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Seasonal resilience of benthic macroinvertebrate communities in a highly urbanized tropical river: The Case of the Lukina River (Kinshasa, DRC)

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Abstract

This study aimed to assess the seasonal resilience of benthic macroinvertebrate communities in the Lukina River, a highly urbanized tropical watercourse in the city of Kinshasa (DRC). The analyses focused on water physicochemical parameters, benthic community structure, ecological indices, as well as the relationships between environmental variables and biological assemblages during both the dry and rainy seasons. Physicochemical results showed mean temperatures of 24.5 ± 1.47 °C in the dry season and 27.6 ± 0.79 °C in the rainy season. Mean conductivity ranged from 150 ± 46.4 µS/cm to 158 ± 56.4 µS/cm, respectively. Dissolved oxygen concentrations remained low during both seasons, averaging 2.46 ± 1.08 mg/L in the dry season and 2.86 ± 0.86 mg/L in the rainy season, reflecting significant organic pollution conditions. High values of BOD_5 (21.8 ± 2.84 mg/L in the dry season; 19.2 ± 1.98 mg/L in the rainy season), COD (25.2 ± 3.81 mg/L; 20.2 ± 3.62 mg/L), nitrates (25.5 ± 13.7 mg/L; 20.9 ± 11.3 mg/L), and phosphates (4.54 ± 1.76 mg/L; 2.05 ± 0.44 mg/L) indicate substantial nutrient enrichment of the system. In total, 1,792 individuals belonging to 15 families were recorded in the dry season, compared to 2,085 individuals across 11 families in the rainy season, representing an overall abundance increase of 16.4%. Benthic communities were heavily dominated by Chironomidae, accounting for up to 94% of the abundance at station Luk1 in the dry season and over 55% across all stations during the rainy season. Tubificidae, Lumbriculid, and Physical were also abundant at the most disturbed stations. Diversity indices revealed a relative improvement in communities during the rainy season. Shannon index values ranged from 0.32 to 1.99 in the dry season and from 1.25 to 1.51 in the rainy season. Palou's evenness values were generally above 0.60 during the rainy season, reflecting a more homogeneous distribution of taxa. Multivariate analyses (Bray–Curtis, UPGMA, and NMDS) demonstrated a seasonal structuring of benthic assemblages. Rainy season stations exhibited relatively homogeneous communities, whereas dry season stations were more differentiated. The low seasonal similarities observed (0.175 to 0.392) indicate limited ecological resilience. Principal Component Analysis (PCA) showed that nitrates, phosphates, conductivity, and turbidity were the main factors influencing benthic community structure. Overall, the results indicate that the Lukina River remains highly subject to urban anthropogenic pressures. Despite a slight improvement in ecological conditions during the rainy season, benthic assemblages remain dominated by pollution-tolerant taxa, reflecting low ecological resilience in this urbanized river system.

Keywords: Benthic macroinvertebrates; Ecological resilience; Lukunga river; Organic pollution; Seasonal variation

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1. Introduction

Rapid urbanization constitutes one of the primary drivers of aquatic ecosystem transformation worldwide. Soil impermeabilization, untreated domestic wastewater discharges, and alterations to hydrologic regimes profoundly alter the structure and functioning of urban streams and rivers (Paul and Meyer, 2001). These alterations lead to a suite of ecological symptoms known as the "urban stream syndrome," which is characterized by physicochemical degradation, habitat simplification, and a reduction in biodiversity (Walsh et al., 2005).

In tropical regions, these effects are amplified by the high seasonal variability of the hydrologic regime. Intense rainfall events cause massive pollutant flushing, increased turbidity, and substrate instability, thereby disrupting biological communities (Dudgeon, 2011). Unlike temperate systems, tropical rivers exhibit marked seasonal dynamics that can play a decisive role in structuring benthic communities.

Benthic macroinvertebrates are widely recognized as excellent bioindicators of the ecological quality of watercourses due to their varying sensitivity to environmental disturbances, relatively long-life cycles, and limited mobility (Boada et al., 2006). Shifts in their taxonomic composition rapidly reflect changes in the physicochemical and hydro morphological conditions of the environment.

Beyond the descriptive assessment of biodiversity, understanding community dynamics requires incorporating the concept of ecological resilience. Introduced by Holling (1973), this concept refers to the capacity of an ecosystem to absorb a disturbance, reorganize, and maintain its essential functions. In urban river ecosystems, resilience can manifest as the ability of benthic communities to recover following seasonal hydrological disturbances.

Several studies conducted in temperate regions have shown that urban disturbances reduce biological diversity and favor tolerant taxa, such as Chironomidae and certain Oligochaeta (Walsh et al., 2005). However, data regarding urban tropical rivers, particularly in Central Africa, remain extremely limited. This knowledge gap is concerning given the accelerated urbanization of African metropolises.

In Kinshasa, the capital of the Democratic Republic of the Congo, the Lukunga River flows through highly urbanized areas subjected to intense anthropogenic pressures. Despite its ecological and socioeconomic importance, few studies have analyzed the seasonal dynamics of its benthic communities through the lens of ecological resilience.

This study aims to assess the seasonal resilience of benthic macroinvertebrate communities in the Lukunga River by comparing their structure between the dry and rainy seasons, and by examining their relationships with physicochemical parameters. We formulate the following hypotheses: (1) the rainy season induces a decrease in species richness; (2) tolerant taxa dominate following hydrological disturbances; and (3) certain community components exhibit relative stability, reflecting an ecological resilience mechanism.

This research aims to fill a scientific gap concerning the ecological dynamics of tropical urban rivers in Central Africa and to provide useful insights for the sustainable management of river ecosystems in contexts of rapid urbanization.

1.1. Study Area

The Lukina River is located in the city-province of Kinshasa, the capital of the Democratic Republic of the Congo. It belongs to the hydrographic network of the Congo River basin and flows through several urban and peri-urban areas subjected to growing anthropogenic pressure linked to population growth and rapid urbanization (Kamb, 2013; Sisa et al., 2018). It flows through the southwestern part of Kinshasa, draining neighborhoods characterized by domestic, agricultural, and commercial activities. It receives numerous diffuse inputs from urban runoff, untreated domestic discharges, and soil erosion factors likely to influence water quality and benthic habitat structure (Kamb, 2018).

The climate of Kinshasa is humid tropical, characterized by two distinct main seasons: a rainy season (roughly October to May) and a dry season (roughly June to September). Average annual rainfall generally exceeds 1,200 mm, with intense precipitation events.

The river substrate is heterogeneous, consisting of sandy, muddy, and occasionally gravelly fractions depending on the station. Riparian vegetation is highly degraded in urbanized zones, although some reaches maintain partial vegetative cover.

In the framework of this study, several stations were selected along the river's course to represent a gradient of anthropogenic pressures. These stations vary in terms of channel width, depth, flow velocity, and the intensity of surrounding human activities.

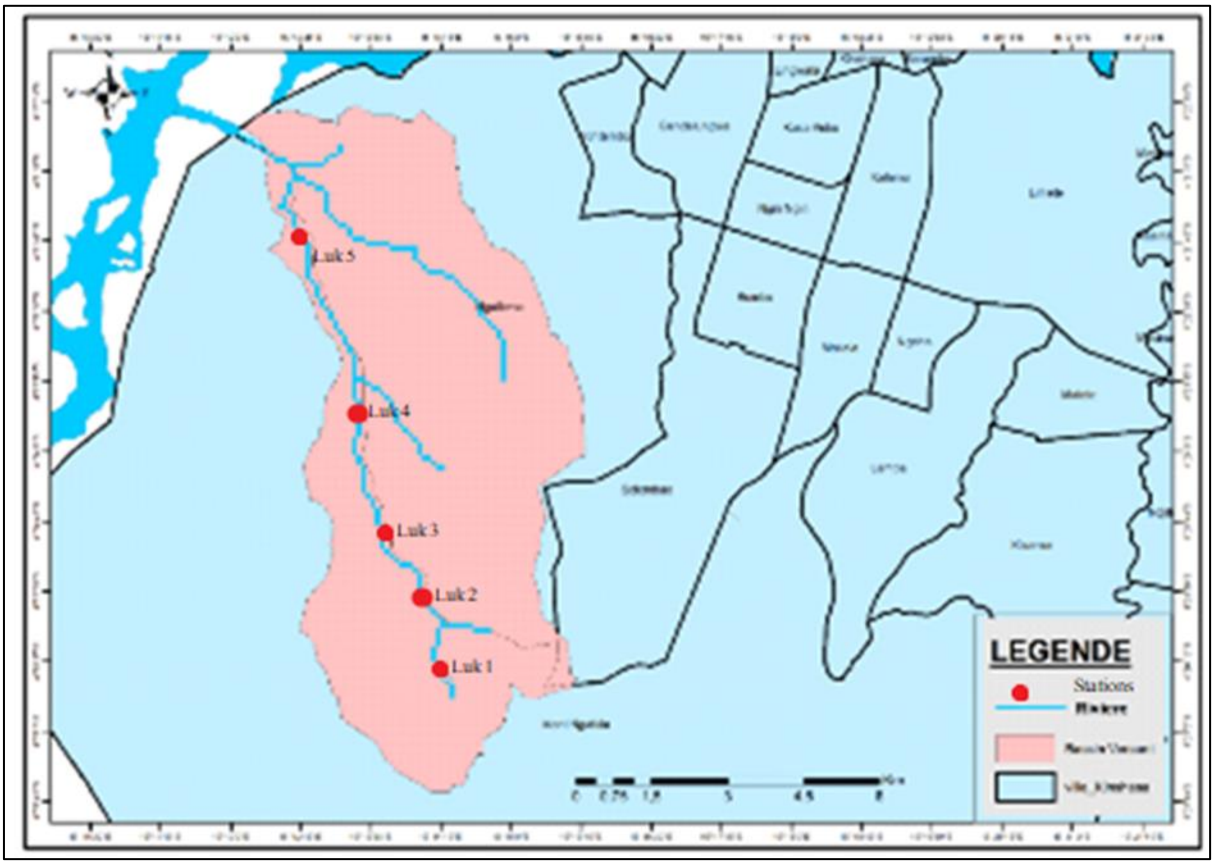


Figure 1 Location of the Lukunga River and the study stations

2. Methods

2.1. Study Design and Sampling Period

The study was conducted in 2024 during two contrasting hydrological periods: the dry season and the rainy season. Sampling was carried out at the different selected stations along the Lukunga River.

Each station was subjected to repeated sampling in order to ensure the spatial representativeness of the data. Physicochemical measurements and biological sampling were performed simultaneously to allow the analysis of relationships between environmental variables and benthic communities.

2.2. Assessment of Physicochemical Parameters

2.2.1. Physical Parameters

Five physical parameters were measured directly in the field (in situ) due to their high sensitivity to environmental conditions and their variability, which may significantly influence the interpretation of the results. These parameters included temperature (°C), conductivity at 20°C (µS/cm), turbidity (Nephelometric Turbidity Units), oxidation-reduction potential (mV), and pH. All these parameters (temperature, conductivity, turbidity, redox potential, and pH) were determined using a SISCO-WQT-7L multiparameter probe.

2.2.2. Chemical Parameters

Dissolved oxygen concentration was measured in situ using an Oxi 315i/7SET oximeter. The other chemical parameters were analyzed in the laboratory at the General Commission for Atomic Energy (CGEA/CREN-K) using water samples collected in the field.

Analyses were performed using a HACH DR/2400 spectrophotometer to quantify the following elements: ammonium (NH_4^+, mg/L), nitrites (NO_2^-, mg/L), nitrates (NO_3^-, mg/L), and phosphates (PO_4^{3-}, mg/L).

Before analysis, water samples were filtered using StonyLab filter papers with a pore diameter of 50 µm. Specific reagents corresponding to each parameter were then added, and the appropriate program (Hach Program, PH) was selected on the spectrophotometer to determine the concentration of the targeted element or ion.

Biochemical Oxygen Demand over 5 days (BOD_5, mg/L) and Chemical Oxygen Demand (COD) were determined after five days of incubation in a thermostatic chamber under standardized conditions (temperature of 20°C, in darkness, and protected from air exposure).

2.3. Sampling of Benthic Macroinvertebrates

Benthic macroinvertebrates were collected using a multihabitat approach to account for substrate heterogeneity. A Surber net (500 µm mesh size) was used for sampling in flowing water areas. At each station, several replicates were collected while covering the different substrate types present (sand, mud, gravel). The sampled area was standardized to allow comparisons among stations and seasons.

In the laboratory, samples were manually sorted using fine forceps and white trays. Benthic macroinvertebrates were identified under a stereomicroscope to the family taxonomic level, in accordance with common bioindication practices (Bonada et al., 2006).

Specimens were identified at the Hydrobiology Laboratory of the National Pedagogical University using the identification keys proposed by Durand and Lévêque (1980), Mary (2010), Evrard (2001), and Tachet et al. (2010).

2.4. Data Analysis

The structure of benthic macroinvertebrate communities was analyzed using classical alpha diversity indicators and multivariate approaches to assess seasonal stability and environment–biology relationships.

Taxonomic richness (S), defined as the total number of families observed per station and per season, was used as a primary measure of community complexity (Magurran, 2004). Although this indicator does not account for abundance distribution, it remains a robust and widely used measure in stream ecology (Allan and Castillo, 2007).

Diversity was estimated using the Shannon–Wiener diversity index (H'), calculated according to the formula: H'= , where Pi represents the relative proportion of family iii in the sample (Shannon, 1948). This index simultaneously integrates richness and the evenness of relative abundances and is recognized for its sensitivity to dominance changes induced by environmental disturbances (Magurran, 2004; Bonada et al., 2006).

Pielou's evenness index (J) was calculated to evaluate the degree of uniformity in the distribution of individuals among families: ($J' = H'/H'_{max}$ où $H'_{max} = \log_2 S$) (Pielou, 1966). A decrease in evenness may indicate an increased dominance of tolerant taxa, a phenomenon frequently observed in degraded systems.

Seasonal comparisons (dry season and rainy season) of biological variables were performed after testing the normality of distributions using the Shapiro–Wilk test. Given the generally non-normal nature of ecological data, non-parametric Kruskal–Wallis H tests were used to compare diversity indices, taxonomic richness, and total abundance between seasons (Zar, 2010). The statistical significance threshold was set at $\alpha = 0.05$. To complement the statistical analysis, relative seasonal variations were expressed as percentages to estimate the magnitude of the observed changes.

Community stability and resilience were evaluated through the analysis of changes in taxonomic composition. A similarity matrix based on the Bray–Curti's index was constructed from abundance data. This index is particularly suitable for quantitative ecological data because it is minimally influenced by joint absences and sensitive to variations in relative abundance (Legendre and Legendre, 2012). High similarity values between seasons were interpreted as indicative of relative community stability. Hierarchical cluster analysis (UPGMA method) was performed to identify station groupings according to their faunal composition (Clarke and Warwick, 2001). When appropriate, non-metric multidimensional scaling (NMDS) was applied to represent seasonal differences within a reduced multivariate space, a robust method for analyzing non-linear ecological assemblages (Legendre and Legendre, 2012).

Seasonal resilience was assessed by examining the persistence of families between seasons, variations in the abundance of dominant taxa, and the degree of overall similarity. According to the conceptual framework proposed by Holling (1973), a community exhibiting low structural variation despite marked environmental fluctuations was considered relatively resilient.

Relationships between physicochemical parameters and community structure were explored using Principal Component Analysis (PCA) performed on standardized environmental variables in order to identify the main gradients structuring the system (Legendre and Legendre, 2012). Associations between biological variables (richness, diversity, abundance) and physicochemical parameters were evaluated using Spearman's correlation coefficient (ρ), which is appropriate for non-parametric data (Zar, 2010).

Hierarchical cluster analysis (UPGMA method) based on the Bray–Curti's similarity matrix was also conducted to identify seasonal groupings of stations. This approach allows visualization of the spatial and temporal structuring of communities (Clarke and Warwick, 2001).

All statistical analyses were performed using Past software version 4.03, which is commonly used in ecology for the analysis of paleoecological and multivariate biological data.

3. Results

3.1. Physicochemical Parameters of Water

The physicochemical parameters of water recorded during the two seasons are presented in Tables 1 and 2.

Table 1 Variation of Physicochemical Parameters during the Dry Season

Parameters	**Station**					
	Luk1	Luk2	Luk3	Luk4	Luk5	Mean
Temperature (°C)	25.2	24.1	24.4	22.4	26.4	24.5±1.47
Conductivity (µS/cm)	143	192	174	73	167	150±46.4
pH	6.92	7.12	7.23	7.5	7.62	7.28±0.28
Turbidity (NTU)	73	96	88	73	82	82.4±9.91
Redox (mV)	23	47	85	149	68	74.4±47.7
Dissolved O_2 (mg/L)	1.67	1.89	3.63	3.64	1.48	2.46±1.08
BOD_5 (mg/L)	18.7	19.5	22.26	22.86	25.8	21.8±2.84
COD (mg/L)	25.6	24.6	22.7	21.8	31.5	25.2±3.81
Ammonium (mg/L)	0.12	0.07	0.102	0.108	0.134	0.11±0.02
Nitrate (mg/L)	41.4	34.86	11.14	11.37	28.52	25.5±13.7
Phosphates (mg/L)	6.1	5.67	3.12	2.19	5.6	4.54±1.76

Table 2 Variation of Physicochemical Parameters during the Rainy Season

Parameters	Station					
	Luk1	Luk2	Luk3	Luk4	Luk5	Mean
Temperature (°C)	27	27.8	27.8	26.8	28.8	27.6±0.79
Conductivity (µS/cm)	114	134	189	111	242	158±56.4
pH	6.22	7.9	7.86	7.4	7.9	7.46±0.72
Turbidity (NTU)	51	74	73	71	120	77.8±25.4
Redox (mV)	88	79	147	168	72	111±43.6
Dissolved O_2 (mg/L)	2.04	2.83	3.31	4.06	2.05	2.86±0.86
BOD_5 (mg/L)	16.5	17.9	19.8	20.2	21.5	19.2±1.98
COD (mg/L)	19.8	21.5	17.26	16.8	25.7	20.2±3.62
Ammonium (mg/L)	0.07	0.06	0.05	0.04	0.05	0.05±0.01
Nitrate (mg/L)	33.4	30	10.4	8.4	22.5	20.9±11.3
Phosphates (mg/L)	2.32	2.14	1.9	1.38	2.51	2.05±0.44

Water temperature ranged from 22.4 to 26.4 °C during the dry season, with a mean value of 24.5 ± 1.47 °C. During the rainy season, it fluctuated between 26.8 and 28.8 °C, with an average of 27.6 ± 0.79 °C. The highest values were recorded at station Luk5 during both seasons.

Conductivity values ranged from 73 to 192 µS/cm in the dry season, with a mean of 150 ± 46.4 µS/cm. During the rainy season, conductivity varied between 111 and 242 µS/cm, with an average of 158 ± 56.4 µS/cm. The maximum peak was observed at Luk5 during the rainy season (242 µS/cm), whereas the lowest value was recorded at Luk4 during the dry season (73 µS/cm).

Turbidity fluctuated between 73 and 96 NTU during the dry season, with a mean value of 82.4 ± 9.91 NTU. In the rainy season, values ranged from 51 to 120 NTU, with an average of 77.8 ± 25.4 NTU. The highest turbidity value was observed at Luk5 during the rainy season.

pH values ranged from 6.92 to 7.62 during the dry season, with a mean of 7.28 ± 0.28. During the rainy season, values fluctuated between 6.22 and 7.9, with an average of 7.46 ± 0.72. Overall, pH remained neutral to slightly alkaline across all stations.

Redox potential varied from 23 to 149 mV during the dry season, with a mean of 74.4 ± 47.7 mV. In the rainy season, it fluctuated between 72 and 168 mV, with an average of 111 ± 43.6 mV. The highest values were recorded at Luk4 during both seasons.

Dissolved oxygen showed low concentrations ranging from 1.48 to 3.64 mg/L during the dry season, with a mean of 2.46 ± 1.08 mg/L. During the rainy season, values ranged between 2.04 and 4.06 mg/L, with an average of 2.86 ± 0.86 mg/L. The maximum concentration was observed at Luk4 during the rainy season.

BOD_5 values ranged from 18.7 to 25.8 mg/L during the dry season, with a mean of 21.8 ± 2.84 mg/L. During the rainy season, they fluctuated between 16.5 and 21.5 mg/L, with an average of 19.2 ± 1.98 mg/L. The highest peaks were recorded at Luk5.

COD values fluctuated between 21.8 and 31.5 mg/L during the dry season, with a mean value of 25.2 ± 3.81 mg/L. During the rainy season, values ranged from 16.8 to 25.7 mg/L, with an average of 20.2 ± 3.62 mg/L. The maximum value was observed at Luk5 during both seasons.

3.2. Distribution of Macroinvertebrates during the Dry Season

Table 3 Distribution of Macroinvertebrates in the Lukunga River during the Dry Season

Classes	Order	Families	Station										N'
			Luk1		Luk2		Luk3		Luk4		Luk5		
			Ni	NI/N	Ni	NI/N	Ni	NI/N	Ni	NI/N	Ni	NI/N	
Insects	Diptera	Chironomidae	1202	0.94	54	0.491	0	0	0	0	0	0	1256
		Culicidae	15	0.01	0	0	0	0	0	0	0	0	15
		Syrphidae	21	0.02	0	0	7	0.076	0	0	0	0	28
	Coleoptera	Hydrophilidae	12	0.01	0	0	0	0	0	0	0	0	12
	Odonata	Libellula	11	0.01	10	0.091	12	0.13	10	0.127	10	0.042	53
		Calopterygid	7	0.01	0	0	0	0	0	0	0	0	7
		Coenagrionid	0	0	0	0	5	0.054	3	0.038	2	0.008	10
		Gomphid	0	0	0	0	0	0	4	0.051	0	0	4
	Hemiptera	Naucorid	0	0	0	0	14	0.152	32	0.405	7	0.03	53
		Neida	0	0	2	0.018	3	0.033	0	0	5	0.021	10
Gastropods	Hygrophila	Physidae	0	0	36	0.327	7	0.076	0	0	4	0.017	47
		Bulinidae	0	0	0	0	0	0	0	0	40	0.169	40
		Lymnaeidae	0	0	0	0	9	0.098	4	0.051	2	0.008	15
Annelids	Haplotaxida	Tubificidae	4	0	0	0	0	0	0	0	106	0.449	110
		Lumbriculid	3	0	0	0	1	0.011	0	0	23	0.097	27
	Arhynchobdellida	Hirudidae	0	0	0	0	2	0.022	0	0	21	0.089	23
Totals			1275		110		92		79		236		1792

Ammonium concentrations ranged from 0.07 to 0.134 mg/L during the dry season, with a mean value of 0.11 ± 0.02 mg/L. During the rainy season, they fluctuated between 0.04 and 0.07 mg/L, with an average of 0.05 ± 0.01 mg/L.

Nitrate concentrations ranged from 11.14 to 41.4 mg/L during the dry season, with a mean of 25.5 ± 13.7 mg/L. During the rainy season, they varied between 8.4 and 33.4 mg/L, with an average of 20.9 ± 11.3 mg/L. The highest concentrations were recorded at Luk1 during both seasons.

Phosphate concentrations ranged from 2.19 to 6.1 mg/L during the dry season, with a mean value of 4.54 ± 1.76 mg/L. During the rainy season, values fluctuated between 1.38 and 2.51 mg/L, with an average of 2.05 ± 0.44 mg/L. The highest concentrations were recorded at Luk1 and Luk5.

From the perspective of total abundance, station Luk1 recorded the highest number of individuals with 1,275 specimens, representing 71.15% of the total abundance recorded during the dry season. It was followed by station Luk5 with 236 individuals (13.17%), then Luk2 with 110 individuals (6.14%), Luk3 with 92 individuals (5.13%), and finally Luk4 with 79 individuals (4.41%).

At the station level, benthic communities were strongly dominated by the family Chironomidae, representing 94% of the total abundance at Luk1 and 49.1% at Luk2. This dominance reflects the importance of organic pollution and trophic enrichment conditions in some stations of the river.

At station Luk1, the dominance of Chironomidae was followed by Syrphidae (2%), while Culicidae, Hydrophilidae, Libellulidae, and Calopterygidae each represented approximately 1% of the total abundance. Tubificidae and Lumbriculidae remained weakly represented.

At station Luk2, after Chironomidae, Physidae constituted the most represented group with 32.7% of the abundance, followed by Libellulidae (9.1%) and Nepidae (1.8%).

At station Luk3, communities appeared more diversified. Naucoridae represented 15.2% of the abundance, followed by Libellulidae (13%), Lymnaeidae (9.8%), Syrphidae and Physidae (7.6% each), Coenagrionidae (5.4%), and Nepidae (3.3%). Lumbriculidae and Hirudidae remained weakly represented.

At station Luk4, Naucoridae largely dominated the assemblages with 40.5% of the individuals, followed by Libellulidae (12.7%), Gomphidae and Lymnaeidae (5.1% each), as well as Coenagrionidae (3.8%).

At station Luk5, Tubificidae constituted the dominant group with 44.9% of the abundance, followed by Bulinidae (16.9%), Lumbriculidae (9.7%), Hirudidae (8.9%), Libellulidae (4.2%), and Naucoridae (3%). The other families remained weakly represented.

Overall, the dry season was characterized by a strong dominance of pollution-tolerant taxa, particularly Chironomidae and Tubificidae, reflecting disturbed ecological conditions and a high organic load in several stations of the Lukunga River.

3.3. Distribution of Macroinvertebrates during the Rainy Season

Table 4 Distribution of Macroinvertebrates in the Lukunga River during the Rainy Season

Class	**Order**	**Families**	**Luk1**		**Luk2**		**Luk3**		**Luk4**		**Luk5**		**N'**
			Ni	NI/N	NI	NI/N	Ni	NI/N	Ni	NI/N	Ni	NI/N	
Insects	Diptera	Chironomidae	310	0.57	270	0.591	250	0.651	240	0.561	153	0.558	1223
		Culicidae	13	0.02	0	0	0	0	0	0	0	0	13
	Odonata	Libellulidae	43	0.08	35	0.077	30	0.078	40	0.093	22	0.08	170
		Coenagrionidae	16	0.03	16	0.035	17	0.044	0	0	0	0	49
	Hemiptera	Naucoridae	27	0.05	23	0.05	25	0.065	32	0.075	0	0	107
	Coleoptera	Hydrophilidae	12	0.02	15	0.033	0	0	16	0.037	0	0	43
Gastropods	Hygrophila	Physidae	17	0.03	30	0.066	15	0.039	22	0.051	15	0.055	99
		Bulinidae	1	0	0	0	0	0	0	0	7	0.026	8
Annelids	Haplotaxida	Tubificidae	60	0.11	40	0.087	32	0.083	45	0.105	45	0.164	222
		Lumbriculidae	22	0.04	28	0.061	15	0.039	33	0.077	32	0.117	130
	Arhynchobdellida	Hirudidae	7	0.01	0	0	0	0	0	0	0	0	7
Totals			542		457		384		428		274		2085

During the rainy season, station Luk1 showed the highest total abundance with 542 individuals, representing 25.99% of the total abundance recorded. It was followed by Luk2 with 457 individuals (21.92%), Luk4 with 428 individuals (20.53%), Luk3 with 384 individuals (18.42%), and Luk5 with 274 individuals (13.14%).

Benthic communities remained dominated by Chironomidae in all stations, with proportions ranging from 55.8% to 65.1% of the total abundance. This generalized dominance indicates the persistence of significant ecological pressure despite the hydrological improvement associated with the rainy season.

At station Luk1, Chironomidae represented 57% of the abundance, followed by Tubificidae (11%), Libellulidae (8%), Naucoridae (5%), Lumbriculidae (4%), and Coenagrionidae (3%). The other families remained weakly represented.

At station Luk2, Chironomidae reached 59.1% of the abundance. They were followed by Tubificidae (8.7%), Libellulidae (7.7%), Physidae (6.6%), Lumbriculidae (6.1%), and Naucoridae (5%).

At station Luk3, Chironomidae represented 65.1% of the abundance. Libellulidae (7.8%), Tubificidae (8.3%), Naucoridae (6.5%), and Coenagrionidae (4.4%) constituted the most important secondary groups.

At station Luk4, the dominance of Chironomidae (56.1%) was followed by Tubificidae (10.5%), Libellulidae (9.3%), Lumbriculidae (7.7%), Naucoridae (7.5%), and Physidae (5.1%).

At station Luk5, Chironomidae represented 55.8% of the abundance. Tubificidae (16.4%) and Lumbriculidae (11.7%) constituted the dominant secondary groups, followed by Libellulidae (8%), Physidae (5.5%), and Bulinidae (2.6%).

Compared with the dry season, rainy-season benthic assemblages appeared relatively more homogeneous and better distributed among stations. However, the persistent dominance of Chironomidae and Annelids indicates the maintenance of degraded ecological conditions associated with significant organic pollution in the Lukunga River.

3.4. Taxonomic Richness, Diversity, and Evenness

Table 5 Ecological Indices of Benthic Communities

Season	Station	N	S	H'	J
Dry season	Luk1	1275	8	0.32	0.15
	Luk2	110	4	1.01	0.73
	Luk3	92	9	1.99	0.90
	Luk4	79	5	1.17	0.73
	Luk5	236	10	1.62	0.70
Rainy season	Luk1	542	11	1.51	0.63
	Luk2	457	8	1.45	0.70
	Luk3	384	7	1.25	0.64
	Luk4	428	7	1.45	0.74
	Luk5	274	6	1.33	0.74

The ecological indices showed an overall improvement in diversity during the rainy season.

During the dry season, station Luk1 exhibited the lowest diversity (H' = 0.32) due to the very strong dominance of Chironomidae. Stations Luk3 and Luk5 showed the highest diversity values, reflecting a better distribution of taxa. During the rainy season, Shannon index values became more homogeneous among stations, with evenness values generally higher than 0.60.

Total abundances increased from 1,792 individuals during the dry season to 2,085 individuals during the rainy season, corresponding to a relative increase of approximately: (2085-1792)/1792 x100

This increase corresponds to approximately 16.4%.

Chironomidae remained dominant during both seasons, reflecting disturbed ecological conditions. However, Odonata, Hemiptera, and some Gastropoda showed higher abundances during the rainy season, indicating a relative improvement in ecological conditions.

3.5. Similarity Analysis and Classification of Stations

The dendrogram obtained using the UPGMA method highlights a spatial and seasonal structuring of benthic macroinvertebrate communities.

Two major ecological groupings can be distinguished:

- First group composed mainly of rainy-season stations, characterized by relatively homogeneous assemblages;
- Second group grouping several dry-season stations, characterized by more differentiated communities dominated by taxa tolerant to organic pollution.

The station Luk1_Dry appears strongly isolated from the other stations due to the exceptional dominance of Chironomidae. This separation reflects a highly disturbed ecological condition.

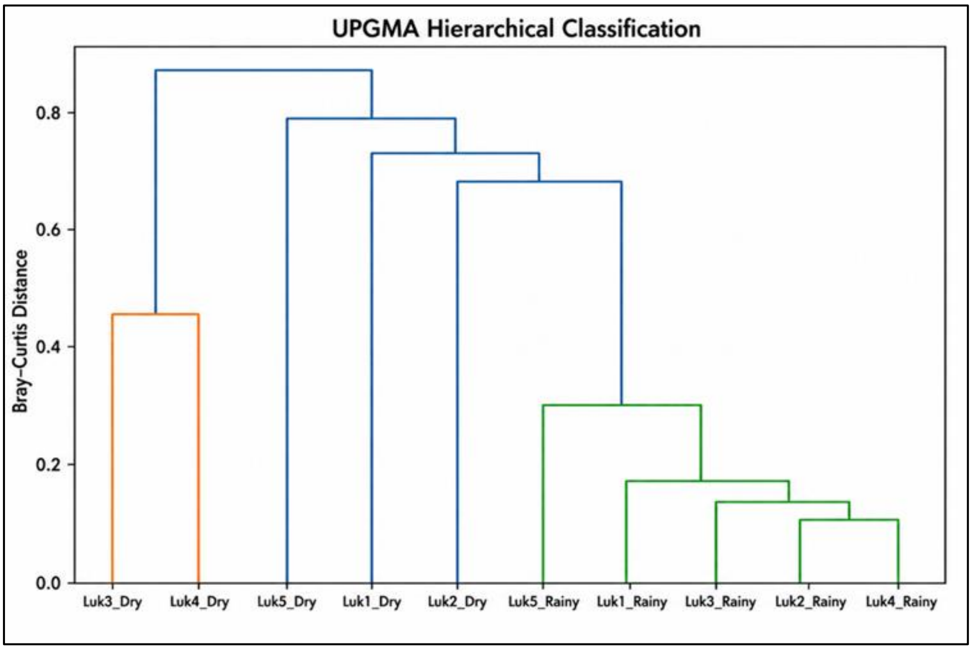


Figure 2 Hierarchical clustering (UPGMA) of Lukunga River stations based on the Bray–Curti's similarity index

The observed groupings suggest that seasonality influences community structure, although local anthropogenic pressures remain a major factor of ecological differentiation.

3.6. Non-metric Multidimensional Scaling (NMDS)

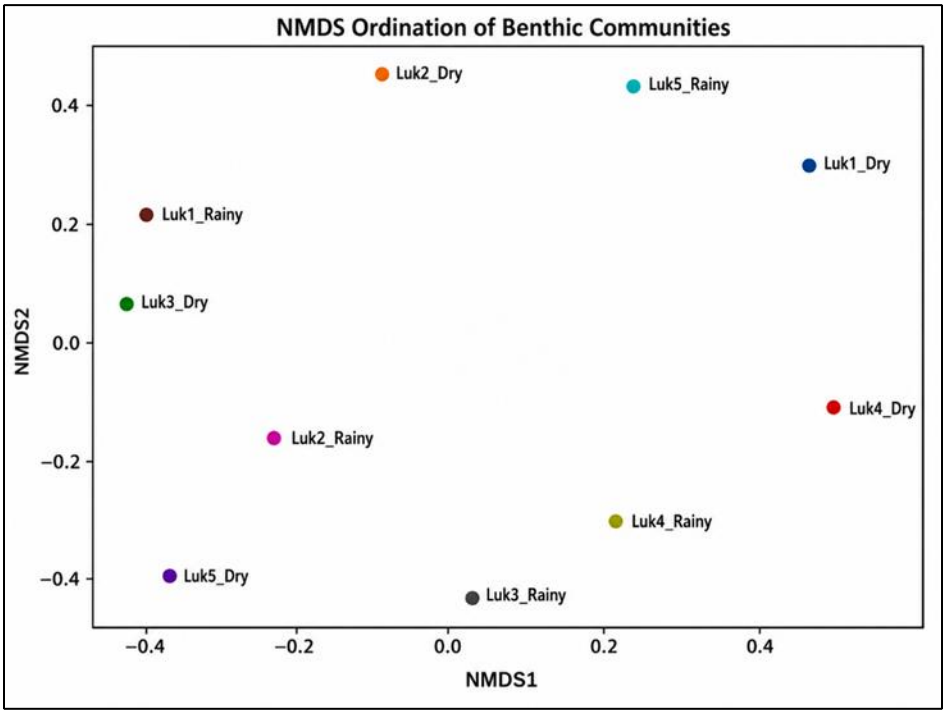


Figure 3 Non-metric multidimensional scaling (NMDS) ordination of benthic communities in the Lukunga River.

The NMDS analysis highlights a partial separation of benthic assemblages according to seasons. Rainy-season stations tended to cluster together in the ordination space, reflecting a greater similarity in taxonomic composition during this period.

Dry-season stations showed greater dispersion, indicating stronger ecological heterogeneity among stations. This variability may be related to the local intensification of anthropogenic disturbances, particularly organic inputs and reduced oxygenation.

The isolated position of certain stations, especially Luk1_Dry, confirms the existence of assemblages strongly dominated by opportunistic and pollution-resistant taxa.

Overall, the ordination reveals a combined influence of seasonality and pollution gradients on the structuring of benthic communities.

3.7. Seasonal Resilience of Benthic Communities

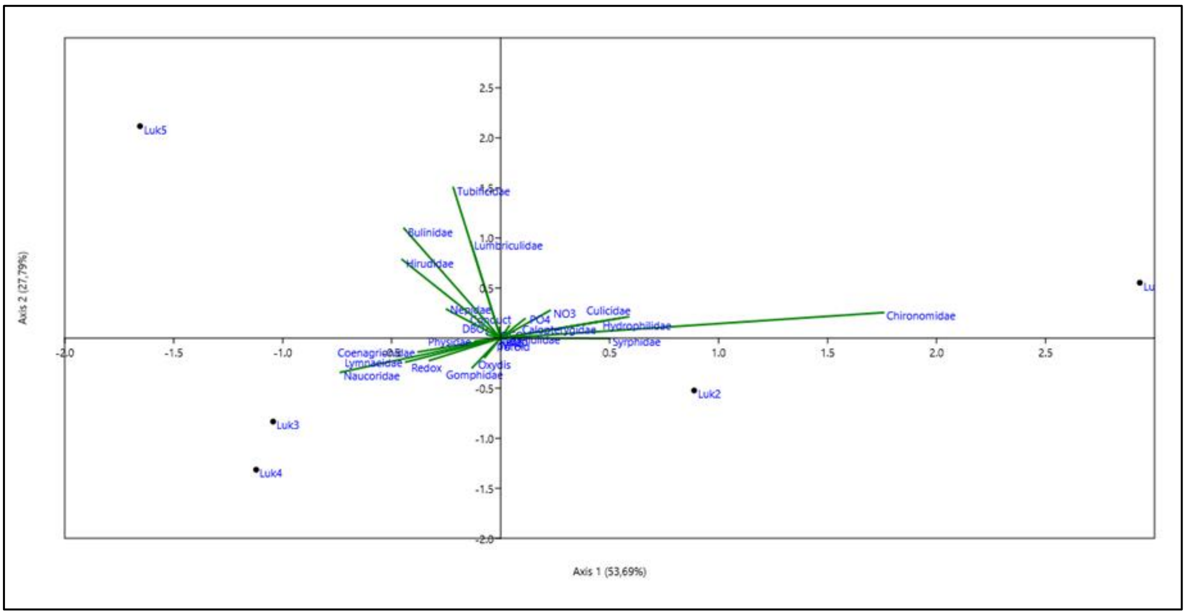
Several families were present during both seasons: Chironomidae, Libellulidae, Naucoridae, Tubificidae, Lumbriculidae, and Physidae. This persistence reflects a certain stability of benthic assemblages despite seasonal fluctuations.

Table 6 Seasonal Resilience of Benthic Communities

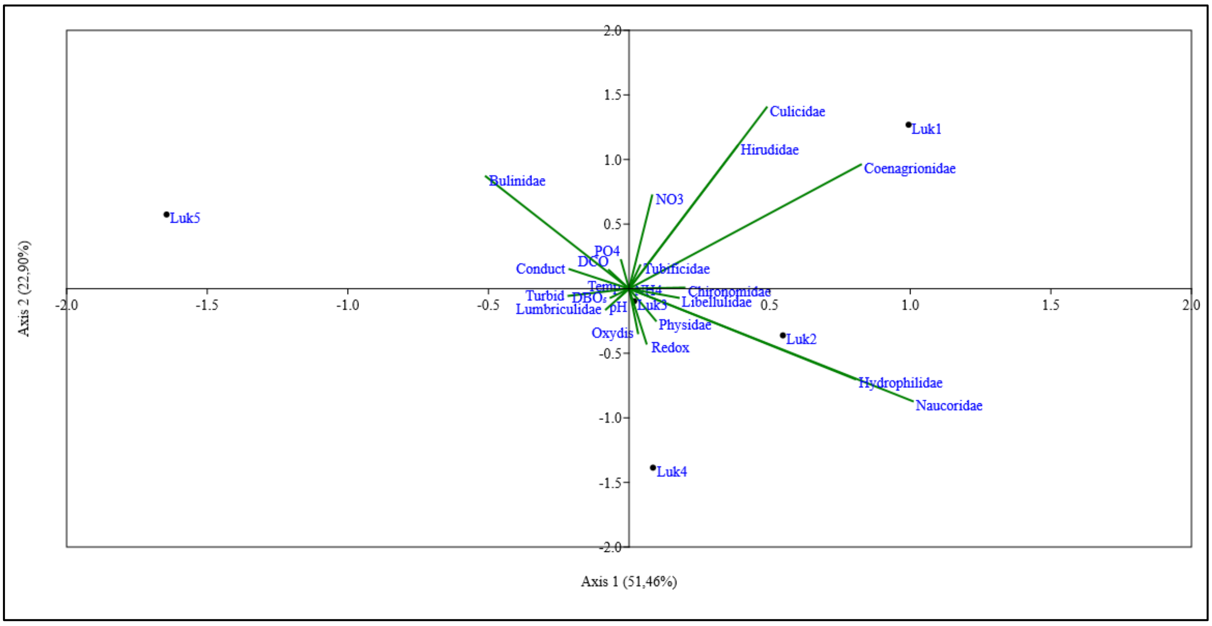
Station	Persistent families	Seasonal similarity	Resilience level
Luk1	6	0.392	Low
Luk2	3	0.336	Low
Luk3	5	0.176	Low
Luk4	2	0.175	Low
Luk5	5	0.360	Low

However, the continuous dominance of tolerant taxa indicates ecological resilience associated with degraded environmental conditions. The weak seasonal differences observed suggest that permanent anthropogenic pressures exert a stronger influence than hydrological variability.

3.8. Relationships between Physicochemical Parameters and Benthic Communities



(A)



(B)

Figure 4 Relationships between physicochemical parameters and benthic communities: (a) dry season; (b) rainy season

Principal Component Analysis (PCA) highlighted the main environmental gradients structuring benthic macroinvertebrate communities in the Lukunga River during the two hydrological seasons.

During the dry season, the first two axes explained 81.49% of the total variance, reflecting a strong ecological structuring of benthic assemblages. The first axis was mainly associated with Chironomidae, Culicidae, Syrphidae, and high nitrate and phosphate concentrations. This configuration reflects the influence of organic and nutrient inputs resulting from anthropogenic activities on community composition. The dominance of Chironomidae at several stations reflects disturbed ecological conditions characterized by high organic loads and low oxygenation. Conversely, Naucoridae, Coenagrionidae, and some Gastropoda appeared negatively correlated with this axis, indicating their relative association with less degraded habitats.

The second axis was strongly dominated by Tubificidae, Lumbriculidae, Hirudidae, and Bulinidae, taxa generally recognized for their tolerance to substrates enriched with organic matter. This organization highlights a secondary gradient related to the accumulation of organic matter and reducing conditions observed at certain stations, particularly downstream.

During the rainy season, the first two axes explained 74.37% of the total variance. The principal axis was positively correlated with Naucoridae, Coenagrionidae, and Hydrophilidae, suggesting a relative improvement in ecological conditions and greater diversification of aquatic habitats due to increased flow rates. However, the negative correlations observed with conductivity and turbidity indicate that some stations remained subjected to significant disturbances linked to urban runoff and suspended matter inputs.

The second axis highlighted the persistent influence of nitrates and certain tolerant taxa such as Culicidae and Hirudidae. Although Chironomidae remained abundant during this period, their relatively weak contribution to the principal axes suggests a more homogeneous distribution among stations, probably favored by the hydrological dilution effect.

Overall, PCA results indicate that physicochemical parameters, particularly nutrients, conductivity, turbidity, and dissolved oxygen, exert a major influence on the structuring of benthic communities in the Lukunga River. Assemblages remained largely dominated by pollution-tolerant taxa, reflecting the importance of anthropogenic pressures in this highly urbanized river system. However, the rainy season appears to induce a slight improvement in ecological conditions and a relative homogenization of benthic communities.

4. Discussion

The physicochemical results obtained in the Lukunga River reveal an ecosystem strongly influenced by anthropogenic pressures associated with the urbanization of the city of Kinshasa. The variations observed between seasons reflect both the effect of tropical hydrological fluctuations and the impact of domestic, organic, and urban inputs on water quality.

Temperatures recorded in the Lukunga River remained relatively high during both seasons, with averages of 24.5 °C during the dry season and 27.6 °C during the rainy season. These values correspond to the thermal characteristics of tropical streams exposed to strong sunlight and limited riparian cover. The increase in temperatures during the rainy season could be related to intensified surface runoff and reduced vegetation shading in urbanized sectors. High temperatures directly influence dissolved oxygen solubility and the structure of aquatic communities.

The conductivity values observed, particularly the high value at Luk5 during the rainy season (242 µS/cm), reflect significant mineralization of the water. This increase may be attributed to domestic wastewater inputs, urban discharges, and soil leaching during rainfall events. Conductivity is considered a relevant indicator of ionic enrichment in aquatic environments subjected to anthropogenic activities.

The pH remained generally neutral to slightly alkaline at all stations. These values remain compatible with the development of many tropical benthic communities. However, the variations observed among stations probably reflect the influence of organic matter and local biological processes.

The high turbidity values observed, particularly during the rainy season, indicate substantial suspended matter inputs related to urban runoff and bank erosion. High turbidity levels can reduce light penetration, modify benthic habitats, and disrupt aquatic trophic chains. The high turbidity recorded at Luk5 suggests significant degradation of aquatic habitats at this station.

The low dissolved oxygen concentrations observed during both seasons, with averages below 3 mg/L, indicate degraded ecological conditions. Such low concentrations generally reflect significant organic pollution and strong bacterial activity associated with organic matter decomposition. The relatively higher values observed at Luk4 could be explained by better water circulation and greater oxygenation.

The high BOD_5 and COD values confirm the existence of a substantial organic load in the Lukunga River. The peaks recorded at Luk5 probably reflect the influence of domestic discharges and urban effluents. High BOD_5 values are generally associated with strong oxygen consumption by decomposer microorganisms. This situation favors the development of pollution-tolerant organisms and reduces the presence of sensitive taxa.

The high nitrate and phosphate concentrations observed at several stations reflect significant nutrient enrichment of the system. The high nitrate concentrations recorded at Luk1 during both seasons could result from domestic wastewater inputs and urban waste leaching. Excessive accumulation of nitrogen and phosphorus is recognized as one of the principal factors responsible for eutrophication in urban aquatic ecosystems.

The analysis of benthic communities showed a strong dominance of Chironomidae during both seasons, particularly at station Luk1 where they represented 94% of the abundance during the dry season. This dominance is characteristic of environments subjected to strong organic pollution and low oxygenation. Chironomidae are recognized as highly tolerant taxa capable of colonizing heavily disturbed habitats through physiological adaptations to low oxygen concentrations.

The high abundance of Tubificidae and Lumbriculidae at Luk5 also confirms the existence of a significant organic load at this station. These annelids are frequently associated with substrates rich in organic matter and hypoxic environments. Their important presence reflects advanced degradation of benthic habitats.

Conversely, stations Luk3 and Luk4 showed relatively higher taxonomic diversity, particularly with the presence of Naucoridae, Coenagrionidae, Gomphidae, and Libellulidae. These groups are often associated with better oxygenated and ecologically diversified habitats. This situation suggests the existence of relatively favorable microhabitats despite the overall anthropogenic pressures exerted on the river.

The increase in benthic abundances during the rainy season (+16.4%) may be related to the expansion of available habitats and the pollutant dilution effect during periods of heavy rainfall. Similar observations have been reported in several African tropical rivers where the rainy season temporarily promotes improved ecological conditions. However, the persistent dominance of Chironomidae and Tubificidae indicates that this improvement remains limited.

The Shannon diversity and evenness indices showed an overall improvement during the rainy season. The very low diversity observed at Luk1 during the dry season (H' = 0.32) reflects the strong dominance of a limited number of tolerant taxa, a situation typical of highly disturbed environments. The increase in diversity values during the rainy season suggests a relative homogenization of communities under more favorable hydrological conditions.

Multivariate analyses (UPGMA and NMDS) confirmed a seasonal structuring of benthic communities. Rainy-season stations showed relatively more homogeneous assemblages, whereas dry-season stations appeared more dispersed and ecologically differentiated. This organization reflects the combined effect of pollution gradients and hydrological variability on benthic assemblage structure.

The low levels of seasonal similarity observed in resilience analyses indicate that benthic communities remain strongly influenced by environmental disturbances. However, the persistence of several families such as Chironomidae, Tubificidae, Physidae, and Libellulidae during both seasons suggests a certain functional stability of assemblages. This persistence may be interpreted as a form of ecological resilience, although dominated by tolerant taxa adapted to disturbed conditions.

Principal Component Analysis showed that nitrates, phosphates, conductivity, and turbidity constitute the principal factors structuring benthic communities in the Lukunga River. The strong association of Chironomidae with these variables confirms their affinity for eutrophic and organically enriched environments. Conversely, Naucoridae and Coenagrionidae appeared associated with relatively less disturbed stations. These observations corroborate studies emphasizing the importance of benthic macroinvertebrates as bioindicators of ecological water quality.

5. Conclusion

This study assessed the seasonal resilience of benthic macroinvertebrate communities in the Lukunga River, which is subjected to strong anthropogenic pressures related to the urbanization of Kinshasa. The results obtained show that the physicochemical parameters of the water reflect a disturbed ecological condition characterized by low oxygenation, high organic load, and significant nutrient enrichment.

The low dissolved oxygen concentrations associated with high BOD_5, COD, nitrate, and phosphate values indicate advanced degradation of water quality. The most disturbed stations, particularly Luk1 and Luk5, showed the highest dominance of pollution-tolerant taxa such as Chironomidae and Tubificidae. This situation reflects the influence of domestic discharges, urban runoff, and organic matter accumulation on the ecological functioning of the river.

Benthic communities showed slight improvement during the rainy season, marked by a 16.4% increase in total abundance and greater homogeneity of diversity indices. However, the persistent dominance of Chironomidae at all stations confirms the maintenance of significant ecological stress. Similarity, hierarchical classification, and NMDS ordination analyses revealed moderate seasonal structuring of assemblages, while the low seasonal similarity values indicate limited ecological resilience.

Principal Component Analysis demonstrated that gradients of organic pollution, nutrients, and turbidity constitute the principal factors controlling the structure of benthic communities in the Lukunga River. Sensitive taxa remained weakly represented, whereas tolerant organisms largely dominated the assemblages.

Overall, this study shows that the Lukunga River remains highly degraded despite some favorable seasonal variations during the rainy period. Benthic macroinvertebrates proved to be effective bioindicators of ecological disturbances in this urbanized tropical system. These results highlight the necessity of implementing integrated management strategies aimed at reducing pollutant inputs, restoring riparian habitats, and sustainably improving the ecological quality of the Lukunga River.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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