ARTICLE

Stream benthic macroinvertebrates of Pansipit River, Batangas, Philippines: Does protection status influence a highly urbanized river ecosystem?

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ABSTRACT

The impact of protection efforts in streams situated in urban settings remains unclear in Philippine lotic ecosystems. Despite the ecosystem services provided, urban lotic environments are exposed to pollution and overexploitation. In this study, we aimed to examine whether the establishment of freshwater protected areas has a significant impact on aquatic environments and biodiversity using benthic macroinvertebrates as biological indicators. Benthic macroinvertebrates and physicochemical parameters were sampled across four sites of Pansipit River categorized by their land use. Multivariate analyses highlighted the variations in water quality of protected areas and their impact on benthic macroinvertebrate communities. Biotic and diversity indices (e.g., EPTC index, Shannon diversity index, and evenness) were calculated to assess macroinvertebrate community structures. The streams with lower dissolved oxygen, higher total dissolved solids and conductivity were correlated with the abundance of pollution-tolerant species, such as *Chironomus* sp. and *Lamprodrilus* sp. Moreover, the streams were observed to have degrading water quality, increased nutrient inputs (i.e., ammonia, phosphate), and low macroinvertebrate diversity from upstream to downstream reaches. Despite its protected status, freshwater protected areas in Batangas revealed poor stream ecosystem conditions, affected by anthropogenic activities. This study highlights the need for immediate and targeted measures to address the issues in Philippine freshwater protected areas, as well as the implementation of mitigation and management strategies to enhance watershed governance and rehabilitation.

INTRODUCTION

Freshwater ecosystems in the Philippines, which exceed 370,000 hectares, play a significant role in shaping the ecological balance, providing sustenance to both the environment and the community (Guerrero III 1991). Despite their importance, the number of freshwater scientific research efforts remains limited (Magbanua et al. 2017), and biodiversity has been poorly assessed in the Philippines. Consequently, several freshwater ecosystems remain unprotected, negatively impacting the environmental and economic aspects of society. The vulnerability of these ecosystems is heightened by the escalating rates of urbanization, industrialization, and agricultural expansion, which are attributed to human extraction of resources in ways that compromise their value as habitats for organisms (Dudgeon et al. 2005). In the Philippines, urbanization continues to increase, from 51.73% in 2015 to 54% in 2020 (Philippine Statistics Authority 2021) along with the continuous rise of industrialization. These increases the risk of having poor water quality and negatively alters the biodiversity by disrupting the physical and chemical properties

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KEYWORDS

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essential for the organisms living within these habitats (Peralta et al. 2019; Jolejole et al. 2021).

Benthic macroinvertebrates (aquatic insects, mollusks, crustaceans, and worms) include both pollution-sensitive and pollution-tolerant taxa are widely recognized as key biological indicators for assessing and monitoring freshwater ecosystem health alterations (Gonzalo and Camargo 2013; Dorothy et al. 2024; Tonkin 2024). Their broad taxonomic diversity enables them to exhibit a wide range of ecological responses, effectively detecting various types of pollution and environmental degradation in river systems (Camargo et al. 2004), including nutrient enrichment, sedimentation (Mathers et al. 2022), and industrial effluents (Gonzalo and Camargo 2013). Among macroinvertebrate communities, aquatic insects in orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) are essential elements in the development of the biotic indices used to assess water quality in freshwater ecosystems (Buss et al. 2015). Current studies utilize EPTC (Ephemeroptera, Plecoptera, Trichoptera, Coleoptera) index as a tool for evaluating freshwater ecosystem health, especially in detecting pollution due to sensitivity of Plecoptera and Trichoptera genera (Barbour et al. 1999). In addition, Ephemeroptera has a broader range of freshwater habitats due to their environmental tolerances and life cycle plasticity. The Plecoptera is highly sensitive to disturbances in water temperature, flow, and oxygen levels (Pedreros et al. 2020). As a result, macroinvertebrate diversity has been used in assessing protected and unprotected areas that may be significantly correlated with anthropogenic stressors in their habitats (Peralta et al. 2019).

The protected and unprotected river basins, exposed to urban systems, are affected by anthropogenic stressors (Townsend et al. 2008; Nuy et al. 2018), including nutrient pollution, habitat destruction, species invasions, and global warming (Jackson et al. 2017). Moreover, the primary contributors to these pollutants are hydrological modifications, agricultural practices, and urban development (Pandey et al. 2014; Nitasha and Sanjiv 2015; Aldridge and Baker 2017; Akhtar 2021). In the Philippines, various protected areas have been established to conserve or rehabilitate the Philippine watersheds and bodies of water connected to these protected areas. The Pansipit River, the lone outlet of Lake Taal and situated within the Taal Volcano Protected Landscape (TVPL), can be considered one of the few identified freshwater protected areas in the country (Mendoza et al., 2015; Peralta et al. 2019). In the 1990s, the introduction of fish cages in the river contributed to the adverse effects experienced, including water flow blockage and a decline in freshwater species such as *Sardinella tawilis* (tawilis) and *Caranx ignobilis* (maliputo). To mitigate these negative impacts, the Philippine Department of Environment and Natural Resources (DENR) collaborated with the Presidential Commission on Tagaytay-Taal to conduct a confiscation and dismantling of the fish cages on September 16, 1996. Following this, the Philippine Fisheries Code (Republic Act 8550) went into effect in 1998, prohibiting the construction of structures that could obstruct the river's flow or impede the migration of migratory fish species (Estigoy 2005). Despite conservation and mitigation efforts for the Taal Volcano Protected Landscape (TVPL), anthropogenically induced pollution and habitat degradation continue to be evident in the protected and unprotected portions of Pansipit River. As such, we aimed to examine whether the freshwater protected areas situated in this stream segment has a significant influence on aquatic environments and biodiversity. We hypothesize that despite the protected status of the upper stream reach, the overall water quality and macroinvertebrate diversity will decline due to ongoing urban activities. This study provides a unique opportunity to assess the status of the Pansipit River using benthic macroinvertebrates as biological indicators of stream habitat conditions and ecological integrity.

MATERIALS AND METHODS

Study Area

The Pansipit River (13° 52' 25.6"N and 120° 54' 54.1"E) is a protected river located within the Taal Volcano Protected Landscape, serving as the sole outlet for Lake Taal. The river has an ~ 8.2 km channel, with an average depth of 4 m, runs through the towns in Batangas Province, including Taal, Lemery, and San Nicolas, before emptying into Balayan Bay (Mendoza et al. 2015). It has a Type I climate with two pronounced seasons: a dry season from November to April, and a wet season from May to October. High rainfall occurs during the months of June to November, with an annual average rainfall of 2,026 mm (Martinez and Galera 2011). According to the Department of Environment and Natural Resources (2016), the Pansipit River is categorized as Class C, primarily used for fisheries, recreational activities (e.g., boating, fishing), and agricultural purposes, including irrigation and livestock watering. In 2020, the human population within the area of the Pansipit River was 217,665 (Philippine Statistics Authority 2021). Currently, the Pansipit River is one of the country's few freshwater-protected areas. Despite the Pansipit River's protection status, it faces significant threats from anthropogenically induced pollution and habitat degradation. With these disturbances and variations in land use and land cover, four sampling sites were investigated for environmental parameters and benthic macroinvertebrate communities (Fig. 1).

Site 1 (Agricultural). Aquaculture activities, such as fish cage farming, became intensive, reducing the river's fish species and causing a poor water quality (Pagulayan and Magbanua 1999, Jacinto 2011).

Site 2 (Forested). This site is surrounded by primary and secondary forest lined by mosses, ferns, and other riparian vegetation (Corpuz et al. 2015; Corpuz et al. 2019). Additionally, the municipalities of Agoncillo and San Nicolas have initiated rehabilitation efforts along the riverbanks of the Pansipit River (Isla et al. 2024).

***Site 3 (Industrial)*.** This downstream site flows through an urbanized area with livestock and anthropogenic disturbances.

***Site 4 (Residential)*.** This site contains dense human settlement, and is affected by sand mining, and unregulated waste disposal.

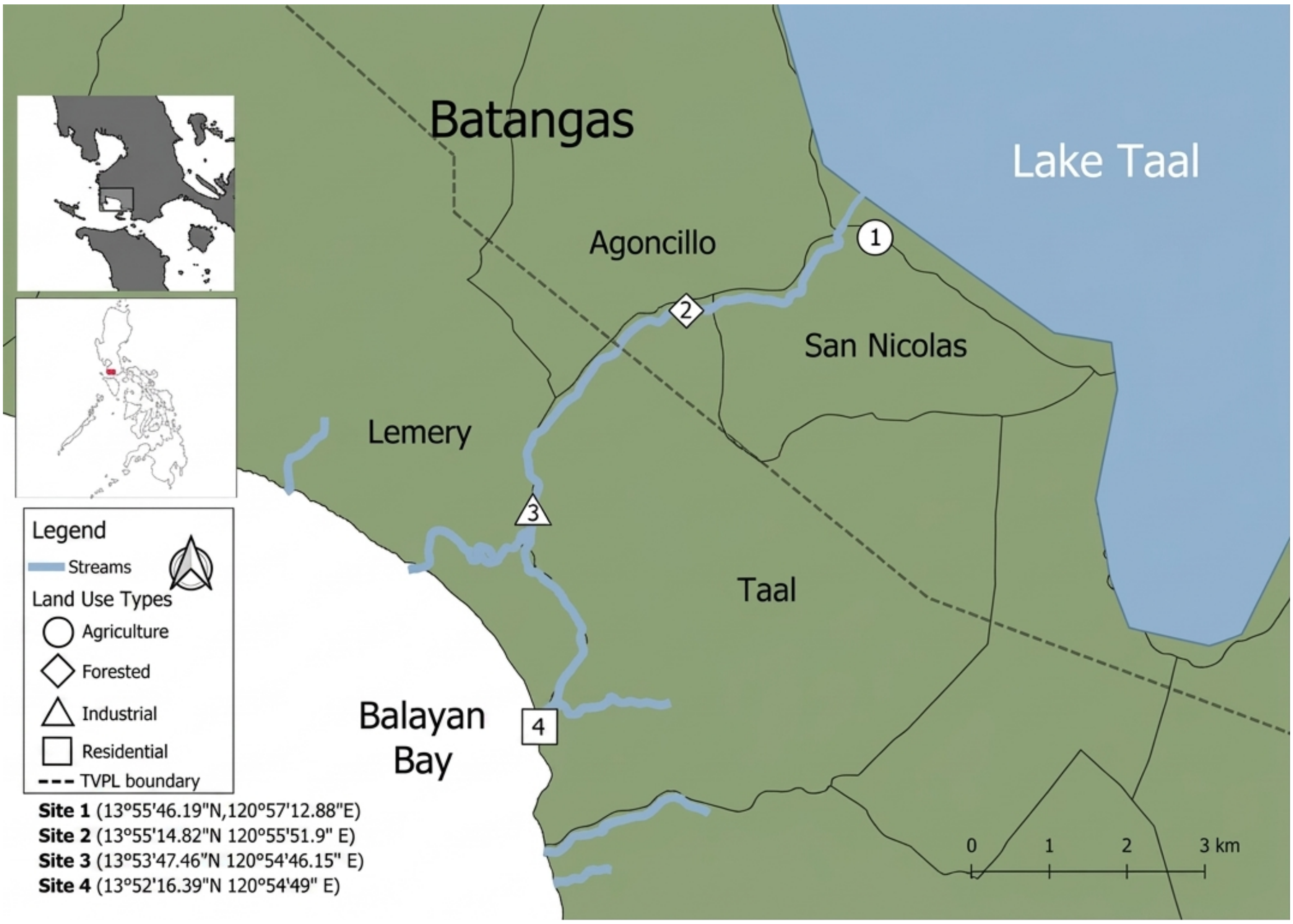

Figure 1: Map of the study area showing the four sampling sites in Pansipit River, Batangas. Broken lines delineate protected (Sites 1-2) and unprotected (Sites 3-4) stream segments according to the coverage of Taal Volcano Protected Landscape.

Environmental Variables

Environmental variables, specifically water physicochemical parameters, temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), conductivity, salinity, flow velocity, and nutrient concentration, were measured in replicates at two sampling points per site. A handheld multiparameter probe (HQ4300; Hach, USA) was used to measure water temperature, pH, total dissolved solids (TDS), conductivity, salinity, and dissolved oxygen (DO). Moreover, a water flow meter was utilized to determine water velocity at each monitoring point. Lastly, nutrient concentrations (ammonia, nitrite, nitrate, and phosphate) at two sampling point were obtained using an API Freshwater Master Test Kit. Water samples were collected and treated with standard solutions, and specific nutrient concentrations were determined by comparing the color of the solutions with the reference color concentration range.

Benthic Macroinvertebrate Assemblages

Benthic macroinvertebrate samples were collected from each study site using a Surber sampler (30 cm x 30 cm; 500 µm mesh) and stored in a labeled resealable bag with 95% ethanol (Peralta et al. 2020). Samples sorted within 24–48 h and stored in glass vials with 95% ethanol. The specimens were identified under a stereo microscope (Motic SMZ-171) down to the lowest taxonomic resolutions (i.e., family and genus) using appropriate taxonomic keys of Pescador et al. 1995; Epler 1996; Dudgeon 1999; Yule and Yong 2004; Mekong River Commission 2006; Chapman 2007; Merritt et al. 2008; Sartori et al. 2008; Madden 2009; and Bae 2010.

Data analyses

To characterize mean values (replicate measurements per sampling point) of all environmental variables, they were subjected to principal component analysis (PCA) (Peralta et al. 2019). Prior to PCA, environmental variables, namely pH, DO, flow velocity, and conductivity were used to characterize the two sampling points of Pansipit River. The latter three parameters (e.g., temperature, salinity, and total dissolved solids) were excluded from the PCA to avoid redundant explanatory variables. Principal components (PCs) with eigenvalues greater than 1.5 were retained for interpretation. Diversity indices (Shannon Diversity Index and evenness) and species richness (S) were computed to assess the biodiversity of local benthic macroinvertebrate species within the sampling sites. The EPTC indices were also calculated using the percentages of the insect orders Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera, which serve as primary bioindicators sensitive to pollution (Selvanayagam and Abril 2015).

Multivariate analysis was employed to investigate the correlation between environmental variables and benthic macroinvertebrates, elucidating how each physicochemical parameter influences the response of these organisms. For this purpose, detrended correspondence analysis (DCA) was employed to assess gradient lengths and determine whether a linear ordination technique is suitable. A canonical correspondence analysis (CCA) was then performed to produce a unimodal ordination triplot, as well as to describe the relationship between the environmental variables and macroinvertebrate assemblages. Rare species (e.g., singletons) were not included in the CCA triplot (Herman and Pouyan Nejadhashemi, 2015; Peralta, 2020). All the analyses were conducted with the assistance of statistical software, including Microsoft Excel (Microsoft Corp., Redmond, WA, USA), IBM SPSS Statistics (IBM Corp., New York, USA), PAST (University of Oslo), and RStudio (RStudio, Inc., Boston, MA).

RESULTS AND DISCUSSION

Physicochemical Environments

Environmental variables (DO, pH, conductivity, TDS, temperature, salinity, and flow velocity) were used as indicators of stream condition across land-use categories (Table 1). Environmental parameters, including conductivity, TDS, and salinity, were lower at Sites 1, 2, and 3, while the DO at Site 4 was the lowest, reflecting the prevailing residential land use in the site (Table 1). The PCA reveals the influence of environmental variables on the land use types across four sampling sites. The Principal Components (PCs) with eigenvalues >1.5, accounted for 70.25% of the cumulative variance. The high loading values (>0.50) of environmental variables such as conductivity, DO, and pH contributed to PC1, while flow velocity significantly contributed to PC2 (Table 2). Based on the PCA biplot, Sites 1 and 2 are characterized by faster flow velocity and elevated conductivity (Fig. 2). Specifically, the distinct separation of Site 3 (industrial) can be observed, characterized by slow flow velocity and low conductivity with high DO and pH values.

Table 1: Mean (± standard deviation) values of environmental variables across four sites in the Pansipit River

Parameter	**Sampling sites**				**Standard values (DENR, 2016)**
	1	**2**	**3**	**4**	
DO (mg/L^{-1})	**7.58** (±0.30)	7.22 (±0.01)	4.22 (±0.08)	0.80 (±0.03)	5.00
pH	8.36 (±0.24)	**8.39** (±0.10)	8.10 (±0.13)	7.33 (±0.13)	6.50-9.00
Conductivity (μS/cm^{-1})	2072.25 (±1.06)	2081.75 (±1.06)	2055.50 (±1.41)	**2139.50** (±21.21)	-
TDS (mg/L^{-1})	949.25 (±1.06)	947.25 (±0.36)	950.50 (±2.12)	**1002.50** (±9.89)	-
Temperature (°C)	29.73 (±0.11)	**30.10** (-)	29.23 (±0.04)	28.68 (±0.04)	25.00-31.00
Salinity (%)	0.96 (-)	0.95 (-)	0.96 (±0.32)	1.01 (±0.01)	-
Flow velocity (RPM)	2691.17 (±150.61)	1868.67 (±569.93)	872.83 (±960.958)	2531.34 (±1261.95)	-
Land use	Agricultural	Forested	Industrial	Residential	

-No computed values and/ or standard error

Table 2: Percentage of total variance associated with the 2 first principal components (PCs) of environmental variables

Environmental variable	**PC1**	**PC2**
Eigenvalues	**2.81**	**1.12**
% variation explained	70.25	27.89
DO (mg/L^{-1})	**-0.53**	0.43
Conductivity (μS/cm^{-1})	**0.56**	-0.23
pH	**-0.58**	-0.21
Flow velocity (RPM)	0.25	**-0.85**

Bold values were considered high (>0.50).

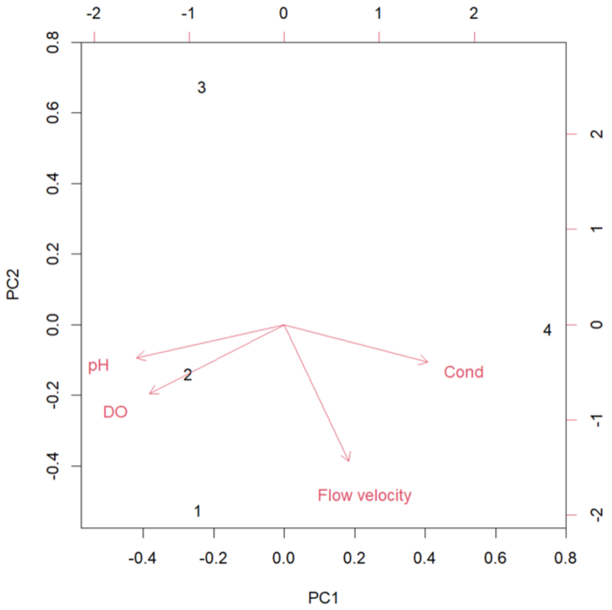

Figure 2: Principal component analysis bi-plot based on the physicochemical parameters across four sites 1-agricultural (aquaculture), 2-forested (natural forest), 3-industrial (port and logistics infrastructure), 4-residential (resorts and local housing) in Pansipit River, Batangas, Philippines.

In this study, the Pansipit River suggests ecological disturbance characterized by high TDS and conductivity levels, along with salinity, which indicates increased nutrient loads resulting from human activities such as domestic and industrial wastes (Gebre-Mariam Zinabu et al. 2002; Rusydi 2018; Peralta 2020). Elevated TDS and conductivity suggest that the streams are exposed to pollutants, indicative of varying extents of disturbance across sites. In addition, the decrease in DO and pH levels in the stream sites near residential areas and industrial port sections indicates an increase in microbial activity, which could be mainly associated with an increased loading of nutrients from domestic effluents. These changes are indicative of Southern Urban Hydrosystem Syndrome (SUHS), which involves the degradation of urban water bodies due to intensified anthropogenic activities (Wantzen et al. 2019; Ramachandra et al. 2020; Peralta et al. 2020), leading to poor water quality of the stream (Morosanu et al., 2016). On the contrary, higher DO (7.58 mg/L^{-1}) in the upstream sites suggests better water quality, with sufficient oxygen levels and an optimal environment that supports aquatic life (EPA, 2023; EPA, 2024). Additionally, an increase in DO level at Lake Taal can support aquatic animals like zooplankton and fish population, contributing to ecosystem productivity and ecological stability (Mendoza et al., 2015; Medallon et al. 2021; Merilles et al. 2021)

Nutrient Analysis

Increased nutrient loading (e.g., ammonia) was significantly associated with the runoff from agriculture, household waste, industrial waste, rainfall outflows, and sewage effluents (Zamparas 2021; Soler et al. 2021). This was evident in the industrial and residential streams of Pansipit River, characterized by excessive amounts of ammonia (2 mg/L^{-1}) and phosphates (2 mg/L^{-1}) (Smith 2003; Badamasi et al. 2019; Peralta et al. 2020). With this, elevated ammonia levels may indicate nutrient enrichment and associated hypoxia, making it unsuitable for the survival of aquatic organisms (Richardson et al. 2021). On the other hand, undetectable concentrations of nitrates and nitrites across all sites may reflect to the slow rate of nitrification. This biological process converts ammonia to absorbable nitrates and nitrites, which are influenced by environmental variables such as pH, temperature, oxygen, and salinity (Ward 2008). Also, it is observed that all sites exceeded the standard ammonia concentration in class C water bodies (0.05 mg/L^{-1}) (DENR 2016).

Benthic macroinvertebrate assemblages

A total of 650 stream benthic macroinvertebrates belonging to 24 families and 19 genera were identified from the four sampling sites. These were dominated by the Order Amphipoda (84.62%), with the most abundant family being Gammaridae and Ingolfellidae. The Shannon diversity index (H') in Pansipit River ranged from 1.01 to 1.80, with Site 2 (forested area) having the highest H' value. Although it had the highest H' value among all sites, we produced a CCA triplot, with 99% constrained variance where two axes of the CCA triplot explained 75.99% of the variation. Axis 1 resulted in 46.53% while 29.46% of the variation in axis 2. Axis 1 was associated with elevated TDS, conductivity, and flow velocity, with lower DO; these conditions were observed at Sites 3 and 4, corresponding to a residential and industrial area, respectively. These factors showed a positive correlation with the presence of the pollution-tolerant families Lumbriculidae (e.g., *Lamprodrilus* sp.) and Chironomidae (e.g., *Brilla* sp., *Chironomus* sp.) in Site 4 which indicate that downstream accumulation of organic pollution favors pollution-tolerant species (Peralta et al. 2020). On the contrary, higher levels of DO and temperature were linked with pollution-sensitive taxa, including Ephemeroptera (e.g., *Baetis* sp., *Bungona* sp.) and other taxa (e.g., Cirolanidae, Neritidae, Argissidae, Parathelphusidae, Ingolfellidae, and Talitridae) predominantly found in Site 1, an agricultural land.

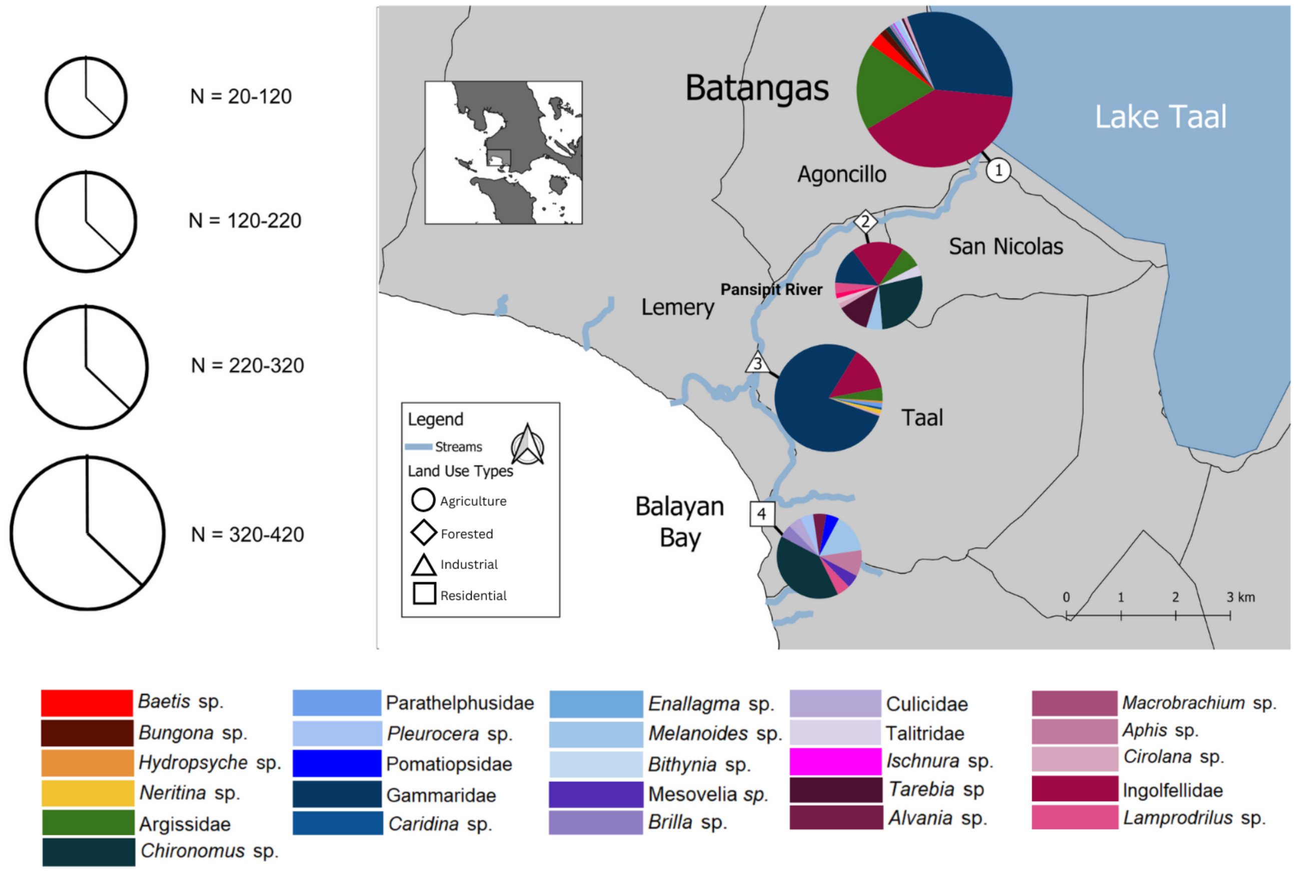

Figure 3: Benthic macroinvertebrate taxa per sampling site in Pansipit River

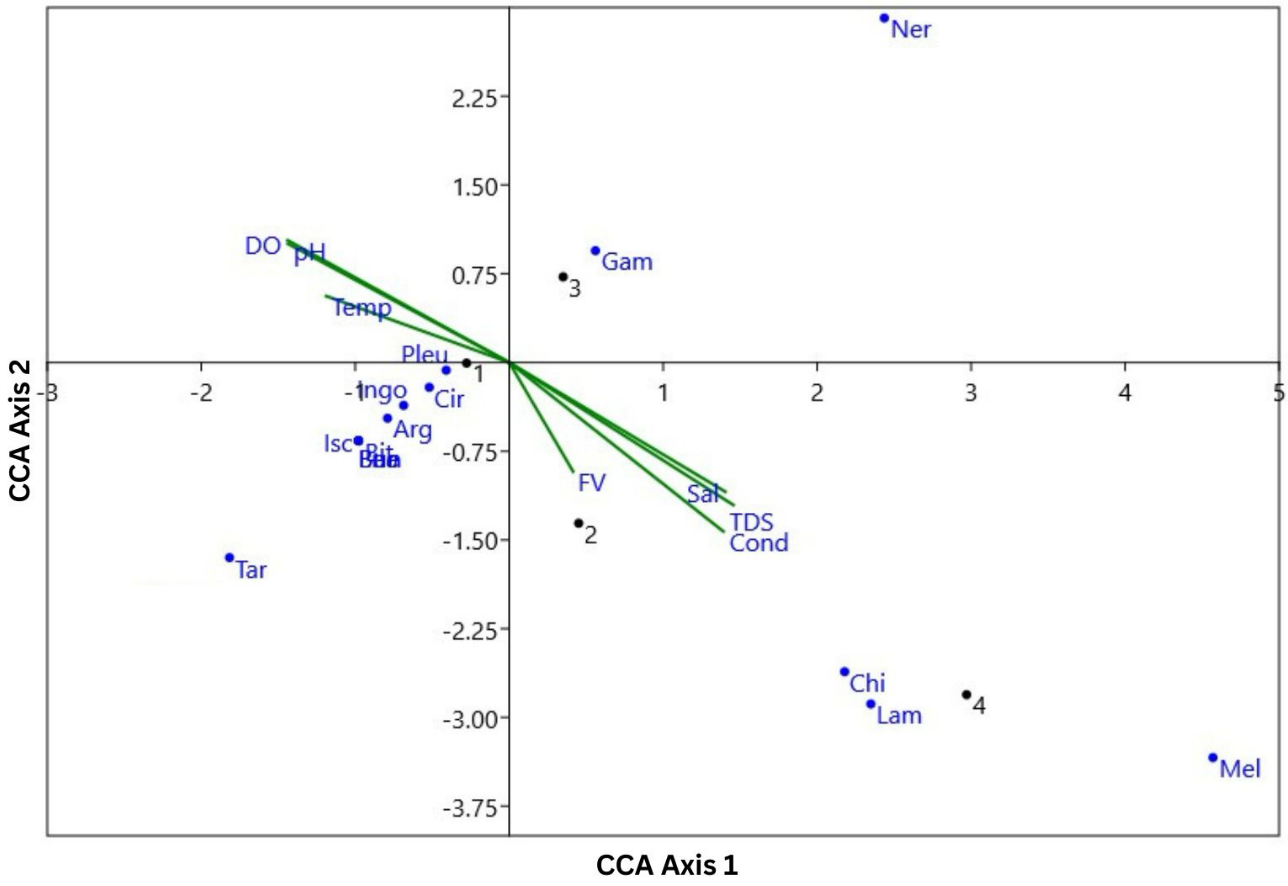

Figure 4: Triplot of the first and second canonical correspondence analysis axes of macroinvertebrate taxa, environmental variables (temperature, dissolved oxygen, total dissolved solids, salinity, conductivity, pH, and flow velocity), and sampling sites in Pansipit River. Taxa from Baetidae: _**Bae**tis_ sp., *Bungona* sp., Chironomidae: _**Br**illa_ sp., _**Chi**ronomus_ sp., Parathelphusidae, Coenagrionidae: *Enallagma* sp., *Ischnura* sp., **Pleu**roceridae: *Pleurocera* sp., Neritidae: _**Ner**itina_ sp., Biithynidae: _**Bi**thynia_ sp., Thiaridae: _**Mel**anoides_ sp., _**Tar**ebia_ sp., Cirolanidae: _**Cir**olana_ sp., Lumbriculidae: _**Lam**prodrilus_ sp., **Gam**maridae, **Ingo**lfellidae, **Argi**ssidae and **Tal**itridae

Table 3: Mean (± standard deviation) values of macroinvertebrate diversity indices across four sites in the Pansipit River

Indices	**Sampling sites**			
	1	**2**	**3**	**4**
Shannon Diversity index	1.67	1.80	1.01	1.33
Hmax	2.40	2.08	1.71	1.61
Evenness	0.48	0.52	0.29	0.38
Taxon richness	11.00 (9.90)	8.00 (1.41)	5.50 (2.12)	5.00 (-)
Taxon density	210.0 (141.42)	26.0 (15.57)	76.00 (94.75)	10.00 (4.24)
EPTC richness	10.50 (14.85)	-	-	-
EPTC abundance	8.97 (12.69)	-	-	-

-No computed values and/ or standard error

The diversity index (H') results show low macroinvertebrate diversity (<1.99) and a high value for evenness reflecting unstable species community (≤0.75) indicating a poor water quality across sites. Undetected EPTC taxa in three out of four sites suggest that the freshwater protected stream is exposed to numerous pollutants derived from direct waste discharges in residential and industrial establishments, as these organisms are sensitive to contaminated water bodies (Herman and Nejadhashemi 2015). In addition, factors influencing low diversity include environmental variables (e.g., high in TDS and conductivity; lower DO and pH level) and anthropogenic stressors (Peralta et al. 2019). However, high taxon richness and density were observed near agricultural zones dominated by Ingolfellidae with 39.38% abundance, recognized as one of the most sensitive families to pollution and thrives in less disturbed streams than those exposed to more anthropogenic impacts, as exemplified by its undetected population in Site 4, near residential areas (de la Ossa-Carretero et al., 2012). Moreover, this is the only site with EPTC taxa. However, only Ephemeroptera (5.01%) was observed among the four orders (EPTC), and its percentage is not far from that of Diptera (2.15%), an order consisting of pollution-tolerant organisms (Deborde et al. 2016; Peralta et al. 2020). All collected Ephemeroptera in this study site belonged to Baetidae, described as relatively sensitive to pollution, as some representatives can withstand the harsh conditions of poor water quality, such as those of *Baetis monnerati* (Buss and Salles 2007; Deborde et al. 2016; Alhejoj et al. 2023). Our results indicate that the condition of the upstream section of the river, habitat conditions remain poor, resulting in low benthic macroinvertebrate diversity.

Benthic macroinvertebrate community response

The association of the family Lumbriculidae with organic enrichment suggests a correlation between their abundance and downstream contamination, as observed at Sites 2 and 4 of the Pansipit River (Hettige et al. 2022). Notably, *Lamprodrilus* sp. was found in residential (Site 4) and forested (Site 2) sites, which could explain the increased levels of TDS and conductivity. With this, organic pollution from waste in these areas likely contributes to their resilience in high TDS environments, as they utilize organic matter as a food source (Jyvasjarvi et al. 2013; Hernandez et al. 2014; Rahman et al. 2021).

This trend is similarly observed in the Chironomidae family, which is present at Sites 2 and 4. Species such as *Brilla* sp. and *Chironomus* sp. are known to thrive in environments with low dissolved oxygen (DO) and high total dissolved solids (TDS) levels because their tubes provide essential channels for respiration and protection in such conditions (Deborde 2016; Podder et al. 2022). Additionally, the presence of hemoglobin in their tissues enhances their survival in generally hypoxic streams (Hilsenhoff 2001; Ramírez and Pringle 2006; Sharma and Chowdhary 2011; Gimenez and Higuti 2017; Peralta et al. 2020). Additionally, the presence of *Melanoides* sp. in Sites 2 and 4 further underscores the stream's pollution status. Pollutants support the proliferation of algae and organic matter in the streams, providing ample food sources for these organisms. Consequently, these areas may pose an increased risk of exposure to diseases transmitted by *Melanoides* sp., which can infect aquatic migratory birds, fish hosts, and humans (Oloyede et al. 2016). Despite the major presence of pollution-tolerant species, sites with higher levels of DO and temperature were also linked to some pollution-sensitive taxa (e.g., *Baetis* sp., *Bungona* sp.), found in Site 1, an agricultural and upstream site with fewer disturbances.

Previous studies have shown that freshwater protected areas contain a higher diversity of macroinvertebrate assemblages and harbor a different community composition (Gonzales et al. 2014; Rim-Rukeh and Irerhievwie 2014; Emmanuel et al. 2016; Peralta et al. 2019). However, our findings indicated that the Pansipit River is dominated by pollution-tolerant taxa thriving in sites with poor water quality conditions. Despite the presence of a designated freshwater protected area in the upper segment of the Pansipit River, the river is currently characterized by disturbed ecosystems and low biodiversity. The exposure of the Pansipit River to documented urban environmental pressures, such as nutrient pollution and habitat disturbances, continues to impact the ecological integrity of lotic ecosystems in the region (Townsend et al. 2008; Nuy et al. 2018; Peralta et al. 2020; Jolejole et al. 2021). In addition, species invasions and global warming are recognized as additional threats to the river's ecological health (Jackson et al. 2017; Gilles et al. 2023; Gilles et al. 2025).

CONCLUSION

This study demonstrated that the protection status of watersheds must meet specific criteria to effectively influence highly urbanized environments. Despite the expected influence of protection efforts on the Pansipit River, it still exhibits elevated nutrient and TDS concentrations, and low DO levels, attributed to pollution and waste from nearby residential areas. Additionally, water quality assessment through benthic macroinvertebrate assemblages revealed low diversity indices and the absence of EPTC taxa across sites. This indicates poor water quality due to anthropogenic stressors, as reflected in land use and water quality, creating an unfavorable environment for benthic macroinvertebrates, particularly those sensitive to pollution. Therefore, the study recommends reinforcing protection and mitigation strategies to maintain the integrity of highly urbanized watersheds. Government agencies and stakeholders should promptly and rigorously implement mitigation measures for urban rivers, particularly those deemed critical to the environment. Specific strategies could include (1) strict law enforcement of environmental laws, (2) establishment of biomonitoring programs,

(3) rehabilitation and protection of riparian and buffer zones, (4) improvement of wastewater management systems, including the regulation of both inorganic and organic effluents from anthropogenic activities.

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CONFLICT OF INTEREST

All authors declare that they have no financial or non-financial interests related directly or indirectly to the work submitted for publication.

CONTRIBUTIONS OF INDIVIDUAL AUTHORS

Narlyn C. Castillo: Methodology, Formal analysis, Investigation, Data curation, Writing—review & editing, Visualization; **Eliza Rose Y. Aquino, Lilian N. Dela Cruz, Miguel L. Estrada, Hannah Lorraine Frias:** Methodology, Formal analysis, Investigation, Data curation, Writing—original draft, Writing—editing, Visualization; **Rey Donne S. Papa:** Supervision, Writing— review & editing; **Milagrosa Martinez-Goss**: Project Leader, Resources, Supervision, Writing—review & editing, Project administration; **Francis S. Magbanua** - Supervision, Conceptualization, Project administration, Writing- review & editing; **Elfritzson M. Peralta** - Conceptualization, Methodology, Formal analysis, Supervision, Project administration. Writing—review & editing. All authors approved the final version of the manuscript.

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APPENDICES

Taxa	Abundance			
	Site 1	Site 2	Site 3	Site 4
Ephemeroptera				
Baetidae				
Baetis sp.	12			
Bungona sp.	6			
Trichoptera				
Culicidae				1
Hydropsychidae				
Hydropsyche sp.			1	
Diptera				
Chironomidae				
Brilla sp.	1			1
Chironomus sp.	4	14		8
Decapoda				
Parathelphusidae			2	
Atyidae				
Caridina sp.			1	
Palaemonidae				
Macrobrachium sp.	1			
Odonata				
Coenagrionidae				
Enallagma sp.	2			
Ischnura sp.	1			
Sorbeoconcha				
Pleuroceridae				
Pleurocera sp.	5			1
Cycloneritida				
Neritidae				
Neritina sp.			2	
Littorinimorpha				
Bithyniidae				
Bithynia sp.	2			
Rissoidae				
Alvania sp.				1
Pomatiopsidae				1
Caenogastropoda				
Thiaridae				
Melanoides sp.		3		3
Tarebia sp.	2	6		
Hemiptera				
Aphididae				
Aphis sp.				2
Mesoveliidae				
Mesovelia sp.				1
Tubificida				
Naididae		1		
Tubificidae		1		
Lumbricomorpha				
Lumbriculidae				
Lamprodrilus sp.		2		1

Isopoda			
Cirolanidae			
Cirolana sp.	3	1	1
Amphipoda			
Argissidae	75	4	6
Gammaridae	133	7	119
Ingolfellidae	165	10	20
Talitridae		2	