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Impact of hydrological and anthropogenic factors on the diversity of macroinvertebrates in a temporary stream of the western highlands of Cameroon

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Abstract

The Toela River, a temporary mountain stream, is difficult to access due to the steepness of its catchment area. However, increasing settlement and market gardening activities, sustained by irrigation from the river, have caused significant water stress, contributing to the temporary nature of the aquatic environment. This study aimed to assess the impact of such anthropogenic activities on the diversity of benthic macroinvertebrates in the Toela River. Environmental variables were measured using standard methods, and benthic macroinvertebrates were collected through a multi-habitat sampling approach. The results revealed strong spatio-temporal variability in physico-chemical parameters. Water temperature remained generally low, while dissolved oxygen reached up to 75% saturation during the rainy season. The acidic pH reflected the volcanic nature of the soils, and high orthophosphate concentrations indicated nutrient pollution of anthropogenic origin. A total of 743 specimens, representing 47 taxa, were identified, mainly arthropods (Diptera, Hemiptera), annelids, and platyhelminths, it is typical of tropical African freshwater systems. Species richness and diversity were significantly lower during the dry season, suggesting organic pollution. EPT taxa and Chironomidae exhibited clear seasonal and spatial variations linked to anthropogenic inputs and fluctuating hydrological conditions. Multivariate analyses highlighted pronounced ecological heterogeneity, distinguishing the downstream station (T3), with better ecological integrity, from the more impacted upstream stations (T1 and T2). Overall, the findings emphasise the combined influence of hydrological and anthropogenic factors in structuring benthic communities and the importance of sustainably managing water resources to preserve aquatic biodiversity in the Toela catchment.

Keywords: Biodiversity; Benthic macroinvertebrates; Anthropogenic pressures; Temporary stream; Ecological quality; Western Cameroon.

1. Introduction

Biodiversity represents a natural capital resulting from several billion years of evolution, characterised by an extraordinarily complex organisation and functioning. It is essential for assessing the condition of aquatic environments, monitoring their evolution, and defining priority actions required for their protection [1]. Among this biological diversity, benthic macroinvertebrates constitute a key component of aquatic ecosystems due to their rapid response to environmental disturbances and their relatively sedentary nature [2]. This characteristic enables them to integrate the cumulative effects of physical, chemical, and biological disturbances experienced within their habitats. As a crucial link in the food chain, they support a wide diversity of aquatic species such as amphibians, birds, and fish [3].

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These organisms, abundant and relatively easy to collect, have a sufficiently long lifespan (ranging from several months to several years) to provide a reliable record of environmental quality, making them excellent bioindicators of river health [4]. A thorough understanding of these organisms and their functioning is therefore indispensable for the effective management of aquatic ecosystems. However, ecological imbalances, largely driven by anthropogenic pressures such as point and diffuse pollution, overexploitation of resources, hydrological modifications, and climate change, represent major threats that exacerbate biodiversity loss in many regions of the world [1]. Moreover, the rapid demographic growth observed in most developing countries amplifies the negative effects of these pressures on the diversity and structure of benthic macroinvertebrate populations, leading to a significant decline in the ecosystem services provided by rivers [5,6]. Understanding these organisms thus allows for a concrete assessment of the impacts of pollution and alterations to aquatic and riparian habitats [7]. The municipality of Babadjou, located in the western part of the Bamboutos Division, is drained by several rivers, including the Lasségue, Tsoumbang, Mogoho, Tsé Deng, and Toela. These rivers are used by local populations for various daily activities such as water consumption, cooking, laundry, dishwashing, crop irrigation, and livestock watering. However, in recent years, there has been a gradual increase in polluting activities, notably the deforestation of hillsides for intensive market gardening, driven partly by demographic pressure. These activities threaten aquatic ecosystems, which have consequently become degraded, with significant repercussions on aquatic biodiversity (Ndi & Wang, 2024). Benthic macroinvertebrates, which serve as reference organisms in assessing the quality of aquatic ecosystems, have already been the subject of numerous studies in various localities across Cameroon, such as Abong-Mbang [8], Mbalmayo [9], Monatélé [10], and Boussibelika [12], among others. However, these aquatic environments are all perennial systems, and few studies such as that of [13] have focused on the biological diversity of macroinvertebrates in temporary aquatic habitats. Yet, temporary streams are among the most characteristic environments of global fluvial networks, more so than permanently flowing rivers [14]. Their spatial distribution may further expand under the combined effects of land-use changes, climate change, and increasing water abstraction for human activities [15,16]. Hence, it is of particular interest to assess the benthic macroinvertebrate fauna of the Toela stream. The objectives are to first determine the abiotic parameters of the environment, then to inventory the benthic macroinvertebrates present, and finally to evaluate the ecological quality of the water based on community structure.

2. Materials and Methods

2.1. Study Site

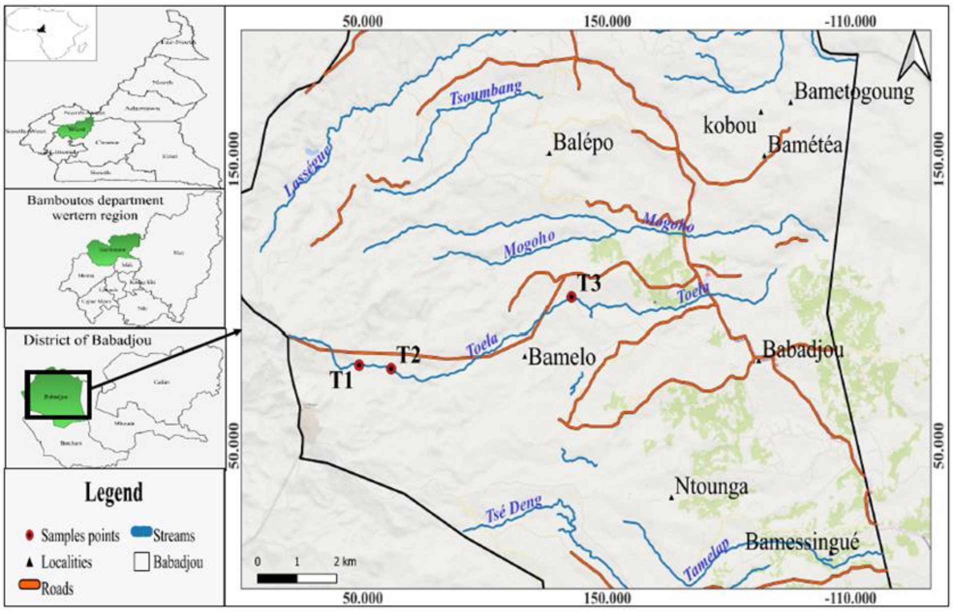


Figure 1 Map showing the location of the different study stations (WGS 84, OSM)

This study was conducted in the municipality of Babadjou, located in the Bamboutos Division, Western Region of Cameroon, at geographical coordinates 5°40'43'' N and 10°12'17'' E. The study area is characterised by a humid tropical equatorial climate with two distinct seasons (dry and rainy), an average temperature of approximately 22 °C, and mean annual rainfall of 916.6 mm. Various soil types occur in this area, including volcanic, sandy–clayey, hydromorphic, and ferralitic soils, along with intertropical vegetation dominated by a humid montane forest [17,18]. The locality is drained by an extensive hydrographic network, notably including the Toela stream. This stream originates on the summit of Mount Bamboutos, flows through the village of Bamélo, and runs west–east through a heavily anthropised catchment, mainly characterised by intensive market gardening with extensive use of agrochemicals. Three sampling stations were selected along the stream according to their accessibility and proximity to pollution sources. Station T1, located closest to the source, is bordered by pepper plantations. Station T2, about 2 km downstream from T1, lies in the heart of a market gardening zone, while Station T3, approximately 10 km downstream from T2, is characterised by fallow riverbanks providing some degree of ecological integrity despite occasional laundry activities (Figure 1). Sampling was carried out over a one-year period, from August 2023 to July 2024, at a monthly frequency. The period of water permanence (April–October) corresponds to the rainy season, whereas the phase of strong hydric stress and stream desiccation (November–March) corresponds to the dry season.

2.2. Anthropogenic Activities Related to Market Gardening

Figure 2 (A) Market gardening in the locality; (B) Insecticides and pesticides used; (C) Network of irrigation pipes; (D) Crop irrigation; (E) Stream desiccation between January and March

Market gardening in Babadjou (Figure 2A), as in many other localities, is characterised by the use of fertilisers, insecticides, pesticides, and fungicides (Figure 2B), which have severe environmental consequences. Among these are soil degradation, loss of forest cover, and particularly the pollution of watercourses, resulting in a significant decline in aquatic biodiversity. In this region, crop irrigation poses a major threat to biodiversity, as the pumping systems installed at the source greatly reduce stream discharge during the dry season, leading to partial or complete desiccation between January and March and the disappearance of many aquatic microhabitats (Figures 2C, 2D and 2E).

2.3. Measurement of Abiotic Parameters

Geographical coordinates and altitude were recorded in the field using a Garmin 60 S GPS. Physico-chemical analyses were conducted both in the field and in the laboratory following standard recommendations [19,20]. In the field, electrical conductivity, total dissolved solids (TDS), pH, salinity, and temperature were measured using a HANNA HI 98130 multimeter (Hanna Instrument LTD, Eden Way, Leighton Buzzard, Bedfordshire LU7 4AD, United Kingdom), while dissolved oxygen was measured using a HANNA HI 9147 oxymeter. For laboratory analyses, water samples were collected during each field campaign at each station in double-capped 1 000 mL polyethylene bottles. Laboratory measurements included suspended solids, turbidity, orthophosphates, and nitrogenous compounds.

2.4. Sampling of Benthic Macroinvertebrates

In the field, benthic macroinvertebrates were collected using a square-frame D-net (30 cm × 30 cm) equipped with a conical net of 500 µm mesh size and 50 cm depth, following a multi-habitat sampling approach [21]. At each station, approximately 20 net sweeps were performed along a stretch equivalent to ten times the stream width, covering an area of about 3 m^2, across different habitats defined by substrate/flow-velocity combinations. During periods of severe hydric stress (more pronounced at stations T1 and T2), samples were collected from permanent water pockets. The retained organisms were carefully picked with fine forceps and preserved in 10% formalin. In the laboratory, specimens were rinsed with tap water to remove formalin and stored in 50 mL vials containing 70% ethanol. They were sorted into Petri dishes according to size and morphology and identified at least to the family level under a Bresser HG878513 stereomicroscope using appropriate identification keys [22,23,24].

2.5. Data Analysis

The Friedman and Wilcoxon tests, performed using R software (version 4.4.1), were used to determine whether differences between seasons and sampling stations were statistically significant represented on graphs as different letters (a–b = significant, a–a = non-significant). The Shannon–Weaver and Simpson indices were used to assess variations in taxonomic diversity, while Pielou's evenness index was used to evaluate the equitable distribution of individuals within communities. To assess the impact of hydric stress during stream desiccation on the diversity of collected organisms, the frequency of occurrence of taxa was calculated based on their presence during both the wet and dry periods at each station.

The Hilsenhoff Family Biotic Index (FBI, 1988), which accounts for the tolerance range assigned to each taxon, was used to determine pollution levels at the different sampling stations [25,26,27]:

$$FBI = \frac{\sum x_{\mathrm{i}}.t_{\mathrm{i}}}{n}$$

where $\mathbf{x_i}$ = number of individuals of the i^{th} taxon, $\mathbf{t_i}$ = tolerance value of the i^{th} taxon, and **n** = total number of individuals in the sample.

Table 1 Evaluation of water quality using the Family-level biotic index (FBI) [25]

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 probable
5.01-5.75	Fair	Fairly substantial pollution 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 likely

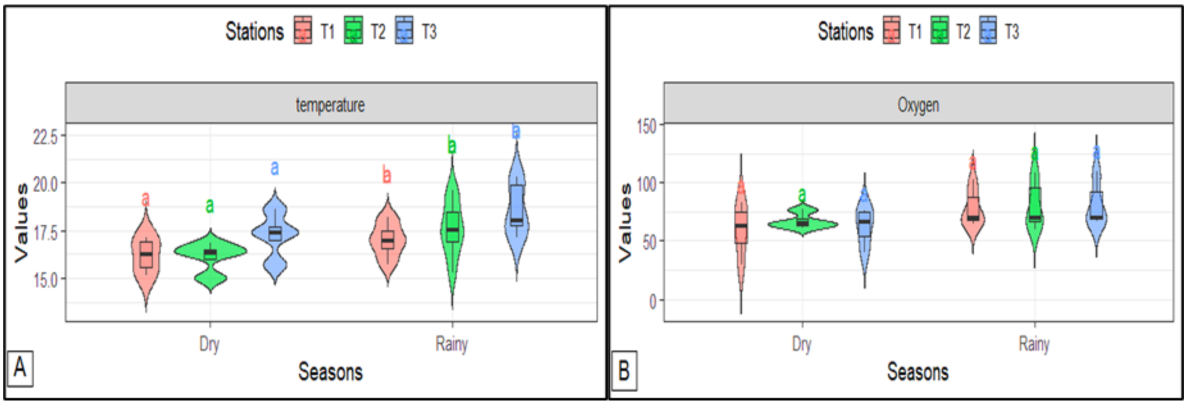
Spearman's rank correlations, hierarchical cluster analysis (HCA), and principal component analysis (PCA) were also performed using R software to determine the influence of abiotic parameters on the benthic macroinvertebrate assemblages.

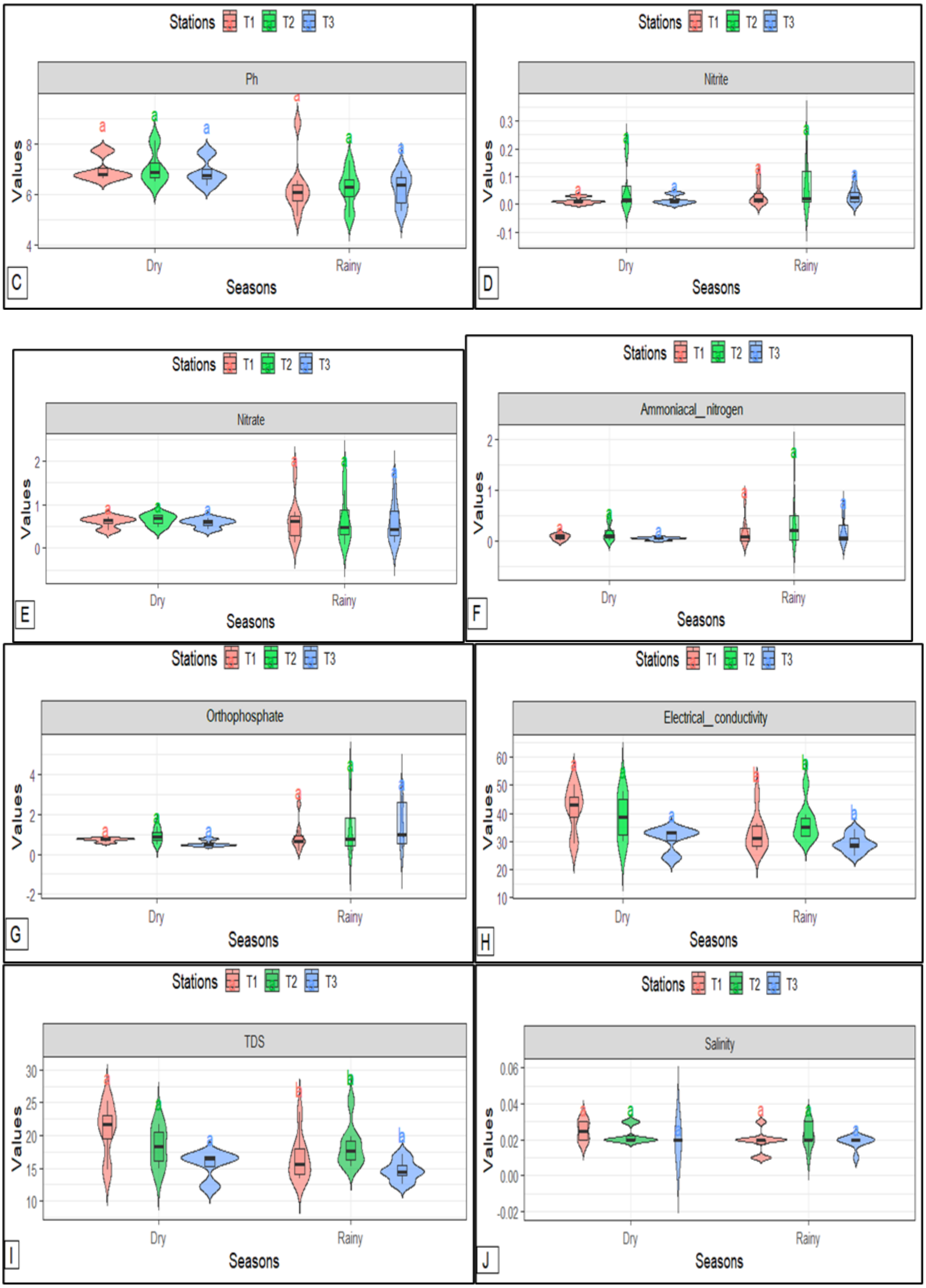
3. Results

3.1. Abiotic Parameters

3.1.1. Physico-chemical Variables

The analysis revealed notable fluctuations in the various measured variables, both temporally (between seasons) and spatially (between stations) along the Toela stream during the study period. The lowest temperature values were recorded during the dry season at stations T1 and T2, while T3 showed slightly higher readings. In the rainy season, temperatures rose slightly at all stations, with a more pronounced increase at T3, reaching up to 20 °C (Figure 3A). The Friedman and Wilcoxon tests indicated no significant spatial differences ($p > 0.05$), but a significant temporal difference ($p < 0.05$) between seasons. The percentage of oxygen saturation remained low during the dry season, particularly at station T1, whereas T2 and T3 exhibited higher values ranging from 65% to 75%. In the rainy season, a clear improvement was observed at all stations, with maximum values around 80–100% at T2 and T3 (Figure 3B). Statistical analyses showed no significant spatio-temporal differences ($p > 0.05$). pH values were generally higher during the dry season, oscillating around neutrality (6.8–7.5 U.C.), with median values close to 7 at all stations. During the rainy season, a marked decrease was observed, with values mainly between 5.8 and 6.5, indicating a tendency towards acidification (Figure 3C). The Friedman and Wilcoxon tests revealed no significant spatio-temporal differences ($p > 0.05$). Nitrogenous compound concentrations fluctuated both seasonally and spatially. Nitrate levels (Figure 3E) were higher in the rainy season, particularly at T2 and T3. Ammonium nitrogen (Figure 3F) also increased at T2 and T3 during the rainy season, though its concentrations remained lower than those of nitrates. Nitrite levels (Figure 3D) were low overall, with a slight increase at T2 during the rainy season. No significant spatio-temporal differences were observed ($p > 0.05$). Orthophosphate concentrations were low (< 1 mg/L) during the dry season at all stations. In the rainy season, values increased markedly, particularly at T2 and T3, sometimes exceeding 3 mg/L (Figure 3G). No significant spatio-temporal differences were detected ($p > 0.05$). Electrical conductivity was higher in the dry season across all stations, with median values of 45 µS/cm at T1, 43 µS/cm at T2, and 32 µS/cm at T3. Conversely, conductivity decreased significantly in the rainy season, with respective medians of 32 µS/cm (T1), 35 µS/cm (T2), and 29 µS/cm (T3) (Figure 3H). The Friedman and Wilcoxon tests revealed significant seasonal differences ($p < 0.05$). Total dissolved solids (TDS) were also higher during the dry season, with medians around 22 mg/L at T1 and 19 mg/L at T2, compared to 16 mg/L at T3. During the rainy season, a significant decrease was observed, particularly at T1 (median ≈ 16 mg/L), while T2 and T3 showed moderate levels (14–18 mg/L) (Figure 3I). Seasonal differences were significant ($p < 0.05$). Salinity was higher in the dry season, with T1 showing the lowest value (0.01 mg/L), and decreased during the rainy season (Figure 3J). No significant spatio-temporal differences were observed ($p > 0.05$). Suspended solid concentrations remained low (< 20 mg/L) during the dry season, but increased markedly during the rainy season at T2 and T3, where values ranged from 50 mg/L to 400 mg/L (Figure 3K). These variations were not statistically significant ($p > 0.05$). Finally, turbidity followed a similar seasonal pattern, with very low values during the dry season and high values during the rainy season, especially at T2 and T3 (Figure 3L). The Friedman and Wilcoxon tests indicated significant spatio-temporal differences ($p < 0.05$).




Stations T1 T2 T3
Ph
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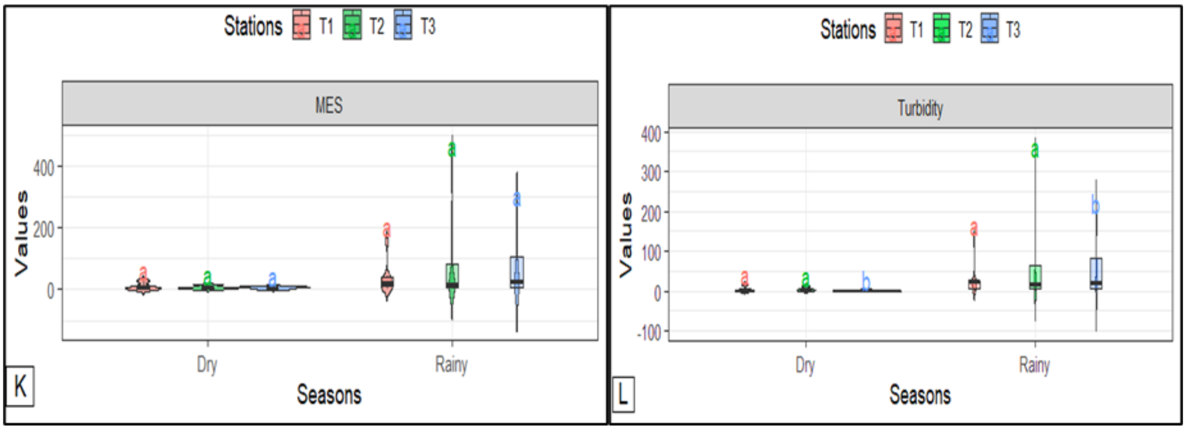


Figure 3 Seasonal variation of temperature (A), dissolved oxygen (B), pH (C), nitrite (D), nitrate (E), ammonium nitrogen (F), orthophosphate (G), electrical conductivity (H), TDS (I), salinity (J), suspended solids (K), and turbidity (L) in the Toela stream during the study period

3.2. Benthic Macroinvertebrates

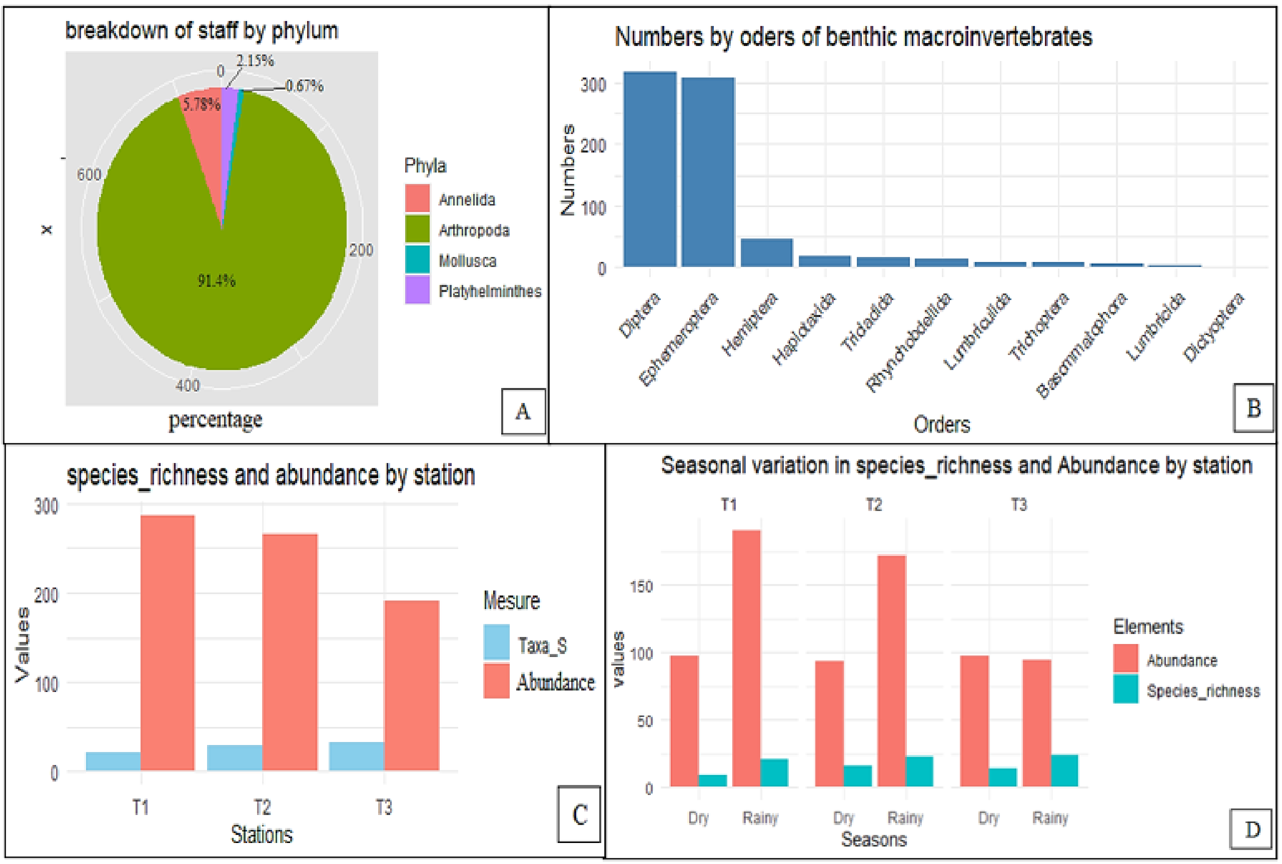


Figure 4 Variation in the percentage of phyla (A), order abundance (B), species richness and abundance by station (C), and seasonal variation (D) of benthic macroinvertebrates in the Toela stream during the study period

A total of 743 specimens were collected, belonging to four phyla, five classes, eleven orders, thirty-two families, and over forty-seven taxa. The phylum Arthropoda predominated, comprising 23 families and 91.4% relative abundance, followed by Annelida (five families, 5.78%), Mollusca (two families, 0.67%), and Plathelminthes (one family, 2.15%) (Figure 4A). Among classes, Insecta was dominant with 23 families (91.4% relative abundance), followed by Oligochaeta (three families, 3.9%). The orders Diptera and Hemiptera were the most represented, with eleven and six families, respectively, corresponding to 43% and 41% of total abundance (Figure 4B). The families Baetidae and Chironomidae were the most abundant, with three and seven species respectively, representing 37% and 32.2% relative abundance, and were present at all stations. Overall, abundance decreased progressively from upstream (39% at T1) to downstream (25% at T3), while species richness increased from upstream (15 families) to downstream (26 families) (Figure 4C). Statistical analyses revealed significant seasonal differences ($p < 0.05$) (Figure 4D). Total Taxonomic Richness (TTR) in the Toela stream reached 43 families: 15 at T1, 21 at T2, and 26 at T3. Insect Taxonomic Richness (TRI) was highest upstream (T1), whereas Dipteran Taxonomic Richness (DTR) peaked downstream (T3). The proportion of Chironomidae was highest at T2. The Hilsenhoff Index ranged from 4.83 (T3) to 5.29 (T1), indicating water quality varying from "good" to "fair", corresponding to probable to substantial organic pollution (Table 2).

Table 2 Variation of metrics describing the structure of benthic macroinvertebrates during the study period.

Metrics	**T1**	**T2**	**T3**
TTR	15	21	26
TRI	12	11	10
DTR	17	20	24
%chiro	74,23	82,11	53,13
H'	1,69	1,64	2,2
E	0,62	0,54	0,68
FBI	5,29	5,17	4,83

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.

Simpson, Shannon–Weaver, and Pielou indices showed generally low values, with a slight increase during the dry season from T1 (H′ = 1,54 bit/ind) to T2 (H′ = 2 bit/ind), before decreasing downstream at T3 (H′ = 1,78 bit/ind). In the rainy season, values increased progressively from upstream (H′ = 2,2 bit/ind at T1) to downstream (H′ = 2,7 bit/ind at T3) (Figure 5).

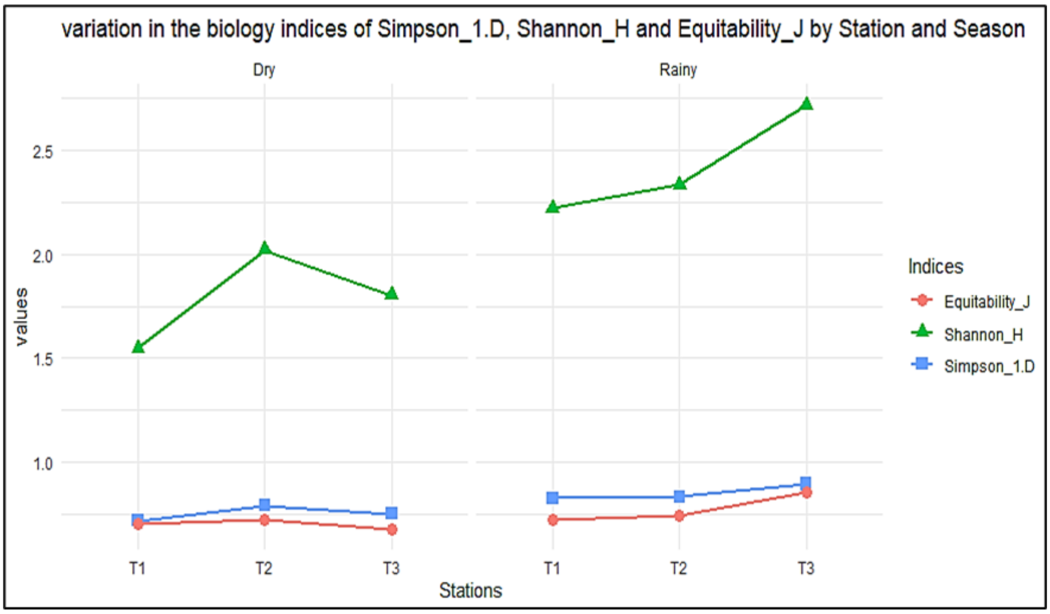


Figure 5 Variation of Simpson (1–D), Shannon–Weaver (H′), and Pielou's Evenness (J) indices across study stations by season

The frequency of occurrence showed that most taxa were rare (< 25%). *Baetis* sp. was the most frequent species (25–50%). The frequency of EPT and Chironomidae groups varied by station (53% EPT at T3 vs. 44% Chironomidae at T1) and by season (54% EPT and 33% Chironomidae in the dry season vs. 34% and 28% respectively in the rainy season). These groups were therefore more abundant during hydric stress (Table 3).

Table 3 Frequency of occurrence of benthic macroinvertebrates collected from the Toela stream.

Families	Species	T1		T2		T3	
		Dry	Rainy	Dry	Rainy	Dry	Rainy
Lymnaeidae	*Biomphalaria pfeifferi*	0	0	0	1 (1%)	0	0
Planorbidae	*Gyraulus sp*	0	3 (2%)	1 (1%)	0	0	0
Blaberidae	////////////	0	0	0	1 (1%)	0	0
Leptophlebiidae	*Adenophlebia sylvatica*	2 (2%)	5 (3%)	0	0	0	3 (3%)
	Adenophlebiodes sp	0	0	0	0	1 (1%)	0
Baetidae	*Acentrella siniaca*	2 (2%)	10 (5%)	4 (4%)	6 (3%)	33 (34%)	1 (1%)
	Baetis sp	34 (35%)	35 (16%)	33 (36%)	59 (34%)	33 (34%)	17 (19%)
	Cleon sp	0	0	0	5 (3%)	0	3 (3%)
Caenidae	*Afrcaenis sp*	8 (8%)	3 (2%)	2 (2%)	2 (1%)	4 (4%)	2 (2%)
Hydropsychidae	*Hydropsyche sp*	0	0	0	3 (2%)	0	2 (2%)
Hydroptilidae	*Tricholeiochiton sp*	0	0	0	0	0	2 (2%)
Chironomidae	*Chironomus flaviplumus*	1 (1%)	8 (4%)	23 (25%)	10 (6%)	1 (1%)	0
	Cryptochironomus sp	0	1 (1%)	0	0	0	0
	Ablabesmyia monilis	4 (5%)	6 (3%)	2 (2%)	19 (10%)	2 (2%)	3 (3%)
	Polypedilum sp	36 (37%)	1 (1%)	10 (12%)	9 (5%)	9 (10%)	2 (2%)
	Cricotopus sylvestris	1 (1%)	60 (32%)	0	24 (14%)	0	0
	Procladius choreus	0	0	3 (3%)	1 (1%)	0	0
	Paratrichocladius tamaater	0	3 (2%)	0	0	0	0
Simulidae	*Prosimuliini sp*	0	1 (1%)	1 (1%)	4 (2%)	2 (2%)	0
Rhagionidae	///////////	0	0	0	0	0	1 (1%)
Athericidae	*Atrichops crassipes*	0	0	0	0	0	3 (3%)
Tipulidae	*Hexatoma sp*	0	5 (3%)	0	1 (1%)	3 (3%)	0
	Tipula furca	0	1 (1%)	1 (1%)	1 (1%)	0	0
Anthomyidae	*Limnophora sp*	0	0	0	0	0	3 (3%)
Empididae	*Empididae*	0	0	0	0	1 (1%)	0
Culicidae	*Culex sp*	0	0	1 (1%)	0	0	0
Thaumaleidae	*Thaumalea sp*	0	32 (16%)	0	11 (6%)	0	2 (2%)
Sciomyzidae	*Anticheata borealis*	0	1 (1%)	0	2 (1%)	0	0
Helodidae	*Cyphon sp*	0	1 (1%)	0	0	0	0
Gyrinidae	*Orectogyrus Régimbart*	0	0	0	0	0	6 (7%)

	Dineutus aereus	0	0	1 (1%)	0	0	0
Hydrophilidae	*Hydrobius sp*	0	0	0	0	0	1 (1%)
	Enochrus sp	0	0	0	1 (1%)	0	0
	Hydrophilus sp	0	1 (1%)	0	0	0	0
Coccinellidae	*Scymnus abietis*	0	0	0	0	0	1 (1%)
Gerridae	*Hynesionella omer-cooperi*	0	0	0	0	0	2 (2%)
	Cylindrostethus quadrivittatus	0	0	4 (4%)	0	0	0
Veliidae	*Microvelia sp*	0	0	3 (3%)	2 (1%)	0	21 (23%)
Corixidae	*Corixa sp*	0	0	0	0	0	2 (2%)
Glossiphoniidae	*Hemiclepsis marginata*	0	0	0	2 (1%)	2 (2%)	0
	Glossiphonia sp	0	1 (1%)	0	0	0	6 (7%)
Erpobdeliidae	*Dina lineata*	0	0	0	0	0	1 (1%)
Lumbricidae	*Eiseniella tetraedra*	0	0	0	1 (1%)	0	3 (3%)
Haplotaxidae	*Haplotaxis sp*	0	6 (3%)	2 (2%)	5 (3%)	1 (1%)	4 (4%)
Lumbriculidae	*Stylodrilus heringianus*	0	1 (1%)	0	2 (1%)	0	3 (3%)
Planariidae	*Polycelis sp*	9 (9%)	0	0	0	1 (1%)	0
Dugesiidae	*Dugesia sp*	0	0	2 (2%)	0	4 (4%)	0
32	47	97 (100%)	190 (100%)	93 (100%)	172 (100%)	97 (100%)	94 (100%)

Very frequent taxa > 50%, frequent taxa 25-50%, rare taxa < 25%

Spearman's rank correlation was used to assess relationships between macroinvertebrate community metrics and physico-chemical parameters. The correlation coefficient (r_s) ranged from −1 to +1, where negative values indicate inverse relationships and positive values indicate co-variation. Temperature correlated positively with total taxonomic richness (TTR), dipteran richness (DTR), Shannon index (H′), and evenness (E) ($r_s \approx 0.5$), and negatively with insect richness (TRI) and the Hilsenhoff Index (FBI) ($r_s = -1$). Dissolved oxygen showed weak to moderate, mostly negative correlations with most biological metrics except DTR ($r_s = 0.5$) and FBI ($r_s = -0.5$). pH was strongly and negatively correlated with TRI ($r_s = -1$), positively with FBI ($r_s = 1$), and moderately with other indices. Nitrites correlated strongly and positively with DTR ($r_s = 0.87$) and negatively with H′ and E ($r_s = -0.87$). Finally, nitrates, ammonium nitrogen, and orthophosphates correlated strongly and negatively with most biological metrics, except for moderate positive correlations with FBI (Figure 6).

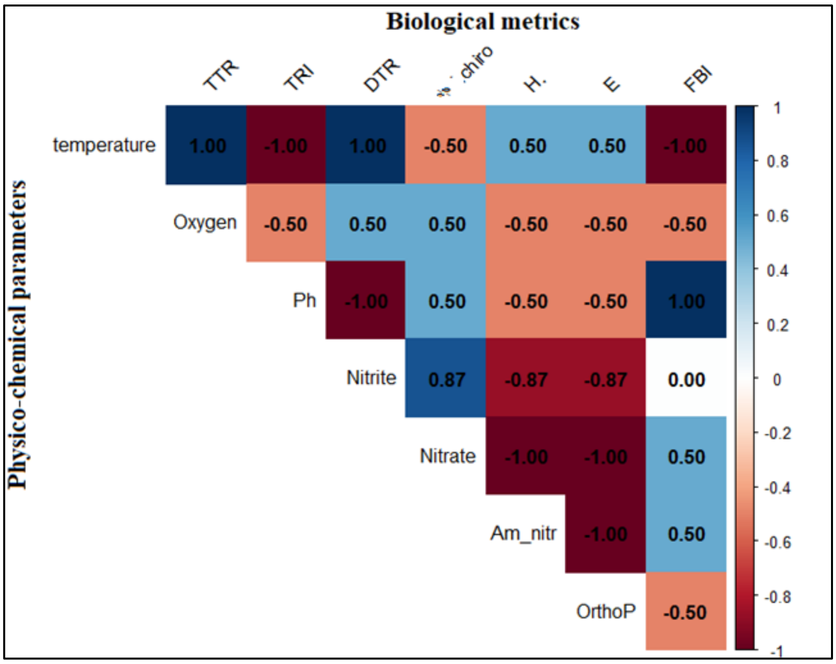


Figure 6 Spearman's rank correlation coefficients between physico-chemical parameters and benthic macroinvertebrate metrics

Hierarchical cluster analysis (HCA) grouped the sampling stations into two clusters based on environmental parameters: Cluster 1 comprising station T3, and Cluster 2 comprising stations T1 and T2 (Figure 7).

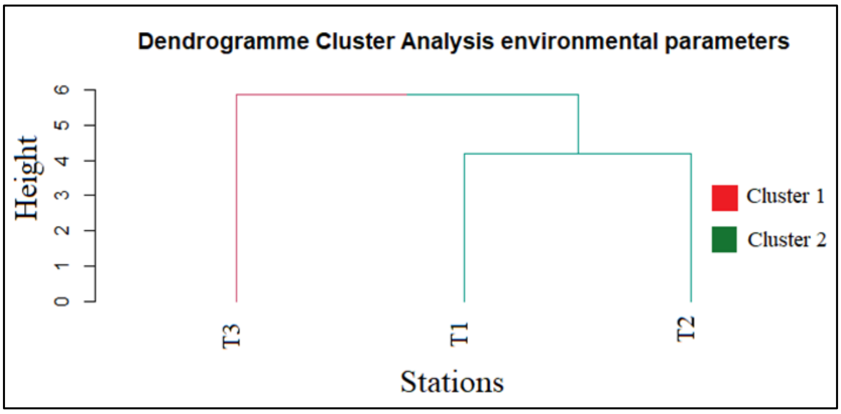
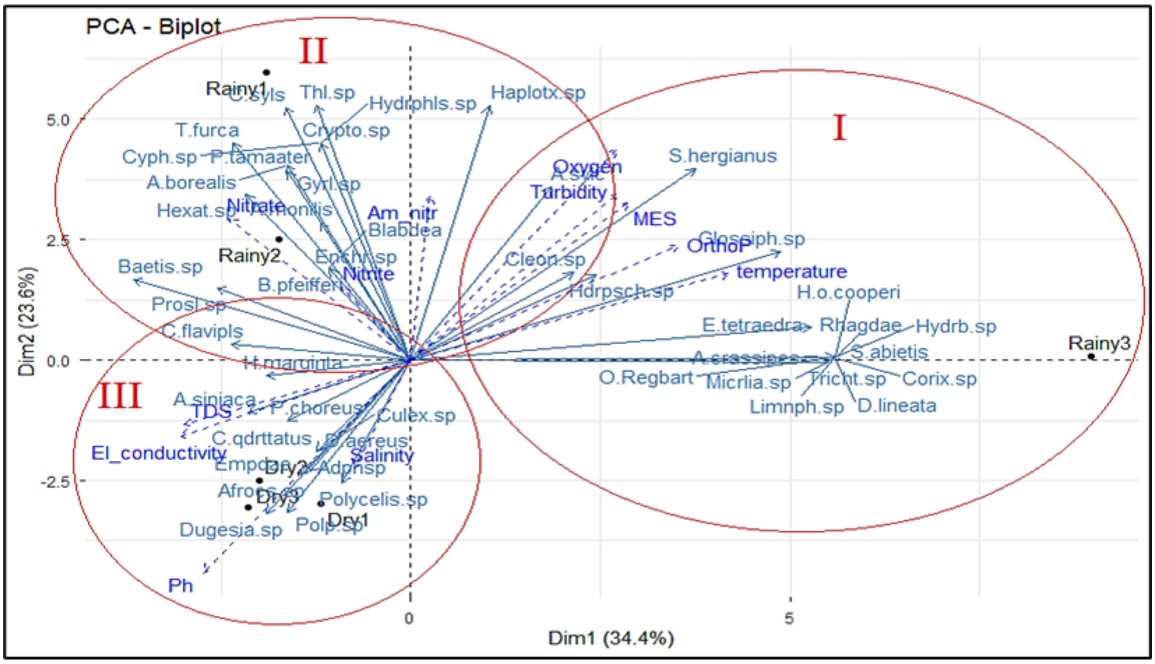


Figure 7 Dendrogram showing similarity among Toela stream stations



B.pfeifferi : Biomphalaria pfeifferi, Gyrl.sp : Gyraulus sp, Blabdea : Blaberidea, A.sylc : Adenophlebia sylvatica, Adphsp : Adenophlebiodes sp, A.siniaca : Acentrella siniaca, Baetis sp, Cleon sp, Afrocs.sp : AfroCaenis sp, Hdrpsch.sp : Hydropsyche sp, Tricht.sp : Tricholeiochiton sp, C.flavipls : Chironomus flaviplumus, Crypto.sp : Cryptochironomus sp, A.monilis : Ablabesmyia monilis, Polp.sp : Polypedilum sp, C.syls : Cricotopus sylvestris, P.choreus : Procladius choreus, P.tamaater : Paratrichocladius tamaater, Prosl.sp : Prosimuliini sp, Rhagdae : Rhagionidae, A.crassipes : Atrichops crassipes, Hexat.sp : Hexatoma sp, T.furca : Tipula furca, Limnph.sp : Limnophora sp, Empdae : Empididae, Culex sp, Thleasp : Thaumalea sp, A.borealis : Anticheata borealis, Cyphon sp, O.Regbart : Orectogyrus Régimbart, D.aereus : Dineutus aereus, Hydrb.sp : Hydrobius sp, Enchr.sp : Enochrus sp, Hydrphls.sp : Hydrophilus sp, S.abietis : Scymnus abietis, H.o-cooperi : Hynesionella omer-cooperi, C.qdrttatus : Cylindrostethus quadrivittatus, Micrlia.sp : Microvelia sp, Corix.sp : Corixa sp, H.marginta : Hemiclepsis marginata, Glossiph.sp : Glossiphonia sp, D.lineata : Dina lineata, E.tetraedra : Eiseniella tetraedra, Haplotx.sp : Haplotaxis sp, S.hergianus : Stylodrilus heringianus, Polycelis.sp, Dugesia sp. Rainy1 : (Toela1, Rainy season), Rainy2 : (Toela2, Rainy season), Rainy3 : (Toela3, Rainy season), Dry1 : (Toela1, Dry season), Dry2 : (Toela2, Dry season), Dry3 : (Toela3, Dry season).

Figure 8 Principal Component Analysis (PCA) between physico-chemical variables and macroinvertebrate species across seasons and stations during the study period

Principal Component Analysis (PCA) conducted between physico-chemical variables and benthic macroinvertebrate species revealed two main dimensions: Dimension 1 explaining 23.6% of variance, and Dimension 2 explaining 34.4%. Three correlation circles (I, II, III) were identified. Circle I, represented by T3 during the rainy season, was characterised by warm, turbid, oxygenated, and orthophosphate-rich waters. These conditions favoured species such as *Cleon* sp., *Hydropsyche* sp., *Orectogyrus* sp., *Hynesionella omer-cooperi*, *Microvelia* sp., *Hydrobius* sp., *Eiseniella tetraedra*, and *Corixa* sp. Circle II included T1 and T2 during the rainy season, distinguished by oxygenated waters rich in nitrogenous compounds, harbouring taxa such as *Baetis* sp., *Tipula furca*, *Biomphalaria pfeifferi*, *Paratrichocladius tamaater*, *Blaberidae*, and *Ablabesmyia monilis*. Circle III comprised all stations during the dry season, characterised by high conductivity and acidic waters. Associated species included *Cylindrostethus quadrivittatus*, *Hemiclepsis marginata*, *Culex* sp., *Dugesia* sp., *Rhagionidae*, *Afrocaenis* sp., *Procladius choreus*, and *Dineutus aereus* (Figure 8).

4. Discussion

The analysis of physico-chemical variables revealed that the relatively low water temperatures recorded in the Toela stream can be explained by its geographical location (high altitude) and the early morning sampling period. According to [28], solar radiation, sampling time, and surrounding environmental conditions strongly influence surface water temperature. Regarding oxygen saturation, the mean value of 74.08 ± 2.11% indicated that the stream is generally well oxygenated. However, this oxygenation level remains relatively low given the hilly relief of the ecosystem (presence of cascades). This situation is partly due to excessive water abstraction for agricultural purposes, which intensifies hydric stress during the dry season and reduces the cascading effect of flowing water, thereby lowering oxygenation levels. As emphasised by [7], stream reaches are continuous systems, and the presence of boulders or cascades creates flow sinuosity that enhances aeration at the water–air interface. The mean pH value (6.47 ± 0.06 U.C.) indicated slightly acidic water, which may be attributed to the geological nature of the ferralitic and hydromorphic soils in the area. According to [29], the pH of natural waters is closely related to the lithology of the substrates they traverse. This result is similar to that obtained by [10] in the Kena stream (6.16 ± 0.54 U.C.), which has comparable geological characteristics. The low mineralisation and salinity of Toela's waters, reflected by mean conductivity and salinity values of 34.33 ± 3.96 µS/cm and 0.02 ± 0.01 mg/L respectively, could be attributed to a low input of allochthonous organic matter into the ecosystem. This is consistent with the Family Biotic Index (FBI), which indicated moderate organic pollution. These findings are similar to those reported by [30] in the Mvila, Upper Nyong, and Mefou basins (34.65 ± 2.45 µS/cm), suggesting a generally low mineralisation of waters in the region. Suspended solids (TSS) averaged 46.36 ± 16.23 mg/L, a value higher than that recorded by [11] in the Magbaba stream (18.75 ± 2.73 mg/L). This difference can be attributed to the destruction of the riparian buffer zone, which otherwise protects aquatic ecosystems. In this respect, [7] pointed out that the absence of dense riparian vegetation increases soil erosion and surface runoff, introducing allochthonous material into the water column. Orthophosphate concentrations averaged 1.07 ± 0.21 mg/L, significantly higher than those obtained by [31] in the Mefou basin (0.18 ± 0.38 mg/L), located in the urban area of Yaoundé. This observation reflects the intensification of market gardening activities within the Toela catchment. As noted by [29], orthophosphate levels exceeding 0.5 mg/L are indicative of pollution. Nitrogenous compound concentrations averaged 0.87 ± 0.15 mg/L. Although this remains moderate compared to SEQeau recommendations, which set a threshold of <1 mg/L for minimally disturbed ecosystems, the value is still critical for biotic communities if no mitigation measures are implemented. According to [32], excessive nitrogen inputs whether as nitrates, ammonium, or organic nitrogen compounds promote eutrophication and disrupt aquatic ecosystem functioning, thereby compromising ecosystem services such as fisheries and recreation.

The benthic macroinvertebrate community of the Toela stream consisted mainly of arthropods (notably insects), annelids, and platyhelminths. All taxa recorded in this study have been previously reported in Central (tropical forest) and Sudano–Sahelian zones [22] and generally reflect the benthic macrofauna composition of African freshwater systems, such as those in Gabon [33], Congo-Brazzaville [34], Algeria [35], Guinea [36], Côte d'Ivoire [37], and Cameroon [9,12,38,42]. Given the pronounced hydric stress caused by excessive water abstraction observed in this ecosystem, the Toela stream may be classified as a temporary stream. Hydrology thus emerges as a key determinant influencing ecosystem dynamics, species life-cycle strategies, and the composition and diversity of habitats within temporary aquatic environments [43]. The variations in species richness between the period of strong hydric stress (dry season: 9, 16, and 14 taxa at T1, T2, and T3, respectively) and the period of hydric abundance (rainy season: 21, 23, and 24 taxa at the same stations) were substantial, yet comparable to those observed in perennial streams [11,34], despite the anthropogenic pressures affecting the catchment. Over the twelve sampling campaigns conducted from August 2023 to July 2024, the benthic macroinvertebrate community comprised 30 families with a total of 743 individuals. These results differ markedly from those reported in the temporary streams of Mayo Kaliao (48 families, 5,954 individuals) and Mayo Tsanaga (51 families, 24,937 individuals) by [13], highlighting the considerable impact of agricultural pollution and excessive water abstraction observed in the Toela catchment. Nevertheless, this stream remains more diverse than the perennial Ebogo stream studied by [44], which contained 23 families and 1,332 individuals in an urban area of Yaoundé. This finding confirms that anthropogenic activity is a primary factor regulating benthic macroinvertebrate diversity in tropical streams. Dipterans, with eleven families representing 34.4% of total taxonomic richness, formed the dominant group. These observations are consistent with findings from other temporary streams [13,43] and certain perennial systems [44,45], but differ from those of most perennial rivers studied by [10,12,34]. As in most perennial streams subject to heavy anthropogenic pressures, the benthic macroinvertebrate fauna of the Toela stream was dominated by Chironomidae (32.17% of total abundance) and Baetidae (37.01%). Similar trends were reported in the Mayo Tsanaga and Mayo Kaliao rivers by Madomguia [13]. According to [46], many Ephemeroptera species in tropical and subtropical regions are multivoltine, exhibiting short life cycles that allow them to survive and thrive in temporary streams. Across the entire stream, the Hilsenhoff Index reflected water quality ranging from "probable" to "substantial" organic pollution, consistent with the elevated Shannon–Weaver, Simpson, and Pielou indices observed. However, the strong anthropogenic pressures in the catchment, particularly from market gardening, contribute to nitrogen enrichment, whose negative correlations with most biological metrics were confirmed by Spearman's analysis. As noted by [47], agriculture remains the main source of pollution in forested river systems. Due to its temporary nature, the stream showed a high proportion of rare taxa, except for *Baetis* sp., which accounted for approximately 30% of relative abundance at each station, especially during the dry season, making it the most frequent taxon. The stream exhibited strong spatio-temporal variations in key biological groups, particularly EPT and Chironomidae, which were most abundant during hydric stress periods. These variations can be attributed to surface runoff from the densely cultivated catchment and discharge fluctuations between the water permanence phase and the persistence of lentic water pockets during severe hydric stress. Similar observations were made by [13] in the Mayo Kaliao and Mayo Tsanaga systems.

5. Conclusion

The results of Hierarchical Cluster Analysis (HCA) and Principal Component Analysis (PCA) revealed high heterogeneity in diversity but strong convergence between the upstream stations (T1 and T2). During periods of strong hydric stress, the stream exhibited the highest abundances, mainly of pollution-tolerant organisms such as Diptera, across all stations. Conversely, the rainy season was associated with greater habitat diversity and consequently higher species diversity, particularly at T3, which maintained the best ecological integrity. The study conducted on the Toela stream, located on the eastern slope of Mount Bamboutos, highlights the predominant influence of hydrological and anthropogenic factors in shaping the structure of the benthic macroinvertebrate community. The pronounced seasonal variability of the hydrological regime characterised by severe hydric stress during the dry season and abundant water availability during the rainy season results in significant variations in species richness and biological diversity between stations and sampling periods. This dynamic pattern is consistent with the temporary nature of the stream, particularly under the influence of excessive water abstraction for agricultural purposes. The observed faunal composition, dominated by arthropods (notably dipteran insects), annelids, and platyhelminths, reflects the typical benthic macrofauna of African tropical freshwater systems. However, overall diversity and ecological balance remain limited, with a marked predominance of pollution-tolerant taxa such as Chironomidae, particularly abundant at upstream stations located near market gardening zones. This proliferation indicates moderate to high levels of organic pollution, corroborated by both physico-chemical parameters and biological indices. Multivariate analyses (Principal Component Analysis and Hierarchical Cluster Analysis) confirmed a strong environmental and biological similarity between the upstream stations (T1 and T2), which are more heavily impacted by human activities, while the downstream station (T3) exhibited a more favourable ecological condition, associated with better environmental integrity. In summary, this study underscores the urgent need for integrated and sustainable water resource management within the Toela stream catchment, in order to mitigate agricultural pressures and safeguard aquatic biodiversity.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest.

Statement of 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.

Contributions

Larry Nathaniel Lactio and Betsi Wilfreid Christiane Noël formed the team that collected the field data and carried out the laboratory analyses. Larry Nathaniel Lactio and Jean Dzavi performed the statistical analyses and prepared the associated graphs. Larry Nathaniel Lactio wrote the manuscript. Professors Foto Menbohan Samuel and Ajeagah Gideon Aghaindum supervised the work and provided the revisions. Miranda Egbe Awo undertook the translation of the document.

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