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Cover: Nile Crocodile *Crocodylus niloticus* regulating body temperature on a warm day. Digital art on Procreate by © Aakanksha Komanduri.



## Fish diversity in selected urban, suburban, and rural wetlands of Vellore District, Tamil Nadu, India

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**Abstract:** Fish diversity in relation to macrophyte distribution and physicochemical parameters was studied across six wetlands in Vellore District, Tamil Nadu, India. A total of 20 fish species were recorded, of which 12 are native to India with a higher prevalence in rural wetlands. Urban wetlands exhibit lower relative diversity due to the dominance of *Oreochromis niloticus* and the presence of *Clarias gariepinus* which may pose threats to native fish populations. Macrophytes, which influence fish habitat and growth, are abundant in both urban and rural sites. Of the 20 macrophytes identified, 14 are native to India. Physicochemical parameters show variations across sites, yet Canonical Correspondence Analysis indicates a positive correlation between environmental factors and fish diversity. These findings highlight the importance of habitat conditions in maintaining fish diversity and emphasize the need for conservation strategies to protect declining native fish species in urban wetlands.

**Keywords:** Catfish, conservation, Cypriniformes, exotic species, fish diversity, invasive species, macrophytes, physicochemical parameters, suburban and rural wetlands, water quality.

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**Author contribution:** Sampling, species identification, data analysis and manuscript writing was performed by API. SJD helped in the identification of macrophytes. DSVK helped in guiding, fish species identification and manuscript editing. NMN provided overall guidance and helped in manuscript editing. The final manuscript has been read and approved by all the authors.

## INTRODUCTION

Freshwater fish diversity is a vital component of aquatic ecosystems, providing ecological, economic, and social benefits. The composition and abundance of fish species are closely linked to the physical and chemical characteristics of their environment, as well as the structure of macrophyte communities. The study of freshwater fish diversity, particularly in the context of urban, suburban, and rural environments, is crucial for understanding the impact of human activities on aquatic ecosystems.

Fish diversity is greatly impacted by physicochemical parameters such as water temperature, pH, dissolved oxygen levels, conductivity, and nutrient concentrations. These factors have a direct impact on fish metabolism, survival, and reproduction, which changes the distribution and abundance of different species (Karr 1981). According to Carpenter *et al.* (1998) excessive nutrient levels may lead to eutrophication, which lowers oxygen levels and has a detrimental effect on fish communities. According to Peuranen *et al.* (1994), fish physiology can be altered by extremely high or low pH levels, which can result in stress or even death.

Macrophytes are essential for maintaining the diversity of freshwater fish. In addition to offering fish habitat, spawning grounds, and food supplies, they also help to stabilize the quality of the water by absorbing nutrients and raising oxygen levels (Chambers *et al.* 2008). There is a feedback loop between fish diversity, macrophyte presence, and water quality as the physicochemical features of the water body affect the diversity and density of macrophytes.

Fish diversity patterns differ between urban, suburban, and rural areas due to varying levels of anthropogenic influence. Freshwater ecosystems in urban areas are frequently polluted, habitat modified, and hydrologically altered as a result of infrastructure development, industrial discharges, and runoff (Walsh *et al.* 2005). As urban water bodies frequently experience lower dissolved oxygen levels and increased nutrient loads, these factors can result in degraded water quality and reduced fish diversity (Paul & Meyer 2008). Suburban areas, on the other hand, may have moderate pollution levels, with fewer industrial impacts but ongoing influence from residential development and agriculture. While rural areas are less affected by industrial and urban runoff, agricultural activities, such as pesticide and fertilizer runoff, can still have an impact on water quality and fish habitat (Allan 2004).

The interaction of physicochemical parameters,

and fish diversity differs between these environments. In urban areas, water quality degradation frequently leads to a decline in macrophyte cover, which further reduces available habitat and food resources for fish, exacerbating the decline in fish diversity (Seilheimer *et al.* 2007). Suburban and rural areas may have more diverse macrophyte and fish communities due to better water quality, but agricultural runoff in rural areas can still pose significant risks (Sponseller *et al.* 2001).

The present study focuses on freshwater fish diversity in relation to physicochemical parameters and macrophytes across urban, suburban, and rural area which sheds light on how human activities can influence the aquatic ecosystems. The present study focuses on the freshwater fish diversity in relation with physicochemical parameter and macrophytes. It emphasizes the importance of effective management strategies addressing pollution, habitat conservation, and water quality maintenance in order to preserve fish diversity in freshwater systems.

## MATERIALS AND METHODS

### Study Areas

The present study was carried out by categorising water bodies in Vellore District, Tamil Nadu, India into urban (Vellore Fort Moat and Nellorepettai Lake), suburban (Seduvai and Mel Kavanur Lakes), and rural (Chinna Kesa Kuppam Lake and Mordhana Dam) categories based on population density and their distance from the district headquarters (Image 1). The present study was conducted only during the post-monsoon period. Seasonal sampling was not undertaken due to resource, water and accessibility constraints within the study period. The post-monsoon season was selected for sampling as it typically represents a period of ecological stability in southern Indian wetlands, when water levels are replenished and both native and invasive species are active, providing a representative snapshot of community structure. In total, eight georeferenced sampling points were selected within each wetland to represent the range of available habitat features such as vegetation cover, flow variation, and accessibility. At each point, multiple replicates were obtained by conducting 5–6 standardized net hauls to capture local variability in fish diversity. Guidelines for Implementing Wetlands (Conservation and Management) Rules, 2017 was followed for the present study. ArcGIS software (version 10.8) was used to prepare the maps.

**Vellore Fort Moat (VFM)** is a water-filled structure

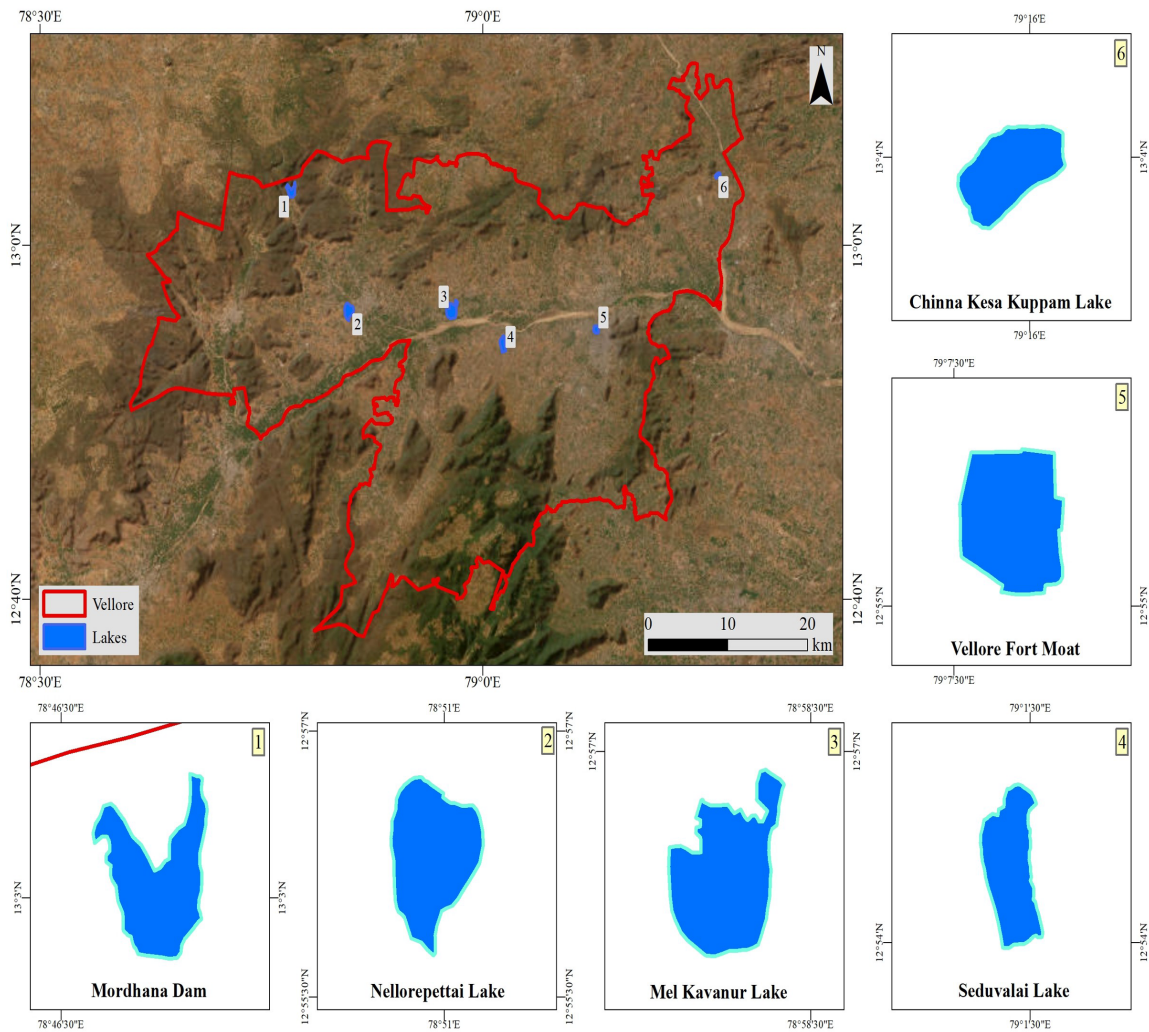


Image 1. Geographic locations of study areas.

that encircles the Vellore Fort, constructed in the 16th century. This moat provides a year-round water supply. VFM covers 50 ha.

**Nellorepettai Lake (NEL)** is a seasonal lake that captures monsoon runoff from Palar and Kosasthalaiyar River located in Vellore District, Tamil Nadu, India. Approximately, 2,500 urban families live around the lake, and regular fishing supports fishermen's families.

**Seduvalai Lake (SEL)** is a natural inland water body, which supports around 1,800 suburban families in local irrigation and sustains surrounding vegetation through its seasonal water inflow, primarily from rainfall.

**Mel Kavanur Lake (MKL)** is a natural inland water body. Around 1,300 suburban families live in MKL, and the lake receives water mainly from local streams and rain. Fishing is done which supports the local fishermen.

**Chinna Kesa Kuppam Lake (CKL)** supports approximately around 600 rural families by serving as a

small reservoir used mainly for agricultural water needs, with seasonal water flow based on rainfall and mountain water nearby.

**Mordhana Dam (MOD)** is a large dam which stretches across 220 meters and manages a catchment area of 300 ha. It serves the needs of about 480 rural families, providing irrigation, fishing and a recreational space.

**Fish Sampling and Identification:** Fish were sampled by experienced local fishermen using gill nets and drag nets from eight randomly selected locations across the study areas. These sampling points were strategically distributed to cover the entire area. At the landing site, fish were recorded, photographed, and identified using established taxonomic keys (Day et al. 1875; Talwar & Jhingran 1991; Jayaram 1999; Froese & Pauly 2000). Species were preserved in 10% formalin for laboratory analysis, and their conservation status was assessed

based on IUCN criteria (IUCN 2025).

**Water Sample Collection and Analysis:** Water quality was analysed through samples taken from the study areas, utilizing standard methods, APHA (Standard Methods Committee 2017) to evaluate both physical and chemical parameters, and IS test method to evaluate parameters like pH, total hardness, total alkalinity, chloride, sulphate, and odour.

**Macrophyte Assessment:** Submerged, free floating, floating-leaved, emergent, and peripheral macrophytes were documented during the survey. Their density was estimated through direct visual assessments, and identification was carried out using established taxonomic references (Cook 1996).

**Data Analysis:** Diversity and evenness indices were calculated using the Shannon diversity index (Shannon 1948), Pielou evenness index (Pielou 1966), Simpson index (Simpson 1949). Margalef index assessed species richness and species dominance. Environmental variables were log-transformed for normality and variance equality, minimizing the impact of dominant species. Canonical correspondence analysis (CCA) was employed to explore the relationship between fish diversity and physicochemical parameters, utilizing PAST software.

## RESULTS

In the present study, a total of 20 fish species were identified from six lakes classified as urban, suburban, and rural lakes. VFM and NEL are situated in urban area, while SEL and MKL are situated in suburban area. CKL and MOD are located in rural area.

At VFM, the species identified were *Catla catla*, *Labeo rohita*, *Channa striata*, and *Oreochromis niloticus*. Among these, *C. catla*, *C. striata*, and *L. rohita* are native to India, while *O. niloticus* is an exotic species. In NEL, the species identified were *C. striata*, *Channa punctata*, *Glossogobius giuris*, *Clarias anguillaris*, *C. catla*, *L. rohita*, and *O. niloticus*. Among these, *C. catla*, *L. rohita*, *G. giuris*, *C. punctata* and *C. striata* are native, while *C. anguillaris* and *O. niloticus* are exotic/invasive (Figure 2; Table 1).

In SEL, the species identified were *O. niloticus*, *O. mossambicus*, *Anabas testudineus*, *C. striata*, and *G. giuris*. Here, both *O. niloticus* and Mozambique tilapia are exotic/invasive, while *A. testudineus*, *C. striata*, and *G. giuris* are native. MKL revealed the presence of *C. catla*, *G. giuris*, *C. striata*, *L. rohita*, *O. niloticus*, Bighead Carp *Hypophthalmichthys nobilis*, and *Clarias gariepinus*.

In this lake, *C. catla*, *L. rohita*, *G. giuris*, *C. striata* are native species, and *H. nobilis* is exotic, *O. niloticus* and *C. gariepinus* are exotic/invasive (Image 2; Table 1).

*C. catla*, *G. giuris*, *C. striata*, *L. rohita*, *O. niloticus*, *Cyprinus carpio*, Orange Common Carp *Cyprinus carpio* var. *auratus* and *Ambassis gymnocephalus* are identified in CKL. Here, *C. catla*, *L. rohita*, *G. giuris*, and *C. striata* are native, while *O. niloticus* is invasive, and both *Cyprinus carpio* and orange common carp are considered exotic. MOD showcased a variety of species such as *Amblypharyngodon mola*, *A. microlepis*, *Ambassis dussumieri*, *O. niloticus*, *C. catla*, *Glossogobius giuris complex*, *L. rohita*, and *Mastacembelus armatus*. In this area, *A. mola*, *A. microlepis*, *A. dussumieri*, *G. giuris complex*, *M. armatus*, *C. catla*, and *L. rohita* are native, while *O. niloticus* is exotic (Image 2; Table 1). The study also, reveals that **Cypriniformes** is the most prevalent order, followed by **Anabantiformes** and **Cichliformes** (Figure 1). Order-wise classification indicates that rural sites host the highest species diversity compared to suburban and urban sites. At the species level, **O. niloticus** dominates with the highest prevalence across most of the sites (Figure 2). This pattern suggests that rural wetlands support greater fish diversity, while certain species, like *O. niloticus*, thrive across different environments, possibly due to their adaptability.

The study underscores the rich diversity of fish species in different habitats, highlighting both native and exotic species across urban, suburban, and rural areas. The findings point to the presence of numerous native species, along with a notable influx of exotic and invasive species that may have implications for local ecosystems.

### Fish Diversity

The analysis of fish diversity across six study areas revealed significant differences in biodiversity. MOD exhibited the highest diversity (1.640) (Table 2) according to the Shannon diversity index, followed by CKL (1.612) and MKL (1.347) (Table 2). VFM had the lowest diversity (0.5164) (Table 2), indicating a less varied fish community.

Simpson's diversity index further supported these findings, with higher diversity at MOD (0.7438) and CKL (0.7345), while VFM showed the lowest value (0.2798) (Table 2), suggesting potential ecological imbalances.

The Margalef index indicated that CKL (1.188) and NEL (1.088) had the highest species richness, while VFM (0.4521) showed the lowest. Pielou's evenness index revealed a more equitable distribution of species at MOD (0.6441) and CKL (0.6268) (Table 2), whereas VFM

**Table 1.** List of recorded Fishes in Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake, Mel Kavanur Lake, Chinna Kesa Kuppam Lake, and Mordhana Dam.

	Species	Order	Family	Urban		Suburban		Rural		Common name	Native/ Exotic/ Invasive	IUCN
				VFM	NEL	SEL	MKL	CKL	MOD			
1	<i>Catla catla</i>	Cypriniformes	Cyprinidae	Y	Y	N	Y	Y	Y	Catla, Indian Carp	Native	LC
2	<i>Labeo rohita</i>	Cypriniformes	Cyprinidae	Y	Y	N	Y	Y	Y	Rohu	Native	LC
3	<i>Channa striata</i>	Anabantiformes	Channidae	Y	Y	Y	Y	Y	N	Striped Snakehead	Native	LC
4	<i>Oreochromis niloticus</i>	Cichliformes	Cichlidae	Y	Y	Y	Y	Y	Y	Nile Tilapia	Exotic/ Invasive	LC
5	<i>Channa punctata</i>	Anabantiformes	Channidae	N	Y	N	N	N	N	Spotted Snakehead	Native	LC
6	<i>Glossogobius giuris</i>	Gobiiformes	Gobiidae	N	Y	Y	Y	N	N	Giant Goby	Native	LC
7	<i>Clarias anguillaris</i>	Siluriformes	Clariidae	N	Y	N	N	N	N	Catfish	Exotic/ Invasive	LC
8	<i>Oreochromis mossambicus</i>	Cichliformes	Cichlidae	Y	N	Y	N	N	N	Mozambique	Exotic/ Invasive	VU
9	<i>Anabas testudineus</i>	Anabantiformes	Anabantidae	N	N	Y	N	N	N	Climbing Perch	Native	LC
10	<i>Hypophthalmichthys nobilis</i>	Cypriniformes	Xenocyprididae	N	N	N	Y	N	N	Bighead Carp	Exotic	LC
11	<i>Clarias gariepinus</i>	Siluriformes	Clariidae	N	N	N	Y	N	N	African Catfish	Exotic/ Invasive	LC
12	<i>Amblypharyngodon mola</i>	Cypriniformes	Danionidae	N	N	N	N	N	Y	Mola Fish	Native	LC
13	<i>Amblypharyngodon microlepis</i>	Cypriniformes	Danionidae	N	N	N	N	N	Y	Small-spotted Mola	Native	LC
14	<i>Ambassis gymnocephalus</i>	Perciformes	Ambassidae	N	N	N	N	Y	N	Glassy Perchlet	Native	LC
15	<i>Ambassis dussumieri</i>	Perciformes	Ambassidae	N	N	N	N	N	Y	Malabar Glassy	Native	LC
16	<i>Glossogobius giuris complex</i>	Gobiiformes	Gobiidae	N	N	N	N	N	Y	Goby complex	Native	LC
17	<i>Mastacembelus armatus</i>	Synbranchiformes	Mastacembelidae	N	N	N	N	N	Y	Zig zag Eel	Native	LC
18	<i>Cyprinus carpio</i>	Cypriniformes	Cyprinidae	N	N	N	N	Y	N	Common Carp	Exotic/ Invasive	LC
19	<i>Ctenopharyngodon idella</i>	Cypriniformes	Xenocyprididae	N	N	N	N	Y	N	Grass Carp	Exotic	LC
20	<i>Cyprinus carpio var. auratus</i>	Cypriniformes	Cyprinidae	N	N	N	N	Y	N	Goldfish	Exotic	LC

Y—Present | N—Absent | LC—Least Concern | VU—Vulnerable | Exotic—Introduced species, non-native to India | Invasive—Non-native species that threaten local biodiversity.

(0.419) displayed dominance by a few species.

The dominance index indicated that VFM had the highest dominance (0.7202), suggesting a community structure heavily skewed towards a few dominant fish species. In contrast, MOD (0.2562) and CKL (0.2655) (Table 2) demonstrated lower dominance, suggesting a more balanced and diverse ecosystem.

The present study highlights significant variations in fish diversity and distribution across the different areas, with urban sites like VFM showing lower diversity and higher dominance. In contrast, rural areas like MOD and CKL exhibited greater biodiversity and more balanced community structures. These findings are essential for understanding the ecological dynamics of these aquatic

systems and guiding conservation strategies.

### Macrophytes

A total of 20 macrophytes were identified across six study areas. Of these, 14 species are native to India, while 6 are exotic or invasive. Among these, six species were 6 submerged (*Hydrilla verticillata*, *Najas marina*, *Ottelia alismoides*, *Blyxa* sp., *Potamogeton nodosus*, and *Vallisneria spiralis*), one is free-floating (*Ipomoea aquatica*), and one species is floating-leaved (*Nymphaea pubescens*), and eight were classified as emergent (*Typha angustifolia*, *Ipomoea carnea*, *Cyperus* sp., *Cyperus difformis*, *Ludwigia grandiflora*, *Ludwigia purslane*, *Scoparia dulcis*, and *Brachiaria* sp.). The remaining four

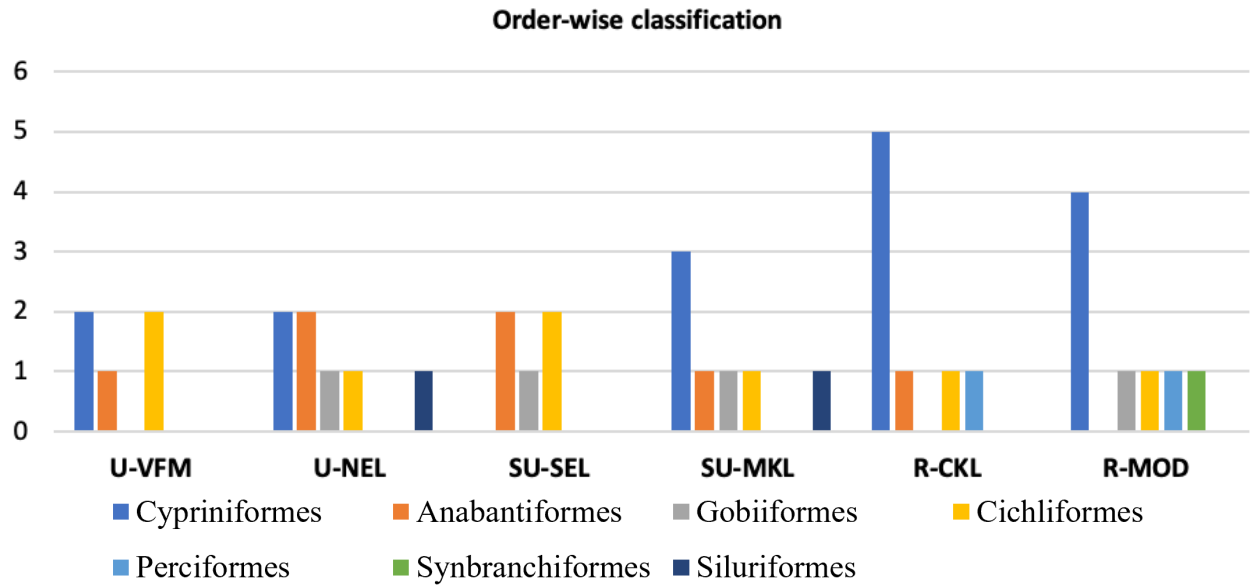


Figure 1. Distribution of fish species by order across different habitat types: Urban – Vellore Fort Moat | Nellorepettai Lake | Sub Urban – Seduvalai Lake Mel Kavanur Lake | Rural – Chinna Kesa Kuppam Lake | Mordhana Dam.

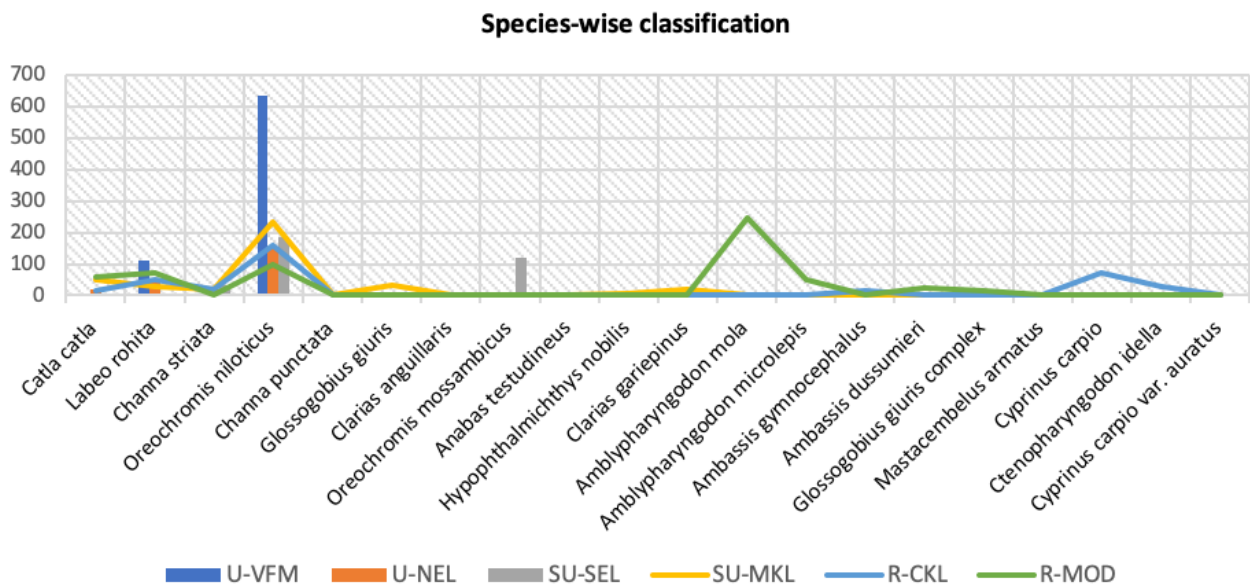


Figure 2. Distribution of fish species by species across different habitat types: Urban – Vellore Fort Moat | Nellorepettai Lake | Sub Urban – Seduvalai Lake Mel Kavanur Lake | Rural – Chinna Kesa Kuppam Lake | Mordhana Dam.

species (*Muntingia calabura*, *Coccinia grandis*, *Borassus flabellifer*, and *Chromolaena odorata*) were identified as terrestrial or marginal plants frequently occurring along the edges of aquatic habitats. Macrophytes were recorded qualitatively through visual observations. Based on these observations, the following species were abundant: *I. aquatica* and *N. pubescens* (VFM), *H. verticillata* and *T. angustifolia* (NEL), and *H. verticillata* and *N. marina* (SEL). In contrast, *N. marina* and *T.*

*angustifolia* (MKL), *I. carnea* and *C. difformis* (CKL), and *O. alismoides* and *V. spiralis* (MOD) were abundant.

In the VFM, the identified macrophytes include *Ipomea aquatica*, *Nymphaea pubescens*, *M. calabura*, and *C. grandis* (Image 3; Table 3), of which *M. calabura* is exotic. At NEL, *H. verticillata*, *N. marina*, *T. angustifolia*, and *I. carnea* were found. *I. carnea* is exotic and all other species are native and supporting local biodiversity.

In SEL, the recorded species include *I. carnea*,

**Table 2. Diversity analysis of Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake, Mel Kavanur Lake, Chinna Kesa Kuppam Lake, and Mordhana Dam.**

	Urban		Suburban		Rural	
	VFM	NEL	SEL	MKL	CKL	MOD
Shannon_H	0.5164	1.276	1.096	1.347	1.612	1.64
Simpson_1-D	0.2798	0.5927	0.6012	0.6094	0.7345	0.7438
Margalef	0.4521	1.088	0.6822	1.007	1.188	1.104
Evenness_e^H/S	0.419	0.512	0.5984	0.5496	0.6268	0.6441
Dominance_D	0.7202	0.4073	0.3988	0.3906	0.2655	0.2562

*Cyperus* sp., *H. verticillata*, *N. marina*, *L. grandiflora*, and *B. flabellifer* (Image 3; Table 3), among these, *I. carnea* and *L. grandiflora* are exotic/invasive and others are native which further enhancing the area's ecological stability. MKL features *N. marina*, *Chromolaena odorata*, *I. carnea*, *T. angustifolia*, *B. flabellifer*, and *O. alismoides*. Among these, *C. odorata* and *I. carnea* is considered invasive, posing a threat to the local flora.

In CKL, *C. difformis*, *S. dulcis*, *I. carnea*, and *T. angustifolia* (Image 3; Table 3) were recorded, of these *T. angustifolia* being native species. MOD showcases *O. alismoides*, *Blyxa* sp., *L. purslane*, *P. nodosus*, *V. spiralis*, *T. angustifolia* and *Brachiaria* sp., of which *L. purslane* and *Brachiaria* sp. are exotic to India and all others are native, highlighting the rich diversity of aquatic plants in the region.

Overall, the varying levels of fish diversity across these lakes correlate with the presence of native macrophytes, highlighting the crucial role that aquatic plants play in supporting fish populations and maintaining ecological balance.

### Physicochemical Parameters

The analysis of 22 physicochemical parameters across the six study areas revealed significant findings. Elevated ammonia levels were recorded in MOD, NEL, CKL, and SEL. High nitrite levels were also observed in MOD, NEL, CKL, and SEL, indicating potential ecological stress (Table 4).

Phosphate concentrations (Table 4) were notably high in MOD, with slight increases in NEL and CKL. Turbidity levels were elevated in MKL, NEL, and CKL. SEL exhibited a very high pH of 12.25 (Table 4), which could indicate alkaline conditions harmful to aquatic life. Additionally, low sulphate levels were detected in CKL and VFM, along with an extremely low magnesium concentration of 1 mg/l (Table 4) in VFM. While other parameters remained normal, the increased levels of ammonia, nitrite, phosphate, turbidity, and extreme pH,

alongside low sulphate and magnesium levels, highlight concerns regarding water quality and the health of local aquatic ecosystems.

### Relationship between Physicochemical Parameters and Fishes

The CCA results indicate clear relationships between fish species distribution and various environmental factors across the study areas. The first two axes explained 68% of the total variation, with axis 1 accounting for the largest proportion (42.41%) (Table 5). The dominance of a single axis suggests that some of the environmental parameters may be correlated (Table 5).

Certain species, such as *A. mola*, *A. microlepis*, and *A. dussumieri*, show strong positive correlations with elevated levels of ammonia and nitrite (Figure 3), suggesting an ecological preference for conditions characterized by these higher concentrations. Additionally, *O. niloticus* and *O. mossambicus* also exhibit similar trends, indicating their affinity for environments with increased nutrient levels (Figure 3).

*O. mossambicus* and *A. testudineus* demonstrate a positive relationship with alkaline conditions, particularly where pH levels are elevated (Figure 3), indicating that these species thrive in environments with more alkaline water. *C. catla* also aligns with these alkaline conditions, further reflecting the adaptability of these species (Figure 3).

In addition, *C. striata*, *C. punctata*, and *H. nobilis* are positively correlated with higher concentrations of sulphate and chloride, suggesting that their distribution is influenced by these specific physicochemical parameters. *C. anguillaris* and *C. gariepinus* may also be found in similar conditions, indicating their tolerance for varied water quality (Figure 3).

Conversely, species such as *L. rohita* and *C. carpio* demonstrate lower associations with the environmental gradients (Figure 3), indicating their narrow tolerance to varying physicochemical conditions. Overall, the CCA

**Table 3. List of recorded Macrophytes in Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake, Mel Kavanur Lake, Chinna Kesa Kuppam Lake, and Mordhana Dam.**

	Species	Order	Family	Urban		Suburban		Rural		Common name	Native/ Exotic/ Invasive	IUCN Red List
				VFM	NEL	SEL	MKL	CKL	MOD			
1	<i>Ipomoea aquatica</i>	Solanales	Convolvulaceae	Y	N	N	N	N	N	Water Spinach	Native	LC
2	<i>Nymphaea pubescens</i>	Nymphaeales	Nymphaeaceae	Y	N	N	N	N	N	Water Lily	Native	LC
3	<i>Muntingia calabura</i>	Malpighiales	Muntingiaceae	Y	N	N	N	N	N	Jamaican Cherry	Native	LC
4	<i>Coccinia grandis</i>	Cucurbitales	Cucurbitaceae	Y	N	N	N	N	N	Ivy Gourd	Native	LC
5	<i>Hydrilla verticillata</i>	Alismatales	Hydrocharitaceae	N	Y	Y	N	N	N	Water Thyme	Native	LC
6	<i>Najas marina</i>	Najadales	Najadaceae	N	Y	Y	Y	N	N	Horned Pondweed	Native	LC
7	<i>Typha angustifolia</i>	Poales	Typhaceae	N	Y	N	Y	N	N	Cattail	Native	LC
8	<i>Ipomoea carnea</i>	Solanales	Convolvulaceae	N	Y	Y	Y	Y	N	Pink Morning Glory	Exotic/ Invasive	LC
9	<i>Cyperus sp</i>	Poales	Cyperaceae	N	N	Y	N	N	N	Sedge species	Native	LC
10	<i>Ludwigia grandiflora</i>	Myrtales	Onagraceae	N	N	Y	N	N	N	Water Primrose	Exotic/ Invasive	LC
11	<i>Borassus flabellifer</i>	Arecales	Arecaceae	N	N	Y	Y	N	N	Palmyra Palm	Native	LC
12	<i>Ottelia alismoides</i>	Alismatales	Hydrocharitaceae	N	N	N	Y	N	Y	Floating Ottelia	Native	LC
13	<i>Chromolaena odorata</i>	Asterales	Asteraceae	N	N	N	Y	N	N	Siam Weed	Exotic/ Invasive	LC
14	<i>Cyperus difformis</i>	Poales	Cyperaceae	N	N	N	N	Y	N	Creeping Flatsedge	Native	LC
15	<i>Scoparia dulcis</i>	Lamiales	Scrophulariaceae	N	N	N	N	Y	N	Sweet Broomweed	Exotic	LC
16	<i>Blyxa sp</i>	Alismatales	Hydrocharitaceae	N	N	N	N	N	Y	Blyxa	Native	LC
17	<i>Ludwigia purslane</i>	Myrtales	Onagraceae	N	N	N	N	N	Y	Water Purslane	Exotic	LC
18	<i>Potamogeton nodosus</i>	Alismatales	Potamogetonaceae	N	N	N	N	N	Y	Pondweed	Native	LC
19	<i>Vallisneria spiralis</i>	Alismatales	Hydrocharitaceae	N	N	N	N	N	y	Eelgrass	Native	LC
20	<i>Brachiaria sp.</i>	Poales	Poaceae	N	N	N	N	N	y	African Grass	Exotic	LC

Y—Present | N—Absent | LC—Least Concern | VU—Vulnerable | Exotic—Introduced species, non-native to India | Invasive—Non-native species that threaten local biodiversity.

results highlight the distinct preferences of fish species based on environmental factors, illustrating how water quality influences species distribution in the studied areas.

## DISCUSSION

### Fish Diversity

The diversity of fish across the six study areas reflects the native and exotic species, habitat conditions, and physicochemical characteristics. Shannon diversity index shows low diversity in urban areas (VFM and NEL) when compared to rural areas (CKL and MOD) (Table

2). This may be due to the record of highest percentage (Figure 2) of invasive species *O. niloticus*, known for its presence in degraded water conditions (Figure 2). Martin et al. (2010) documented that *O. niloticus* often outcompetes native species in polluted environment. Similar pattern is observed in the present study, where native fish diversity was comparatively lower in the urban areas. Historically, Nile Tilapia *O. niloticus* was first introduced into Indian freshwater systems during the mid-20<sup>th</sup> Century, primarily to enhance aquaculture production due to its rapid growth, high reproductive capacity, tolerance to water quality, and strong market demand (Sugunan 1995; De Silva et al. 2004). Over time, accidental and intentional releases from fish farms

**Exotic/Invasive Species**



*Oreochromis niloticus*



*Oreochromis mossambicus*



*Cyprinus carpio*



*Ctenopharyngodon Idella*



*Cyprinus carpio var. auratus*



*Clarias anguillaris*



*Clarias gariepinus*



*Hypophthalmichthys nobilis*

**Native Species**



*Amblypharyngodon mola*



*Ambassis dussumieri*



*Amblypharyngodon microlepis*



*Ambassis gymnocephalus*



*Channa striata*



*Channa punctata*



*Labeo rohita*



*Catla catla*



*Glossogobius giuris*



*Anabas testudineus*



*Mastacembelus armatus*



*Glossogobius giuris complex*

**Image 2.** Fishes recorded in Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake, Mel Kavanur Lake, Chinna Kesa Kuppam Lake and Mordhana Dam. © Annie Pushpa Isaac.

**Table 4. Physicochemical parameters of water samples collected from Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake Mel Kavanur Lake, Chinna Kesa Kuppam Lake, and Mordhana Dam.**

	Acceptable limit	Maximum permissible limit in the absence of alternative source	Urban		Suburban		Rural	
			VFM	NEL	SEL	MKL	CKL	MOD
<b>I. PHYSICAL PARAMETERS</b>								
1. Appearance	-	-	Slightly turbid	Slightly turbid	clear	Slightly turbid	Slightly turbid	Slightly turbid
2. Colour	-	-	slightly yellowish	slightly yellowish	colourless	slightly yellowish	slightly yellowish	slightly greenish
3. Odour	Agreeable	Agreeable	odour some	odour some	none	odour some	odour some	odour some
4. Turbidity NTU	1	5	2	6	0	6	6	2
5. Total dissolved solids <sub>Mg/L</sub>	500	2000	1396	942	1017	1540	473	446
6. Electrical conductivity micro mho/cm	-	-	1994	1345	1453	2200	675	637
<b>II. CHEMICAL PARAMETERS</b>								
7. pH	6.5–8.5	6.5–8.5	7.1	7.42	12.25	7.54	7.16	7.04
8. Alkalinity pH as CaCO <sub>3</sub> mg/L	-	-	-	-	-	-	-	-
9. Alkalinity Total as CaCO <sub>3</sub> mg/L	200	600	300	272	228	300	172	148
10. Total Hardness as CaCO <sub>3</sub> mg/L	200	600	400	336	244	380	260	22
11. Calcium as Ca mg/L	75	200	70	67	48	76	31	45
12. Magnesium as mg/L	30	100	1	40	30	46	19	26
13. Iron Total as Fe mg/L	0.3	1	0	0	0	0	0	0
14. Manganese as Mn mg/L	0.1	0.3	0	0	0	0	0	0
15. Free Ammonia as NH <sub>3</sub> mg/L	0.5	0.5	0.058	0.67	1.04	0.25	0.7	0.6
16. Nitrite as NO <sub>2</sub> mg/L	0.2	0.2	0.04	0.1	0.11	0.03	0.1	0.25
17. Nitrate as NO <sub>3</sub> mg/L	45	45	20	14	17	23	10	5
18. Chloride as Cl mg/L	250	1,000	442	210	264	470	97	85
19. Fluoride as F mg/L	1	1.5	0.4	0.8	0.6	0.6	0.4	0.4
20. Sulphate as SO <sub>4</sub> mg/L	200	400	79	111	105	160	40	34
21. Phosphate as PO <sub>4</sub> mg/L	-	-	0.13	0.21	0.17	0.06	0.23	0.34
22. Tidys Test 4Hrs.as O <sub>2</sub> mg/L	-	-	0.1	0.1	0.1	0.1	0.1	0

facilitated its spread into rivers, lakes, and reservoirs. These same traits that make it a valuable aquaculture species with broad dietary range, aggressive foraging, and adaptability have also enabled it to dominate wild habitats, often displacing native species (Sugunan 1995; De Silva et al. 2004). Beyond competition with native fish, Nile tilapia are omnivorous fish that feed on both plants and invertebrates. Their feeding behaviour and waste production can modify the nutrient composition of the water, often increasing concentrations of nitrogen and phosphorus (Tesfahun & Temesgen 2018).

In the suburban study areas, SEL and MKL showed an intermediate level of diversity (Table 2). Native species like *C. striata* and *G. giuris* were recorded along with invasive species such as *O. mossambicus* and *C.*

*garipepinus* (Image 2). The African Catfish *C. garipepinus* native to African river systems, was introduced to India in the 1990s to boost aquaculture yields (Singh et al. 2015). However, its ability to survive in low-oxygen waters, tolerate wide temperature fluctuations, and consume a wide variety of prey has contributed to its invasive success. In many cases, its predatory nature has severely impacted small indigenous fish species through both direct predation and competition for resources. Reports from various Indian states have documented significant alterations in aquatic food webs following its establishment (Singh et al. 2015). *C. garipepinus* may also influence macrophyte communities by disturbing sediments during benthic foraging, which can uproot aquatic vegetation and alter habitat structure. This

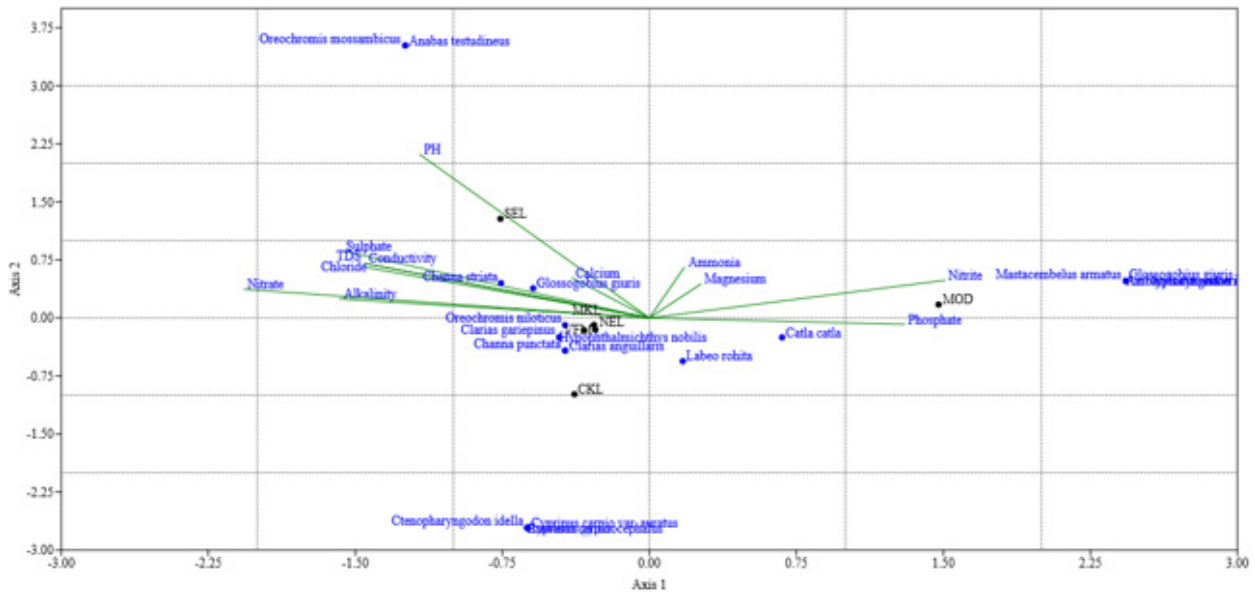


Figure 3. Relationship of fish species with physicochemical parameters using canonical correspondence analysis.

Table 5. Canonical correspondence analysis axis eigenvalues and statistics.

Axis	Eigen value	% of constr. in.	% of total inertia
1	0.6053	42.56	42.41
2	0.3637	25.57	25.48
3	0.2677	18.82	18.76
4	0.1253	8.811	8.78
5	0.06012	4.228	4.213

behaviour, similar to that of the common carp, can lead to a reduction in macrophyte abundance and diversity (Miller & Crowl 2006). The introduction of *C. gariepinus* into non-native ecosystems has led to negative impacts on the small indigenous fish species. Their predatory behaviour can cause declines in native fish populations through direct predation and competition for resources (Kadye & Booth 2012). As per Yam et al. (2015), suburban wetlands often support both native and exotic species due to moderate levels of human activities. According to Leidy et al. (2011) such environments allows both groups to coexist, but invasive species can still impact native fish through competition for various resources, which may explain the intermediate diversity observed in the present studied suburban areas.

In the present study rural areas, CKL and MOD showed the highest diversity (Table 2). Native species like *C. catla*, *L. rohita*, *A. mola*, *A. dussumieri*, and *M. armatus* were recorded, with minimal invasive fish species (Image 3; Table 3).

*I. carnea* (NEL, SEL, MKL, CKL), *L. grandiflora* (SEL) and *C. odorata* (MKL) were the most frequent exotic/invasive macrophytes found in the study area (Table 3). Dense *Ludwigia* sps. is reported to form thick surface mats that shade the water column and lower DO. Decomposition of this macrophyte further intensify hypoxia conditions, which affects sensitive native fishes and favour tolerant taxa (Pelella et al. 2023). In southern Asian wetlands, increasing cover of invasive plants, especially *I. carnea* has been linked to significant DO decline and higher free CO<sub>2</sub>/alkalinity, with shifts in aquatic biota and reduced fish diversity as coverage increases (Pandey et al. 2020). Terrestrial invasive, *C. odorata* at wetland margins can also alter riparian structure and nutrient/light regimes, indirectly affecting macrophyte mosaics and fish habitat (Rai & Singh 2024). Although *T. angustifolia* is native, extensive *Typha* expansion in many systems similarly reduces nearshore DO and fragments open-water access, constraining fish movements; this helps explain lower diversity where emergent belts dominate littoral zones (Lishawa et al 2023).

In VFM, *M. calabura* occurs along the water edge, with branches overhanging the moat, fruits and leaf litters regularly falling into the water, potentially influencing nutrient cycling and providing organic matter to aquatic biota. Similarly, in MKL, *B. flabellifer* trees were observed growing in the middle of the inundated zone, likely due to seasonal water level changes, thereby contributing shade, structural habitat, and detritus to the aquatic environment. Previous studies have recognized that riparian and emergent vegetation

can significantly influence aquatic ecosystem structure and function through shading, organic matter input, and habitat complexity (Gregory et al. 1991; Allan 2004). Thus, their inclusion reflects their ecological role within the aquatic habitats.

In the urban area, VFM, macrophytes such as *I. aquatica*, *N. pubescens*, *M. calabura*, and *C. grandis* are prevalent (Image 3; Table 3). Native fish species like *C. catla* and *L. rohita* were also observed in VFM (Image 2). These macrophytes provide essential cover and help regulate oxygen levels, creating a supportive habitat for these native species (Petr 2005). Though macrophytes are recorded more in VFM the presence of invasive species *O. niloticus*, which outcompetes native species. This may be one of the reasons for less fish diversity in VFM. At NEL, macrophytes such as *H. verticillata*, *N. marina*, *T. angustifolia*, and *I. carnea* were recorded (Image 3; Table 3). These plants enhance local biodiversity by supporting fish species. *H. verticillata* and *N. marina*, known for their water oxygenation properties, benefit fish populations by creating breeding-friendly conditions (Durborow 2014).

In the suburban areas, SEL and MKL, a wider range of macrophytes, including *H. verticillata*, *N. marina*, *Cyperus* sp., *T. angustifolia*, and *O. alismoides* were recorded, which supports fish diversity by providing the oxygen-rich environment created by these macrophytes (Image 3; Table 3). However, in MKL, the presence of the invasive macrophyte *C. odorata* is concerning as it can overshadow native vegetation and reduce habitat, potentially affecting native fish species over time.

In the rural sites, CKL and MOD, a diverse macrophytes, such as *C. difformis*, *S. dulcis*, *T. domingensis*, *P. nodosus*, and *V. spiralis* are found, which supports a high level of fish diversity (Image 3; Table 3). These rural sites show a healthier ecosystem, where species like *C. catla*, *L. rohita*, *A. mola* and *M. armatus* are observed (Image 2). Earlier studies confirm that complex habitat and stable water conditions are provided by native macrophytes (*P. nodosus* and *V. spiralis*) which also supports native fishes for spawning (Johnston 1991; Flint & Madsen 1995; Brendonck et al. 2003; Tang et al. 2021). Macrophytes like *Blyxa* spp., *Ludwigia purslane*, and *Brachiaria* spp. recorded in MOD contribute to fish habitat structure, which benefits smaller species, such as *A. mola*, *A. microlepis*, *Ambassis dussumieri*, and larger native species. According to Petr (2005), macrophyte-rich habitats in less-disturbed areas support a wide range of native fish due to the availability of shelter and nutrient cycling provided by these macrophytes.

Overall, the macrophyte diversity at each site

appears to impact fish diversity. Urban areas with higher macrophyte diversity and invasive species favour resilient exotic and invasive fish, while suburban and rural areas with richer macrophytes support a higher diversity of native species.

### Influence of Physicochemical Parameters on Fish Diversity

The relationship between fish diversity and macrophyte presence in the studied wetlands highlights the crucial role of macrophytes in mitigating the effects of increased physicochemical parameters. Despite increased ammonia concentrations observed at sites such as MOD, NEL, CKL and SEL (Table 4), certain fish species shows resilience to these conditions, which is supported by diverse macrophytes.

In NEL, the coexistence of native species such as *C. striata* and *L. rohita* with the invasive *O. niloticus* demonstrate the complex dynamics which shows positive relation with ammonia (Figure 3). Macrophytes like *H. verticillata* and *T. angustifolia* are providing habitat complexity and enhancing water quality (Longstreth 1989; Zhou et al. 2018). According to Kalengo et al. (2021) the nutrient uptake by these macrophytes can mitigate the impacts of elevated ammonia, thereby supporting fish populations.

MOD also records elevated ammonia levels and decreased chloride, sulphate and nitrate (Table 4) levels but maintains a diverse fish community, including *A. mola* and *M. armatus* (Image 2). CCA shows small native fishes shows positive correlation with these nutrients (Figure 2). The presence of native macrophytes such as *P. nodosus* and *V. spiralis* contributes to ecological stability, offering shelter and breeding grounds for fishes, even in nutrient-stressed environments (Marwat et al. 2011; Tang et al. 2021).

CKL exhibits high fish diversity despite limited aquatic macrophytes and elevated ammonia level decreased calcium, magnesium and other vital nutrients (Table 4). The lake's primary water sources are rainfall, mountain runoff and agricultural runoff. While mountain runoff can introduce both beneficial nutrients and pollutants (Molla et al. 2022), agricultural runoff is a known source of excess nutrients and other contaminants (Rao et al. 2022). Macrophytes, such as *T. domingensis*, typically enhance water quality and provide habitat in aquatic ecosystems (Dhir et al. 2009; Talevska et al. 2009; Kalengo et al. 2021) however, their physicochemical changes in CKL suggests other factors are influencing the fish community. The influx of nutrients and potentially unique thermal conditions from mountain runoff may

**Exotic/Invasive Species**



*Chromolaena odorata*



*Ipomea carnea*



*Muntingia calabura*



*Cyperus difformis*



*Brachiaria sp*



*Scoparia dulcis*



*Ludwigia purslane*



*Ludwigia grandiflora*

**Native Species**



*Potamogeton nodosus*



*Ottelia alismoides*



*Vallisneria spiralis*



*Nymphaea pubescens*



*Cyperus sps.*



*Blyxa sp*



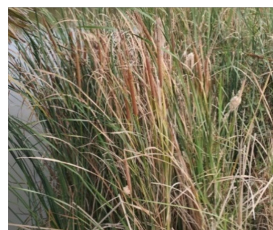
*Hdrilla verticillata*



*Najas marina*



*Ipomea aquatica*



*Typha angustifolia*



*Borassus flabellifer*



*Coccinia grandis*

**Image 3. Macrophytes recorded in Vellore Fort Moat, Nellorepettai Lake, Seduvalai Lake Mel. Chinna Kesa Kuooam Lake and Mordhana Dam.  
© Annie Pushpa Isaac.**

be supporting the diverse fish population, particularly various carp species present in CKL (Table 2). Further research is needed to fully understand the complex interplay of these factors in maintaining the lake's high fish diversity.

SEL shows high pH of 12.25 (Table 4), potentially harmful to aquatic life. *O. mossambicus* and *A. testudineus* demonstrate a positive relationship with alkaline conditions according to CCA (Figure 3) which is found abundant in SEL and it is supported by Thammaratsuntorn et al. (2016) *O. mossambicus* thrive in alkaline conditions, which shows adaptability. Research suggests that such resilience can be linked to the presence of macrophytes that enhance habitats despite challenging water quality (Van der Cruysse et al. 2024).

The interaction between elevated physicochemical parameters and macrophyte presence enhance the importance of macrophytes in maintaining ecosystem. Although these factors cause stress in some locations, native macrophytes improves water quality and add structural complexity, promotes fish diversity and ecological sustainability in various wetland types.

### Limitations

While this study calculated a range of physicochemical parameters (such as nitrate, phosphate, ammonia, and conductivity) to assess water quality and infer potential pollution sources, direct measurements of specific pollutant level and agricultural pollutants (pesticide and fertilizer residues) were not conducted. Therefore, the attribution of elevated nutrient levels in urban, suburban and rural wetlands is based on indirect evidence rather than compound-specific analysis. Future studies incorporating targeted chemical analyses would strengthen the ability to link observed nutrient enrichment to specific anthropogenic activities.

### CONCLUSION

The study shows that fish diversity is related to the presence of macrophytes and the physicochemical parameters of wetlands. The presence of diverse macrophyte species, along with favourable water quality conditions, promotes increased fish diversity. However, wetlands that are subjected to the dominance of invasive species have lower fish diversity, particularly in urban areas. Based on the findings, an integrated management strategy combining physical removal, biological control (e.g., enhancement of native predators, sterile male

release), and habitat restoration is recommended. Removal of *C. gariepinus* and *O. niloticus* is recommended from the study area, as they pose significant predatory, competitive, and reproductive threats to native small indigenous fishes. *O. niloticus*, in particular, can rapidly dominate fish communities due to its high reproductive rate and adaptability, leading to reduced native species abundance. Management of invasive macrophytes, which can alter habitat structure and restrict native macrophyte growth, should also be prioritized through mechanical removal or biological control measures. These findings highlight the importance of habitat restoration and improved management strategies for preserving wetland biodiversity. Additionally, monitoring and mitigating changes in physicochemical parameters, particularly nutrient enrichment, can help to maintain optimal water quality and prevent further ecological disruption.

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