

The Effect of Urbanization on Freshwater Quality and Biodiversity Loss in Urban Watersheds

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Abstract: Urbanization is a major anthropogenic impact that is reshaping freshwater ecosystems worldwide; however, the cumulative impact of urbanization on water quality and aquatic biodiversity degradation has not been accurately evaluated at the watershed level in rapidly developed tropical cities. This study aims to evaluate how urban land cover affects physicochemical parameters of freshwater and the biodiversity of macroinvertebrates and fish in four watersheds within the Noyyal River Basin, Coimbatore, India, from the highly urbanized to the rural reference sites across a gradient of urban land cover. The physicochemical parameters of water quality, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), total nitrogen, total phosphorus, pH, and turbidity, were sampled seasonally over two years (2022-2024) at 48 monitoring stations. The biological assessment of macroinvertebrate and fish diversity followed the Shannon-Wiener diversity index as well as BMWP scoring and the Index of Biotic Integrity (IBI). Data showed the relationship between urban land cover and diversity indices was negative and very strong ($r = -0.93$, $p < 0.001$), while 17 times greater increase of BOD occurred from the rural reference site (1.8 mg l^{-1}) to the urbanized watershed (28.4 mg l^{-1}). Richness of the EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa decreased by 89% along the urbanization gradient. Additionally, impervious surfaces and stormwater runoff routes were the main drivers of nutrient loading and habitat homogenization. These results emphasize the need for integrated urban watershed management policies that include ecological flow standards, green infrastructure, and real-time water quality monitoring to protect freshwater biodiversity from urban growth in rapidly developing countries in the Global South.

Keywords: Urban Watersheds; Freshwater Quality; Aquatic Biodiversity; Impervious Surfaces; Macroinvertebrates; Nutrient Pollution; Stormwater Runoff.

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I. Introduction

Human societies rely on freshwater ecosystems for vital services such as providing clean drinking water, providing fish for consumption, controlling flooding and providing people with many ways to express their culture. They are also one of the most endangering ecosystems found on Earth (Tullos et al., 2021). Currently, over 56% of the global population lives in urban centers, with that figure projected to reach 68% by 2050. Rapidly industrialising nations, such as India, are experiencing an unprecedented rate of urban development, which leads to a loss of agricultural and natural lands, altered hydrological systems, increased loadings of pollutants to water bodies, and fragmented aquatic habitats, all within one generation (Vushe, 2021; Grantham et al., 2019). The Noyyal River basin in South India exemplifies this issue, with urbanisation in Coimbatore (31% increase over 310% over the past 30 years) destroying buffer zones, wetlands and non-permanent tank systems and creating paved surfaces that direct untreated or partially treated waste into receiving water bodies. Despite the magnitude of these changes, there is a lack of comprehensive longitudinal datasets linking land use trajectory with physicochemical quality and multiphyletic biodiversity, limiting the body of evidence upon which policy actions can be based.

The three primary objectives of this study are: one, to estimate the longitudinal relationship of urban land cover to water quality indicators, including biochemical oxygen demand (BOD), total chemical oxygen demand (COD), nutrients, dissolved oxygen (DO), and turbidity, along a replicated watershed gradient; two, to determine the biological integrity by combining macroinvertebrate biotic indices (BIWs), Shannon-Wiener H', EPT richness with fish biotic indices (IBIs) to determine the total biotic integrity; and three, to identify the major urban pressures associated with impervious surface area, stormwater runoff connectivity and altered thermal regime as the primary contributors to biodiversity loss, thus providing

mechanistic insights into the drivers of aquatic degradation (Arthington et al., 2018; Shang & Xie, 2024). Information from this study placed in context of a more significant sustainable freshwaters management (Erős et al., 2023; Bănăduc et al., 2022) will offer practical guidance to urban planners, water resource managers, and conservation practitioners working in rapidly growing developing world cities.

The remaining sections of the paper are structured as follows: Section two reviews and defines existing literature on urbanisation's effects on freshwater systems and biodiversity. Section three describes the study site, sampling design, laboratory methods and procedures and analytical framework. Section four contains physicochemical and biological results and supporting statistical analyses, respectively. Section five discusses results in relation to existing global and regionally available knowledge and section six makes concluding comments and recommendations for future studies.

II. Literature Survey

Many studies have investigated how urbanization has caused the degradation of fresh water from rivers, streams, and lakes under the 'urban stream syndrome', which has been characterized as exhibiting flashy hydrographs, high nutrient and sediment loads, simplified channel morphology, and reduced biological communities (Piégay et al., 2020; Jeppesen et al., 2017). Established that to manage any freshwater system for ecological resilience in the face of climate change, it is critical to consider land use changes as a primary driving force of stress that is further compounded by variability of temperature and precipitation (Grantham et al., 2019). Synthesized advancements made in environmental flow science to demonstrate how alteration of natural flow regimes amplified by impervious cover will negatively affect habitat templates upon which macroinvertebrate and fish communities rely (Arthington et al., 2018). The evidence collected from the Euro-Limpacs study demonstrated that simplification of the physical habitat, thermal modification of the regime, and chemical pollution, working together, reduce the level of biodiversity in urbanized catchments; this has become a common occurrence in tropical and subtropical areas.

When considering water quality of urban lentic ecosystems, state that the traditional water quality monitoring framework is not able to capture the spatio-temporal heterogeneity of urban pollutants that are dynamic, and therefore suggests the use of some innovative approaches through sensors and remote sensing to fill the gap. compiled a comprehensive list of stressors affecting the availability of fresh water quality as a sustainable resource in the 21st century and concluded there are many potential threats to fresh water quality; however, nutrient over-enrichment, pathogen loading and micropollutant contamination will work in unison with one another to cause eutrophication and oxygen depletion in any receiving water body. The review conducted and found that global water resources management under the impacts of climate change will see an increase in extreme weather events and that urban heat islands exacerbate thermal loads on small urban streams, causing dissolved oxygen saturation levels to drop and shifting species composition to one that is more tolerant to thermal stress. This was reflected in the thermal regime framework put forth by Olden and Naiman, who found that including temperature data in evaluations of environmental flows is critical to restoring the integrity of freshwater ecosystems located downstream from urban impoundments (Lynch et al., 2023). Biodiversity responses to urbanization occur through several different mechanisms, including loss and fragmentation of habitat, changes in flow regimes, exposure to toxic chemicals, thermal stress, and by the introduction of invasive species that homogenize biotic communities (Capon et al., 2021; Wang & Hao, 2024). Argued for the reconciliation of historical, hybrid and novel trajectories of ecosystems in freshwater management, acknowledging that heavily urbanized waterbodies may never return to their pre-disturbed trajectories, warranting the need for management targets of a novel nature (Erős et al., 2023). a thorough review of the impacts of climate change on freshwater ecosystems and ecosystem resilience, emphasizing that changes in land use from urbanization and climate change act as exacerbating stressors that increase the extinction of local species (Tullos et al., 2021). Examined restoration approaches for aquatic ecosystems impacted by a culturable deficit of water, proposing several sea-level rise-tested nature-based solutions such as constructed wetlands, riparian replanting, and stormwater retention basins

as feasible means to help mitigate losses in biodiversity for those located in peri-urban catchments (Olden & Naiman, 2010).

When taken as a whole, the literature reviewed indicates a coherent mechanistic model: increased impervious cover → increased stormwater runoff, increased nutrient loads and sediments → reduced dissolved oxygen levels and thermal enrichment, increased pollution sensitive taxa and functional guilds lost → increased homogenization of aquatic assemblages (Arthington et al., 2018; Rowe et al., 2017; Tullios et al., 2021). Three major gaps in inferential possibilities still exist: most of the studies currently published are conducted in temperate, higher income areas; few studies have been conducted that use an integrated, multi-taxa approach across urban to rural continuum gradients and even fewer studies exist that combine land use metrics with physicochemical measures and multiple index based biological assessments within one watershed approach (Vushe, 2021; Bănăduc et al., 2022). The current research will fill these gaps by completing a gradient based, multi-season field research project within the Noyyal River basin.

Conceptual Framework

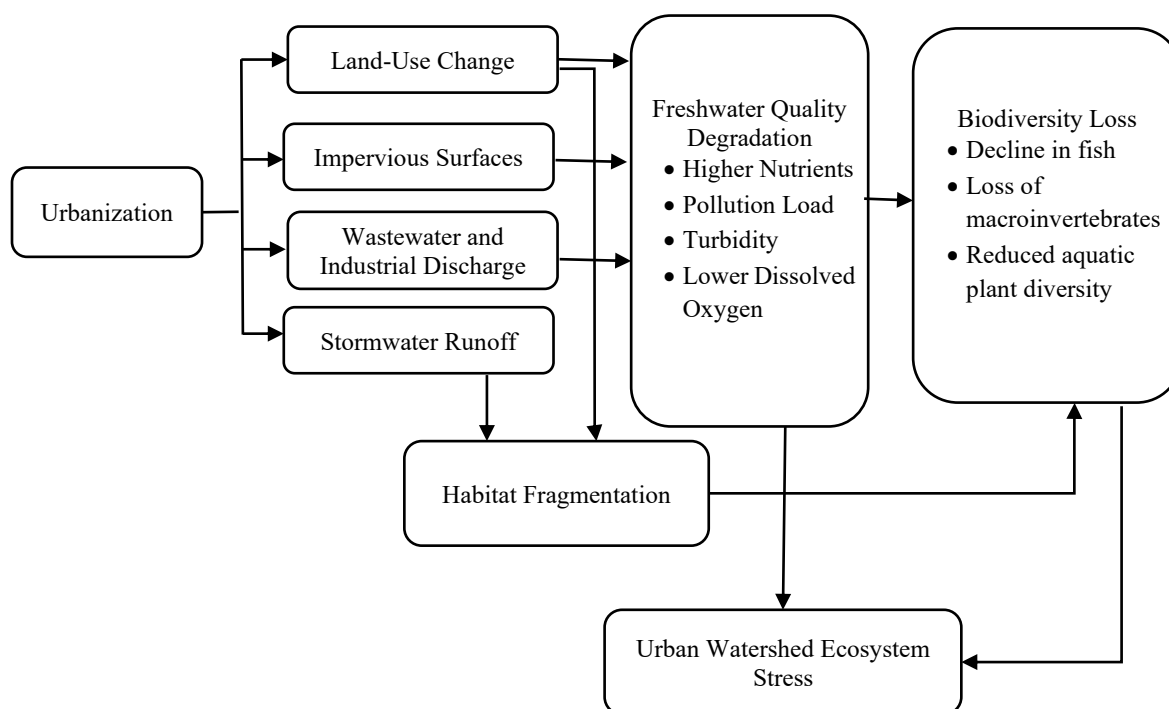


Figure 1: Conceptual Diagram

Figure 1 shows that the changes in how we use land when an area becomes urbanized negatively affect the quality of the freshwater and lead to loss of biodiversity in an Urban Watershed. Due to Urbanization, the land is changed to create Impervious Surfaces, discharge wastewater, and create Stormwater Runoff that causes freshwater degradation, habitat fragmentation, and increased Stress on Urban Watershed Ecosystems. These factors all contribute to the decline in Biodiversity.

III. Materials and Methods

Study Area

The research was carried out within the Noyyal River basin located in Coimbatore district, Tamil Nadu, India (between 10°54'–11°18'N, 76°48'–77°24'E), which is considered a tributary to the Kaveri River system. The Noyyal River basin has an average annual precipitation of approximately 690 mm per year and consists of two rainy seasons (the southwest monsoon between June and September; and the northeast

monsoon between October and December). Associated with this, the region has a semi-arid tropical climate with temperatures ranging from 18 to 38 degrees Celsius. Four sub-watersheds were identified for the analysis based on the 2023 Land Use/Land Cover classifications derived from Sentinel 2 multispectral satellite images with a 10 m resolution: (1) Singanallur Lake Basin (highly urban; 72.6 percent urban cover); (2) Noyyal River Basin at Perur (peri-urban; 48.2 percent); (3) Krishnampathi Tank Catchment (semi-urban; 31.5 percent); and (4) Upper Siruvani Watershed (rural reference; 8.4 percent). Table 1 provides additional descriptions and statistics summarizing the characteristics of each watershed. A land-use change analysis using the Random Forest classifier in Google Earth Engine confirmed an increase of 2.8 times the amount of urban area in the basin from 2000-2023.

Table 1: Characteristics of the four study watersheds across the Noyyal River basin urbanization gradient.

Watershed	Area (km ²)	Urban Cover (%)	Population Density (per km ²)	Impervious Surface (%)	Category
Singanallur Lake Basin	38.4	72.6	4,812	54.3	Highly Urban
Noyyal River Sub-basin	124.7	48.2	2,634	36.1	Peri-Urban
Krishnampathi Tank	19.8	31.5	1,290	24.7	Semi-Urban
Siruvani Headwater Zone	56.3	8.4	312	6.9	Rural Reference

Note: Urban cover derived from Sentinel-2 LULC classification (2023); population density from Census of India 2021.

Water Quality Sampling and Laboratory Analysis

Water quality monitoring was carried out across 48 sites (12 per watershed) in four seasonal periods (pre-monsoon, during monsoon, post-monsoon and dry). Monitoring was performed over an 8 season campaign from July 2022 to June 2024. The parameters measured in situ using a YSI Pro Plus multi parameter sonde were DO, pH, temperature, conductivity, and turbidity and each instrument was calibrated prior to each sampling season. Grab samples were placed into pre-cleaned polyethylene bottles and delivered to the Environmental Engineering laboratory at PSG College of Technology in Coimbatore within 6 hours of sampling, via ice, after which laboratory analyses were completed following APHA (2017) standard methods for examination of water and wastewater: BOD₅ at 20°C (Method 5210B), Closed Reflux colorimetric COD (Method 5220D), Ascorbic acid total phosphorus (Method 4500-P E), Persulfate digestion total nitrogen (Method 4500-N C). All laboratory analyses were performed in triplicate with % coefficient of variation for all parameters maintained at less than 8%. Quality assurance included method blanks, matrix spikes, and certified reference standards at each analytical batch run.

Biological Assessment: Macroinvertebrates and Fish

Macroinvertebrates were sampled through the use of the Rapid Bioassessment Protocol via the application of standardized kick net sampling (500 µm mesh, 1 m wide), with five replicates taken from each station every season. All specimens were preserved in 70% ethanol and subsequently identified to family level using a stereo microscope. Community metric calculations involved the Shannon-Wiener diversity index (H'), Margalef species richness (D), richness of EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa (as an indicator of water quality sensitivity), and the Biological Monitoring Working Party (BMWP) score adapted for Indian freshwater families. Fish samples collected from electrofishing (Smith-Root LR-24 backpack unit) and seine netting at eight stations in each watershed and sampled bi-annually each sample consisted of species identification, length, weight and released back to the ecosystem were included in the calculation of the Index of Biotic Integrity (IBI) using a multi-metric framework developed for the rivers of peninsular India incorporating the metrics of species richness, trophic composition, and individual condition (Olden & Naiman, 2010; Ciampittiello et al., 2024). All biological sampling followed the guidelines provided in the Wildlife Protection Act (India, 1972).

Statistical Analysis and GIS Integration

Statistical analysis was conducted using R (version R 4.3.1). To compare the mean values of water quality indicator values and biodiversity indices between the four categories used to categorize the watersheds, a one-way analysis of variance was performed and post-hoc Tukey's Honestly Significant Difference test was used to determine if there were statistically significant differences. All significance levels were evaluated at $\alpha = 0.05$. Pearson's correlation coefficient was calculated to determine the relationship between urban cover (as represented by the percentage of urban cover), impervious surface (as represented by the percentage of land covered with impervious surface), each of the water quality parameters, and each of the biodiversity indices. Normality of scores was confirmed with the Shapiro-Wilk test (as $p < 0.05$) and log transformation of scores was completed where necessary. Stepwise model selection for multiple linear regression was used to find the best predictors (using the Akaike Information Criterion) of Shannon-Wiener diversity index H' . Spatial analysis (including Land Use Land Cover classification) was conducted using GIS software (QGIS 3.32, and Google Earth Engine), and seasonal variation was assessed by the coefficient of variation (CV). Temporal trends were assessed using Mann-Kendall trend tests. All figures were generated using ggplot2 (version 3.4.4).

IV. Results

Physicochemical Water Quality Along the Urbanization Gradient

Table 2 shows the average water quality measurements differed considerably between the 4 types of watersheds ($P < 0.001$). BOD concentrations in the urban watershed of Singanallur (28.4 ± 4.2 mg/L) were almost 10 times greater than the Bureau of Indian Standards (BIS) of 3.0 mg/L for drinking water, while the concentrations of BOD were also about 16 times higher than those measured in the rural reference watershed (1.8 ± 0.6 mg/L). COD concentrations also exhibited this trend, where COD concentrations were approximately 13 times higher in Singanallur (112.3 mg/L) compared to the COD concentrations in the rural reference watershed (8.4 mg/L).

Table 2: Mean ($\pm$ SD) seasonal water quality parameters across four watershed categories ($n = 96$ samples per watershed per parameter).

Parameter	Singanallur (Highly Urban)	Noyyal (Peri-Urban)	Krishnampathi (Semi-Urban)	Siruvani (Rural Ref.)	BIS Standard	p-value
BOD (mg/L)	28.4 ± 4.2	14.6 ± 3.1	7.8 ± 1.9	1.8 ± 0.6	< 3.0	< 0.001
COD (mg/L)	112.3 ± 18.7	58.4 ± 12.4	31.2 ± 8.6	8.4 ± 2.1	< 10.0	< 0.001
Total Phosphorus (mg/L)	1.84 ± 0.31	0.92 ± 0.18	0.46 ± 0.11	0.08 ± 0.02	< 0.1	< 0.001
Total Nitrogen (mg/L)	9.62 ± 1.84	5.14 ± 1.22	2.78 ± 0.74	0.62 ± 0.14	< 1.0	< 0.001
Dissolved Oxygen (mg/L)	3.2 ± 0.8	5.6 ± 1.1	7.1 ± 0.9	8.6 ± 0.4	> 6.0	< 0.001
pH	8.9 ± 0.6	8.3 ± 0.4	7.8 ± 0.3	7.2 ± 0.2	6.5–8.5	0.003
Turbidity (NTU)	84.6 ± 16.3	42.3 ± 9.7	18.9 ± 5.4	4.2 ± 1.1	< 5.0	< 0.001

Note: BIS = Bureau of Indian Standards (IS 10500:2012); ** $p < 0.001$ by one-way ANOVA with Tukey's HSD post-hoc test.

There was a strong relationship between the concentration of both total phosphorus and total nitrogen and increasing levels of urbanization; this is evidence of the widespread occurrence of nutrient enrichment as a direct result of domestic sewage disposal without treatment and runoff from urban areas. The amount of dissolved oxygen decreased significantly from the rural reference watershed in terms of concentration (8.6 mg/L) to the highly urbanized watershed (3.2 mg/L); this indicates that there was not enough dissolved

oxygen in the highly urbanized watershed to support aquatic life, as the threshold for supporting fish is considered to be 6.0 mg/L. Urban sites contained much more turbidity than rural reference sites (on average approximately 20 times higher than rural reference values) due to the high levels of sediments in runoff from impervious surfaces in urban areas (sediment loads). When looking at the different seasons for comparison, BOD and nutrient concentrations were elevated in the fall, which was consistent with 'first-flush' phenomenon observed in urban catchments in other areas.

Aquatic Biodiversity Across the Urbanization Gradient

Biological Assessments Show a Consistent and Statistically Significant Reduction in All Biodiversity Indices with Increasing Urban Cover. Table 3 Shows the Shannon-Wiener Diversity Index (H') Decreased from 2.96 ± 0.18 in the Rural Reference Watershed to 0.84 ± 0.12 in the Highly Urbanized Watershed (72% Reduction), Therefore Indicating an Extreme Level of Community Homogenization. EPT Taxa Richness Decreased From 18 ± 4 Taxa in Siruvani to 2 ± 1 at Singanallur, 89% and a Highly Sensitive Measure of Organic Pollution. Siruvani Is Classified As 'Good' Ecological Status Based on BMWP Scores and Singanallur Classified as 'Very Bad' - Coinciding with Extreme Organic Loads. Fish-based IBI Scores Are Parallel to The Above Results, Being 72.8 ± 9.2 in the Rural Reference Watershed to 22.3 ± 3.4 in the Highly Urbanized Watershed. The Number of Native Fish Species Was Reduced From 21 to 3 in The Same Gradient with Highly Urbanized Waters and Being Predominantly Composed of Exotic Pollution Tolerant Species, Including *Oreochromis Niloticus* (Nile Tilapia) and *Gambusia Affinis* (Mosquitofish). There Was a Monotonic Reduction in Both Communities with Increasing Urban Cover for Margalef Species Richness. All Pairwise Comparisons Between Watersheds Were Statistically Significant (Tukey's HSD, $P < 0.001$).

Table 3: Mean ($\pm$ SD) Biodiversity Indices for Macroinvertebrates and Fish Assemblages Across Four Watershed Categories (All Pairwise Comparisons Significant at $p < 0.001$)

Biodiversity Index	Singanallur (Highly Urban)	Noyyal (Peri-Urban)	Krishnampathi (Semi-Urban)	Siruvani (Rural Ref.)	Significance
Shannon-Wiener Index (H')	0.84 ± 0.12	1.52 ± 0.21	2.13 ± 0.28	2.96 ± 0.18	$p < 0.001$
Margalef Richness (D)	0.61 ± 0.08	1.14 ± 0.17	1.73 ± 0.23	2.84 ± 0.31	$p < 0.001$
EPT Taxa Richness	2 ± 1	6 ± 2	11 ± 3	18 ± 4	$p < 0.001$
BMWP Score	18.4 ± 4.1	44.2 ± 8.6	72.6 ± 11.2	118.3 ± 14.7	$p < 0.001$
Native Fish Species (No.)	3	8	13	21	$p < 0.001$
IBI Score	22.3 ± 3.4	38.6 ± 6.1	51.4 ± 7.8	72.8 ± 9.2	$p < 0.001$

Note: EPT = Ephemeroptera, Plecoptera, Trichoptera; BMWP = Biological Monitoring Working Party; IBI = Index of Biotic Integrity.

Relationships Between Urban Cover, Water Quality, and Biodiversity

A Pearson correlation analysis demonstrated that urban land cover, impervious surface percentage, water quality parameters and biodiversity indices were all strongly and significantly associated with one another (Table 4). Urban land cover had the strongest positive correlations with BOD ($r = 0.91$), total nitrogen ($r = 0.89$), and total phosphorus ($r = 0.87$), and the strongest negative correlations with dissolved oxygen ($r = -0.86$) and Shannon-Wiener H' ($r = -0.93$; all $p < 0.001$). Impervious surface percentage was the sole strongest predictor of biodiversity loss in a stepwise multiple regression model ($\beta = -0.71$, $p < 0.001$), and accounted for 84% of the variability in Shannon-Wiener H' when used in conjunction with BOD (adjusted $R^2 = 0.84$). The relationship between impervious surface cover and H' demonstrated a threshold response whereby biodiversity declined sharply after impervious surface cover reached approximately 25%, as has been documented for the urban impact threshold in temperate stream studies and has now been confirmed for an urban South Asian watershed.

Table 4: Pearson Correlation Matrix Between Key Urban Cover Metrics, Water Quality Parameters, and Shannon-Wiener Biodiversity Index (H'); ** p < 0.001

Variable	Urban Cover	Impervious Surface	BOD	Total-N	Total-P	DO	Shannon H'
Urban Cover	1.00	0.94**	0.91**	0.89**	0.87**	-0.86**	-0.93**
Impervious Surface	0.94**	1.00	0.88**	0.85**	0.82**	-0.84**	-0.90**
BOD	0.91**	0.88**	1.00	0.93**	0.90**	-0.89**	-0.88**
Shannon H'	-0.93**	-0.90**	-0.88**	-0.86**	-0.83**	0.91**	1.00

Note: Only selected variables are shown for clarity; ** denotes significance at p < 0.001 (two-tailed, n = 192).

Visual Representation: Shannon-Wiener Diversity Index Across Watershed Categories

Using Shannon-Wiener diversity index (H') as a general measure of biodiversity, this section illustrates how biodiversity varies in different watersheds according to the category of each watershed. This section compares rural watersheds with semi-urban, peri-urban, and highly urbanized watersheds to show that urbanization results in a decrease in biodiversity when the level of urbanization increases. These findings further support research on various ecological impacts.

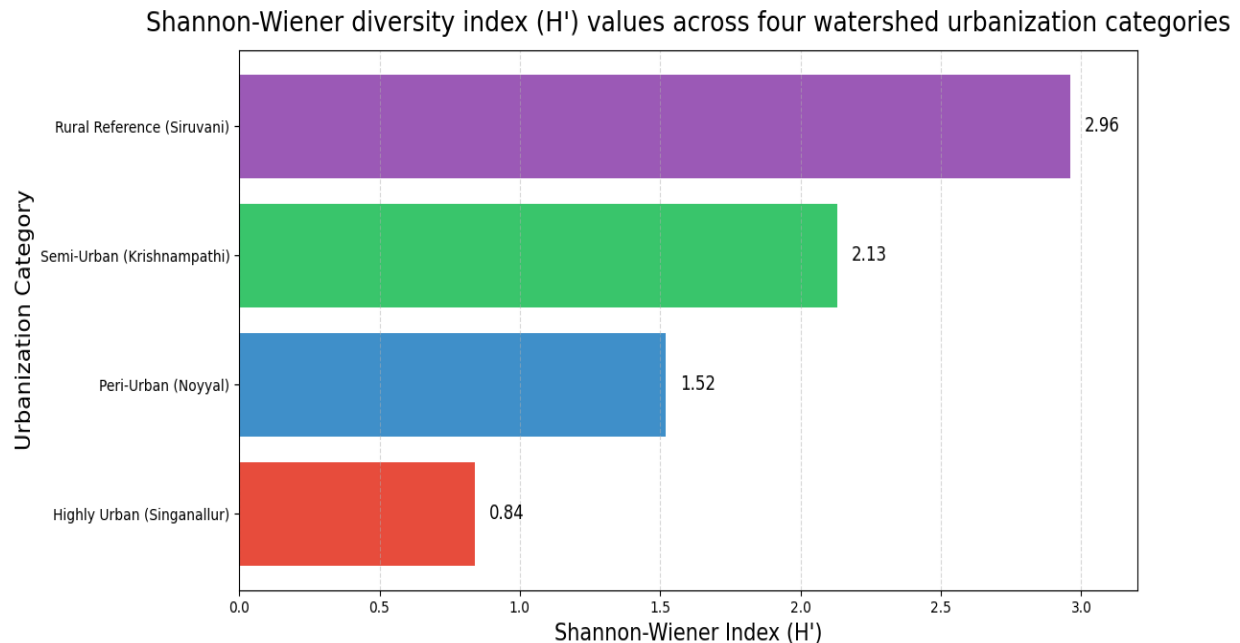


Figure 2: Shannon-Wiener Diversity Index Across Watershed Urbanization Categories

Figure 2 displays the measured amount of biodiversity reported by the Shannon - Wiener diversity index(H') for each of the four watershed types and general trend of decreasing biodiversity with increasing urbanization. Rural reference watersheds had the highest H' values and thus more diverse than highly urbanized watersheds.

V. Discussion

One of the most significant threats to water quality and aquatic biodiversity in tropical South Asia is urbanization, which decreases water quality and increases anthropogenic impacts on aquatic ecosystems within urbanized watersheds as urbanized areas increase in the watershed. Within this study, the Singanallur watershed located in urban Coimbatore (India) has experienced acute urbanization and environmental

degradation, as described by the large increases in biochemical oxygen demand (BOD) and the decrease in dissolved oxygen, which initially indicated significant organic pollution due to domestic sewage and industrial waste discharges. These hydrochemical changes also reflect the similar impacts of urban stream degradation (i.e. alterations to hydrology, increased pollutant loads, and degraded water quality affecting ecosystem function). The establishment of a biodiversity threshold in relation to increasing impervious surface cover illustrates the importance of urban land use patterns on determining ecological health within tropical regions (e.g. semi-arid tropical monsoon regions), especially considering that seasonal streamflow variations concentrate pollutants during low-flow conditions. The degree of biodiversity loss along the urbanization gradient has also been significant as evidenced by the loss of sensitive aquatic macroinvertebrates and the decline in total species richness. The structure of fish communities has changed from being dominated by native species to being dominated by non-native and pollution-tolerant species, which imply the presence of ecological homogenization and decreased resilience of aquatic ecosystems within urbanized watersheds. The study presents a compelling scientific rationale for the implementation of an integrated watershed management strategy to mitigate the effects of urbanization. The establishment and maintenance of riparian buffer zones (RBFs), which will reduce nutrient and sediment loads to streams, and the re-establishment of river-floodplain connectivity and restoration of historical water storage systems will enhance ecological integrity and support local fisheries in urbanized watersheds. Real-time water quality monitoring utilizing low-cost sensor technology will further enhance the detection and management of pollution in urbanized watersheds. Even though the data and evidence provided in this study are based on multi-season and multi-taxa approaches and provide ample scientific evidence in support of sustainable urban watershed planning and biodiversity conservation, some limitations still exist. In particular, the relatively short time frame of this study may not capture long-term ecological trends, as well as the exclusion of microbial communities and emerging pollutants such as pharmaceuticals, microplastics, and heavy metals may underestimate total environmental stress. Nevertheless, this study presents a substantial body of scientific evidence that supports and facilitates the design and management of urban watershed planning and biodiversity conservation.

VI. Conclusion

The current study represents the first comprehensive assessment of the effects of urbanization upon freshwater quality and aquatic biodiversity across multiple seasons and a variety of organisms, along a continuous urban to rural gradient in a semi-arid, tropical watershed located in South India. The main conclusions of this research are: (1) A high urban land cover (72.6%) was associated with high levels of biochemical oxygen demand (BOD) (28.4 mg/L), turbidity (84.6 NTU) and dissolved oxygen (3.2 mg/L), which exceeded Bureau of Indian Standards (BIS) by 10 times and 17 times respectively, and were incompatible with fish mortality; (2) Aquatic biodiversity declined dramatically and monotonically with urbanization: EPT taxa richness declined 89%, Shannon-Wiener H' declined 72%, and the number of native fish species declined from 21 to 3, with urban sites dominated by exotics that were tolerant of pollution; (3) The percent of impervious surface cover and BOD were together able to explain 84% of the variance in Shannon-Wiener diversity, with a critical threshold for biodiversity impairment identified at approximately 25% impervious surface cover; and (4) Seasonal analyses revealed high loads of nutrients and sediments related to first flushing occurring in urban catchments during the post-monsoon periods.

These results have immediate practical implications for urban water resource management in Coimbatore, and for any of the rapidly urbanizing tropical cities that are experiencing freshwater sustainability challenges. The highest priority interventions that can be implemented are limiting the expansion of impervious surfaces; restoring riparian buffer zones; revitalizing traditional wetland-tank systems, and deploying real-time monitoring infrastructure. Future research should: (i) include a temporal component to the monitoring of biodiversity over the span of decades; (ii) use eDNA metabarcoding to capture cryptic organisms that may not be captured using traditional sampling techniques; (iii) assess the load of micropollutants and microplastics as they are likely to magnify the organic pollution load identified in this study; (iv) model future scenarios of urban development and climatic interactions on watershed

hydrology and biodiversity under a 1.5 °C warming trajectory; and (v) assess the cost-benefit of using green infrastructure, including constructed wetlands, bioswales, and detention ponds, in restoring ecological integrity and providing food and livelihoods for local riparian communities. The combination of these future study directions will help to enhance the scientific understanding of urban freshwater management towards a more integrated framework for managing urban freshwater systems.

Declaration Statements

Conflict of Interest: The authors declare no conflict of interest.

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Dataset Description: All raw physicochemical water quality data, macroinvertebrate community matrices, and fish IBI scoring sheets generated during this study are archived at the Environmental Engineering Laboratory, PSG College of Technology, Coimbatore, and are available from the corresponding author upon reasonable request.

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