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Assessing the Impact of Urbanization on Aquatic Ecosystem Health Through Water Quality Habitat Transformation and Biodiversity Analysis

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Abstract: Freshwater ecosystems are changing rapidly in response to an increase in impervious surfaces, wastewater discharge, stormwater runoff, and riparian encroachment; however, the cumulative effects on water quality, ecosystem condition, and biological communities are not typically measured in one framework. The present study compared the health of aquatic ecosystems across an urbanization gradient in a tropical urban river–wetland corridor. In 2024, a total of 60 stations were sampled in four seasons, 15 stations in each season, in 15 urbanization areas representing low, moderate, and high urbanization. The Water Quality Index (WQI), Habitat Integrity Score, biodiversity indicators, correlation and regression, Kruskal–Wallis tests, and principal component analysis were used to estimate twelve physicochemical parameters, land-use and habitat indicators, and macroinvertebrate and fish communities. All these components were combined into an Aquatic Ecosystem Health Index (AEHI). The dissolved oxygen (DO) decreased between the low- to high-urbanization zones, from 7.2 to 3.1 mg L-1, while BOD_5 increased from 2.1 to 12.6 mg L-1 and nitrate-N from 0.82 to 5.93 mg L-1. The WQI rose from 38.6 to 162.7, and impervious cover accounted for 83% of the variability for dissolved oxygen. Riparian cover and Shannon diversity decreased by 79.6% and 57.0%, respectively, while the taxa of the tolerant group increased to 72.6% and the EPT abundance decreased to 3.2%. The AEHI decreased from 0.83 to 0.19, while PC1 accounted for 68.4% of the total variance. The results indicate that urbanization causes simultaneous degradation of water quality, habitat structure, and biodiversity. Wastewater control, riparian restoration, and impervious-surface management are thus priorities in the urban aquatic ecosystem conservation program.

Keywords: Urbanization; Aquatic Ecosystem Health; Water Quality; Habitat Transformation; Biodiversity; Land Use Change; Ecological Assessment.

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I. Introduction

Urban Expansion and Pressure on Aquatic Ecosystems

Urban populations are growing faster than urban areas, replacing farmland, floodplains, and wetlands with impervious surfaces. Municipal wastewater is discharged into rivers, lakes, and wetlands within or below the city; untreated sewage and stormwater runoff are discharged to these bodies of water; and infrastructure occupies watercourses, straightening them and causing embankments. These changes affect multiple aspects of hydrology, chemistry and physical structure simultaneously and render urban aquatic systems among the most modified in the developing world.

Urbanization as a Multi-Dimensional Aquatic Stressor

Urban pressure has multiple interrelated pathways and cumulative impacts on water quality, habitat condition and aquatic biodiversity. The volume and velocity of stormwater runoff as a result of impervious surface expansion carries sediments, nutrients, organic matter, oils, metals and other pollutants to rivers and wetlands. Meanwhile, wastewater discharge and loss of riparian vegetation add to the nutrient and organic load, and also result in reduced shading, bank stability, and natural filtration capacity. These changes may result in altered water flow, higher turbidity and sedimentation, lower dissolved oxygen and simplified aquatic habitats. As a result, biological communities are impacted by the loss of suitable feeding, spawning, shelter and refuge conditions. Species that have evolved in polluted systems show higher

tolerances and more general requirements for habitat, and are gradually replacing sensitive organisms that are susceptible to pollution, leading to reduced richness, diversity, and ecological integrity. This study therefore focuses on the pathway that involves a series of stresses that are intimately connected to urbanization– land-use change, which affects water quality and, in turn, affects habitat change and biological response. Each component can feed on the next one; for instance, an increase in turbidity can also lead to smothering of benthic substrates, decrease habitat complexity, and eliminate sensitive grazers and filter-feeders, all of which can increase the degradation of the ecosystem.

Importance of Ecosystem Health Indicators for Urban Water Management

Assessment methods must be able to translate complex environmental information into measures of ecological condition that are clear and interpretable in order to be able to manage urban rivers and wetlands effectively. Each indicator (e.g., dissolved oxygen, nutrient levels, riparian cover or species diversity) is useful, but may not provide a sufficient representation of an aquatic system on its own. A unified approach that incorporates water-quality status, habitat integrity, and biodiversity response allows us to compare sites that have varying degrees of urban influence. It can also serve as a tool for identifying relatively unaltered reaches and moderately to severely degraded reaches and for prioritizing restoration and pollution control actions. The creation of such an integrated ecosystem-health indicator is thus essential for the cohesion of scientific evaluation and urban aquatic management, and for long-term monitoring.

Research Gap

Studies show the ability to understand the combined effects of urban intensification on physicochemical water quality, aquatic habitat, and aquatic biological communities, and to provide a metric for management that integrates the effects of urban intensification on ecosystem health.

Aim and Objectives

The goal is to assess the effects of various degrees of urbanization on the health of aquatic ecosystems with a comprehensive approach that combines water quality and alterations to aquatic habitat and biodiversity. The specific objectives are to:

1. Determine the water quality changes along a low–moderate–high urbanization gradient;
2. Describe the changes in habitats caused by urbanization;
3. Evaluate the response of sensitive and tolerant species and biodiversity;
4. Create statistical links between urban pressure and ecosystem-health indicators;
5. Identify priority areas and interventions for aquatic ecosystem management.

The research background, problem, gap, aim, and objectives are introduced in Section 1, whereas Section 2 reviews the previous studies on the impacts of urbanization on aquatic ecosystems. Study Design: The study design, sampling process, environmental indicators, and statistical methods are described in Section 3. The major findings regarding water quality, habitat transformation, biodiversity, and ecosystem health are included in Sections 4 and 5. The findings are discussed in terms of their significance, and the implications for management practices are discussed in Section 6, while Section 7 summarizes the key findings and future research directions.

II. Literature Review: Urbanization–Aquatic Ecosystem Interaction Framework

Urban Land Transformation and Aquatic Connectivity

Fragmentation of longitudinal and lateral connectivity through land conversion and modification of riverbanks, wetland encroachments, and channelization isolates floodplain habitats from main channels.

There has been a greater decline in the populations of freshwater vertebrates than in those of terrestrial or marine species, and alteration of habitats is always cited as a primary cause of the decline in freshwater vertebrates (Albert et al., 2021; Dudgeon & Strayer, 2025). The policy reviews also confirm that IWRM, environmental flows and strategic conservation planning are critical to prevent the loss of freshwater biodiversity in landscapes dominated by humans (Van Rees et al., 2021).

Pollution Pathways from Urban Landscapes

High-urbanization scenarios predict that river contamination is likely to get worse as populations become more urbanized, with sewer-connected urban populations becoming a common point source of a variety of pollutants, including nutrients, microplastics, chemicals and pathogens (Strokal et al., 2021; Koelmans et al., 2022). It is estimated that a significant proportion of municipal wastewater is still discharged untreated, and that the quality of surface waters is affected by degradation, which significantly increases water scarcity in rapidly urbanizing areas (Strokal et al., 2021; Van Vliet et al., 2021). The organic load, nutrient levels, and suspended solids that are generated in the domestic sewage system and industry (road runoffs), and the emerging and persistent risk dimension of plastic particles and associated contaminants generated in urban waters are of concern (Akhtar et al., 2021).

Habitat Transformation Processes

Urban habitat transformation involves loss of riparian vegetation, alteration of channel structure, sediment deposition, loss of habitat heterogeneity, shoreline hardening and altered flow regimes. The nutrient enrichment due to these modified catchments causes eutrophication, algal growth and oxygen depletion (Akinnawo, 2023). Experimental studies have shown that the most significant effects of deposited fine sediment and reduction in flow velocity on abundance, diversity, and functional redundancy of stream macroinvertebrates are when these factors occur in combination with nutrient enrichment (Juvigny-Khenafou et al., 2021).

Ecological Responses to Urban Stress

Urban stress results in reduced richness of fish, macroinvertebrates, plankton and aquatic vegetation, as well as the loss of pollution sensitive taxa and the dominance of pollution tolerant 'generalists'. Long-term data from Europe indicates that invertebrate communities were less resilient to urban development, and that the improvement of biodiversity has stalled downstream of urban centres (Haase et al., 2023). Bad water quality also spreads danger to people by providing polluted water and exposure to disease, connecting ecosystem health to public health (Lin et al., 2022).

Integrated Conceptual Framework

The various parameter selections, weighting and aggregation in Water Quality Index models generate uncertainty that needs to be recognized (Uddin et al., 2021). The index-based profiling method is able to enhance source identification and spatial interpretation using multivariate statistics, which can be used to underpin multi-component ecosystem-health assessment.

Previous research has extensively investigated the impacts of urbanization on freshwater systems, but has largely investigated these issues individually water quality, habitat alteration, or biodiversity loss. Few studies have focused on the understanding of the interaction of these components simultaneously on various levels of urban intensity. Few studies integrate physicochemical water-quality data, land-use or habitat measures and biological responses into a single assessment system, in particular. This reduces the capacity to identify multiple pathways of degradation and to separate the effects of chemical pollution, physical habitat alteration, and their combined effect from ecological degradation. Moreover, the application of ecosystem health indices which combine several environmental responses into a single management-oriented index is still relatively few. So, an integrated approach, considering the intensity of urbanization and water quality, habitat alteration, biodiversity change and the overall health of aquatic ecosystems, is needed for better monitoring, restoration and urban water-resource management.

III. Aquatic Ecosystem Assessment Design

Study Area and Urbanization Gradient

The study system is a tropical urban river–wetland corridor (≈ 38 km main channel with two connected wetlands) under a monsoon climate passing through a dense urban core from a peri–urban catchment of agriculture. Using built-up land cover and impervious surface cover within 500-m buffers, 15 stations were divided into three classes: Low (built-up < 20%, impervious < 15%), Moderate (built-up 20–50%, impervious 15–45%) and High (> 50%, > 45%), where the number of stations in each class was 5.

Sampling Design and Environmental Data

Sampling was conducted at 15 stations at varying levels of urbanization in four seasons throughout 2024 annual cycle. Water samples were taken for physicochemical analysis at each station, habitat characteristics were recorded using standard field observations, and the surrounding land use were recorded through spatial data processing. Macroinvertebrate and fish were also sampled to assess how the biota responded to urban pressure.

As urbanization intensity goes up, aquatic ecosystem health goes down via interconnected environmental pathways, as illustrated in figure 1. Water quality and habitat condition changes due to land-use alteration, impervious surfaces, wastewater discharge and stormwater runoff. These changes, in turn, impact biological communities by decreasing species diversity, loss of sensitive species and an increase in tolerant species. Responses from water quality, habitat, and biodiversity are combined in the Aquatic Ecosystem Health Index (AEHI) that can be used to classify ecosystem condition and prioritize management.

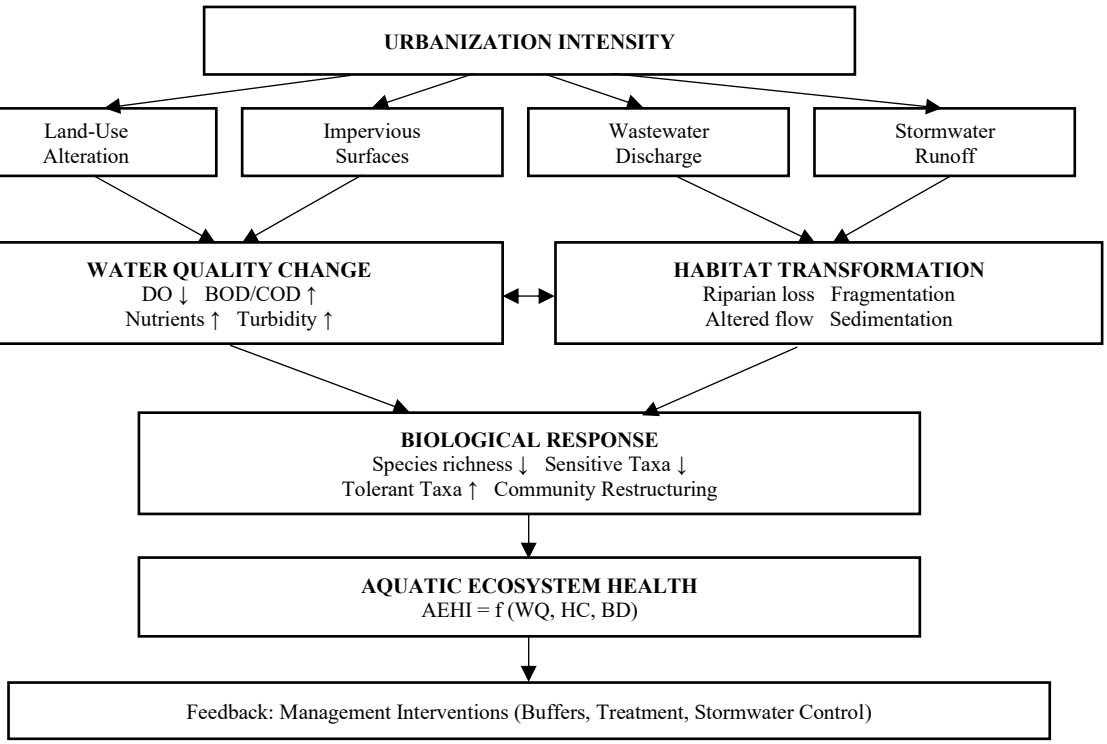


Figure 1: Urbanization–Aquatic Ecosystem Health Framework

Water Quality Indicators

The chosen water-quality parameters are those major physical, chemical, nutrient and ionic parameters that are sensitive to urban stresses. Physical changes as described by temperature, turbidity, and TSS, are

associated with runoff and the movement of sediments; chemical condition and organic pollution are described by pH, dissolved oxygen, BOD_5, and COD. Nutrient enrichment from wastewater and urban runoff was evaluated by the presence of nitrate-N, phosphate, and ammonia-N while EC and TDS are representative of the dissolved ionic content. Implementing the analytical methods and standard values found in table 1 will enable the Water Quality Index to be calculated with a consistent basis and for the low, moderate and high urbanization zones, to enable water-quality conditions to be compared.

Table 1: Water quality parameters, analytical methods and standard values (Si) used in WQI

Category	Parameter (unit)	Analytical method	S_i
Physical	Temperature (°C)	Multiparameter Probe	–
Physical	Turbidity (NTU)	Nephelometric	5
Physical	TSS (mg L^{-1})	Gravimetric, 103–105 °C	100
Chemical	pH	Electrometric	8.5
Chemical	DO (mg L^{-1})	Winkler, Azide Modification	5
Chemical	BOD_5 (mg L^{-1})	5-day Incubation, 20 °C	3
Chemical	COD (mg L^{-1})	Open-Reflux Dichromate	10
Nutrients	Nitrate-N (mg L^{-1})	UV Spectrophotometric	10
Nutrients	Phosphate (mg L^{-1})	Ascorbic Acid	0.1
Nutrients	Ammonia-N (mg L^{-1})	Phenate	0.5
Ionic	EC (µS cm^{-1})	Conductometric	1000
Ionic	TDS (mg L^{-1})	Gravimetric, 180 °C	500

Habitat Transformation Indicators

Habitat indicators comprised impervious-surface percentage, riparian vegetation cover within 30-m bank strips, habitat fragmentation (barriers km-1), shoreline modification, channelized length, land-use conversion and fine-sediment cover. Ten habitat metrics (substrate, embeddedness, velocity–depth regime, sediment deposition, channel alteration, bank stability, bank vegetation, riparian width, flow status and shoreline condition) were rated on a 0 to 20 scale and then rescaled between 0 and 1 to create a Habitat Integrity Score (HIS).

Biodiversity Assessment

Biodiversity was evaluated based on the presence of macroinvertebrates and fish at each sampling point. Macroinvertebrates were identified to family and/or genus level, and fish were identified to species level. The community condition was assessed based on taxa richness, diversity, evenness, the relative abundance of the EPT group, the proportion of tolerant taxa, and the ratio of sensitive-to-tolerant taxa, to determine the community response to the rising urban pressure.

Aquatic Ecosystem Health Assessment

Health of overall aquatic ecosystem was assessed by combining the three elements—water quality, habitat condition and biodiversity—into a single assessment framework. Individual component scores were normalized from 0-1 and equally weighted in the Aquatic Ecosystem Health Index (AEHI) using a normalized water quality (WQ_n), a normalized habitat integrity score (HC_n), and a normalized biodiversity score (BD_n). The index that resulted was then applied to categorize sampling sites from very healthy to severely degraded along an urbanization continuum.

Statistical Analysis

Shapiro–Wilk was used for testing normality. One-way ANOVA or Kruskal–Walli's test followed by Dunn's post hoc test (Bonferroni adjusted) were used to determine differences among zones. Urban pressure–response relationships were quantified using Pearson and Spearman correlations, and multiple linear regression (VIF < 5). Dominant gradients and station groupings were identified by PCA on station means and station standardization and Ward's hierarchical cluster analysis. The significance level was set as $\alpha = 0.05$.

IV. Urbanization Gradient and Water Quality Response

Spatial Pattern of Urban Development

Increasing urbanization intensity is clearly reflected in the land-use composition in figure 2. Low urbanization areas had more vegetation and agricultural land, while moderate and high urbanization areas exhibited a decrease in vegetation and agricultural land, and an increase in built-up and impervious surfaces. Vegetation and agricultural areas were significantly reduced along the gradient, as built-up land rose from 11.2% to 71.3%. In looking at mean impervious cover, the difference between low-urbanization and high-urbanization was 62.8%, up from 8.6% in low-urbanization areas. This pattern suggests high rates of natural/semi-natural land use to developed surface, potentially leading to higher runoff, diminished infiltration, and higher pressures to neighbouring water bodies.

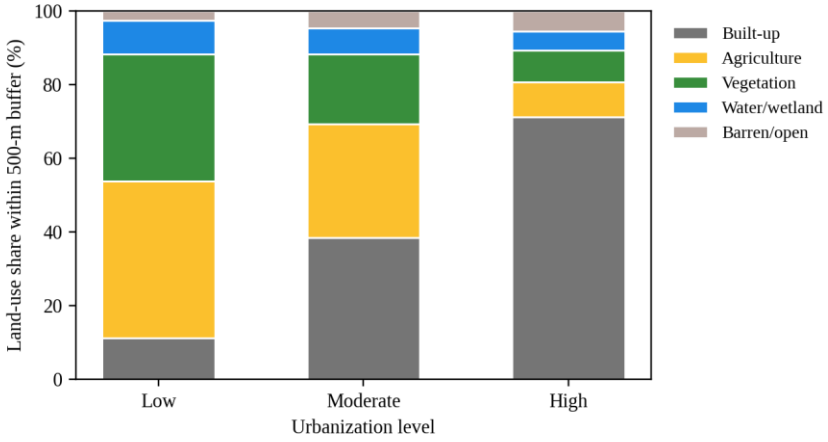


Figure 2: Land-Use Composition within 500-m station buffers across urbanization levels

Physicochemical Water Quality Variation

The results, which are displayed in table 2, seemed to vary significantly across zones ($p < 0.001$), with the exception of temperature. All the seasons of DO in high-urbanization fell below the standard value, while BOD, ammonia and phosphate had values of 4.2, 3.7 and 7.1 times higher, respectively, than the standard values.

Table 2: Water Quality Characteristics Across Urbanization Levels (Mean ± SD, n = 20 per Zone)

Parameter	Low	Moderate	High	p-value
Temperature (°C)	26.8 ± 1.9	27.9 ± 2.1	29.4 ± 2.3	0.002
pH	7.4 ± 0.3	7.6 ± 0.4	7.9 ± 0.5	0.018
DO (mg L^{-1})	7.2 ± 0.6	5.4 ± 0.8	3.1 ± 0.9	< 0.001
BOD_5 (mg L^{-1})	2.1 ± 0.5	5.8 ± 1.4	12.6 ± 3.2	< 0.001
COD (mg L^{-1})	9.8 ± 2.4	22.5 ± 5.1	46.3 ± 9.8	< 0.001
Turbidity (NTU)	8.4 ± 2.6	21.7 ± 6.3	48.9 ± 12.4	< 0.001
TSS (mg L^{-1})	14.2 ± 4.1	36.8 ± 9.7	82.5 ± 18.6	< 0.001
Nitrate-N (mg L^{-1})	0.82 ± 0.21	2.46 ± 0.68	5.93 ± 1.47	< 0.001
Phosphate (mg L^{-1})	0.06 ± 0.02	0.24 ± 0.08	0.71 ± 0.19	< 0.001
Ammonia-N (mg L^{-1})	0.09 ± 0.03	0.48 ± 0.15	1.86 ± 0.52	< 0.001
EC (µS cm^{-1})	312 ± 48	586 ± 92	1124 ± 186	< 0.001
TDS (mg L^{-1})	199 ± 31	375 ± 59	719 ± 119	< 0.001
WQI	38.6 ± 6.2	84.2 ± 11.5	162.7 ± 21.8	< 0.001

Water Quality Index Across Urban Zones

The water with low urbanization rated as good (38.6), moderate as very poor (84.2) and high as unsuitable (162.7) according to WQI. High-urbanisation reaches experienced peak WQI during pre-monsoon season (178.4) due to low dilution of sewage inputs while monsoon peaks in low and moderate zones were due to runoff-induced turbidity as depicted in figure 3.

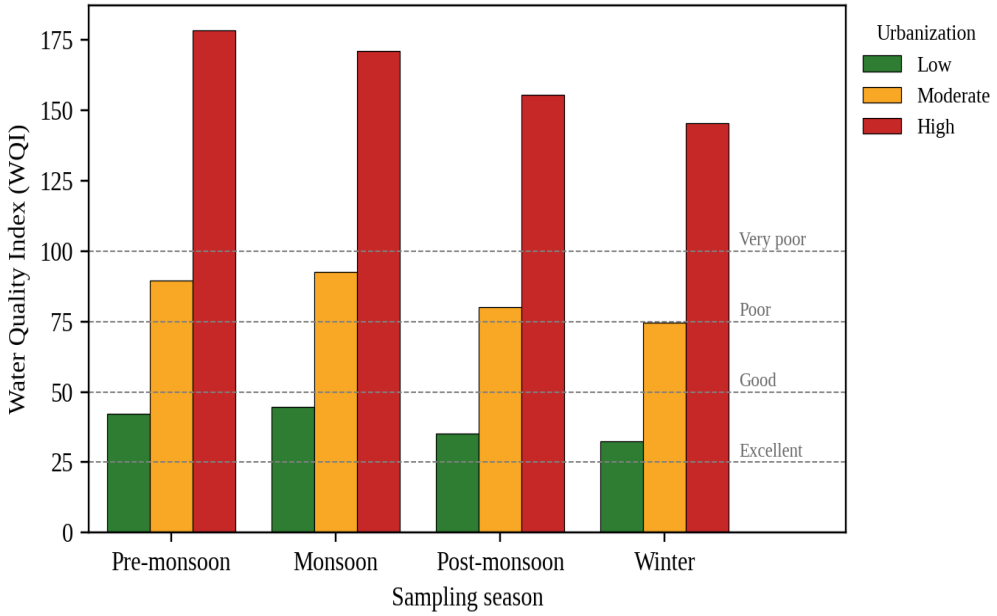


Figure 3: Seasonal Variation in Water Quality Index Across Urbanization Levels

Urbanization–Water Quality Relationships

Table 3 and figure 4 shows that impervious surface cover was a significant factor in water-quality degradation in the urbanization gradient. Table 3 shows strong correlations between impervious cover and dissolved oxygen ($r = -0.91$, $R^2 = 0.83$), BOD_5 ($r = 0.92$, $R^2 = 0.85$), and WQI ($r = 0.93$, $R^2 = 0.86$), with all relationships statistically significant at $p < 0.001$. The findings suggest that as imperviousness was increased, oxygen availability was reduced and the water quality was polluted by organic substances and overall water quality degradation. Multiple regression further indicated that the three variables—impervious cover, riparian cover, and outfall density—all together explained 89% of the variation in WQI (adjusted $R^2 = 0.89$, $F = 38.4$, $p < 0.001$), with impervious cover exhibiting the highest standardized effect ($\beta std = 0.58$). Figure 4(a) visually demonstrates this trend, with dissolved oxygen decreasing significantly with an increase in impervious cover, and $R^2 = 0.83$. Figure 4(b) demonstrates a strong positive correlation between impervious cover and nitrate-N concentration (Pearson $r = 0.89$, $R^2 = 0.79$, $p < 0.001$) suggesting that the concentration of nutrients was increasing with increased urbanization. The table and figure show that there is a close relationship between increasing impervious surfaces and decreasing water quality of aquatic environments.

Table 3: Relationships Between Urban Pressure and Water Quality Indicators (station means, n = 15)

Predictor → Response	Pearson r	Slope (β)	R^2	p-value
Impervious cover → DO	−0.91	−0.071	0.83	< 0.001
Impervious cover → BOD_5	0.92	0.187	0.85	< 0.001
Impervious cover → WQI	0.93	2.21	0.86	< 0.001

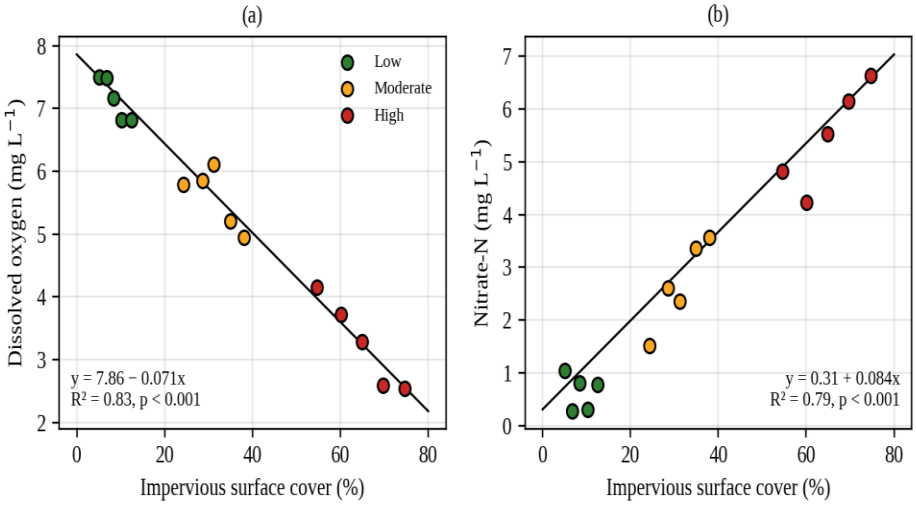


Figure 4: Linear Relationships Between Impervious Surface Cover and (a) Dissolved Oxygen and (b) nitrate-N

V. Habitat Transformation and Biodiversity Response

Physical Transformation of Aquatic Habitats

Riparian vegetation cover decreased from 72.4% to 14.8% (−79.6%) from low to high zones, channelized length increased from 4.2% to 68.3%, and fine-sediment cover increased from 12.6% to 61.2% from low to high zones. The number of barriers was increased from 0.2 to 1.8 barriers km-1 and HIS was decreased from 0.81 to 0.24 in table 4.

Biodiversity Patterns Across Urbanization Levels

Table 4: Habitat and biodiversity indicators across the urban gradient (mean values)

Indicator	Low	Moderate	High	Change (%)
Impervious Surface (%)	8.6	31.4	64.8	+653.5
Riparian Cover (%)	72.4	41.6	14.8	−79.6
Channelized Length (%)	4.2	27.5	68.3	+1526.2
Fine-sediment Cover (%)	12.6	34.8	61.2	+385.7
Habitat Integrity Score (0–1)	0.81	0.52	0.24	−70.4
Macroinvertebrate Richness	34.2	21.6	9.8	−71.3
Fish Species Richness	18.4	11.2	5.6	−69.6
Shannon Index (H′)	2.86	2.12	1.23	−57.0
Simpson Index (1 − D)	0.91	0.79	0.54	−40.7
Pielou Evenness (J′)	0.84	0.71	0.49	−41.7
Sensitive EPT Taxa (%)	38.6	16.4	3.2	−91.7
Tolerant Taxa (%)	14.8	39.5	72.6	+390.5
Sensitive:Tolerant Ratio	2.61	0.42	0.04	−98.5

Table 4 and figure 5 shows that habitat quality and biodiversity strongly decreased as urbanisation increased. Riparian cover decreased by 79.6% as impervious surface cover rose from 8.6% in low urbanization areas to 64.8% in highly urbanized areas, channelized length increased significantly and Habitat Integrity Score dropped from 0.81 to 0.24. Biological response patterns were similar, with a 71.3% reduction in macroinvertebrate richness, 69.6% reduction in fish species richness and 57.0% reduction in Shannon diversity. The number of sensitive EPT taxa decreased from 38.6% to 3.2%, whereas the percentage of tolerant taxa rose from 14.8% to 72.6%, meaning that the ratio of sensitive to tolerant taxa

has dropped 98.5%. These patterns are confirmed by figure 5(a) which shows a gradual decline in Shannon diversity from low to high urbanization levels, with significant differences between urbanization levels (Kruskal–Wallis H = 48.6, p < 0.001). Likewise, the EPT relative abundance decreased significantly along the urbanization gradient (Kruskal–Wallis H = 50.2, p < 0.001; figure 5(b). Combined, these findings suggest that the process of urbanization is linked to habitat simplification, loss of biodiversity and a clear decline in sensitive to pollution aquatic communities.

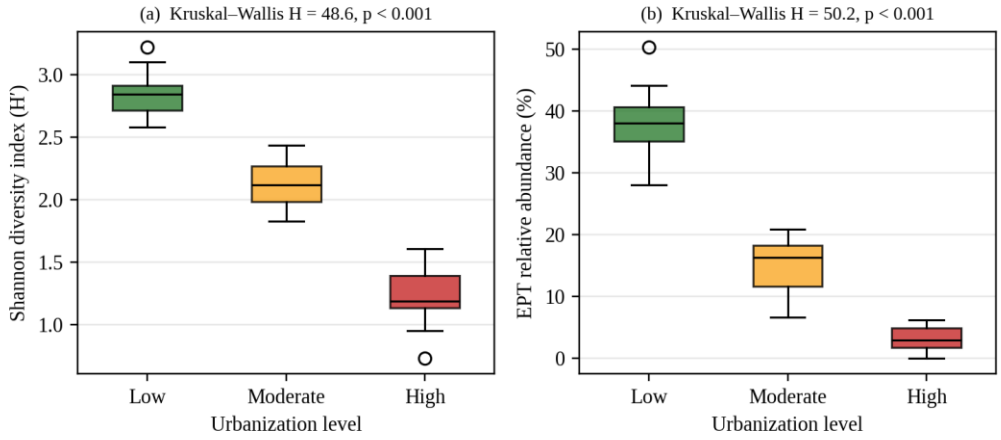


Figure 5: Distribution of (a) Shannon Diversity and (b) EPT Relative Abundance Across Urbanization levels (n = 20 per zone)

Sensitive and Tolerant Species Response

Change in the community was more than just a loss; it was a replacement. Low zones were dominated by mayflies (Baetidae, Heptageniidae) and caddisflies (Hydropsychidae), while high zones were dominated by Chironomidae, Tubificidae, Physa snails and exotic fish and/or air-breathing species (Oreochromis, Clarias). The S:T ratio decreased 98.5%, reflecting almost complete restructuring to pollutant-tolerant assemblages.

Link Between Habitat Condition and Biodiversity

The relationships of habitat integrity and impervious cover indicate a strong, positive correlation with macroinvertebrate richness ($r = 0.92, R^2 = 0.85, p < 0.001$) and a strong, negative correlation with EPT abundance (Spearman ρ=-0.93, p<0.001) as shown in figure 6.

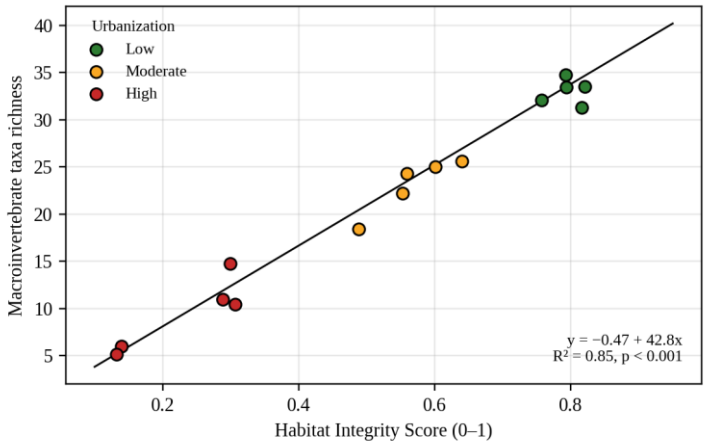


Figure 6: Relationship between Habitat Integrity Score and Macroinvertebrate Taxa Richness

Integrated Ecosystem Health Classification

The level of urbanisation in the area increased, AEHI decreased, as detailed in table 5, from 0.83 (very healthy) in low to 0.50 (moderate) in moderate and 0.19 (severely degraded) in high-urbanisation zones. At all stations three were very healthy, three healthy, three moderate, three degraded, and three severely degraded. Ward's clustering was in good agreement with the three urbanization classes, with 93.3% of agreement, and no zone weights were altered by a weight perturbation of ±20%.

Table 5: Normalized Component Scores and AEHI Across Urbanization Levels

Urbanization	WQ_n	HC_n	BD_n	AEHI	Condition
Low	0.82	0.81	0.85	0.83	Very Healthy
Moderate	0.47	0.52	0.51	0.50	Moderate
High	0.16	0.24	0.18	0.19	Severely Degraded

VI. Discussion

The results indicate that urbanization is linked to major changes in water quality, habitat quality, and aquatic community structure that affect aquatic ecosystem health. Higher impervious surface cover, wastewater discharge, and lower riparian vegetation cover correlated with increased organic and nutrient loading, lower dissolved oxygen, increased sediment, and decreased aquatic habitat complexity. The PCA also identified a dominant urban-pressure gradient, with 68.4% of the total variation accounted for by the PC1. The variables of impervious cover, BOD, and nitrate exhibited an increasing trend along this gradient, while dissolved oxygen, riparian cover, EPT abundance, and Shannon diversity showed a decreasing trend. Macroinvertebrate richness, which has a strong relationship with habitat integrity (85% of the variation explained), also suggests that ecological recovery is tied to improved water quality as well as recovery of physical habitat. The decline in the Aquatic Ecosystem Health Index with increasing urbanization suggests that aquatic systems have limited ability to withstand chronic urban stressors. The outcomes from these studies indicate that integrated management strategies that incorporate wastewater treatment, stormwater control, riparian restoration, wetland protection and ongoing wetland ecosystem monitoring are recommended. The study, however, was conducted over a single annual cycle, a limited number of sampling sites (15) and two major biological groups. Longer monitoring periods, more species and emerging pollutants (e.g. heavy metals, microplastics) should be added to future assessments for improved ecological interpretation and management relevance.

VII. Conclusion

The study examined the impacts on aquatic ecosystem health caused by urbanization by bringing together water quality, habitat conditions and biodiversity responses across three levels of urbanization: low, moderate and high. An increase in urban intensity was always related to ecological degradation. Various parameters of water quality showed significant reduction in dissolved oxygen, and significant increases in BOD_5, nitrate, phosphate, and WQI, all of which suggest continued water-quality degradation. Habitat integrity was reduced by 70.4% because of loss of riparian areas, channelization and sedimentation; Shannon diversity decreased by 57.0% and sensitive EPT taxa were replaced by pollution-tolerant taxa. Impervious cover and WQI ($R^2 = 0.86$), impervious cover and dissolved oxygen ($R^2 = 0.83$), and habitat integrity and macroinvertebrate richness ($R^2 = 0.85$) were the relationships with strong correlations. A dominant urban-pressure gradient was also identified by PCA which accounted for 68.4% of total variation. The biochemical health index (BHI), physical health index (PHI), and chemical health index (CHI) were combined with each other, showing a decline from 0.83 to 0.19 in highly urbanized areas as opposed to low-urbanization areas, indicating cumulative degradation with respect to the biochemical, physical, and chemical health of the water. These results highlight the need for wastewater management, stormwater control, riparian restoration and protection of wetlands. Extended monitoring over several years and representation of additional biological groups and emerging contaminants should be included in future studies to improve long-term ecosystem management.

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