

Original Research

Do Urban Rivers Provide Sanctuary to Macroinvertebrates? A Case Study of an Urban Stretch of the Apies River in Pretoria, South Africa

Mapurunyane C. Selala, Refentje M.V. Mokwena, Boikoketso Ramokolo, Abram Melamu, Tebatso V. Mmako, Jeffrey Lebepe^{°*}

Department of Biology and Environmental Sciences, School of Science and Technology, Sefako Makgatho Health Sciences University, Pretoria 0204, South Africa

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Abstract

The present study aimed to investigate macroinvertebrate assemblage in relation to water quality and habitat availability along the longitudinal gradient of an urban Apies River in Pretoria, South Africa. Macroinvertebrate and water sampling were conducted during dry and wet seasons, from December 2019 to March 2020, and between February 2021 and December 2022 at the three sites in the Apies River. The water exhibited neutral to slightly alkaline pH in all sites throughout the study, whereas significant differences were observed for nutrients and sulphate levels between the three sites. The nutrient levels exhibited oligotrophic, eutrophic, and mesotrophic conditions at Sites 1, 2, and 3, respectively. Moreover, the macroinvertebrate assemblage showed an association with habitat scores and water quality. The diversity was relatively higher at Sites 1 and 3 compared to Site 2. However, sensitive taxa were associated with Site 1, whereas tolerant taxa were associated with Sites 2 and 3. The average score per taxon ranged from 4.88-5.68, 3.27- 4.07, and 3.83-4.61 at Sites 1, 2, and 3, respectively. The findings of this study highlight the importance of urban Apies Rivers in providing habitats for aquatic biota and the role of anthropogenic litter in shaping macroinvertebrate community structure.

Keywords: Wastewater effluents, urban river, anthropogenic litter, nutrient pollution, Chironomidae, Hirudinea, Atyidae

Introduction

Rivers are the most disturbed freshwater ecosystems, suffering from impoundments, channel

modification, and pollution [1]. A healthy river plays a crucial ecological and societal role due to its ability to regulate floods, cycle nutrients, provide food, support cultural and recreational values, etc. [2]. An increase in anthropogenic activities such as agriculture, mining, wastewater works, industrial activities, and urbanization is threatening the integrity of macroinvertebrate communities of river systems [3, 4] by changing river

*e-mail: jlebepe@yahoo.com

[°]ORCID iD: 0000-0001-9802-2846

morphology, riparian ecotones, alluvial aquifer storage, hydrologic regime, and water quality [5, 6]. According to Khudhair et al. [7], physical habitat plays a huge role in shaping macroinvertebrate communities in river systems. Nevertheless, river landscapes naturally vary longitudinally, with headwaters showing a relatively narrow channel with a closed canopy and fast-flowing water, the middle stretch widening with a partially to completely closed channel, and the lower stretch being wide open with enough sunlight penetration and a significantly reduced flow [8, 9]. As a result, macroinvertebrate communities may change as the river flows downstream.

Similar to habitat, water quality may also vary along the longitudinal gradient as the tributaries join the mainstem, resulting in a shift in macroinvertebrate communities [10]. The water quality may change naturally as the geology of the area changes [11]. In contrast, anthropogenic stressors such as industries, agriculture, mining, urbanization, and wastewater effluents may result in a drastic decline of water quality [4]. Poor water quality may result in a decline or elimination of sensitive taxa and colonization of tolerant ones [10, 12]. This was observed in both natural and urban rivers globally, with the latter showing to suffer more due to its already degraded water and physical habitat quality [13-15]. It is, therefore, important to integrate both water quality and physical habitat when exploring the ecological role of urban rivers in the urban landscape.

Urban rivers are regarded as futile due to their already degraded water quality and physical habitat. The former could be associated with the surface runoffs from impervious surfaces, effluents from wastewater plants, and raw sewage as a result of inevitable pipe bursts due to system congestion [16, 17], whereas the latter could be influenced by anthropogenic activities such as channelization and littering. Anthropogenic litter has recently received increasing attention due to its potential to substitute macroinvertebrate habitat where there is none [16, 18, 19]. Wilson et al. [16] further emphasised that reducing anthropogenic litter or having it completely removed may not be beneficial for local biodiversity. Therefore, for the implementation of effective urban river management strategies, it is imperative to understand the dynamics of the urban landscape and the role of all habitat components in relation to biodiversity.

The Apies River originates from Fountains Valley and flows through the impervious Pretoria town catchment before feeding the Bon Accord Dam, north of Pretoria. The central business district (CBD) stretch is threatened by sporadic sewage leaks, runoff from impervious surfaces, and inadequately treated wastewater effluents from wastewater treatment plants [20-22]. As a result, the Apies River is regarded as one of the most polluted urban systems in South Africa. Most of the CBD stretch is channelized with concrete, and the natural substrate continues immediately after Pretoria

CBD. This kind of channel modification is common in urban rivers, and its effects include an increase in flow velocity, which washes away natural habitat during floods and elevated peak discharges, and relocates the anthropogenic litter [23].

The effect of this irregular urban habitat, complemented by anthropogenic litter in shaping macroinvertebrate communities, is poorly understood, particularly in urban rivers that receive effluents as they exit the CBD. Therefore, the present study aims to explore the dynamics of an urban river with regard to macroinvertebrate assemblage and the effect of anthropogenic litter. It was hypothesised that the site immediately after CBD would exhibit relatively lower macroinvertebrate diversity and assemblage in relation to water quality and physical habitat, compared to the headwaters, and the site further downstream would show a significant improvement compared to the site immediately after CBD.

Materials and Methods

Study Area

The Apies River drains a catchment characterized by Pretoria Group sedimentary and volcanic rocks, the Bushveld Igneous complex, and the Karoo Supergroup [24, 25]. The catchment is approximately 742.66 km² and receives a summer rainfall (November-January), with an annual precipitation ranging from 400 to 700 mm. The annual flow of the Apies River is estimated to be 78.7 mm³ [25]. The Apies River is formed by a convergence of a few valleys in and around the urban Groenkloof Nature Reserve in the south of Pretoria CBD in South Africa. The CBD stretch drains an impervious urban catchment with multiple water channels; hence, it serves as a stormwater drainage [20]. Before exiting the CBD, it receives effluents from an under-capacitated wastewater treatment work (WWTW) and stormwater from a cement factory. The sampling was carried out at the headwaters (Site 1) situated in the Groenkloof Nature Reserve, a site downstream of the WWTW, and a cement factory stormwater discharge point (Site 2), and a site further downstream (Site 3) (Fig. 1). Sites were selected based on accessibility and availability of all three biotopes. Site 1 is located in the headwaters (upstream of the Pretoria CBD) in the Groenkloof Nature Reserve and is characterized by a narrow and shallow channel, approximately 2 m wide, with a depth ranging from 20 to 40 cm. Site 2 is located just after the river exits Pretoria town, approximately one kilometre downstream of the effluent discharge point, and is approximately 6 m wide, with a depth ranging from 40 to 60 cm. Site 3 is located farther downstream, about 20 km from Site 2, and is approximately 10 m wide, with a depth ranging from 20 to 80 cm.

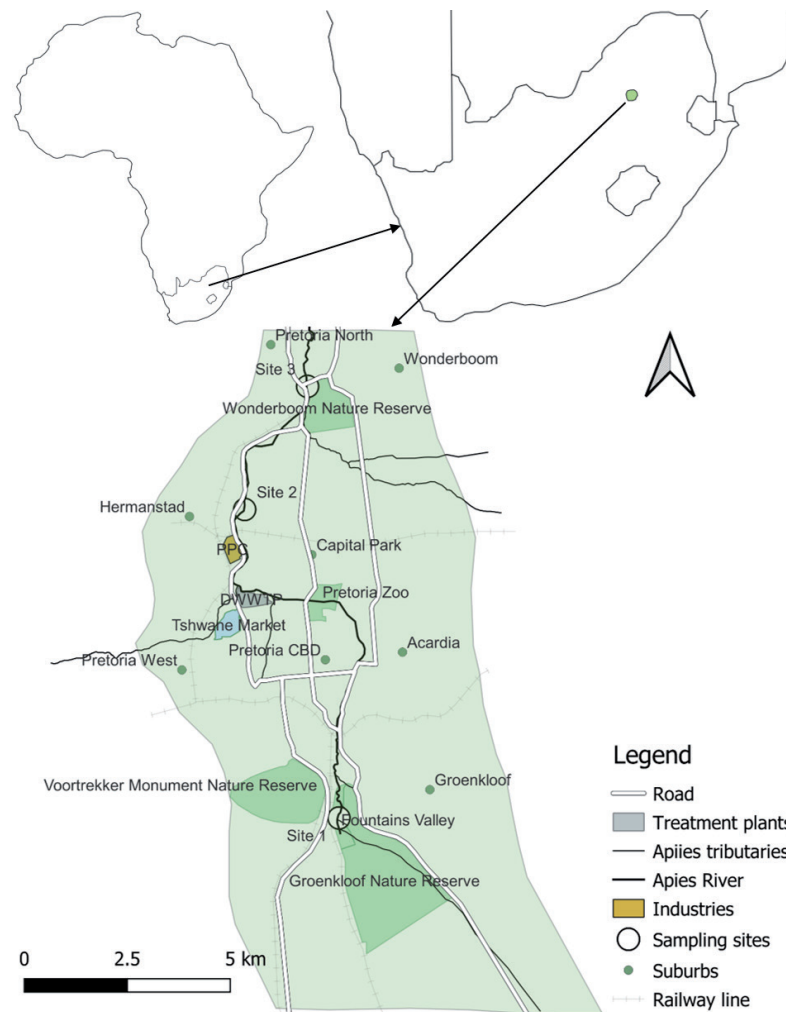


Fig. 1. The urban Apies River catchment with three sampling sites clearly labelled.

Water Sampling and Analysis

Sampling was conducted during dry and wet seasons, from December 2019 to March 2020 and between February 2021 and December 2022 at the three sites in the Apies River. No sampling was conducted between April 2020 and January 2021 due to the stringent COVID-19 measures. Three water samples were collected at each site to form a composite sample. The temperature (°C), dissolved oxygen (DO), pH, total dissolved solids (TDS), and conductivity were measured

in situ using a HANNA multi-parameter instrument (Model: HI98194). Water samples were collected using 1-litre acid pre-treated polyethylene bottles, kept in ice, and later transferred to the fridge in the laboratory. Nutrient analysis in the water was carried out using a spectrophotometer (Merck Pharo 100 Spectroquant™) with Merck cell test kits. The DWAF [26], WHO [27], and US-EPA [28] were used for water quality evaluation. The trophic status of the river was evaluated as per DWAF [26] following the ranges in Table 1.

Macroinvertebrates Habitat Assessment

The macroinvertebrate habitat assessment was carried out following McMillan [29], which was modified by Lebepe et al. [19] to include an anthropogenic litter component (Appendix A). Scores ranging from 0 to 5 were assigned to physical characteristics and stream habitat for macroinvertebrates based on the condition and/or potential effect. The habitat score was comprised of the physical characteristics (45%) and stream habitat for macroinvertebrates (55%). The physical characteristics included river make-up, stream width (cm), stream depth (cm), stream velocity,

Table 1. The concentration ranges and trophic status of the total nitrogen (N).

Conditions	N Concentration range (mg/l)	P Concentration range (mg/l)
Oligotrophic	<0.5	<5
Mesotrophic	0.5-2.5	5-25
Eutrophic	2.5-10	25-250
Hypertrophic	>10	>250

water colour, recent disturbances, bank/riparian vegetation, surrounding impacts, anthropogenic litter and anthropogenic litter effect, left bank cover (%), and right bank cover (%) (rocks and vegetation) (Appendix A). The stream habitat of macroinvertebrates included three categories: stone in current (SIC), vegetation, and other habitats. The SIC included the total length (m) of broken water (riffles/rapids), total length (m) of submerged stones in current (run), the number of separate SIC areas kicked, average size (cm) of stones kicked (gravel<2; bedrock>20), amount of stone surface clear (of algae, sediment, silt, etc.). The vegetation habitat included length (m) of fringing vegetation sampled (banks), amount (m²) of aquatic vegetation/algae sampled, fringing vegetation sampled (m²), types of vegetation (% leafy veg. vs. stems/shoots). The other habitats included stone out of current (SOC), bedrocks, gravel, sand, and mud (GSM), algae presence, and anthropogenic litter such as tyres, plastic bags, clothes, steel and plastic pipes, plastic fragments, etc. (Appendix A). Anthropogenic litter varied in size, types, and structure; their evaluation was captured as absent, similar types, or mixture (Fig. A1) [19]. The overall habitat condition was classified following Appendix B.

Macroinvertebrates Sampling and Identification

Macroinvertebrates were sampled four times at each site between December 2019 and March 2020 and between February 2021 and December 2022. The wet season sampling was conducted after the flow had slowed down. According to Khumalo et al. [30], macroinvertebrate communities fully recover 5 weeks after a flash flood; therefore, macroinvertebrates were sampled at least 5 weeks after rainfall. Macroinvertebrate sampling was conducted following the South African Scoring System (SASS5) protocol [31], with some amendments. The three biotopes: gravel, sand, and mud (GSM); stone; and vegetation - were sampled. Substrates were disturbed by kicking stones and collecting dislodged macroinvertebrates with a dip net. Big rocks were lifted by hand, and the attached macroinvertebrates were scraped into the tray. Vegetation was swept using a dip net, and the macroinvertebrates collected were transferred into a tray. Gravel, sand, and mud were disturbed, and the dip net was used to collect dislodged macroinvertebrates. Each biotope/habitat was disturbed for 5 minutes at each site. Available solid materials (anthropogenic litter) such as tyres, plastic bags, clothes, steel and plastic pipes, plastic fragments, etc., were also lifted for macroinvertebrate collection. Macroinvertebrates were identified to the lowest taxonomic level possible using Gerber and Gabriel [32], Gerber and Gabriel [33] illustration, and field guides, and Smith et al. [34]. Most macroinvertebrates were identified to family levels. Other specimens were preserved in 70% alcohol for further identification and auditing by a SASS5-accredited person. Collected macroinvertebrates were

also assigned to suitable functional feeding groups (FFGs) as per Chun and Ro [35], Cummins et al. [36], and Min et al. [37].

Diversity Indices and Average Score per Taxon

The Shannon-Weiner diversity index was used to determine the taxa diversity across the three sites as per Bufebo et al. [38] using Equation (1). The SASS5 score and average score per taxon (ASPT) were calculated following Dickens and Graham [31]. For SASS5 calculations, each taxon was assigned a quality value based on its sensitivity to pollution (Appendix C), and the values for all observed taxa were summed to give a SASS score. The ASPT was calculated by dividing the SASS score by the total number of taxa observed [31].

$$H' = \left(- \sum P_i * \ln(P_i) \right) \quad (1)$$

H' is the Shannon-Wiener Diversity Index, and P_i is the proportion of each taxon in the group, whereas ln(P_i) is the natural logarithm of this proportion.

Data Analysis

Analysis of variance (ANOVA) was used to evaluate the difference in water parameters between the three sites. Analysis of similarity was carried out using the ANOSIM function in the vegan package [39]. The principal component analysis was carried out to visualize the association between macroinvertebrates and environmental factors using the fviz_pca_biplot function in the devtools package [40].

Results

Water Quality

Water parameters exhibited no seasonal variation across all sites (p>0.05) except electrical conductivity, which showed a significantly higher level during the dry season at Site 1 (p<0.05). Nitrate has also shown a significantly higher level during the wet season across all sites (p<0.05). Mean values for the levels of water parameters are reported in Table 2. A neutral pH was observed at Site 1, whereas a neutral to slightly alkaline pH was observed at Sites 2 and 3. No significant difference was observed for the temperature, pH, and dissolved oxygen between the three sites (p>0.05). The conductivity and total dissolved solids were significantly higher at Sites 2 and 3 compared to Site 1 (p<0.05) (Table 2). Nitrite was below detection level at Site 3 throughout the study, whereas notable concentrations were observed at Sites 1 and 2 (Table 2). Moreover, NO₃ exhibited significantly higher concentrations at Sites 2 and 3 compared to Site 1 (p<0.05). In contrast,

Table 2. Mean levels of water parameters reported at the urban stretch of the Apies River during 2019-2022 surveys.

Parameters	Site 1	Site 2	Site 3	Guidelines
Temperature (°C)	20.15±2.11	19.85±1.86	18.74±1.17	-
DO (mg/l)	6.61±0.57	6.33±0.58	5.52±1.47	-
pH	7.05-7.42	7.66-8.17	7.54-8.07	6.5-9.0 (CCME 2012)
TDS (mg/l)	103.05±20.54	254.45±45.78	221.87±33.49	-
Conductivity (mS/cm)	0.19±0.07	0.33±0.01	0.35±0.01	-
NO ₂ (mg/l)	0.20±0.00	0.10±0.00	bd	0.06 (CCME 2012)
NO ₃ (mg/l)	0.10±0.00	2.57±0.25	2.63±1.43	13 (CCME 2012)
NH ₃ (mg/l)	0.10±0.01	2.25±1.32	0.10±0.01	0.007 (DWAF 1996)
PO ₄ (mg/l)	0.04±0.00	2.23±1.06	0.16±0.00	0.1 (USEPA 1986)
SO ₄ (mg/l)	14.66±0.75	57.67±2.48	17.51±1.98	-

bd: below detection level.

NH₃ exhibited a significantly higher concentration at Site 2 compared to Sites 1 and 3. Similarly, PO₄ and SO₄ showed significantly higher concentrations at Site 2 compared to Sites 1 and 3 ($p < 0.05$).

Macroinvertebrate Habitats

No significant seasonal variation was observed in the habitat score ($p > 0.05$) across all sites, as most components remained the same except stream depth, water velocity, and water colour. Site 1 was characterised by a closed canopy and a narrow stream with little light penetration. There were a few tree logs to provide habitat for macroinvertebrates, and the aquatic vegetation included mat sedge and reeds. The habitat scores ranged from 70% to 78% throughout the study. Site 2 was dominated by algae-covered rocks, with a few stones with vegetation scattered along the riverbank. The river was wide open, and the habitat scores ranged from

55% to 70%, with some anthropogenic litter, i.e., tyres, plastic bags, steel and plastic pipes, clothes, and tins of varying sizes, providing habitat for macroinvertebrates (Fig. A1). Good quality habitat was observed at Site 3, with the scores ranging from 87% to 90%. The stream was wide with stones and cobbles covered with algae, and gravel and sand. The site exhibited both submerged to emergent vegetation, with a notable abundance of anthropogenic litter (Fig. A1).

Macroinvertebrate Assemblage

A total of 2238 macroinvertebrates with different pollution tolerance levels were recorded across the three sites throughout the study, and no alien taxa were observed. Sites 1 and 3 showed a significantly higher abundance during the wet season compared to the dry season ($p < 0.05$), whereas no seasonal variation was observed for Site 2 ($p > 0.05$) (Fig. 2). Atyidae

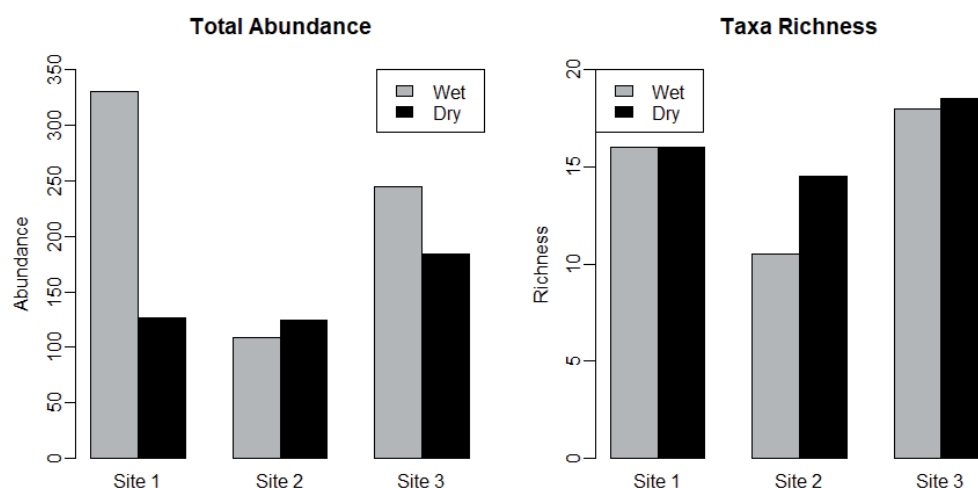


Fig. 2. The total abundance and taxa richness observed in wet and dry seasons during the 2019-2022 surveys.

showed a higher relative abundance at Site 1, whereas Chironomidae and Hirudinea exhibited a higher relative abundance in Sites 2 and 3, respectively (Table 3). Moreover, taxa richness showed no seasonal variation across the three sites (Fig. 2); however, spatial variation was observed, with Site 3 showing a higher mean value for taxa richness (21), followed by Site 1 (20) and Site 2 (17), respectively (Table 3). The evenness was also higher at Site 3 compared to the other sites. Atyidae, Baetidae, and Coenagrionidae contributed 63.72% of the total abundance of macroinvertebrates at Site 1, whereas Chironomidae, Culicidae, Physidae, and Oligochaetes contributed 69.32% of the total abundance at Site 2 (Table 3). Hirudinea, Baetidae, Physidae, Oligochaetes, and *Hydropsyche* sp. contributed 61.26% of the total abundance at Site 3.

The community structures were balanced with all sites harbouring predators-scavengers, collector-gatherers, collector-filterers, collector-shredders, and scrapers (Table 3). Moreover, the collector-gatherers and collector-shredders were highly abundant at Site 1 (Table 2). Gerridae, Gyrinidae, Coenagrionidae, and Atyidae were statistically more abundant at Site 1 (ANOSIM, $p < 0.05$), whereas Culicidae were more abundant in Site 2 (ANOSIM, $p < 0.05$) (Fig. 3). Moreover, *Hydropsyche* sp., Simuliidae, Tipulidae, Hirudinea, and Lymnaeidae were significantly abundant at Site 3 (ANOSIM, $p < 0.05$) (Fig. 3). Taxa richness was 20, 17, and 21 for Sites 1, 2, and 3, respectively (Table 3). Moreover, the diversity showed no significant difference between the three sites ($p < 0.05$) with Shannon-Weiner indices of 2.13, 2.23, and 2.58 being recorded at Sites 1, 2, and 3, respectively.

Table 3. Macroinvertebrate relative abundance observed in the urban stretch of the Apies River during 2019-2022 surveys.

Taxa	FFGs	Abundance			Relative Abundance		
		Site 1	Site 2	Site 3	Site1 (%)	Site2 (%)	Site3 (%)
Aeshnidae	Predators	34	4	22	3.72	0.86	2.57
Amphipoda	Collector-gatherer	3	0	0	0.33	0	0
Atyidae	Collector-shredder	358	0	0	39.13	0	0
Baetidae	Collector-gatherer	118	21	103	12.9	4.51	12.02
Belostomatidae	Predators	3	0	15	0.33	0	1.75
Chironomidae	Collector-filter	0	146	51	0	31.33	5.95
Coenagrionidae	Predators	107	20	45	11.69	4.29	5.25
Culicidae	Collector-filter	0	73	5	0	15.67	0.58
Gerridae	Predators	53	0	13	5.79	0	1.52
Gomphidae	Predators	30	2	10	3.28	0.43	1.17
Gyrinidae	Predators	60	0	0	6.56	0	0
Hirudinea	Predators	1	17	195	0.11	3.65	22.75
Hydrometridae	Predator-scavenger	2	1	2	0.22	0.21	0.23
Hydropsychidae	Collector-filter	10	16	61	1.09	3.43	7.12
Lestidae	Predators	10	0	6	1.09	0	0.7
Libellulidae	Predators	18	0	15	1.97	0	1.75
Lymnaeidae	Scrappers	2	10	33	0.22	2.15	3.85
Notonectidae	Predators	13	6	10	1.42	1.29	1.17
Oligochaetes	Collector-gatherers	10	44	70	1.09	9.44	8.17
Physidae	Scraper	32	60	96	3.5	12.88	11.2
Platycnemididae	Predator	33	11	16	3.61	2.36	1.87
Potamonautidae	Collector-gatherer/ Shredder	18	16	27	1.97	3.43	3.15
Simuliidae	Collector-filter	0	10	28	0	2.15	3.27
Tipulidae	Predator-shredder	0	9	34	0	1.93	3.97
Taxa richness		20	17	21			

Average Score per Taxon

Coinciding with the taxa richness, the mean ASPT ranged from 4.88-5.68, 3.27-4.07, and 3.83-4.61 at Sites 1, 2, and 3, respectively. There was no significant seasonal variation for the ASPT across all sites ($p>0.05$). Sites 2 and 3 were dominated by tolerant taxa such as Chironomidae, Culicidae, Hirudinea, and Oligochaeta, whereas sensitive taxa such as Aeshnidae, Atyidae, Lestidae, and Platynemididae were dominant at Site 1 (Fig. 3).

Discussion

Water Quality

Water quality is among the crucial factors influencing macroinvertebrate assemblages in river systems [41]. In the present study, the pH ranged from neutral to slightly alkaline across the three sites, whereas the total dissolved solids, conductivity, total nitrogen, PO_4 , and SO_4 were relatively higher at Sites 2 and 3 compared to Site 1. Phosphate was above the US-EPA [28] guideline for Sites 2 and 3, whereas NH_3 exceeded the DWAF [26] guideline at all three sites. Concentrations of water parameters observed in the present study are comparable

to those reported in other related studies in Florida's Indian River [42] and the River Wandle in southwest London [43]. Wastewater effluents affect nutrient enrichment, total dissolved solids, and the electrical conductivity in a river system [44, 45]. Moreover, low-energy processes such as desorption and mineralisation, and high-energy processes such as runoff and landslides may mobilize pollutants in impervious urban catchments [46]. Therefore, wastewater effluents from the wastewater work and runoff from the impervious catchment in Pretoria Town may be the explanation for the levels of water parameters observed at Sites 2 and 3 in the Apies River. Moreover, Site 1 exhibited oligotrophic water, whereas eutrophic and mesotrophic waters were observed at Sites 2 and 3, respectively. River self-cleanses as it flows over a long distance through mechanisms such as sedimentation, adsorption, dilution, aeration, absorption, floatation, and chemical and biological reactions [47, 48]. Therefore, the self-purification capacity of the Apies River could be the explanation for the nutrient level trend observed for Sites 2 and 3.

Macroinvertebrate Assemblage

The present study observed higher macroinvertebrate diversity at the headwaters compared to Sites 2

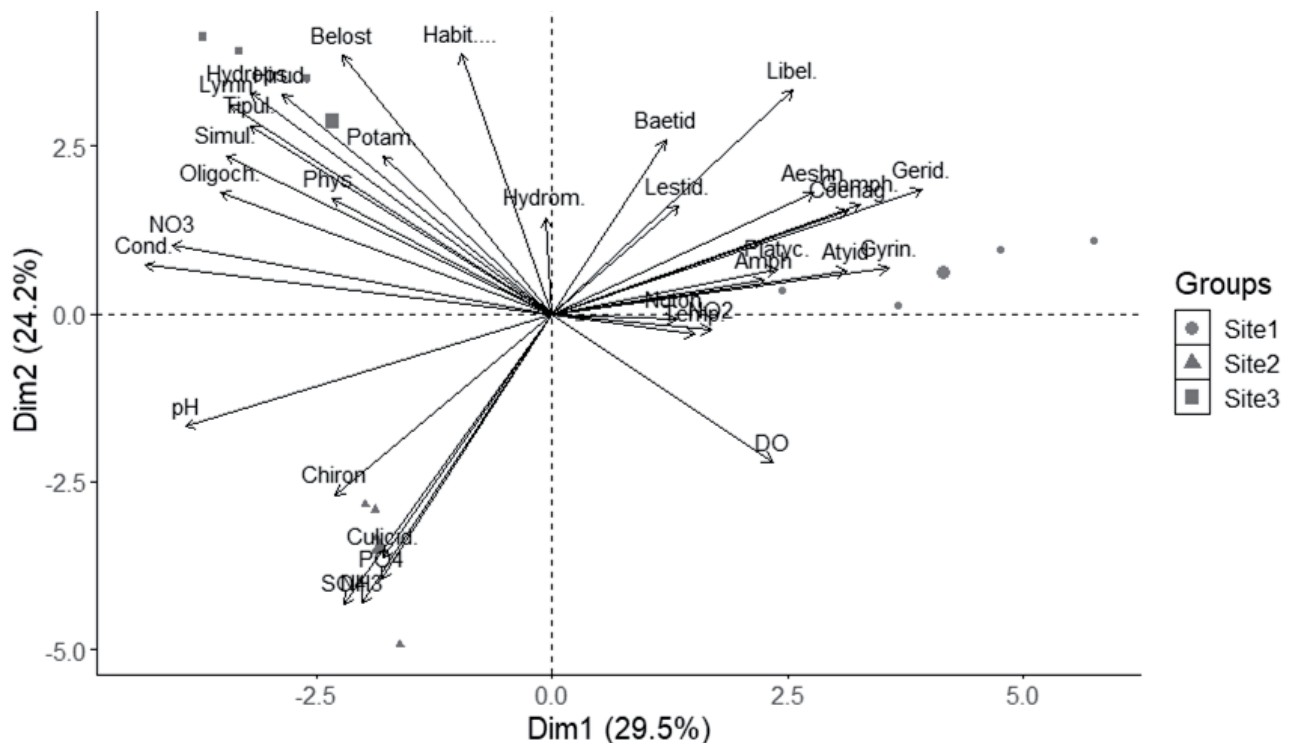


Fig. 3. Principal component analysis ordination plot showing the association between environmental variables, habitat, taxa, and sampling sites, with the larger symbol representing the median. Aeshn = Aeshnidae, Amph = Amphipoda, Atyid = Atyidae, Baetid = Baetidae, Belost = Belostomatidae, Chiron = Chironomidae, Coenag = Coenagrionidae, Culicid = Culicidae, Gerid = Gerridae, Gomph = Gomphidae, Gyrin = Gyrinidae, Hirud = Hirudinea, Hydrom = Hydrometridae, Hydrops = Hydropsychidae, Lestid = Lestidae, Libel = Libellulidae, Lymn = Lymnaeidae, Noton = Notonectidae, Oligoch = Oligochaeta, Phys = Physidae, Platyc = Platynemididae, Potam = Potamonautidae, Simul = Simuliidae, Tipul = Tipulidae, Temp = Temperature, Cond = Conductivity.

and 3. The dominant taxa in the headwaters included Aeshnidae, Atyidae, Lestidae, and Platycnemididae, which are sensitive to pollution [10, 31]. These findings are comparable to those observed in the headwaters of other streams in other parts of the world [49, 50]. The headwater stream is known to be characterised by water quality and heterogeneous and undisturbed physical habitats, which result in high macroinvertebrate diversity [51, 52]. Moreover, the water temperature and DO play a huge role in shaping the macroinvertebrate communities in river stretches [53]. Site 1 was characterised by an adequate physical habitat with a closed canopy and good-quality water, which was complemented by taxa richness, including sensitive taxa.

Site 2 has shown a significantly lower macroinvertebrate diversity and abundance compared to Sites 1 and 3. The site is dominated by pollution-tolerant taxa such as Chironomidae, Culicidae, Hirudinea, Physidae, Oligochaeta, and Potamonautidae. This site is located just after the river exits Pretoria town, approximately a kilometre downstream of the effluent discharge point; hence, it showed higher levels of nutrients and total dissolved solids compared to Site 1. Sensitive macroinvertebrates may be substituted by tolerant taxa in polluted urban stretches [54], and the low diversity observed at Site 2 was related to the observed water quality. Similar results were observed in a river impacted by mining activities [55] and a eutrophic urban river [19]. Xu et al. [56] and Abdel Gawad [57] reported that the presence of Chironomidae, Hirudinea, and Oligochaeta could be an indication of extremely polluted waters. Therefore, it is likely that the poor water quality and physical habitat could be linked with the poor macroinvertebrate diversity and abundance at Site 2.

In contrast, macroinvertebrate diversity was higher at Site 3 than at Site 2, whereas no difference was observed between Sites 1 and 3. A high diversity at Site 3 coincided with improved water quality. Nevertheless, pollution-tolerant taxa such as Chironomidae, Culicidae, Hirudinea, and Oligochaeta still dominated the community at this site. This community structure is comparable to those observed in other related studies [5, 19, 58] and differs from that observed by Carrasco-Badajoz et al. [14]. Moreover, Medupin [41] recorded an extreme abundance of Chironomidae and Oligochaeta in all urban stretches of the River Medlock in the UK, whereas Zemo et al. [59] observed a high abundance of Chironomidae, Culicidae, and Oligochaeta in polluted water in various urban streams in Yaoundé, Morocco. Moreover, Liu et al. [54] and Gallardo et al. [60] reported a high abundance and diversity of tolerant taxa in highly disturbed urban rivers in Shenzhen, South China, and Argentina, respectively. According to Richardson and Soloviev [17] and Zhang et al. [61], urban stretches are characterised by heavily modified physical structures, poor water quality, alien invasion, and noise pollution, which negatively affect macroinvertebrate assemblage. However, Wilson et al. [16] reported a considerable

abundance of macroinvertebrates in the urban stretch due to the presence of anthropogenic litter. Although anthropogenic litter may serve as a substitute for natural habitat where there is none, the quality of the habitat it provides remains poor [16, 58]. According to Kunz et al. [62], plastic garbage contributes to microplastic pollution in urban rivers. However, a complete removal of anthropogenic litter in urban rivers may not be good for local biodiversity, particularly where the natural habitat is poor [16]. Furthermore, Carrasco-Badajoz et al. [14] reported a significant decrease in taxa diversity in an urban stretch with poor water quality and highly disturbed physical habitat. In contrast, the present study exhibited considerable taxa diversity, which could be associated with the anthropogenic litter in the Apies River. Moreover, the improved water quality as a driver, particularly at the site further downstream (Site 3), could also not be ruled out.

The average score per taxon showed spatial variability along the longitudinal gradient, with the highest score being observed at Site 1, followed by Site 3, and the lowest score at Site 2. Sensitive taxa were found at Site 1, whereas tolerant taxa such as chironomids and oligochaetes were dominant at polluted Sites 2 and 3. These findings corroborate the trend observed by Lebepe et al. [19] in the urban Palmiet River, Bere and Nyamupingidza [63] in streams draining Chinhoyi Town in Zimbabwe, Kebede et al. [13] in an urban Awash River in Ethiopia, and Glińska-Lewczuk et al. [64] in rivers draining urbanized catchments in Northern Poland. Rivers draining urbanized catchments tend to exhibit poor water quality as they exit urban areas and improve as they flow further downstream [65]. The Apies River showed a similar trend, where Site 2 was highly polluted, with some improvement as it flows further downstream to Site 3.

The macroinvertebrate assemblage was shown to coincide with the water quality, where an improvement was observed at Site 3 compared to Site 2. Another factor that influenced the assemblage of the macroinvertebrate community is the habitat availability, which was complemented by anthropogenic litter in the form of garbage and other solid materials. Nevertheless, the improved macroinvertebrate assemblage was dominated by tolerant taxa and a few sensitive ones, which does not signify good ecological integrity.

Association between Functional Feeding Groups and Habitat

The physical habitat influences the community structure of macroinvertebrates in a river system. The headwater streams are known to harbour collectors, shredders, and gatherers as the food production is primarily characterised by leaves falling into the river from completely closed canopies, allochthonous [66, 67]. As the river widens, the canopy opens, and sufficient sunlight penetrates, resulting in autochthonous food production for aquatic biota [68]. This trend was also

supported in the present study, where collector-gatherers (Amphipoda) and shredders (Athyidae) dominated the headwater stream (Site 1), and filterers (Chironomidae, Hydropsychidae, Simuliidae, and Culicidae) and scrapers (Physidae) dominated Sites 2 and 3. Damanik-Ambarita et al. [69] recorded a higher abundance of scrapers and predators at the lower stretch of the Guayas River basin in Ecuador relative to the headwaters, whereas Cabrera et al. [70] and Martins et al. [71] recorded a high abundance of scrapers at the lowland Amazonian streams. Similarly, Mangadze et al. [72] reported a high abundance of collector-gatherers in the headwaters of the Bloukrans River system in South Africa.

Scrapers and collector-filterers are associated with sites polluted by organic contaminants as they feed on algae from productive waters [73]. This trend was also observed in the present study, where scrapers (Physidae) and collector-filterers (Chironomidae, Hydropsychidae, Simuliidae, and Culicidae) were dominant at Sites 2 and 3. Corroborating these findings, Fu et al. [74] and Van Echelpoel et al. [75] observed scrapers and filterers dominating the lowland streams threatened by organic pollution. Moreover, Edegbene et al. [73] observed a high abundance of scrapers and filterers in a water body impacted by urban and agricultural activities. In contrast, Carrasco-Badajoz et al. [14] observed scrapers in stretches exhibiting good quality water. Nevertheless, sufficient light penetration in the river waters may result in algal production, hence, the prevalence of scrapers and filterers. It is evident that the morphology and diet input could be one of the drivers for structuring macroinvertebrate communities.

Conclusions

Urban streams form an integral part of urban landscapes, and they have the potential to provide ecosystem services like natural rivers. In the present study, the Apies River showed a pollution gradient, with Site 1 being oligotrophic, Site 2 being eutrophic, and a mesotrophic status being recorded at Site 3. The pollution trend showed no association with taxa richness and diversity. However, the community composition showed a clear separation between sites with regard to pollution tolerance. Sites 2 and 3 were dominated by tolerant taxa, whereas Site 1 comprised intolerant ones. Moreover, macroinvertebrate communities showed a clear association with habitat and available food sources along the river. It is evident that the urban Apies River provides a sanctuary for aquatic biota, and pollution is causing a change in the macroinvertebrate community structure across the three sites. The hypothesis that there would be an association between macroinvertebrate assemblages, water quality, and habitat availability was supported. Moreover, a high accumulation of anthropogenic litter, such as plastic garbage, plastic bags, clothes, and plastic and steel pipes, seems to provide habitat for tolerant taxa, which is not

good for biodiversity integrity, given that plastics result in microplastic pollution. More studies are recommended to explore remediation strategies for urban rivers and to determine the quantity of anthropogenic litter that can supplement macroinvertebrate habitat without significantly impacting ecological integrity, as well as water and sediment quality in urban rivers.

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Conflict of Interest

The authors declare no conflict of interest.

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Appendix

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