluku &Bagalwa, 2021). Katana hosts diverse aquatic ecosystems, including streams, rivers, lakes, wetlands, and ponds. The present study was carried out over one year at three sampling sites chosen for their accessibility and ecological representativeness along the Cirhanyobowa River, a major tributary flowing into the western shore of Lake Kivu. The river originates in the high-altitude forests of Kahuzi-Biega National Park (above 2,000 m) and flows through an intensively cultivated agro-ecosystem before discharging into Lake Kivu at 1,463 m. Its total course extends approximately 14.8 km, with a depth varying between 28 and

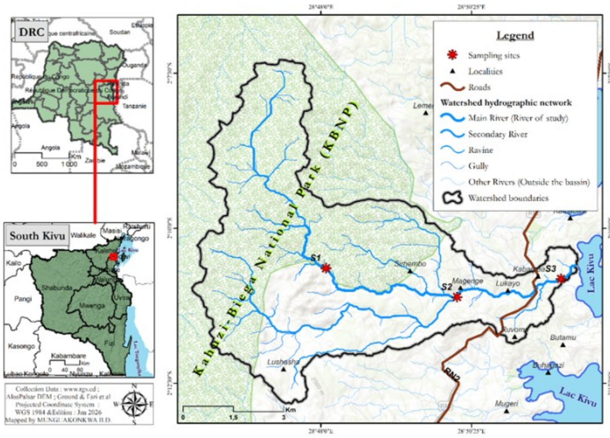

Figure 1. River Cirhanyobowa and sampling sites

250 cm and an average width of around 2.5 m. The watershed covers an estimated area of 59 km². The upstream site (Site 1: Batanga) is located at 1,854 m altitude (02°10.643′ S; 28°48.081′ E), near the boundary of Kahuzi-Biega National Park, in a relatively undisturbed forested environment. It served as the reference (control) site. Riparian vegetation includes *Sericostachys scandens*, *Myrianthusholstii*, *Pennisetum purpureum*, *Commelinadiffusa*, *Cyperus distens*, *Toddalia asiatica*, *Melanthera scandens*, *Polygonum senegalense*, and *Persicariaserrulata*. The middle-course site (Site 2: Ruvoma), situated at 1,602 m altitude (02°11.108′ S; 28°50.186′ E), is located 10 m upstream of the Ruvoma bridge on the Bukavu–Goma National Road.

This section is heavily impacted by anthropogenic activities, including livestock watering, pig washing, domestic bathing, laundry, and dishwashing. The surrounding area is dominated by cultivated fields (food crops and banana plantations). Aquatic vegetation is mainly composed of *Cynodondactylon*, *Pennisetum purpureum*, *Digitariavestita*, *Commelina benghalensis*, and *Bambusa vulgaris*. The downstream site (Site 3: Munywero), located at 1,479 m altitude (02°10.816′ S; 28°51.853′ E), lies within a marshy zone about 10 m from the river mouth (Figure 1.. Riparian vegetation is dominated by *Cyperus latifolius*, *Cyperus papyrus*, *Phragmites mauritianus*, and *Polygonum senegalense*.

Methods

Inventory of Macroinvertebrates: Benthic macroinvertebrates (insects, annelids, crustaceans, and mollusks) were collected using a dip net with a 30 cm opening, following the qualitative multi-habitat (QMH) sampling method described by Olivier & Schneiderman (1956) and widely used in tropical biomonitoring programs. The QMH approach consists of sampling all microhabitats present at each site to maximize taxonomic representativeness. The sampling effort was standardized to a duration not exceeding 10 minutes per site.

All available substrates were sampled, including hard substrates (fixed rocks, movable stones) and soft substrates (sand, silt, mud). Complementary manual visual collection was carried out on natural supports such as dead leaves, roots, and stones to capture mobile or cryptic taxa less accessible to net sampling. This combined strategy improves the probability of detecting rare or sensitive taxa and ensures a more complete assessment of benthic community composition.

Table 1. Inventory of Macroinvertebrate Species at the Sites During the Year

	Site 1	Site 2	Site 3	Total	Total per family	Frequency per family (%)
Embranchment of Arthropoda						
Class of insect						
Order Trichoptera						
Familyof Limnephilidae						
Pschopschescabripennis	0	0	1	1		
Limnephiliscombunatus	18	1	15	34		
Limnephilisconsocius	6	7	0	13		
Hesperophylaxdesignatus	12	0	0	12		
Neophylaxconcinnis	3	0	0	3	63	1.51
FamilyofRhyacophilidae						
Ryacophila fenestra	1	1	4	6		
Agrypnia staminea	2	0	0	2	8	0.19
Family ofLepidostomatidae						
Lepidostomasp	546	430	468	1444	1444	34.55
Family ofLeptoceridae						
Leptocerus americanus	10	0	11	21	21	0.50
Family ofHydropsychidae						
Hydropsyche simulans	114	121	102	337	337	8.06
Family ofPhilopotamonidae						
Philopotamon sp	35	19	10	64		
Chimanaaterina	25	8	6	39	103	2.46
Family ofPolycentropodidae						
Polycentopussp	10	0	0	10	10	0.24
Orderof Diptera						
Family ofPsychodidae						
Psychodasp	19	6	11	36	36	0.86
Family ofThaumaleidae						
Thaumaleidessp	1	0	0	1	1	0.02
Family ofTupulidae						
Tipula sp	4	5	0	9	9	0.22
Family ofSimilidae						
Simuliusvenastum	50	40	0	90	90	2.15
Family of Chironomidae						
Chironomus tentans	38	5	31	74	74	1.77
Family ofCeratopagonidae						
Palpomyiasp	9	4	0	13	13	0.31
Order ofHétéroptère						
Family ofMesovelidae						
Mesoveliamesanti	1	1	1	3	3	0.07
Family ofNaucoridae						
Pelocorisfermoratus	0	1	0	1	1	0.02
Family of Corixidae						
Corris sp	4	0	2	6	6	0.14
Family ofPleidae						
Plea striola	3	0	0	3		
Plea sp	4	0	0	4	7	0.17
Family ofElmidae						
Stenelmis lateralis	5	2	0	7		
Phanocerusclavicornis	16	7	2	25	32	0.77
Family of Gerridae						
Gerrisnotatura	1	0	0	1		
Gerrislacustris	1	0	0	1	2	0.05
Ordeeof Ephemeroptera						
Family ofHeptagenidae						
Iron humeralis	13	3	0	16		
Isogenus modesta	6	0	0	6		
Afronussp	7	3	0	10		
Heptageniasp	7	1	0	8	40	0.96
Family ofBaetidae						
Baetissp	20	10	15	45		
Acantrellasp	4	0	0	4	49	1.17
Family ofCaenidae						
Caenis sp	14	4	2	20	20	0.48
FamilyofAdenophlebiodidae						
Adenophlebiodessp	6	0	0	6	6	0.14
Family ofHastaperdidae						
Hastaperla brevis	3	0	0	3	3	0.07

Continune …

OrderofOdonate						
Family ofAeschnidae						
Aeschiasp	7	18	4	29	29	0.69
Family ofLibellulidae						
Lepidopotamonsp	0	10	21	31		
Tachopteryxthoreyi	307	302	143	752	783	18.74
Family ofGomphidae						
Progomphusobscuris	90	82	54	226	226	5.41
Family ofCoenagrionidae						
Coenagrionsp	160	210	247	617	617	14.76
Family ofPsychodidae						
Psychodasp	5	1	0	6	6	0.14
Orderof Coleoptera						
Family ofElimidae						
Phanocerusclavicorni	0	1	0	1		
Stenelmis lateralis	1	5	0	6	7	0.17
Family ofGyrinidae						
Gyrinus notatore	4	2	1	7	7	0.17
Orderof Megaloptera						
Family ofCorylidae						
Cornidaluscornitus	2	0	0	2	2	0.05
OrderofAnnelides						
Family ofLubriculidae						
Lumbriculus lumbriculus	5	3	8	16	16	0.38
Family ofGlossiphonidae						
Glossiphoniacomplonata	0	3	10	13		
Hoemopissansuga	1	0	5	6		
Hoemopis grandis	0	2	10	12	31	0.74
OrderofGordiidea						
Family ofGordidae						
Gordius robustus	13	2	9	24	9	0.22
Orderof Arenidae						
Family ofAgynectidae						
Agyonecta aquatica	6	12	5	23	23	0.55
OrderofHemiptere						
Family ofNepidae						
Plea striola	6	0	0	6		
Nepa apiculate	1	1	2	4		
Nepa cirenea	2	0	0	2	12	0.29
Orderof Decapoda						
Family ofPotamonidae						
Potamonsp	15	3	0	18	18	0.43
Total	1643	1336	1200	4179	38	100

Sorting and Identification of Macroinvertebrates: Sorting was conducted directly in the field immediately after sampling. Macroinvertebrates were preserved in tubes containing 4% buffered formalin and transported to the Malacology Laboratory of the Natural Sciences Research Centre (CRSN-Lwiro) for identification. Specimens were examined under a binocular microscope at 40× to 100× magnification, and identification was performed to the lowest possible taxonomic level using standard identification keys (Pennak, 1953; Tachet&Noiset, 1980; Micha &Noiset, 1982). After identification, individuals belonging to each taxon were counted in Petri dishes to obtain abundance data.

Measurement of Physicochemical Parameters: Physicochemical measurements were conducted during both the rainy and dry seasons to account for seasonal variability. In situ parameters—including water temperature, pH, electrical conductivity, and dissolved oxygen—were measured using a HANNA Instruments portable multiparameter probe, following standard procedures recommended by APHA (2017). Water depth was measured using a graduated probe, while current velocity was estimated using the float method (distance/time). Water samples were collected and transported to the CRSN-Lwiro laboratory for analysis. Calcium (Ca^{2+}) concentrations were determined using complexometric titration with EDTA in accordance with Golterman *et al*. (1978) and APHA (1995). Total nitrogen (N-total) and total phosphorus (P-total) were quantified by UV–Vis spectrophotometry after acid digestion following protocols described by Wetzel & Likens (2000). These parameters were used to characterize spatial gradients of anthropogenic pollution and relate them to benthic community structure.

Statistical Analysis and Data Processing: Species richness was defined as the number of taxa recorded at each sampling site and used as an indicator of community structure and local biodiversity. Data were analyzed using both univariate and multivariate statistical methods with PAST software version 4.x (Hammer *et al*., 2001). Spatiotemporal variations in species richness, abundance, and community composition were examined. Comparisons of physicochemical variables and species richness between sites were performed using Student's *t*-test, with a significance threshold set at $p < 0.05$, in order to identify statistically significant differences between less and more impacted sites along the river.

RESULTS

Inventory of Benthic Macroinvertebrates in the Cirhanyobwa River: The results obtained for the inventory of benthic macroinvertebrates and the species richness of the species at each sampling site are presented.A total of 4,179 benthic macroinvertebrate specimens were collected during one sampling year at three selected sites in the Cirhanyobwa River.These macroinvertebrate species are presented in Table 1. Analysis of benthic macroinvertebrates in the Cirhanyobowa River reveals a diverse community of 4,179 individuals belonging to 38 families. The majority of organisms belong to the phylum Arthropoda, primarily the class Insecta aquatica, with a strong representation of the orders Trichoptera, Ephemeroptera, Odonata, and Diptera. Among the families, Lepidostomatidae (Trichoptera) is clearly dominant, representing 34.55% of the collected individuals, indicating relatively favorable ecological conditions in certain areas. Other abundant families include Libellulidae (18.74%), Coenagrionidae (14.76%), Hydropsychidae (8.06%), and Gomphidae (5.41%), typical of well-oxygenated lotic environments. The spatial distribution of macroinvertebrates reveals notable differences between the three study sites. Site 1, located upstream in an area with low human impact, exhibits the highest abundance (1643 individuals) and significant diversity of sensitive species such as *Lepidostoma sp.*, *Hydropsyche simulans*, *Baetis sp.*, and *Heptagenia sp.*, which are recognized indicators of good ecological quality. At site 2, in an intermediate zone, abundance decreases to 1336 individuals, while the proportion of species more tolerant to disturbances, such as certain Odonata (Coenagrionidae, Libellulidae) and Diptera, increases. Site 3, downstream and subject to greater anthropogenic pressure (domestic waste, agricultural runoff), has the lowest abundance (1200 individuals) and a community dominated by pollution-resistant taxa, notably Chironomidae, Simuliidae, Coenagrionidae, and certain annelids (Lumbriculidae, Glossiphonidae).

These differences reflect a marked ecological gradient along the river, ranging from a pristine upstream section to a more degraded downstream area. The high presence of Trichoptera, Ephemeroptera, and Odonata at the upstream site confirms the good quality of this zone, while the increasing dominance of Diptera and annelids downstream suggests degradation linked to organic inputs and changes in aquatic habitats. In total, twelve invertebrate orders were recorded, with Trichoptera predominating, comprising seven families, while four orders are represented by only one family each. The Lepidostomatidae family was the most frequent at all three sites, while the Thaumaleidae and Naucoridae families were the least abundant (0.02%).

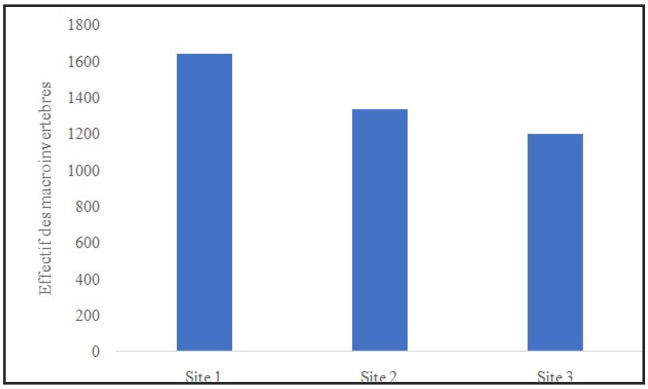

Figure 2. Macroinvertebrate population size per site throughout the year

The relative frequency of the different families varied significantly during the sampling period ($p < 0.05$), illustrating the dynamics of benthic communities in response to changing environmental conditions.

Overall, the observed faunal composition confirms that macroinvertebrates are relevant bioindicators of water quality and aquatic habitats in the Cirhanyobowa River, which are sensitive to anthropogenic pressures and ecological alterations. The distribution of macroinvertebrate populations collected at the three sampling sites along the Cirhanyobowa River is shown in Figure 2. The figure clearly shows that macroinvertebrate abundance varies between sites, with the highest concentration at the upstream site (Site 1), which represents 39.3% of the total specimens collected. Conversely, the downstream site (Site 3) shows the lowest abundance, with only 28.7% of the total population. The intermediate site (Site 2) has a value between these two extremes. This spatial distribution of benthic populations is significantly influenced by the position of the sites along the river ($p < 0.05$), thus reflecting an ecological gradient where habitat quality and physicochemical conditions gradually degrade from upstream to downstream. The greater abundance at the upstream site can be attributed to more favorable conditions, such as better oxygenation and less human pressure, while the decreased numbers downstream suggest a greater impact from disturbances related to human activities. The monthly variation in the numbers of macroinvertebrates collected at the different sites along the river is shown in Figure 3.

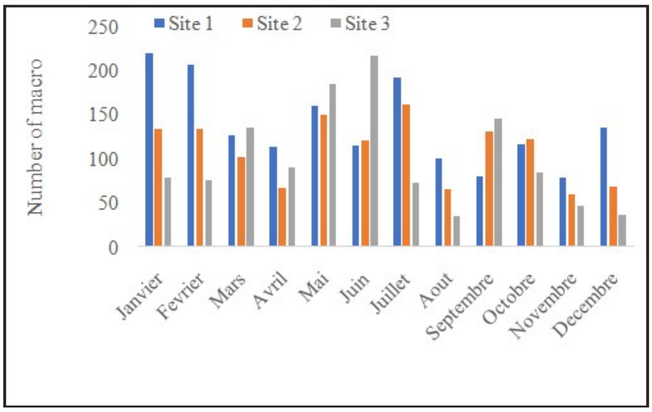

Figure 3. Monthly variation in the number of macroinvertebrates collected at the different sites

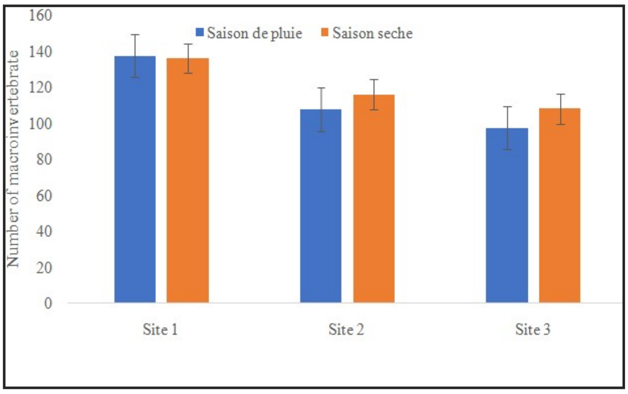

Figure 4. Monthly average of the seasonal variation in macroinvertebrate populations at different sites .

Generally, the upstream site (Site 1) exhibits a higher abundance than the other sites throughout the year, with the exception of March, May, June, and September, when the downstream site (Site 3) shows a higher number of specimens. This fluctuation indicates that benthic population dynamics vary according to the seasons and sites, likely in response to variations in environmental conditions such as flow rate,

Table 2. Physicochemical Characteristics of the Sampling Stations

Sites	Température (°C)	pH	DO (mg/l)	Ca (mg/l)	TP (µmol/l)	TN (µmol/l)	Profondeur (cm)	Vitesse (m/s)
S1	14.6±0.4	6.9±0.3	8.9±2.7	0.79±0.1	0.06±0.02	2.5±0.21	57.7±3.8	1.1±0.4
S2	18±0.7	6.8±0.4	7.4±0.7	3.1±0.5	0.06±0.01	4.4±0.2	82.05±2.9	0.9±0.2
S3	20.7±0.4	7.5±0.4	4.6±0.4	0.9±0.2	0.5±0.02	6.6±0.7	79.5±6.2	0.8±0.2

temperature, and water quality. Macroinvertebrate numbers show marked variations throughout the study year, highlighting a temporal dynamic influenced by both seasonal natural factors and local anthropogenic pressures. The monthly averages of macroinvertebrate numbers during the two seasons are presented in Figure 4. This figure shows that the upstream site (Site 1) has, on average, higher populations than the intermediate and downstream sites. However, the variation in populations between the two seasons (rainy season and dry season) is not statistically significant ($p > 0.05$), suggesting some seasonal stability in the abundance of benthic communities. A general trend of decreasing average populations is also observed from upstream to downstream of the Cirhanyobowa River, likely reflecting the increasing influence of anthropogenic disturbances and changes in physicochemical conditions along the watercourse. 3.2. Physicochemical Characteristics of the Sites Eight physicochemical parameters were studied, and their averages are presented in Table 2. These are temperature (°C), potential of hydrogen (pH), dissolved oxygen (mg/L), calcium (mg/L), total phosphorus (µmol/L), total nitrogen (µmol/L), depth (cm), and water current velocity (m/s), measured at the different sampling sites.

The temperature increases significantly from upstream to downstream, rising from 14.6 ± 0.4 °C at site 1 to 20.7 ± 0.4 °C at site 3 ($p < 0.05$).This temperature increase downstream may result from greater sun exposure due to less vegetation cover and shallower river depth.pH also varies between sites: it is slightly acidic to neutral at site 1 (6.9 ± 0.3) and site 2 (6.8 ± 0.4), then becomes slightly alkaline at site 3 (7.5 ± 0.4), which could be related to inputs of organic matter or increased biological activity downstream. Dissolved oxygen decreases significantly downstream, with a high concentration upstream (8.9 ± 2.7 mg/L) and a notable decrease downstream (4.6 ± 0.4 mg/L).This reduction could be explained by the degradation of water quality due to increased organic load and pollutants, leading to increased oxygen consumption by decomposition processes.

Calcium is present at a higher concentration at the median site (3.1 ± 0.5 mg/L), which could be attributed to specific geological or anthropogenic inputs in this area.Total phosphorus and total nitrogen show a marked increase downstream, reaching 0.5 ± 0.02 µmol/L and 6.6 ± 0.7 µmol/L, respectively, at site 3. These excess nutrients are often associated with agricultural runoff, wastewater, and other human activities, promoting eutrophication and affecting water quality. In terms of physical characteristics, site 2 is the deepest (82.05 ± 2.9 cm), while the current velocity is highest upstream (1.1 ± 0.4 m/s), reflecting a hydrodynamic profile typical of a sloping river where the flow is faster upstream and slows downstream due to the decrease in gradient and the increase in depth. Overall, these physicochemical variations reflect an ecological gradient along the Cirhanyobowa River, where conditions are gradually deteriorating under the influence of human activities, potentially impacting aquatic biodiversity and habitat quality.

DISCUSSION

Analysis of the benthic macroinvertebrate structure of the Cirhanyobowa River reveals significant species diversity, marked by a predominance of Trichoptera, particularly the family *Lepidostomatidae*. This contrasts with patterns observed in other regions, such as in Morocco, where Chironomidae (Diptera) dominate under disturbed conditions (El Imrani& Kettani, 2012). Such differences reflect local variations in pollution sources, land use, and habitat characteristics, emphasizing the need for region-specific ecological assessments (Mureithi *et al*., 2025). The comparison between the upstream reference site—situated in a protected forest zone—and the mid- and downstream sites subjected to intense human pressures reveals clear environmental gradients shaping benthic macroinvertebrate assemblages. Habitat structure, physicochemical water quality, and riparian land-use practices emerge as key determinants, consistent with previous findings indicating that macroinvertebrates are highly sensitive to watershed-scale disturbances (Woodcock & Huryn, 2007; Ndatimana *et al*., 2025). Upstream, cool and well-oxygenated waters favor sensitive taxa such as Ephemeroptera and Trichoptera, which are known indicators of good water quality and stable environmental conditions (Qiu, 2013). The physicochemical profile—near-neutral pH, dissolved oxygen above 9 mg/L, and low nutrient loads—mirrors conditions documented in other minimally disturbed tropical streams (Foto Menbohan *et al*., 2013; Tchakonté, 2016; Harissou *et al*., 2023). These characteristics explain the abundance of pollution-sensitive rheophilic species. Progressing downstream, the river shows signs of ecological deterioration. Higher temperatures, more alkaline pH values, reduced dissolved oxygen, and elevated nitrogen and phosphorus concentrations suggest inputs from agricultural runoff, domestic wastewaters, and livestock activities. Similar degradation patterns with increasing pollution tolerance, including dominance of Chironomidae, Coenagrionidae, and Oligochaeta, have been reported in multiple African rivers (Onana *et al*., 2016; Ngoay-Kossy *et al*., 2018; Ouma *et al*., 2025). Reduced flow velocity and greater depth downstream also promote organic matter accumulation and eutrophic conditions, a trend widely observed in tropical streams facing anthropogenic pressures (Tchakonté *et al*., 2015; Birám à Ngon *et al*., 2024).

The overall taxonomic richness (57 species) observed along the Cirhanyobowa River is comparable to other river systems in Central and East Africa (Madomguia *et al*., 2016; Norbert *et al*., 2017) but remains lower than that reported in relatively undisturbed forested catchments in Cameroon and Rwanda (Birám à Ngon *et al*., 2024; Ndatimana *et al*., 2025). This moderate diversity likely reflects cumulative stressors such as agricultural encroachment, habitat simplification, and nutrient enrichment. Recent advances in biomonitoring offer promising tools that could complement conventional macroinvertebrate sampling. In particular, environmental DNA (eDNA) metabarcoding enables higher taxonomic resolution, detection of cryptic taxa, and rapid biodiversity assessment, proving useful in dynamic tropical systems (Zinger *et al*., 2019;

Mureithi *et al*., 2025). Coupled with multivariate statistics and emerging biotic indices developed in Africa (Assefa *et al*., 2023), such approaches can support more accurate and scalable assessments of river ecosystem health. Overall, this study confirms the effectiveness of benthic macroinvertebrates as bioindicators of anthropogenic impacts in tropical African rivers. The progressive changes in community composition and environmental parameters from upstream to downstream highlight the urgent need for integrated watershed management. Reducing agricultural runoff, limiting domestic pollution inputs, and conserving upstream forest ecosystems are critical strategies for preserving aquatic biodiversity and ensuring the ecological integrity of the Cirhanyobowa River.

CONCLUSION

The assessment of the Cirhanyobowa River reveals a clear ecological gradient driven by increasing anthropogenic pressures from upstream to downstream. The upstream forested area maintains good ecological integrity, characterized by high dissolved oxygen, low nutrient concentrations, and the dominance of pollution-sensitive taxa such as Ephemeroptera and Trichoptera. Moving downstream, progressive deterioration in physicochemical quality—including elevated nutrient loads, higher temperatures, and reduced oxygen—corresponds with a shift toward pollution-tolerant groups such as Chironomidae, Oligochaeta, and Coenagrionidae. This pattern reflects the combined impacts of agricultural runoff, domestic effluents, and riparian habitat degradation. The structure and composition of benthic macroinvertebrate communities proved to be highly responsive to these environmental changes, confirming their value as bioindicators for evaluating the ecological status of tropical African rivers. The moderate overall diversity and the functional shifts observed highlight the vulnerability of the Cirhanyobowa River to increasing anthropogenic disturbances. Ensuring the conservation of upstream forest areas and improving downstream watershed management are essential measures for preserving ecological integrity and maintaining water quality.

This study contributes new knowledge on the ecological status of a poorly documented river system in the Lake Kivu basin and reinforces the importance of using benthic macroinvertebrates for biomonitoring in tropical regions facing rapid land-use change.

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