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(Review Article)

Biodiversity of macroinvertebrates assemblages in the aquatic systems in four touristic sites in the Centre Region of Cameroon and impact of environmental factors

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Abstract

Macroinvertebrates, which are small aquatic animals without backbones, can be useful indicators of pollution in streams and rivers, particularly near tourist sites in Cameroon. Their presence, diversity, and abundance can reflect the health of the water ecosystem, as some species are more sensitive to pollution than others are. All aquatic macroinvertebrates start life as eggs. Some aquatic macroinvertebrates spend their entire life in water, such as water boatmen and snails. They do not change much as they grow – they only get bigger (like humans do). Others, such as dragonflies and mayflies, spend part of their life in the water and part on land. The immature phases (larvae and nymphs) live in the water, and then they metamorphose (transform into adults) and spend the rest of their life on land. Basic aquatic macroinvertebrate adaptations: Antennae: Used for sensing food andsurroundings. Specialized mouthparts: Help with eatingfood and are adapted based on their diet.Specialized feet: Used to collect and eat food as well as hold onto substrate in riverbeds and ponds. Compound eyes: Help detect motionand see in all directions.Gills: Help with breathing dissolved oxygen in the water. Tails: Used for swimming and steering.

Keywords; Macroinvertebrates; Physicochemistry; Touristic sites; Yaounde and environs

1. Introduction

Macroinvertebrates, which are small aquatic animals without backbones, can be useful indicators of pollution in streams and rivers, particularly near tourist sites in Cameroon. Their presence, diversity, and abundance can reflect the health of the water ecosystem, as some species are more sensitive to pollution than others are. In Cameroon, studies have shown that urban development and associated pollution (domestic and industrial waste, solid and liquid waste disposal) can negatively impact these macroinvertebrate communities, leading to a decrease in diversity and an increase in pollution-tolerant species(Akele,2016).

All aquatic macroinvertebrates start life as eggs. Some aquatic macroinvertebrates spend their entire life in water, such as water boatmen and snails. They don't change much as they grow – they only get bigger (like humans do). Others, such as dragonflies and mayflies, spend part of their life in the water and part on land. The immature phases (larvae and nymphs) live in the water, then they metamorphose (transform into adults) and spend the rest of their life on land. In many cases, aquatic macroinvertebrates live in the water for months to several years and are adults for a very short time. For example, dragonfly larvae can live in water for months to several years, but the adults survive on land for a few short weeks. During their adult phase, dragonflies mate and lay their eggs in or near water, so the life cycle can continue. Dragonfly larval and adult forms do not look alike, but they are both skilled predators that survive well underwater and on land. Aquatic macroinvertebrates live in many different types of aquatic habitats. Some live in fast moving streams, consuming leaves, twigs, and other plant material that falls into the water. Others live in wider, sunnier

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rivers or shallow ponds, scraping algae off rocks or on the surfaces of large aquatic plants. Many are predators, and prey upon other macroinvertebrates. Some live within the soft sediments at the bottom of lakes and ponds and others capture food that is drifting along in the current. In all these settings, macroinvertebrates provide an important food source for fish and other predators. Because different types of macroinvertebrates tolerate different stream conditions and levels of pollution, their presence or absence is used to indicate clean or polluted water. Sometimes, it is easy to tell if a stream or pond is polluted. Strange colors, smells, and dead fish are often indicators of poor water quality, but scientists need to know about water quality problems long before this point (Ajeagah, 2013, Ajeagah et al. 2014) . Some of scientists most helpful partners in detecting decreasing water quality are aquatic macroinvertebrates because they react quickly to changing water conditions (Akiro and Olawale. 2007, Amiro,2015).

To evaluate the health of waterways, biologists look at the types of macroinvertebrates who live there. Different species have different tolerance levels to pollution. Some aquatic organisms are more sensitive to pollution or poor water quality, meaning they cannot survive or reproduce in poor water conditions, while others are more tolerant of polluted water (Ajeagah et al, 2013). When scientists see many of the more sensitive macroinvertebrates in a water body, it is a good sign that the water is clean, or clean enough to support diverse life (but not clean enough to drink!). However, the absence of sensitive macroinvertebrates in a water body does not necessarily indicate the water quality is poor. Other natural factors (such as temperature, flow, sediment, and more) may explain their absence. Many natural and human-influenced factors can influence the presence, absence, and health of aquatic macroinvertebrates. Seasons: Life histories of invertebrates are tied to food availability. For example, macroinvertebrates that eat algae are most abundant in the summer when algae production is at its highest. Dissolved Oxygen: Macroinvertebrates breathe oxygen that is dissolved in the water. In their immature stage, many species require high levels of dissolved oxygen to survive The materials found at the bottom of a waterbody will affect the types of macroinvertebrates that live there. Nutrient enrichment: Added nutrients from wastewater, fertilizer, or agricultural practices can accelerate the growth of algae and other plants. When plants die, decomposition by microorganisms can use up dissolved oxygen in the water.pH: Industrial pollutants and stormwater runoff from urban environments and human activities can change the pH levels in the water. Low pH can weaken shells and exoskeletons and kill macroinvertebrates. Removal of riparian vegetation: The vegetation growing on the banks of a waterbody provide food and habitat for macroinvertebrates. Removing this vegetation impacts their survival. Most aquatic macroinvertebrates make their home in the rocks, leaves, and sediment of a water body (Arimo and Ikomo,2008). The main objectif of this research is to assess the biodiversity of benthic macroinvertebrates in relationship to physicochemical parameters in touristic sites in Yaounde and its environs.

2. Materials and Methods

To elucidate the riverine ecosystem status and identify major pollutants that structure macroinvertebrates assemblages of four touristic water system (figures 1 to 5), and benthic macroinvertebrates were sampled from 4 sites along the zqtersystems. physicochemical variables such as Electrical conductivity (EC), salinity, total suspended solids (TDS), pH, and water temperature were determined in situ with a portable multi-parameter probe (PCTestr 35, Eutech/Oakton Instruments, Singapore). Dissolved oxygen (DO) was measured in situ using a DO meter (DO 850045, Per Scientific, Taiwan). Turbidity was determined using a turbidity meter (AL250T-IR, Aqualytic, Germany). Water samples for the analysis of other physicochemical variables were collected from 50 cm below the water surface. In order to avoid microbial activities, 1 mL concentrated sulphuric acid was added to the collected samples and the samples were stored in a 500 mL polyethylene bottle. Afterwards, samples were taken to the laboratory in an ice chest at 4 °C. Analyses of the samples were performed immediately the samples arrived the laboratory. Ammonium nitrogen (NH_4N), nitrates (NO_3), nitrites (NO_2), phosphates (PO_4), Sulphate (SO_4), Chlorine (Cl), were analysed according to APHA (1998) methods.

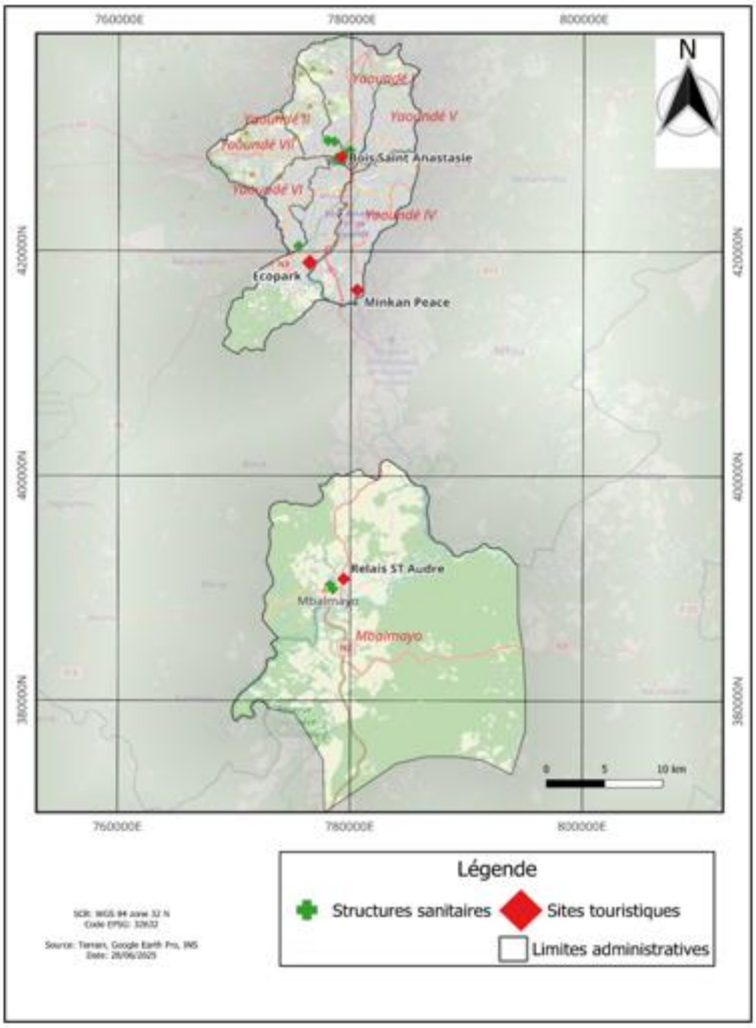

Figure 1 Geographical location of the four tourist sites considered in the study

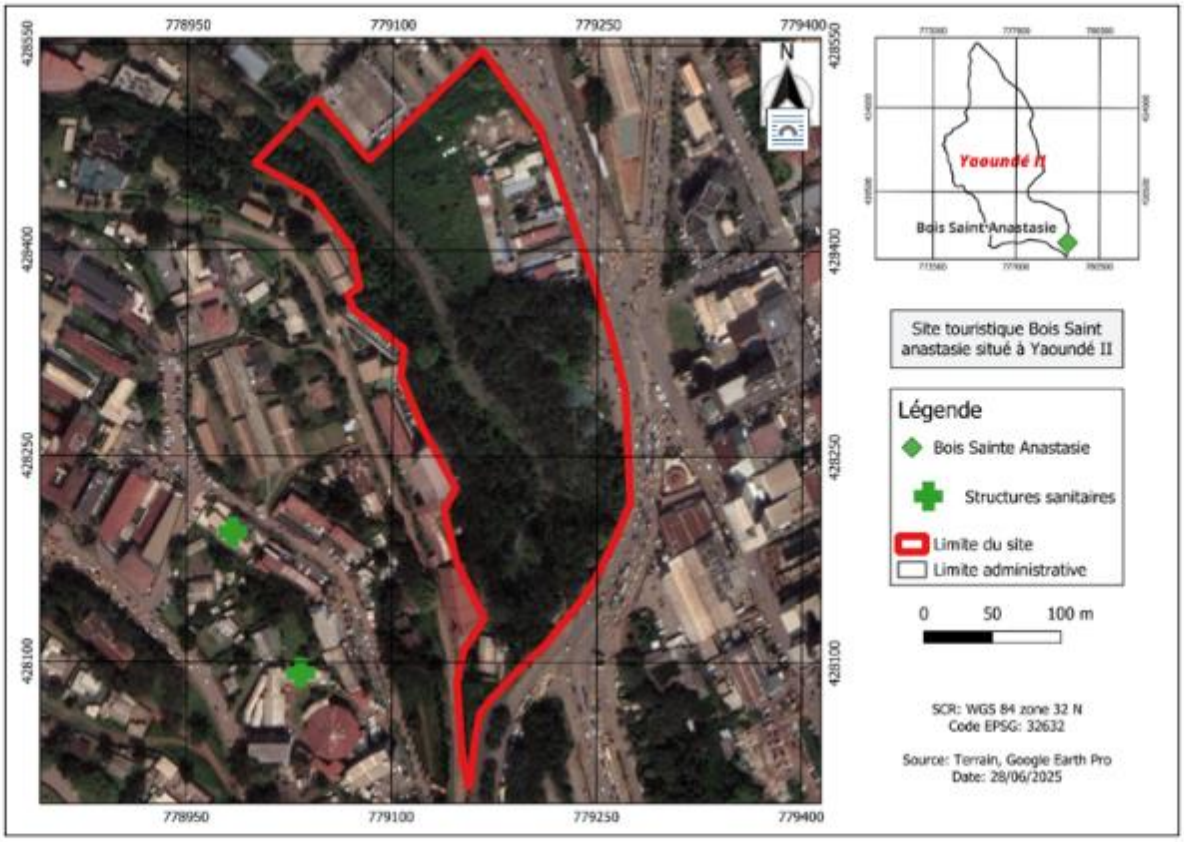

Figure 2 ST ANAS tourist site

Figure 3 MINK tourist site

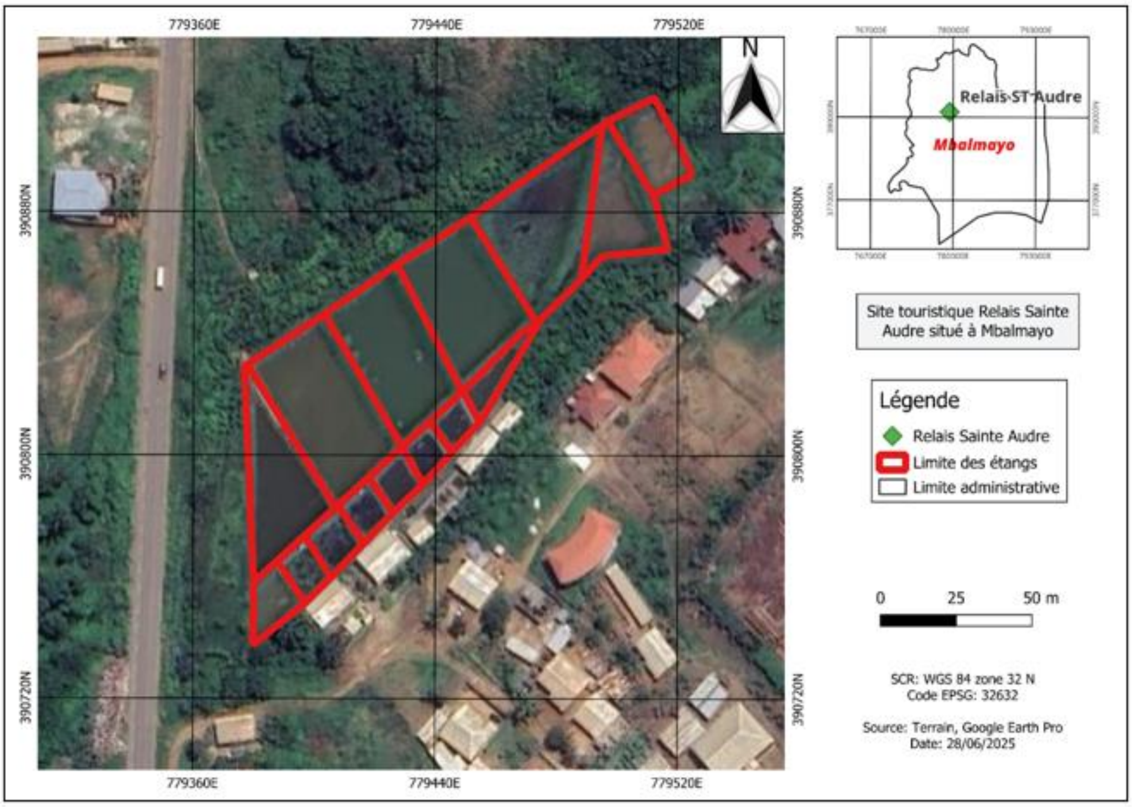

Figure 4 BAL tourist site

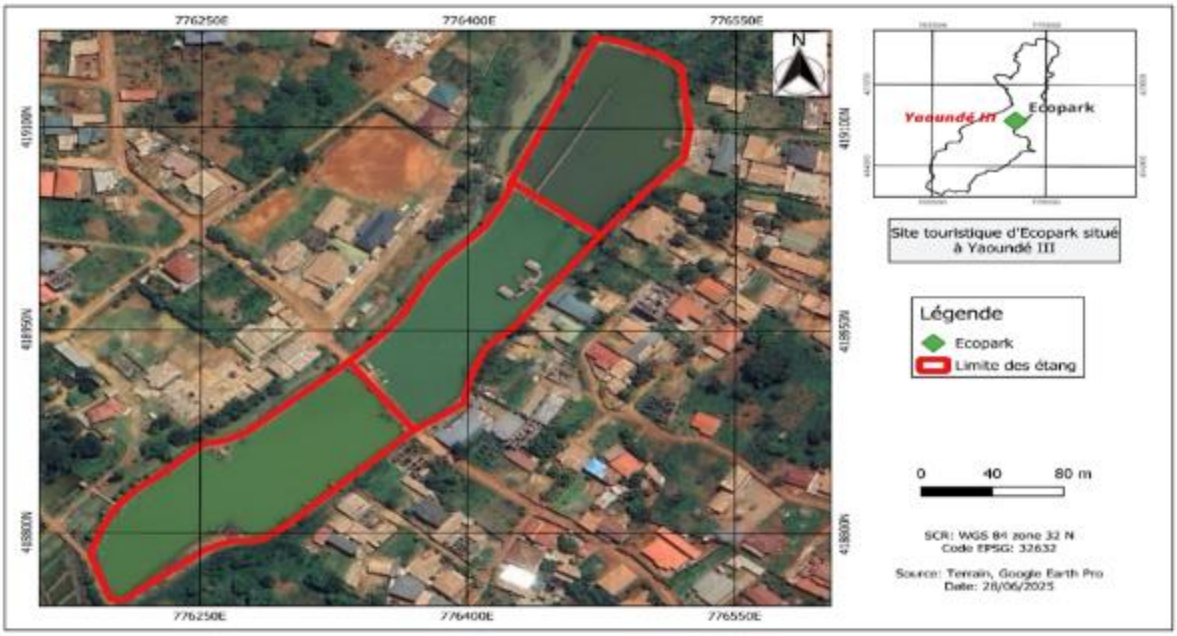

Figure 5 ECO tourist site

Benthic macroinvertebrates sample collection was performed using the kick sampling procedure as demonstrated by Dickens and Graham (2002), where rocks and sediments are agitated by kicking with the foot while sweeping into the net in a zig-zag pattern as to eject stuck/anchored macroinvertebrates, using a hand-held kick net (dimension 30 × 30 cm, mesh size 500 µm, 1.5 m handle). At every sampled site, all freshwater habitats (runs, riffles, pools and vegetation) were sampled for macroinvertebrates in about 6-min. samples of macroinvertebrates from all habitats per sampling event were pooled as a composite sample for each site. The composite samples were then preserved with 70%

ethanol and taken to the laboratory for processing. In the laboratory, processed samples of macroinvertebrates were identified to the family taxonomic level , according to the procedure of Merritt and Cummins (1996), Day et al. (2002) and De Moor et al. (2003). We also made references to the indigenous species of (see Arimoro and James 2008; Arimoro et al., 2012).The physicochemical variables were compared among the study sites for both water course using a One-way analysis of variance (ANOVA). Prior to ANOVA, tests for homogeneity of variances and normality of distribution were performed using Levene's and Shapiro-Wilk's tests, respectively. Significant ANOVAs ($P < 0.05$) were followed by Turkey' post hoc HSD test. All analyses were performed using SPSS version 16.0 (SPSS Inc, 2007). Summaries of common metrics and diversity indices, such as abundance, number of taxa, taxa richness (Margalef's index), diversity index (Shannon index) and evenness indices were calculated using the computer BASIC programme (Ludwig and Reynolds 1988).

3. Results and Discussion

These water animals have many special adaptations that allow them to live in different environments. An adaptation is a change in structure, function, or behavior that helps a living organism had better survive in its environment. These adaptations can be a physical change, such as a body part, or a behavioral change like building a case out of sticks for protection and shelter.Aquatic macroinvertebrates that live in rapidly-moving water may have physical adaptations like flat, streamlined bodies that move well in fast water or specialized feet that help them hold onto rocky or hard substrates (organic materials at the bottom of a stream or lake), such as hooked feet or suction cups. Macroinvertebrates that make homes deep in muddy substrates may have adaptations for low oxygen environments, such as air tubes or oxygen trapping hemoglobin (red protein that helps transport oxygen in the blood) in their tissue. Basic aquatic macroinvertebrate adaptations: Antennae: Used for sensing food and surroundings. Specialized mouth parts: Help with eating food and are adapted based on their diet.Specialized feet: Used to collect and eat food as well as hold onto substrate in riverbeds and ponds. Compound eyes: Help detect motion and see in all directions.Gills: Help with breathing dissolved oxygen in the water. Tails: Used for swimming and steering as presented in figures 1 to 13 and tables 1 to 4 as presented by Awojuh ,2005;Bonada, 2006,

Table 1 Diversity of macroinvertebrates in the aquatic systems of the touristic sites

Stations	**Belostomidae**	**Nepidae**	**Notonectidae**	**Gerridae**	**Mesoveliidae**	**Chironomidae**	**Noteridae**	**Elmidae**
Bal 1	5	1	1	0	1	2	0	0
Bal 2	0	1	0	2	0	0	2	0
Bal 3	0	8	6	2	0	4	3	0
Anas 1	0	0	0	0	0	4	0	0
Anas 2	0	0	0	0	0	0	0	2
Anas 3	1	0	0	0	0	9	0	0
Eco 1	1	11	0	0	0	0	0	0
Eco 2	1	1	0	3	0	0	0	0
Eco 3	7	6	0	0	0	7	0	0
Mink 1	0	0	0	0	0	0	0	0
Mink 2	0	0	0	0	0	0	0	0
Mink 3	0	0	0	0	0	3	0	0

Stations	hydrophilidae	Coenagrionidae	Libellulidae	Thiaridae	Lymnaeidae
Bal 1	5	1	3	2	0
Bal 2	0	0	9	0	0
Bal 3	0	1	4	0	0
Anas 1	0	0	0	0	0
Anas 2	0	0	0	0	0

Anas 3	0	0	0	0	0
Eco 1	4	0	0	4	0
Eco 2	0	1	0	0	0
Eco 3	2	23	1	0	0
Mink 1	0	0	1	2	0
Mink 2	0	0	7	44	0
Mink 3	0	0	0	176	6

The table presents data on the presence and abundance of different benthic macroinvertebrate groups across the four stations included in the study (Bal, Anas, Eco, Mink). Benthic macroinvertebrate community composition is universally recognized as a robust indicator of the ecological quality of aquatic ecosystems (Rosenberg & Resh, 1993; Bonada et al., 2006).The Anas and Eco3, with a strong predominance of Chironomidae and Haplotaxidae, are consistent with numerous studies showing that these groups are reliable indicators of organic pollution and eutrophication. For example, Pradhan et al. (2020) showed in Indian rivers that areas polluted by domestic discharges were characterized by a dominance of Chironomidae and Oligochaetes, while unpolluted areas had a greater diversity and abundance of sensitive taxa such as Ephemeroptera, Plecoptera and Trichoptera (EPT). The absence of EPT in the obtained data reinforces the pollution hypothesis (Bonada; 2006; Masesa et al. (2022)).

The presence of Noteridae, Elmidae, Coenagrionidae, and Libellulidae at Bal stations, and to a lesser extent Eco 1, 2, and Mink, is a positive sign. Studies such as that of Gómez-Rodríguez et al. (2021) in Spain have demonstrated that Odonata are indicators of good water quality and riparian habitat structure. Their high abundance is often correlated with good oxygenation and minimal anthropogenic disturbance.

The co-occurrence of Elmidae and Noteridae (Coleoptera) with Odonata is a common pattern in healthy aquatic ecosystems, as reported by Masesa et al. (2022) in East African rivers, where these groups were abundant in less disturbed sites. The case of Mink 3, with a very high abundance of Libellulidae and at the same time Chironomidae and Haplotaxidae, illustrates the complexity of ecosystems. This could indicate spatial heterogeneity within the station (different micro-habitats), intermittent pollution sources, or resilience of odonates to certain pressures if other conditions (e.g. presence of vegetation, varied substrate) remain favorable. Studies such as that of Chefaoui et al. (2018) on Mediterranean ecosystems have shown that the presence of refuge habitats and structural complexity can maintain sensitive macroinvertebrate populations even in the presence of certain disturbances.

In summary, analysis of benthic macroinvertebrates in data from the four tourist sites included in the study reveals variability in ecological quality between stations. The Bal stations appear to exhibit the best ecological quality, characterized by the presence of organisms sensitive to pollution. The Anas and Eco 3 stations show clear signs of degradation, likely due to organic pollution, as evidenced by the dominance of Chironomidae and Haplotaxidae. The Mink stations are more nuanced, with positive indicators (Libellulidae) but also signs of stress (Chironomidae, Haplotaxidae), suggesting a heterogeneous ecological situation or specific pressures. For a comprehensive assessment, it is imperative to integrate physicochemical data, habitat observations, and the application of recognized biotic indices. However, based on biological data alone, it is possible to rank the stations from best to worst ecological quality as follows: Bal > Eco (1, 2) > Mink > Anas (and Eco 3)(Masesa et al, 2022; Nzombi et al, 2025).

Table 2 Physicochemical parameters in the aquatic systems of the touristic sites

	BAL1	**BAL2**	**BAL3**	**MINK1**	**MINK2**	**MINK3**	**ECO3**
dissolved oxygen (mg/L)	15	20	13	16	14	21	25.5
CO2 dissous(mg/L)	14	12.32	35.2	28.16	36.96	21.12	21.12
Ph(UC)	7.53	7.6	7.7	8.35	8.46	8.43	9.55
Conductivity (µS/cm)	130	109	92	92	126	97	224
Salinity (ppm)	57	53	46	46	63	48	112
temperature (°C)	27.6	30	35.2	26.5	26.8	26.7	25.9

Total alkalinity (mg/L)	20	19	21	20	28	27	28
Hardness (mg/L)	2	1	0	0	0	1	0
Acide cyanurique(mg/L)	25	24	23	26	27	28	18
Chlore total(mg/L)	0.3	0.6	0.7	0.4	0.3	0.4	0.3
Chlore libre(mg/L)	0.2	0.2	0.3	0.1	0.2	0.3	0.1
Brome libre(mg/L)	0.1	0.1	0	0	0	0	0
Nitrate(mg/L)	26	27	28	25	30	27.8	28
Nitrite(mg/L)	0.5	3	1.5	2	3	4	1.1
Fer(mg/L)	2	0.1	1	0	0	0	0
Chrome/Cr(VI)(mg/L)	1	0.9	1.2	1.3	1.1	4.1	0
Plomb(mg/L)	0	0	0	0	0	0	0
Cuivre(mg/L)	0.5	0.4	0.1	0.3	0.4	0.6	1
Mercure(mg/L)	0.003	0.004	0.003	0.001	0.002	0.01	0.01
Fluorure(mg/L)	150	160	140	155	152	160	160
Racine de carbonate(mg/L)	15	10	11	12	14	13	14
Azote ammoniacal (mg/L)	0.2	0.3	0.1	0.01	0.25	0.12	0.1
phosphates (ppb)	300	298	330	310	400	500	150

	ST ANAS1	**ST ANAS2**	**ST ANAS3**	**ECO1**	**ECO2**	**ECO3**
Dissolved Oxygen (mg/L)	22.5	23	21	19	18.5	25.5
Dissolved CO2 (mg/L)	19.36	26.4	8.8	17.6	3.2	21.12
Ph (UC)	8.39	8.57	8.46	9.42	9.71	9.55
Conductivity (µS/cm)	287	295	221	225	207	224
Salinity (ppm)	148	148	110	112	103	112
Temperature (°C)	26.5	26.5	26.4	27.4	25.7	25.9
Total Alkalinity (mg/L)	18	25	12	27	21	28
Hardness (mg/L)	0	1	0	0	0	0
Cyanuric Acid (mg/L)	22	20	23	17	16	18
Total Chlorine (mg/L)	0.8	0.7	0.6	0.4	0.7	0.3
Free Chlorine (mg/L)	0.2	0.3	0.4	0.3	0.2	0.1
Free Bromine (mg/L)	0	0	0	0	0	0
Nitrate (mg/L)	20	22	15	8	27	28
Nitrite (mg/L)	2.5	1	0.3	1.2	1.5	1.1
Iron (mg/L)	0	0	0	0	0	0
Chromium/Cr(VI) (mg/L)	0.1	0	0	0.2	0.1	0
Lead (mg/L)	0	0	0	0	0	0
Copper (mg/L)	0.2	0	0	0.2	0.5	1

Mercury (mg/L)	0.004	0.01	0.01	0.05	0.01	0.01
Fluoride (mg/L)	170	145	150	160	170	160
Carbonate (mg/L)	15	16	16	15	12	14
Ammoniacal Nitrogen (mg/L)	0.6	0.33	0.7	0.1	0.6	0.1
Phosphates (ppb)	450	500	400	200	200	150

Table 3 Relationship between the Physicochemical parameters and the biodiversity of macroinvertebrates in the aquatic systems of the touristic sites

	Belostomidae	Nepidae	Notonectidae	Gerridae	Mesoveliidae	Chironomidae	Noteridae	Elmidae
Belostomidae	1	0.495	0.103	-0.104	0.442	0.311	-0.363	-0.246
Nepidae	0.495	1	0.434	0.431	0.141	0.012	0.434	-0.282
Notonectidae	0.103	0.434	1	0.251	0.604*	0.256	0.5	-0.134
Gerridae	-0.104	0.431	0.251	1	-0.172	-0.207	0.679*	-0.172
Mesoveliidae	0.442	0.141	0.604*	-0.172	1	0.047	-0.134	-0.091
Chironomidae	0.311	0.012	0.256	-0.207	0.047	1	0.034	-0.28
Noteridae	-0.363	0.434	0.5	0.679*	-0.134	0.034	1	-0.134
Elmidae	-0.246	-0.282	-0.134	-0.172	-0.091	-0.28	-0.134	1
Hydrophilidae	0.764**	0.603*	0.289	-0.326	0.631*	0.079	-0.254	-0.172
Coenagrionidae	0.624*	0.610*	0.543	0.362	0.367	0.328	0.152	-0.21
Libellulidae	-0.164	0.239	0.42	0.281	0.234	-0.158	0.609*	-0.28
Thiaridae	-0.119	-0.158	-0.063	-0.463	0.195	-0.32	-0.36	-0.244
Lymnaeidae	-0.246	-0.282	-0.134	-0.172	-0.091	0.14	-0.134	-0.091
Hydrobidae	0.246	-0.282	-0.134	-0.172	-0.091	0.514	-0.134	-0.091
Physidae	0.158	-0.277	-0.36	-0.175	-0.243	0.329	-0.36	0.536
Haplotaxidae	-0.363	-0.416	-0.198	-0.255	-0.134	-0.129	-0.198	0.739**
oxygen	0.154	-0.226	-0.592*	-0.35	-0.306	0.322	-0.355	0.394
CO2	-0.528	-0.183	0.167	-0.304	-0.219	-0.082	0.108	0.219
Ph	0.374	0.094	-0.571	-0.051	-0.481	-0.069	-0.512	0.219
Conduct	0.347	-0.021	-0.38	-0.348	-0.044	0.082	-0.498	0.481
Salini	0.304	-0.062	-0.44	-0.349	-0.132	0.107	-0.5	0.439
Tempera	-0.349	0.337	0.595*	0.153	0.308	-0.188	0.655*	-0.132
Alca	0.107	0.252	-0.119	-0.178	-0.176	-0.224	-0.208	0.132
Hardness	-0.071	-0.122	0.223	-0.064	0.577*	-0.189	0.081	0.367
cyanide	-0.477	-0.511	0.148	-0.279	0.219	-0.013	0.089	-0.219
Chloreto	-0.423	-0.121	-0.022	0.464	-0.402	0.048	0.311	0.313
free chlorine	-0.129	-0.038	0.128	-0.022	-0.139	0.21	0.128	0.277
bromine	0.146	0.209	0.349	0.213	0.674*	-0.173	0.349	-0.135
nitrate	-0.13	0.121	0.251	0.319	-0.044	0.032	0.34	-0.219

nitrite	-0.683*	-0.236	-0.267	0.203	-0.394	-0.311	0.237	-0.307
iron	0.041	0.444	0.840**	0.405	0.631*	0.064	0.684*	-0.172
chrome	-0.48	-0.055	0.336	0.074	0.132	-0.249	0.277	-0.397
Copper	0.357	0.182	-0.068	0.067	0.264	-0.026	-0.187	-0.44
Mercury	0.422	0.264	-0.403	-0.043	-0.273	0.13	-0.28	0.227
Fluoride	0.121	0.052	-0.574	0.148	-0.268	-0.115	-0.272	-0.402
Racarbo	0.319	-0.301	-0.169	-0.708**	0.221	0.246	-0.648*	0.442
ammoni	-0.012	-0.427	-0.277	0.158	-0.044	0.113	-0.157	0.22
phospha	-0.668*	-0.772**	-0.054	-0.361	-0.132	0.128	-0.113	0.439

hydrophilidae	**Coenagrionidae**	**Dragonfly**	**Thiaridae**	**Lymnaeidae**	**Hydrobidae**	**Physidae**	**Haplotaxidae**
0.764**	0.624*	-0.164	-0.119	-0.246	0.246	0.158	-0.363
0.603*	0.610*	0.239	-0.158	-0.282	-0.282	-0.277	-0.416
0.289	0.543	0.42	-0.063	-0.134	-0.134	-0.36	-0.198
-0.326	0.362	0.281	-0.463	-0.172	-0.172	-0.175	-0.255
0.631*	0.367	0.234	0.195	-0.091	-0.091	-0.243	-0.134
0.079	0.328	-0.158	-0.32	0.14	0.514	0.329	-0.129
-0.254	0.152	0.609*	-0.36	-0.134	-0.134	-0.36	-0.198
-0.172	-0.21	-0.28	-0.244	-0.091	-0.091	0.536	0.739**
1	0.441	0.044	0.231	-0.172	-0.172	-0.154	-0.254
0.441	1	0.216	-0.331	-0.21	-0.21	0.066	-0.31
0.044	0.216	1	0.044	-0.28	-0.28	-0.55	-0.414
0.231	-0.331	0.044	1	0.537	-0.244	-0.654*	0.168
-0.172	-0.21	-0.28	0.537	1	-0.091	-0.243	0.604*
-0.172	-0.21	-0.28	-0.244	-0.091	1	0.243	-0.134
-0.154	0.066	-0.55	-0.654*	-0.243	0.243	1	0.264
-0.254	-0.31	-0.414	0.168	0.604*	-0.134	0.264	1
0	-0.139	-0.543	-0.356	0.175	0.175	0.762**	0.433
-0.198	-0.099	0.337	0.329	0.087	-0.394	-0.172	0.234
0.046	0.122	-0.568	-0.094	-0.044	0.087	0.496	0.145
0.276	-0.074	-0.583*	-0.331	-0.306	0.131	0.781**	0.178
0.208	-0.089	-0.555	-0.336	-0.307	0.132	0.804**	0.143
0.157	-0.123	0.606*	0.303	0.044	-0.308	-0.699*	-0.076
0.268	0.224	0.066	0.464	0.264	-0.484	-0.134	0.284
0.182	-0.068	0.144	0.167	0.367	-0.21	-0.15	0.543
-0.248	-0.36	0.451	0.591*	0.481	0	-0.574	0.151
-0.592*	-0.172	-0.392	-0.636*	-0.134	0.089	0.467	0.16

-0.17	-0.334	-0.418	0.019	0.277	0.509	0.041	0.41
0.34	0.117	0.554	-0.036	-0.135	-0.135	-0.361	-0.199
-0.152	0.462	0.623*	0.129	0.219	-0.394	-0.305	-0.027
-0.488	-0.367	0.265	0.388	0.482	-0.482	-0.415	0.081
0.265	0.392	0.648*	-0.138	-0.172	-0.172	-0.461	-0.254
-0.139	-0.146	0.407	0.674*	0.485	-0.397	-0.846**	0.011
0.337	0.466	0.224	0.333	0.396	-0.44	-0.267	-0.084
0.234	-0.004	-0.703*	-0.136	0.227	0.227	0.41	0.336
0.009	-0.036	-0.309	0.014	0.178	-0.268	0.127	-0.2
0.302	-0.234	-0.562	0.006	-0.133	0.442	0.557	0.264
-0.389	-0.223	-0.34	-0.445	-0.132	0.485	0.555	0.087
-0.572	-0.581*	-0.265	0.165	0.439	0.176	0.2	0.648*

oxygen	CO2	pH	I drive	Pray.	tempera	Auk	Hardness	cyanide
0.154	-0.528	0.374	0.347	0.304	-0.349	0.107	-0.071	-0.477
-0.226	-0.183	0.094	-0.021	-0.062	0.337	0.252	-0.122	-0.511
-0.592*	0.167	-0.571	-0.38	-0.44	0.595*	-0.119	0.223	0.148
-0.35	-0.304	-0.051	-0.348	-0.349	0.153	-0.178	-0.064	-0.279
-0.306	-0.219	-0.481	-0.044	-0.132	0.308	-0.176	0.577*	0.219
0.322	-0.082	-0.069	0.082	0.107	-0.188	-0.224	-0.189	-0.013
-0.355	0.108	-0.512	-0.498	-0.5	0.655*	-0.208	0.081	0.089
0.394	0.219	0.219	0.481	0.439	-0.132	0.132	0.367	-0.219
0	-0.198	0.046	0.276	0.208	0.157	0.268	0.182	-0.248
-0.139	-0.099	0.122	-0.074	-0.089	-0.123	0.224	-0.068	-0.36
-0.543	0.337	-0.568	-0.583*	-0.555	0.606*	0.066	0.144	0.451
-0.356	0.329	-0.094	-0.331	-0.336	0.303	0.464	0.167	0.591*
0.175	0.087	-0.044	-0.306	-0.307	0.044	0.264	0.367	0.481
0.175	-0.394	0.087	0.131	0.132	-0.308	-0.484	-0.21	0
0.762**	-0.172	0.496	0.781**	0.804**	-0.699*	-0.134	-0.15	-0.574
0.433	0.234	0.145	0.178	0.143	-0.076	0.284	0.543	0.151
1	-0.24	0.419	0.667*	0.680*	-0.557	-0.002	0.103	-0.36
-0.24	1	-0.13	-0.298	-0.245	0.272	0.508	-0.158	0.414
0.419	-0.13	1	0.554	0.592*	-0.709**	0.517	-0.463	-0.654*
0.667*	-0.298	0.554	1	0.989**	-0.441	0.032	-0.055	-0.675*
0.680*	-0.245	0.592*	0.989**	1	-0.481	0.067	-0.142	-0.657*
-0.557	0.272	-0.709**	-0.441	-0.481	1	-0.014	0.385	0.427
-0.002	0.508	0.517	0.032	0.067	-0.014	1	-0.08	-0.044

0.103	-0.158	-0.463	-0.055	-0.142	0.385	-0.08	1	0.366
-0.36	0.414	-0.654*	-0.675*	-0.657*	0.427	-0.044	0.366	1
0.185	-0.201	0.023	0.233	0.23	-0.123	-0.508	-0.148	-0.41
0.043	-0.134	0.067	0.16	0.114	0.209	-0.114	0.12	-0.05
-0.195	-0.389	-0.649*	-0.195	-0.26	0.522	-0.359	0.701*	0.26
-0.316	0.462	-0.063	-0.54	-0.469	0.17	0.535	0.015	0.353
-0.169	0.313	-0.213	-0.48	-0.404	0.261	0.178	-0.006	0.483
-0.506	-0.074	-0.754**	-0.423	-0.489	0.740**	-0.291	0.485	0.23
-0.661*	0.442	-0.565	-0.845**	-0.846**	0.583*	0.13	0.165	0.742**
0.016	-0.109	0.078	-0.261	-0.239	-0.128	0.429	0.214	0.178
0.623*	-0.496	0.685*	0.614*	0.582*	-0.374	0.213	-0.004	-0.633*
0.34	-0.437	0.338	0.211	0.257	-0.389	0.013	-0.217	-0.299
0.442	-0.126	0.291	0.771**	0.738**	-0.307	-0.057	0.066	-0.225
0.304	-0.555	0.163	0.474	0.488	-0.355	-0.481	0.085	-0.216
0.141	0.375	-0.232	0.021	0.035	0.067	-0.149	0.253	0.484

Chloreto	**chlorelibre**	**brome**	**nitrate**	**nitrite**	**iron**	**chromium**	**copper**
-0.423	-0.129	0.146	-0.13	-0.683*	0.041	-0.48	0.357
-0.121	-0.038	0.209	0.121	-0.236	0.444	-0.055	0.182
-0.022	0.128	0.349	0.251	-0.267	0.840**	0.336	-0.068
0.464	-0.022	0.213	0.319	0.203	0.405	0.074	0.067
-0.402	-0.139	0.674*	-0.044	-0.394	0.631*	0.132	0.264
0.048	0.21	-0.173	0.032	-0.311	0.064	-0.249	-0.026
0.311	0.128	0.349	0.34	0.237	0.684*	0.277	-0.187
0.313	0.277	-0.135	-0.219	-0.307	-0.172	-0.397	-0.44
-0.592*	-0.17	0.34	-0.152	-0.488	0.265	-0.139	0.337
-0.172	-0.334	0.117	0.462	-0.367	0.392	-0.146	0.466
-0.392	-0.418	0.554	0.623*	0.265	0.648*	0.407	0.224
-0.636*	0.019	-0.036	0.129	0.388	-0.138	0.674*	0.333
-0.134	0.277	-0.135	0.219	0.482	-0.172	0.485	0.396
0.089	0.509	-0.135	-0.394	-0.482	-0.172	-0.397	-0.44
0.467	0.041	-0.361	-0.305	-0.415	-0.461	-0.846**	-0.267
0.16	0.41	-0.199	-0.027	0.081	-0.254	0.011	-0.084
0.185	0.043	-0.195	-0.316	-0.169	-0.506	-0.661*	0.016
-0.201	-0.134	-0.389	0.462	0.313	-0.074	0.442	-0.109
0.023	0.067	-0.649*	-0.063	-0.213	-0.754**	-0.565	0.078
0.233	0.16	-0.195	-0.54	-0.48	-0.423	-0.845**	-0.261

0.23	0.114	-0.26	-0.469	-0.404	-0.489	-0.846**	-0.239
-0.123	0.209	0.522	0.17	0.261	0.740**	0.583*	-0.128
-0.508	-0.114	-0.359	0.535	0.178	-0.291	0.13	0.429
-0.148	0.12	0.701*	0.015	-0.006	0.485	0.165	0.214
-0.41	-0.05	0.26	0.353	0.483	0.23	0.742**	0.178
1	0.349	-0.232	-0.343	0.038	-0.052	-0.271	-0.577*
0.349	1	-0.206	-0.349	-0.243	0	-0.101	-0.593*
-0.232	-0.206	1	0.033	-0.033	0.765**	0.131	0.261
-0.343	-0.349	0.033	1	0.442	0.235	0.395	0.572
0.038	-0.243	-0.033	0.442	1	-0.106	0.635*	0.337
-0.052	0	0.765**	0.235	-0.106	1	0.315	0.046
-0.271	-0.101	0.131	0.395	0.635*	0.315	1	0.263
-0.577*	-0.593*	0.261	0.572	0.337	0.046	0.263	1
0.162	0.476	-0.27	-0.391	-0.31	-0.42	-0.567	-0.02
0.11	-0.403	-0.066	-0.084	0.448	-0.413	-0.101	0.5
-0.027	0.392	-0.197	-0.600*	-0.629*	-0.344	-0.584*	-0.403
0.513	0.321	0.065	-0.288	-0.15	-0.157	-0.559	-0.281
0.329	0.478	-0.26	-0.093	0.222	-0.185	0.176	-0.427

Mercury	**Fluoride**	**Racarbo**	**ammonium**	**phosphate**
0.422	0.121	0.319	-0.012	-0.668*
0.264	0.052	-0.301	-0.427	-0.772**
-0.403	-0.574	-0.169	-0.277	-0.054
-0.043	0.148	-0.708**	0.158	-0.361
-0.273	-0.268	0.221	-0.044	-0.132
0.13	-0.115	0.246	0.113	0.128
-0.28	-0.272	-0.648*	-0.157	-0.113
0.227	-0.402	0.442	0.22	0.439
0.234	0.009	0.302	-0.389	-0.572
-0.004	-0.036	-0.234	-0.223	-0.581*
-0.703*	-0.309	-0.562	-0.34	-0.265
-0.136	0.014	0.006	-0.445	0.165
0.227	0.178	-0.133	-0.132	0.439
0.227	-0.268	0.442	0.485	0.176
0.41	0.127	0.557	0.555	0.2
0.336	-0.2	0.264	0.087	0.648*
0.623*	0.34	0.442	0.304	0.141

-0.496	-0.437	-0.126	-0.555	0.375
0.685*	0.338	0.291	0.163	-0.232
0.614*	0.211	0.771**	0.474	0.021
0.582*	0.257	0.738**	0.488	0.035
-0.374	-0.389	-0.307	-0.355	0.067
0.213	0.013	-0.057	-0.481	-0.149
-0.004	-0.217	0.066	0.085	0.253
-0.633*	-0.299	-0.225	-0.216	0.484
0.162	0.11	-0.027	0.513	0.329
0.476	-0.403	0.392	0.321	0.478
-0.27	-0.066	-0.197	0.065	-0.26
-0.391	-0.084	-0.600*	-0.288	-0.093
-0.31	0.448	-0.629*	-0.15	0.222
-0.42	-0.413	-0.344	-0.157	-0.185
-0.567	-0.101	-0.584*	-0.559	0.176
-0.02	0.5	-0.403	-0.281	-0.427
1	0.318	0.391	0.24	-0.146
0.318	1	-0.219	0.151	-0.33
0.391	-0.219	1	0.388	0.338
0.24	0.151	0.388	1	0.328
-0.146	-0.33	0.338	0.328	1

The combined analysis of biological and physicochemical data allows for a nuanced but clear assessment of ecological quality.The consistency between biological and physicochemical pollution indicators at the ANAS and ECO3 stations classifies them as highly degraded and polluted. The dominance of Chironomidae and Haplotaxidae, coupled with high levels of ammonia, conductivity, salinity, and especially phosphates, clearly indicates severe organic pollution and proven eutrophication. The presence of lead at ANAS3 is an additional toxicity factor quite characteristic of the pollution level. The abnormally high oxygen levels at these stations are the only inconsistency that could be explained by diurnal photosynthetic peaks in a eutrophic environment. These observations are in perfect agreement with studies showing that Chironomidae and Oligochaetes (Haplotaxidae here) are reliable markers of organic pollution and hypoxia/anoxia resulting from eutrophication. Pradhan et al. (2020) and Kone et al. (2023) clearly demonstrated this relationship in India and Ivory Coast, respectively, where sites polluted by domestic or agricultural discharges showed a dominance of these tolerant taxa.

Stations BAL and MINK show apparently better biological quality, with a significant presence of odonates and other sensitive taxa. However, their nitrate and especially phosphate levels are extremely alarming, indicating potential or actual eutrophication that may not yet have fully impacted the benthic community, or that other resilience factors are at work. The presence of chromium at MINK3 is also a major toxic risk factor. These stations require proactive monitoring to prevent future degradation. Stations ECO1 and ECO2 show mixed indicators: better biological quality than ECO3, but very basic pH and elevated phosphates, suggesting pressure, albeit less severe than ST ANAS and ECO3.In summary, stations ST ANAS and ECO3 are the most concerning. Stations BAL and MINK are under high nutrient pressure, and for MINK3, the presence of heavy metals requires immediate attention to prevent future biological degradation despite their apparently better current status. General observations on the indices reveal a large variability between samples, each group presenting distinct ecological characteristics in terms of community structure.

Table 4 Overview of biodiversity index values in aquatic systems of tourist sites

	Bal 1	**Bal 2**	**Bal 3**	**Anas 1**	**Anas 2**	**Anas 3**
Taxa_S	9	4	7	2	3	4
Individuals	21	14	28	12	16	14
Dominance_D	0.161	0.4592	0.1862	0.5556	0.5938	0.4592
Simpson_1-D	0.839	0.5408	0.8138	0.4444	0.4063	0.5408
Shannon_H	1.989	1.029	1.791	0.6365	0.7356	1.029
Equitability_J	0.9053	0.7419	0.9203	0.9183	0.6696	0.7419
	Eco 1	Eco 2	Eco 3	Mink 1	Mink 2	Mink 3
Taxa_S	4	5	7	2	2	4
Individuals	20	7	50	3	51	186
Dominance_D	0.385	0.2653	0.2736	0.5556	0.7632	0.8967
Simpson_1-D	0.615	0.7347	0.7264	0.4444	0.2368	0.1033
Shannon_H	1.122	1.475	1.571	0.6365	0.3999	0.2577
Equitability_J	0.8096	0.9165	0.8074	0.9183	0.577	0.1859

In terms of species richness (Taxa S), samples Bal 1 (9), Bal 3 (7), and Eco 3 (7) show the greatest diversity of species types. Conversely, Anas 1, Mink 1, and Mink 2, with only two species, indicate communities with very little diversity. The total abundance index (Individuals) reveals that Mink 3 stands out for its remarkably high abundance, followed by Bal 3 (28) and Bal 1 (21), which have relatively large numbers. Bal 1 (0.84), Bal 3 (0.81), Eco 2 (0.735), and Eco 3 (0.726) exhibit high diversity, consistent with their low dominance scores, while Mink 3 (0.1033), Mink 2 (0.2368), Anas 1 (0.444), and Mink 1 (0.4444) display very low diversity, confirming the observed high dominance.

The Mink group, particularly Mink 3, stands out for having the least diverse communities by almost all metrics. This is mainly due to extreme dominance and low species richness. Meanwhile, the Bal group generally represents more diverse communities, characterized by a good number of species and a more balanced distribution of individuals.

Caddisflies, order Trichoptera, is the largest order of entirely aquatic insects. Caddisfly have hardened plates on all three of the thorax segments, and branched filamentous gills on the bottom of most abdomen segments. Caddisfly larvae resemble a caterpillar.They cannot tolerate water pollution.

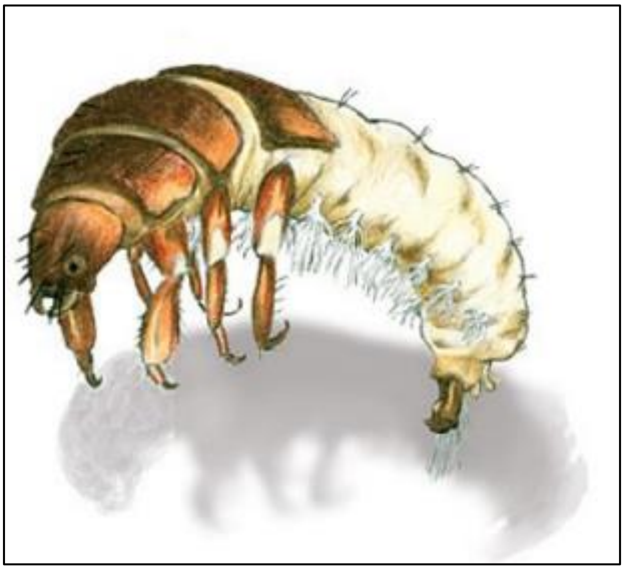

Figure 6 Morphologie of Caddisflies, order Trichoptera

Damselflies, order Odonata, have an elongate body and most noticeably have three long gills projecting from the abdomen. The head is wider than the thorax and the abdomen. Damselflies are considered facultative, in that they prefer good water quality but are somewhat tolerant of degraded water quality.

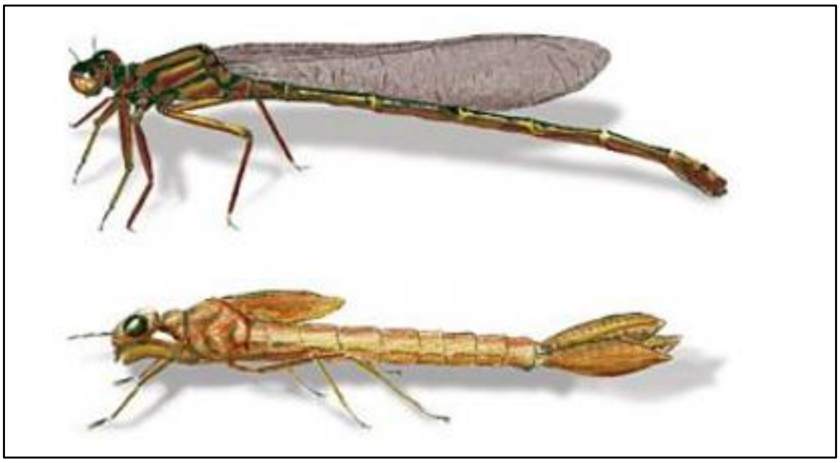

Figure 7 *Morphologie of Odonata*

Dragonflies, order Odonata, are similar to damselflies, but the body of the nymph tends to be long and stout or oval and flattened. Dragonflies do not have gills on the abdomen. Three short, stiff, pointed structures occur at the end of the abdomen. Like damselflies, dragonflies are predators and as adults move fast to capture prey. Also like damselflies, they tolerate some level of impaired water quality. Both adults and nymphs are predators.

Figure 8 Morphologie of Dragon Flies

Dobsonflies, order Megaloptera, are a small group whose larvae have flattened, elongated bodies. They have prominent chewing mouth parts and three pairs of segmented legs. At the end of the abdomen there is a pair of pro-legs (unsegmented appendages) with two claws on each. The adults are distinguished by a pair of long wings that have many veins. Dobsonflies are considered beneficial to the water body which they inhabit as they increase diversity. They thrive in clean to moderately clean water.

Figure 9 Dobsonflies, order Megaloptera

Mayflies, order Ephemeroptera, are known for their short adult lifespan, often only a few hours. The nymph have elongated bodies that are slightly flattened. The wingpads and three pairs of legs are on the thorax. Each leg has a claw at the end for grasping material to move around. Three long tails usually occur at the end of the body. Mayflies do not tolerate pollution well.

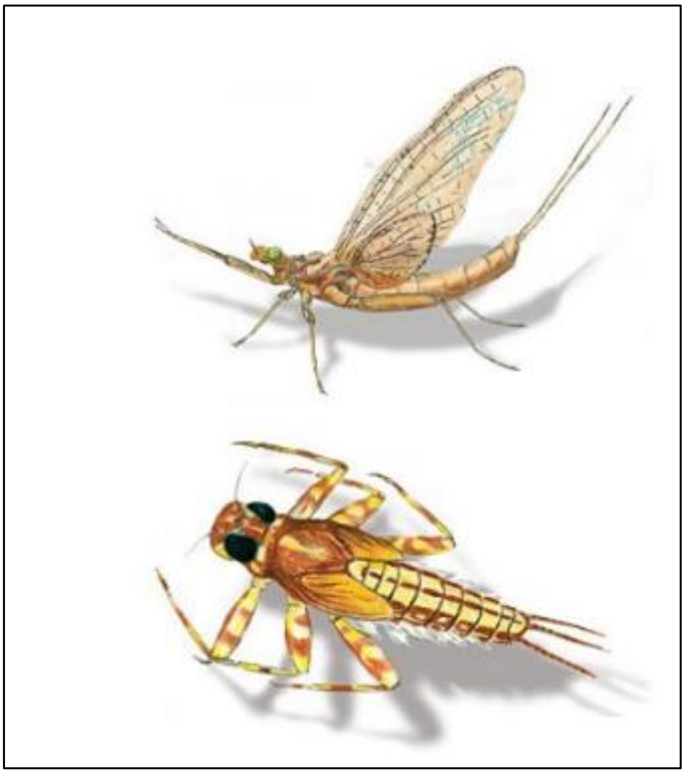

Figure 10 Motphology of Dobsonflies, order Megaloptera

Stoneflies, order Plecoptera, are distinguished by two long thin tails projecting from the rear of the abdomen. The body is somewhat flattened, and there are two claws that extend from the three pairs of segmented legs. Stoneflies are considered crawlers and crawl around looking for food. They are not tolerant of water pollution.

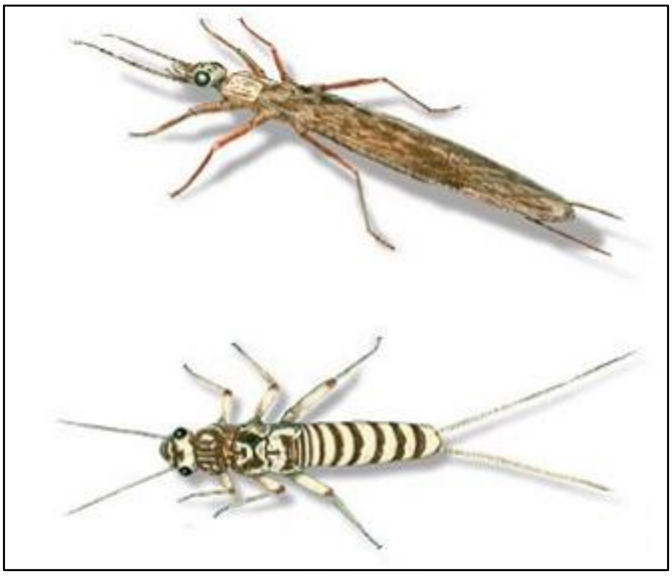

Figure 11 Morphologie of stone flies; plecoptera

Crayfish, order Decapoda, are often called crawdads. They are usually brownish green in color but can change color to reflect the surface they are on. They have five pairs of walking legs and one pair of long antennae. The first two or three pairs of legs have a hinged claw at the end. A broad flipper extends from the lower abdomen. Crayfish live in shallow water or burrow in the mud of a wetland. They are an important part of the food chain of most wetlands. Crayfish are tolerant of temperature, pH and alkalinity, but are sensitive to toxic substances such as metals. In fact, the district has used crayfish to track bioaccumulation of pesticides in restoration projects. They are partially tolerant of degraded water quality.

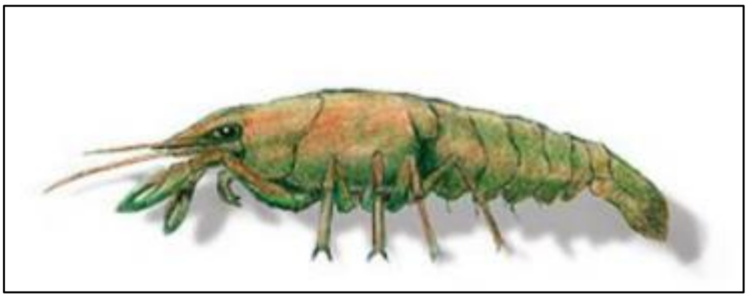

Figure 12 Morphology of Cray fish; Order Decapoda

Mussels, are bivalves, meaning they have two shells that are opposite each other and are strongly connected by a hinge. The shells can vary in color from light green to blackish. Mussels are filter feeders and can contribute to purification of the water in which they live. Mussels are sensitive to pollution/degraded water quality.

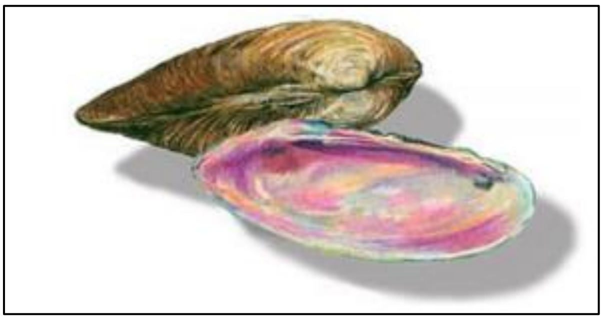

Figure 13 Morphology of Mussels; Bivalves

Gill-breathing snails, have a single shell that is usually coiled and elongate. They have a large muscular foot for stability. Their gill is located on the body inside the shell. Like crayfish, snails occupy an important part of the food chain as they consume algae off plants. Gilled snails are somewhat sensitive to water pollution degraded water quality.

Figure 14 Morphology of gill breathing snails

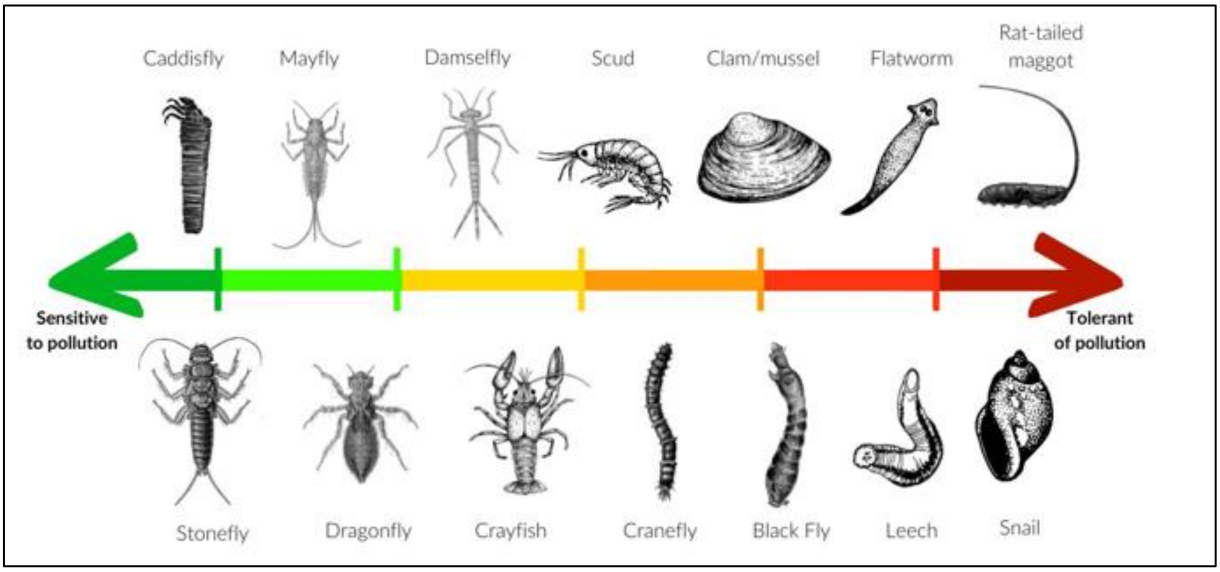

Figure 15 Sensitivity of macroinvertebrates with respect to water quality

This scale is intended for general reference only. Water conditions change constantly. Some macroinvertebrates may handle pollution better than others may depending on the location and natural factors(Anonymous).

Some macroinvertebrates, like mayflies, stoneflies, and caddisflies (EPT taxa), are sensitive to pollution and indicate good water quality. Other species, such as certain types of flies (Diptera), worms (Oligochaeta), and snails (Gastropoda), are more tolerant to pollution and can thrive in degraded environments. A healthy stream will typically have a diverse community of macroinvertebrates, with a good representation of both sensitive and tolerant species. Pollution can lead to a decrease in overall diversity and an increase in the abundance of pollution-tolerant species. By studying macroinvertebrate communities, researchers can assess the health of a waterbody and identify potential pollution sources. Urbanization, with its associated activities like waste disposal and industrial effluent discharge, is a major factor contributing to water pollution in Cameroon. Studies in cities like Douala have shown that urban streams are facing significant pollution problems due to uncontrolled urbanization and waste disposal. This can lead to a decrease in macroinvertebrate biodiversity and an increase in pollution-tolerant species(Anonymous).

The Kondi stream in Douala, for instance, receives both municipal and industrial waste, and its macroinvertebrate community is dominated by pollution-tolerant species. In the littoral region of Cameroon, some streams show high levels of organic pollution. The Nkolbisson artificial lake in Yaoundé is experiencing sedimentation and degradation due to pollution, affecting its recreational and tourism value. The quality of water in and around tourist sites is important for both the environment and the tourism industry. Poor water quality can deter tourists and negatively impact the local ecosystem.Regular monitoring of macroinvertebrate communities can help track changes in water quality and identify areas of concern. Effective waste management practices, including proper disposal of solid and liquid waste, are crucial for reducing pollution. Integrating water resource management into urban planning is essential to ensure the long-term health of water bodies and the sustainability of tourist sites. These sites hosted mainly pollution-tolerant taxa (e.g., high Diptera (Nzombi Azonfack et al. (2025)), and can be considered as disturbed reaches with poor. Physicochemical conditions and toxic substances in the water also affect the aquatic biota [18]. Some groups or species. Macroinvertebrates are organisms that are large (macro) enough to be seen with the naked eye and lack a backbone (invertebrate) (Ajeagah, 2013; 2014)

Macroinvertebrates are often called macros. They are invertebrates (animals without a backbone) that you can see without using a microscope or magnifying glass. Slimy snails are macros, and so are crawly crayfish.There are many different types of macros. Macros that live on or in the ground beneath the water are called benthic macros. Snails, mussels, crayfish, worms and leeches are all benthic macros. Some larval, or young, insects are also benthic macros, though they live above the water when they are older.Scientists survey benthic macros to measure a water body's water quality. Scientists know that certain types of macros can tolerate polluted water, while other types cannot. So as pollution increases in a water body, non-tolerant macros die. If scientists look along the bottom of a lake and only find tolerant benthic macroinvertebrates, they know a lake is polluted. Because pollution tends to reduce the variety of organisms surviving in one place, healthy waters usually have many different kinds of macros. A variety of macros in one place is called diversity, and is a sign of good water quality. For many aquatic insects, district scientists collect and study the young phase (nymph or larva) in the water(Predhan, 2020, Nzombi Azonfack,2025). .

4. Conclusion

In Cameroon, studies have shown that urban development and associated pollution (domestic and industrial waste, solid and liquid waste disposal) can negatively impact these macroinvertebrate communities, leading to a decrease in diversity and an increase in pollution-tolerant species. So as pollution increases in a water body, non-tolerant macros die. If scientists look along the bottom of a lake and only find tolerant benthic macroinvertebrates, they know a lake is polluted.Because pollution tends to reduce the variety of organisms surviving in one place, healthy waters usually have many different kinds of macros.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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