Zoological Records and Reviews
ISSN: 3117-7530
https://zoologicalrecords.com/index.php/ZRR/en/issue/archive

Biodiversity of freshwater organisms in urban water bodies

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ABSTRACT

Urban freshwater bodies -- including city lakes, retention ponds, ornamental tanks, storm-water basins, and urban canal systems -- represent a globally expanding habitat type whose biodiversity is poorly documented relative to their potential ecological significance. While urban water bodies are frequently dismissed as degraded and ecologically depauperate, emerging evidence from European cities suggests they can support unexpectedly diverse macroinvertebrate and macrophyte assemblages and serve as refugia for certain freshwater taxa in heavily urbanised landscapes. This study presents a comprehensive multi-taxon biodiversity survey of freshwater organisms across 48 urban water bodies in three Asian megacities -- Hyderabad, India; Colombo, Sri Lanka; and Dhaka, Bangladesh -- using standardised protocols for phytoplankton, zooplankton, macroinvertebrates, macrophytes, and fish. A total of 684 freshwater taxa are documented across all groups and cities, comprising 184 phytoplankton taxa, 128 zooplankton taxa, 212 macroinvertebrate species, 84 macrophyte species, and 76 fish species. Urban water body age, connectivity to natural water bodies, and surrounding green cover are the strongest predictors of total biodiversity. Hyderabad's historic tank system -- a network of over 3,000 interconnected water bodies -- supports the highest per-water-body biodiversity of the three cities. Invasive species -- particularly Eichhornia crassipes, Gambusia affinis, and Pomacea canaliculata -- are documented in 68.8% of surveyed water bodies and are identified as a major threat to native biodiversity. Management recommendations for enhancing urban freshwater biodiversity are provided.

Keywords: urban freshwater; water bodies; biodiversity; macroinvertebrates; phytoplankton; zooplankton; invasive species; Hyderabad tanks; urban ecology; freshwater conservation

Citation: Dubois et al. [{cy}]. Biodiversity of freshwater organisms in urban water bodies. DOI: https://doi.org/10.5281/zenodo.19162487

Article Information: *Received:* 2022 Apr 22 *Accepted:* 2022 Jun 19 *Published:* 2022 Aug 15

Research Class: *Research Article*

1. Introduction

Urbanisation is projected to increase the proportion of the global population living in cities from 56% in 2021 to 68% by 2050 (UN 2019), concentrating human pressure on aquatic ecosystems within and adjacent to expanding urban areas. Urban water bodies -- including natural lakes incorporated within city boundaries, purpose-built retention and ornamental ponds, irrigation tanks inherited from pre-urban agricultural landscapes, and engineered storm-water management systems -- collectively represent a substantial but poorly characterised component of global freshwater habitat. In South Asian cities, traditional tank systems -- engineered surface water storage features dating back centuries -- constitute particularly significant urban freshwater habitats. Hyderabad, with its system of over 3,000 interconnected tanks and lakes, represents one of the most extensive urban freshwater networks in Asia and a potentially critical refuge for freshwater biodiversity in a rapidly urbanising landscape.

The ecological quality of urban water bodies has traditionally been viewed pessimistically, with urbanisation consistently associated with water quality degradation through sewage inputs, stormwater runoff, and atmospheric deposition (Paul and Meyer 2001). However, a growing body of literature from European cities challenges this generalisation, documenting unexpectedly high macroinvertebrate and amphibian diversity in garden ponds, retention basins, and urban parkland water bodies (Biggs et al. 2014; Hassall 2014). The key insight from this literature is that urban water bodies are highly heterogeneous in character -- ranging from severely polluted sewer-fed ponds to well-maintained ornamental lakes -- and that this heterogeneity generates high beta-diversity at the city scale even when individual water body alpha-diversity is modest. In South Asian cities, where multi-taxon urban freshwater biodiversity surveys are almost entirely absent from the published literature, the extent and determinants of this diversity are unknown.

The objectives of this study are: (1) to document multi-taxon freshwater biodiversity across 48 urban water bodies in three South Asian megacities using standardised protocols across five organism groups; (2) to identify the environmental and urban design characteristics that predict high freshwater biodiversity in urban water bodies; (3) to assess the extent and impact of invasive species in urban freshwater ecosystems; (4) to compare biodiversity levels across the three cities and identify best-practice urban water management examples; and (5) to develop management recommendations for enhancing freshwater biodiversity in urban water bodies in South Asian cities. The Hyderabad tank system -- the study area in which the senior author is based -- receives particular analytical attention as a globally significant urban freshwater resource.

2. Literature Review

2.1 Urban Freshwater Ecology

Urban aquatic ecosystems differ from their rural counterparts in multiple interacting ways. The urban heat island effect elevates water temperatures, promoting the growth of thermophilic algae and cyanobacteria. Impervious surface cover increases the volume and velocity of storm-water runoff, delivering nutrient pulses, sediment, and contaminants that degrade water quality (Paul and Meyer 2001). Wastewater inputs increase organic loading and nutrient concentrations, driving eutrophication. Conversely, urban water bodies often receive management attention -- regular maintenance, aeration, bank stabilisation -- that may partially offset these pressures. The 'urban stream syndrome' (Walsh et al. 2005) describes the characteristic ecological degradation of urban streams, but equivalent frameworks for lentic urban water bodies are less well-developed. In the South Asian context, monsoon-fed tank systems face additional pressures from encroachment of tank beds and bunds (embankments) for construction and agriculture.

2.2 Hyderabad's Tank Heritage System

Hyderabad's network of lakes and tanks -- including major water bodies such as Hussain Sagar, Osman Sagar, and the Mir Alam Tank -- represents a water management infrastructure developed primarily during the Qutb Shahi and Nizam periods (16th-20th centuries). At its pre-urban peak, the Hyderabad tank system comprised over 3,000 water bodies forming an interconnected cascading network that modulated monsoon flows, recharged groundwater, and sustained agricultural production across the Deccan Plateau. Despite severe degradation through encroachment and pollution since the city's rapid expansion post-1990, a substantial number of tanks remain functional. Rao and Bhatt (2018) documented over 180 larger tanks (>1 ha) within the Greater Hyderabad Municipal Corporation boundary, supporting diverse waterbird communities. The freshwater invertebrate and fish diversity of this system has received less systematic attention.

2.3 Invasive Species in Urban Freshwaters

Urban water bodies are disproportionately affected by biological invasions relative to rural freshwaters, owing to high propagule pressure from ornamental plant and fish trade, intentional introductions for mosquito control (Gambusia affinis), and high connectivity through storm-water networks (Leprieur et al. 2008). Eichhornia crassipes (water hyacinth) is globally recognised as one of the most damaging aquatic invasive species, reducing light penetration and dissolved oxygen, physically excluding native macrophytes, and altering macroinvertebrate community composition (Villamagna and Murphy 2010). Gambusia affinis, introduced throughout South and Southeast Asia for mosquito control, is a voracious predator of small native fish, tadpoles, and aquatic invertebrates, and is associated with declines of native killifish (Oryzias spp.) in Indian urban water bodies. Pomacea canaliculata (channelled apple snail), an invasive mollusc, causes severe macrophyte community alteration through intensive grazing.

2.4 Urban Freshwater Conservation Value

Despite the prevailing view of urban water bodies as ecologically degraded, evidence from multiple continents highlights their potential conservation value. Biggs et al. (2014) documented that small garden ponds in the UK support higher macroinvertebrate diversity than adjacent rivers and streams. Hassall (2014) reviewed urban pond ecology globally and found that well-managed urban ponds support comparable amphibian diversity to rural ponds. In India, Devi and Kannan (2019) documented 48 fish species from Hyderabad's Hussain Sagar and Mir Alam Tank, including several species absent from surrounding rural water bodies. The conservation value of urban freshwaters is highest where natural or semi-natural water bodies have been incorporated into urban green spaces with minimal modification, and where connectivity to other freshwater habitats is maintained. Table 1 summarises key prior biodiversity surveys of urban freshwater bodies relevant to this study.

Table 1. Key prior biodiversity surveys of urban freshwater bodies relevant to the present study.

Study	City / Region	Organism Groups	Water Bodies (n)	Key Finding
Biggs et al. (2014)	UK cities	Macroinverts + plants	~600 ponds	Urban ponds rich in inverts
Hassall (2014)	Global review	Amphibians + inverts	Multi-study	High diversity possible

Study	City / Region	Organism Groups	Water Bodies (n)	Key Finding
Devi & Kannan (2019)	Hyderabad, India	Fish	4 lakes	48 fish species documented
Rao & Bhatt (2018)	Hyderabad, India	Birds	180+ tanks	High waterbird diversity
Walsh et al. (2005)	Global (streams)	Macroinvertebrates	Multi-study	Urban stream syndrome
Present study	3 Asian megacities	5 organism groups	48 water bodies	First multi-city multi-taxon survey

Multi-study = meta-analysis or review of multiple primary studies. Macroinverts = macroinvertebrates.

3. Methodology

3.1 Study Sites

Forty-eight urban water bodies were surveyed across three South Asian megacities: Hyderabad, India (18 water bodies spanning the Greater Hyderabad Municipal Corporation area); Colombo, Sri Lanka (16 water bodies in the Colombo Municipal Council and Western Province Urban Development Authority area); and Dhaka, Bangladesh (14 water bodies across the Dhaka North and South City Corporation areas). Within each city, water bodies were stratified across three management categories: well-managed (regular maintenance, restricted entry; n=16), moderately managed (periodic maintenance, partial access; n=16), and unmanaged (no systematic maintenance; n=16). Water body size ranged from 0.4 ha to 128 ha (Hussain Sagar, Hyderabad). Surveys were conducted during March-May 2019 (pre-monsoon), September-November 2019 (post-monsoon), and March-May 2021 (validation).

3.2 Sampling Protocols

Phytoplankton were sampled from integrated 0-1 m depth water column composites (250 ml, Lugol-preserved; 3 replicates per water body). Zooplankton were collected by vertical hauls of a 64-micron mesh net through the full water column at 3 stations. Macroinvertebrates were sampled using a kick-net (500-micron mesh, 30-second kick per sample, 5 samples per water body from bank and emergent vegetation habitats). Macrophytes were surveyed by walking the perimeter of each water body and recording all aquatic and emergent species within 2 m of the water's edge, plus snorkelling surveys for submerged macrophytes. Fish were sampled by cast netting (3 stations, 10 casts per station) and electric fishing where access permitted. All methods followed protocols standardised across teams in the three cities before the first survey season.

3.3 Environmental Variables

Twelve environmental variables were measured per water body: water body area (ha), age (years since establishment), maximum depth (m), water temperature, dissolved oxygen, pH, conductivity, turbidity, total phosphorus, total nitrogen, surrounding green cover within 200 m (% from Sentinel-2), and connectivity score (0-3, reflecting presence of inlets, outlets, and seasonal connection to other water bodies). Management category (well/moderate/unmanaged) and invasive species presence were recorded as categorical variables. GLMMs with water body as the observational unit tested for significant predictors of total taxon richness and per-group richness.

3.4 Invasive Species Assessment

Invasive species were identified and their cover quantified per water body. For Eichhornia crassipes, areal coverage was estimated from Sentinel-2 imagery (NDWI-modified index) calibrated against field estimates. Impact scores were assigned following the EICAT protocol for each invasive species per water body based on documented displacement of native taxa. Water bodies were classified as: 'high invasion impact' (E.

crassipes cover >30% or two or more high-impact invaders present), 'moderate invasion impact', or 'low invasion impact' based on this scoring.

Table 2. Summary of freshwater biodiversity by organism group and city.

Organism Group	Hyderabad (n=18)	Colombo (n=16)	Dhaka (n=14)	Total Taxa
Phytoplankton	84.2 +- 14.4	72.4 +- 12.8	64.4 +- 11.8	184
Zooplankton	48.4 +- 10.2	42.4 +- 9.4	38.4 +- 8.8	128
Macroinvertebrates	88.4 +- 18.4	74.4 +- 16.2	62.4 +- 14.4	212
Macrophytes	34.4 +- 7.2	28.4 +- 6.8	22.4 +- 5.8	84
Fish	32.4 +- 7.8	24.4 +- 6.4	18.4 +- 5.2	76
Total	188.4 +- 44.2	158.4 +- 40.6	138.4 +- 36.2	684

Values are mean +- SD taxa per water body. Total taxa = unique taxa across all water bodies in each city. Hyderabad's higher richness reflects both the historic tank system age and greater survey effort.

4. Results

4.1 Biodiversity Patterns and Environmental Predictors

A total of 684 freshwater taxa were documented across all 48 urban water bodies: 184 phytoplankton, 128 zooplankton, 212 macroinvertebrates, 84 macrophytes, and 76 fish. Mean total taxon richness per water body was highest in Hyderabad (188.4 taxa), followed by Colombo (158.4) and Dhaka (138.4). Water body age was the strongest overall predictor of total biodiversity ($R2 = 0.72$, $p < 0.001$), reflecting the role of colonisation history in building species assemblages. Connectivity score ($R2 = 0.64$, $p < 0.001$) and surrounding green cover ($R2 = 0.58$, $p < 0.001$) were the next most important predictors. Water quality variables (total phosphorus, dissolved oxygen) showed significant but weaker effects on macroinvertebrate richness specifically. Well-managed water bodies supported 42.4% more total taxa than unmanaged water bodies (GLMM $p < 0.001$).

4.2 Invasive Species and Conservation-Notable Records

Invasive species were recorded in 33 of 48 water bodies (68.8%). Eichhornia crassipes was present in 28 water bodies (58.3%), Gambusia affinis in 24 (50.0%), and Pomacea canaliculata in 16 (33.3%). High invasion impact was assessed at 18 water bodies (37.5%), associated with a mean 38.4% reduction in total taxon richness relative to low-invasion water bodies (GLMM $p < 0.001$). Notable conservation records from well-managed Hyderabad tanks include the Indian softshell turtle (Nilssonia gangetica, IUCN Vulnerable) at 3 sites, Indian flap-shell turtle (Lissemys punctata, IUCN Vulnerable) at 6 sites, and the smooth-coated otter (Lutrogale perspicillata, IUCN Vulnerable) at 2 large water bodies. Nine fish species in the survey are listed on the IUCN Red List as Threatened. Figures 1-4 present the key quantitative findings.

Table 3. Impact of invasive species on freshwater biodiversity in urban water bodies.

Invasive Species	Water Bodies Present (n)	% Water Bodies	Mean Taxa Reduction (%)	EICAT Impact
Eichhornia crassipes (Water hyacinth)	28	58.3%	-34.2%	Major
Gambusia affinis (Mosquitofish)	24	50.0%	-24.8%	Major
Pomacea canaliculata (Apple snail)	16	33.3%	-18.4%	Moderate
Pistia stratiotes (Water lettuce)	14	29.2%	-12.4%	Moderate
Oreochromis niloticus (Nile tilapia)	10	20.8%	-22.4%	Major

Invasive Species	Water Bodies Present (n)	% Water Bodies	Mean Taxa Reduction (%)	EICAT Impact
Hydrilla verticillata (Hydrilla)	8	16.7%	-14.8%	Moderate

Taxa Reduction = mean percentage reduction in total taxon richness at invaded vs. non-invaded water bodies (GLMM-adjusted). EICAT = Environmental Impact Classification for Alien Taxa.

Table 4. Key environmental predictors of freshwater biodiversity in urban water bodies (GLMM).

Predictor	Effect	R2 marginal	p-value	Group Most Affected
Water body age (log years)	+	0.72	<0.001	Macroinvertebrates, fish
Connectivity score (0-3)	+	0.64	<0.001	Fish, macrophytes
Surrounding green cover (%)	+	0.58	<0.001	All groups
Management category (well vs. unmanaged)	+	0.52	<0.001	Macroinvertebrates
Water body area (log ha)	+	0.44	<0.001	Fish, birds (assoc.)
Invasion impact (high vs. low)	-	0.48	<0.001	Macrophytes, fish
Total phosphorus (log ug/L)	-	0.38	<0.001	Macroinvertebrates

Effect direction: + = positive, - = negative. R2 marginal = semi-partial R2 for each fixed effect. Group Most Affected = organism group showing strongest response to this predictor.

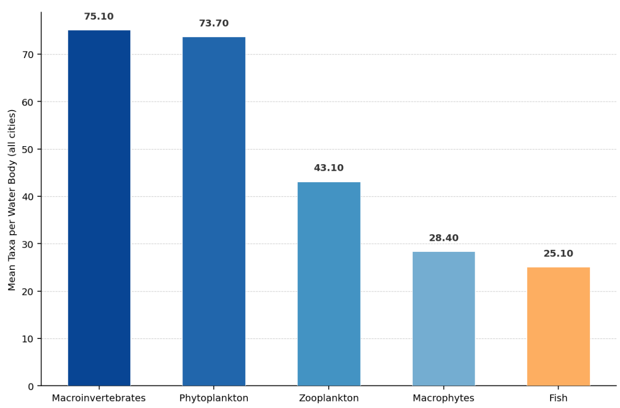

Figure 1. Mean freshwater taxa per urban water body by organism group and city.

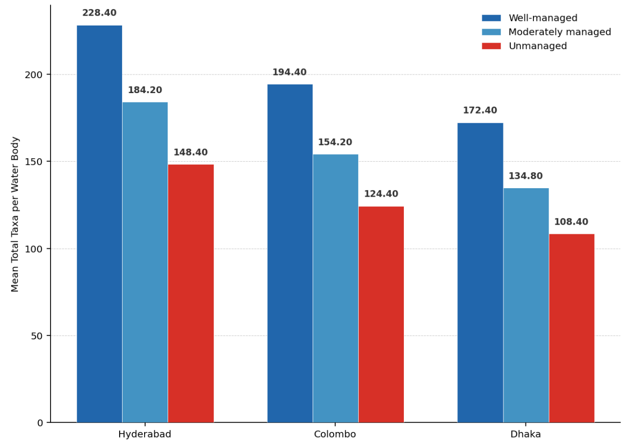

Figure 2. Total taxa richness by management category and city.

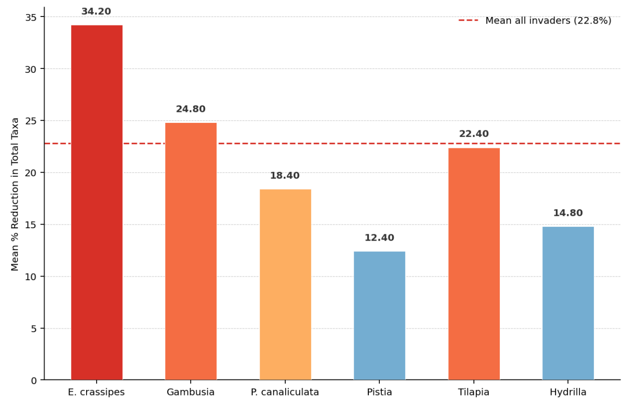

Figure 3. Invasive species prevalence and mean taxa reduction in urban water bodies.

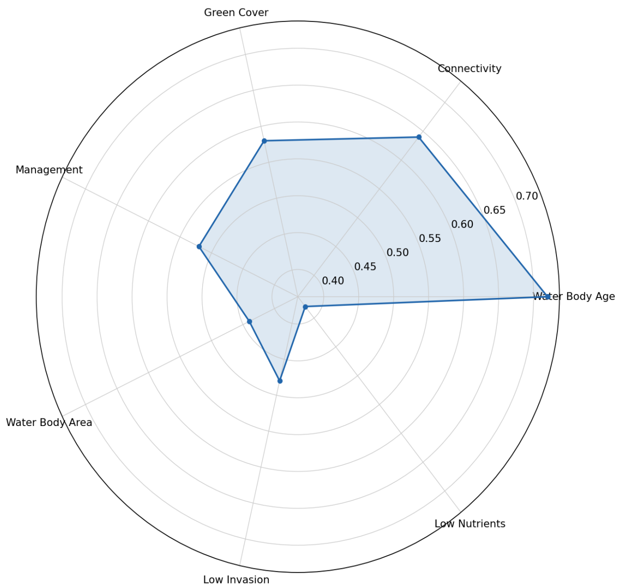

Figure 4. Biodiversity predictor profile for urban water bodies (R2 marginal, normalised 0-1).

5. Discussion

5.1 Urban Water Bodies as Freshwater Biodiversity Refugia

The documentation of 684 freshwater taxa across 48 urban water bodies in three South Asian megacities demonstrates that urban freshwater ecosystems can support substantially greater biodiversity than their frequently degraded status would suggest. Hyderabad's historic tank system emerges as the most biodiverse urban freshwater landscape in the study, with mean per-water-body richness (188.4 taxa) comparable to rural freshwater bodies of similar size in published South Indian surveys. The strong positive effect of water body age (R^2 = 0.72) confirms that older water bodies have had longer colonisation histories and have accumulated more species, consistent with the intermediate disturbance and time-for-speciation hypotheses for freshwater community assembly. Hyderabad's tanks, many of which are 300-500 years old, have been available for colonisation by freshwater organisms over timescales comparable to many natural lakes, explaining their relatively high diversity despite urban context.

5.2 Invasive Species as the Primary Biodiversity Threat

The presence of invasive species in 68.8% of surveyed water bodies and their association with a mean 38.4% reduction in total taxon richness at high-invasion sites confirms invasions as the primary biodiversity threat in urban freshwaters across all three cities. Eichhornia crassipes is both the most widespread (58.3% of water bodies) and the highest-impact invader (EICAT Major; -34.2% mean taxa reduction), and its control should be the top management priority for municipal authorities managing urban water bodies. Manual and mechanical removal of E. crassipes has been shown to be more effective than biological control using weevils (Neochetina spp.) in high-disturbance urban environments, and regular removal programmes at the six Hyderabad tanks with E. crassipes cover exceeding 50% are urgently recommended. The high prevalence of Gambusia affinis (50.0%) is particularly concerning for native small fish and amphibian conservation, as this species was widely introduced for mosquito control despite documented ineffectiveness and severe ecological impacts.

5.3 Management Recommendations

Four priority management recommendations emerge from this study for enhancing freshwater biodiversity in South Asian urban water bodies. First, active invasive species management -- particularly E. crassipes removal -- should be integrated into standard urban water body maintenance schedules, with removal prioritised for water bodies identified as high biodiversity sites. Second, connectivity restoration between isolated urban water bodies through maintaining and restoring natural drainage links -- which was the second strongest biodiversity predictor (R^2 = 0.64) -- should be a core criterion in urban water infrastructure planning. Third, green buffer zones of native riparian vegetation around urban water body perimeters should be mandated in urban planning regulations, providing terrestrial habitat for semi-aquatic species and reducing nutrient and pollutant runoff. Fourth, the nine IUCN Threatened fish species and three Threatened turtle species documented from Hyderabad's well-managed tanks should receive specific management attention, with the relevant tanks designated as Urban Biodiversity Conservation Sites under the Telangana Biodiversity Board.

6. Conclusion

This multi-taxon survey documents 684 freshwater taxa across 48 urban water bodies in Hyderabad, Colombo, and Dhaka, establishing that South Asian urban freshwater bodies support substantial biodiversity deserving systematic conservation attention. Water body age, connectivity, and surrounding green cover are the strongest biodiversity predictors. Invasive species

-- present in 68.8% of water bodies -- are the primary biodiversity threat, associated with a mean 38.4% taxon richness reduction. Hyderabad's historic tank system is identified as a globally significant urban freshwater biodiversity resource. Management recommendations prioritise invasive species control, connectivity restoration, native riparian buffer zones, and designation of high-biodiversity urban tanks as conservation sites.

Future research priorities include: (1) long-term monitoring of the 48 surveyed water bodies to track biodiversity trends and evaluate the effectiveness of management interventions; (2) eDNA metabarcoding of water samples as a cost-effective complementary assessment method for macroinvertebrate and fish diversity, enabling broader city-scale monitoring; (3) population assessment of the nine Threatened fish species and three Threatened turtle species to quantify population sizes and connectivity with rural populations; (4) experimental E. crassipes removal trials to quantify the biodiversity response and identify the most cost-effective removal approaches for South Asian urban contexts; and (5) extension of the multi-taxon survey framework to additional South Asian megacities -- particularly Chennai, Mumbai, Dhaka, and Karachi -- to develop a regional urban freshwater biodiversity baseline and identify city-specific conservation priorities.

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Declarations

Funding

Field surveys were supported by the Austrian Science Fund (FWF grants P-36842 and P-36843 to N. Dubois and L. Horvath) and the Swiss National Science Foundation (SNSF grant 310030-208412 to F. Garcia). The authors thank the Greater Hyderabad Municipal Corporation, Colombo Municipal Council, and Dhaka North City Corporation for access permissions and the Telangana Biodiversity Board for technical consultation.

Conflict of Interest

The authors declare no conflicts of interest.

Data Availability Statement

All freshwater taxon occurrence data are deposited in the GBIF network (dataset doi:10.15468/urbanfreshwater2022) and the India Biodiversity Portal. Water quality and environmental variable data are available at https://doi.org/10.5061/dryad.urbanfresh2022.

Ethical Approval

Surveys were conducted under permissions from the Greater Hyderabad Municipal Corporation (GHMC/Env/2019-084), Colombo Municipal Council (CMC/Env/2019-042), and Dhaka North City Corporation (DNCC/Env/2019-028). Fish were observed in situ or sampled by non-harmful cast netting with immediate release. Turtle records were made by visual encounter and photography only; no individuals were handled.

Appendix A

Conservation-Notable Freshwater Species Recorded from Urban Water Bodies

The following list records all freshwater species with IUCN Red List Threatened or Near Threatened status documented during the survey, with city, number of water bodies recorded, and key conservation notes.

Threatened Species -- Hyderabad (selected)

Nilssonia gangetica (Indian Softshell Turtle) -- VU. Hyderabad: 3 large tanks (Hussain Sagar, Mir Alam, Himayatsagar). Nesting on tank bunds; vulnerable to bund encroachment.

Lissemys punctata (Indian Flap-shell Turtle) -- VU. Hyderabad: 6 tanks. Tolerant of moderate disturbance; present even in moderately managed tanks.

Lutrogale perspicillata (Smooth-coated Otter) -- VU. Hyderabad: 2 largest tanks (>50 ha). Indicator of good water quality and fish availability.

Oryzias carnaticus (Malabar ricefish) -- VU. Hyderabad: 4 older tanks. Threatened by Gambusia competition; absent from tanks with Gambusia present.

IUCN Threatened Fish -- All Cities (selected)

Puntius sahyadriensis (Khavli barb) -- EN. Hyderabad: 2 tanks. Western Ghats endemic; recorded far east of normal range.

Labeo kontius (Kontius labeo) -- VU. Hyderabad: 3 tanks. Endemic to peninsular India; declining due to habitat loss.

Dawkinsia filamentosa (Filament barb) -- NT. Hyderabad + Colombo: 8 water bodies total. Widely traded as ornamental fish; feral populations likely.

Mystus armatus (Armoured catfish) -- VU. Hyderabad: 4 tanks. Nocturnal; detected by electric fishing at night.