

Impact of Wetland Pollution on Fish Diversity

Sincy V.^{1,4}, Jaishanker R.⁴, Asulabha K.S.^{1,4} and Ramachandra T.V. ^{1,2,3*}

Abstract

Aquatic ecosystems provide a wide range of ecological services, such as the provision of food, fodder, and water, remediating contaminants, moderating microclimate, providing cultural services, etc., which sustain the livelihoods of dependent populations. However, aquatic ecosystems are in peril throughout the world due to unplanned developmental activities leading to changes in land cover, sustained inflow of untreated or partially treated domestic sewage and industrial effluents, climate change, introduction of exotic or alien species, overexploitation, habitat modification, and degradation. Native fish species production in inland wetlands has been significantly contributing to the regional economy through food security, nutrition, employment creation, and the reduction of poverty. The fisheries sector significantly contributes to global food security, nutrition, and livelihoods, ensuring economic prosperity, sustainable food systems, and biodiversity as per the United Nations Sustainable Development Goals. In this context, the current research presents fish diversity along with the water quality in the urban lakes of the Bangalore city. The linkages between fish diversity and water quality parameters were assessed through canonical correspondence analysis (CCA). The study reveals that the degradation of aquatic habitats has affected native species' fish diversity and production, which has impacted the livelihood of the fishing community due to impaired ecosystem services. Hence, there is an urgent need to formulate strategies for promoting conservation to sustain fish diversity and productivity and support the livelihood of people.

Keywords: Lakes, Fish, Water Pollution, Diversity, Ecosystem Services.

1. Introduction

Aquatic ecosystems offer essential

¹Energy & Wetlands Research Group [CES TE15], Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India.

²Centre for Sustainable Technologies (astra), Indian Institute of Science, Bangalore, India.

³Centre for infrastructure, Sustainable Transportation and Urban Planning (CiSTUP), Indian Institute of Science, Bangalore, India.

⁴Indian Institute of Information Technology and Management-Kerala (IIITM-K), Kerala, India

provisioning, regulating, and cultural services to the dependent population and sustain the livelihood of the vulnerable sections of society (Ramachandra *et al.*, 2024; Sincy *et al.*, 2024). Fish production from inland wetlands significantly contributes to food and economic security by providing animal protein, essential nutrients, and income (Ramachandra *et al.*, 2022). Diverse fish species provide easily digestible proteins, vitamins, minerals, and polyunsaturated fatty acids and hence play a significant role in regional socioeconomic growth (Maulu *et al.*, 2021). Fish production contributes 1.24 per cent to the country's gross value added (GVA) and over 7.28 per cent to agricultural GVA, according to the economic survey for 2021–22. The transition from capture to culture based fisheries in inland aquatic ecosystems has enabled India to sustain a blue economy (National Fisheries Development Board, 2023).

The 2030 Agenda for Sustainable Development, adopted by all UN agencies, outlines seventeen Sustainable Development Goals (SDGs), three of which are particularly relevant in the context of aquatic ecosystems (Duarah & Mall, 2020): Goal-1 (no poverty), Goal-2 (zero hunger), and Goal-12 (sustainable consumption and production). Freshwater fishes are the most diversified group of vertebrates in the world, but they are also the most endangered due to unplanned developmental activities like urbanization, dam construction, irrigation, industry, water

pollution, etc. The global database Fish Base 2023 lists 35,332 species spread across 5,198 genera, 623 families, 84 orders, and 10 classes, and there are 1010 species in freshwater aquatic ecosystems in India.

Fish diversity in an aquatic ecosystem provides insights about habitat conditions and aids in monitoring ecosystem health over longer periods of time, and fish are often referred to as bioindicators (Tabrez *et al.*, 2022; Mahamood *et al.*, 2021). Low species biodiversity indicates potential environmental pollution in the aquatic ecosystem (Rasyad *et al.*, 2020). As aquatic habitats are influenced by climatic regimes (air temperatures and precipitation patterns), fish are highly susceptible to climate change (Makki *et al.*, 2023). Fish assemblage in a particular aquatic ecosystem is dependent on habitat conditions reflecting physical and chemical factors, such as water level fluctuation, water velocity, stream order, bottom substrate, turbidity, conductivity, pH, and dissolved oxygen (Menon *et al.*, 2023; Soo *et al.*, 2021; Svobodova *et al.*, 1993). The interplay and fluctuations of temperature, pH, and precipitation over the elevational gradient determine the composition or assemblage of freshwater fish species (Roy *et al.*, 2021). Freshwater ecosystems have become vulnerable due to emerging anthropogenic factors, such as sustained inflow of untreated wastewater from domestic and industrial sectors, unplanned rapid urbanization, industrialization, increasing water extraction,

habitat degradation, overexploitation, invasive species introduction, water diversions, etc., which will have wide ranging deleterious effects on the life cycle, distribution, and composition of freshwater fish (Sincy *et al.*, 2022; Beltrán-López *et al.*, 2023), necessitating inventorying and recording fish diversity and water quality in aquatic ecosystems. The literature review highlights scant information on fish diversity in lakes in Bangalore city, which necessitated monitoring lakes to compile fish related information. The current study focuses on (a) water quality monitoring of select urban lakes, (b) evaluation of fish diversity, (c) a review of the fisheries sector in India (the Blue Revolution), and (d) the effect of water pollution on fish diversity and economic values. The outcome of the research aids in identifying major risks to biodiversity, which would aid in developing policy strategies and plans for prudent management measures to protect aquatic habitats.

2. Materials and Methods

2.1. Study Area

Greater Bangalore, which spans 741 square kilometres (situated 920 meters above mean sea level) is located between latitudes $12^{\circ} 49' 5''$ N and $13^{\circ} 08' 32''$ N and longitudes $77^{\circ} 27' 29''$ E and $77^{\circ} 47' 2''$ E. It serves as the major administrative, cultural, economic, industrial, and knowledge capital of the Karnataka state.

The undulating terrain of Bangalore city has three watersheds, namely the Hebbal-Nagavara, Koramangala-Challaghatta, and Vrishabhavathi watersheds. The temperature in summer ranges from 18°C to 38°C , while during winter, it ranges from 12°C to 25°C . In the current study, 36 lakes in Greater Bangalore (Figure 1) are being monitored for water quality and the diversity of fish (Ichthyofauna).

2.2. Fish Sample Collection

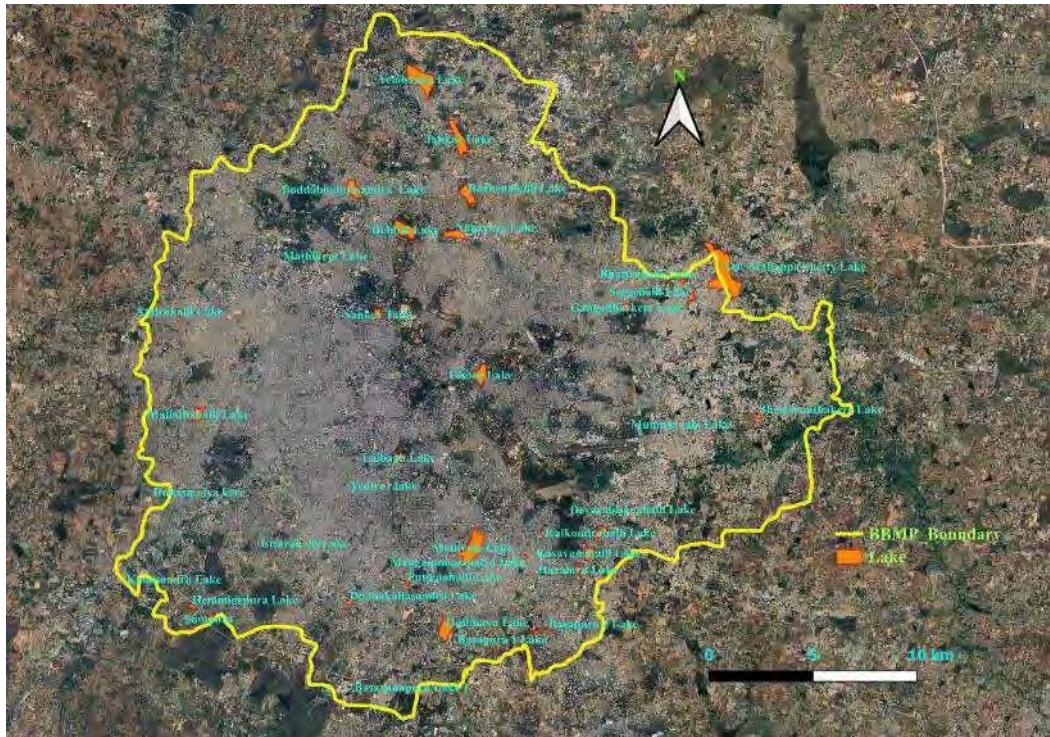
Fish specimens were collected from lakes with the help of local fishermen using gill nets or cast nets. The location of the sampling of species occurrences is recorded using the Garmin Etrex Global Positioning System (GPS). The collected fish specimens were identified at the species level using morphological keys and standard literature. The unidentified specimens were preserved in a 10 per cent formaldehyde solution. Taxonomic analysis was conducted using standard keys, reference books (Jayaram, 1999; Talwar & Jhingran, 1991), and an online data portal, Fish Base. Open-source GIS software QGIS⁴ was used for spatial analyses of various fish orders in 36 lakes in Greater Bangalore.

2.3. Water Sample Collection and Laboratory Analyses

Water samples from 36 lakes were collected

⁴<https://qgis.org>

Figure 1: Bangalore City with the Spatial Distribution of Lakes



Source: Authors' Compilation

for physicochemical analysis between 2018 and 2020. Parameters such as water temperature (WT), dissolved oxygen (DO), pH, and total dissolved solids (TDS) were measured in the field using a portable meter (Extech), while other parameters such as total hardness (TH), total alkalinity (TA), chemical oxygen demand (COD), biochemical oxygen demand (BOD), turbidity, orthophosphate

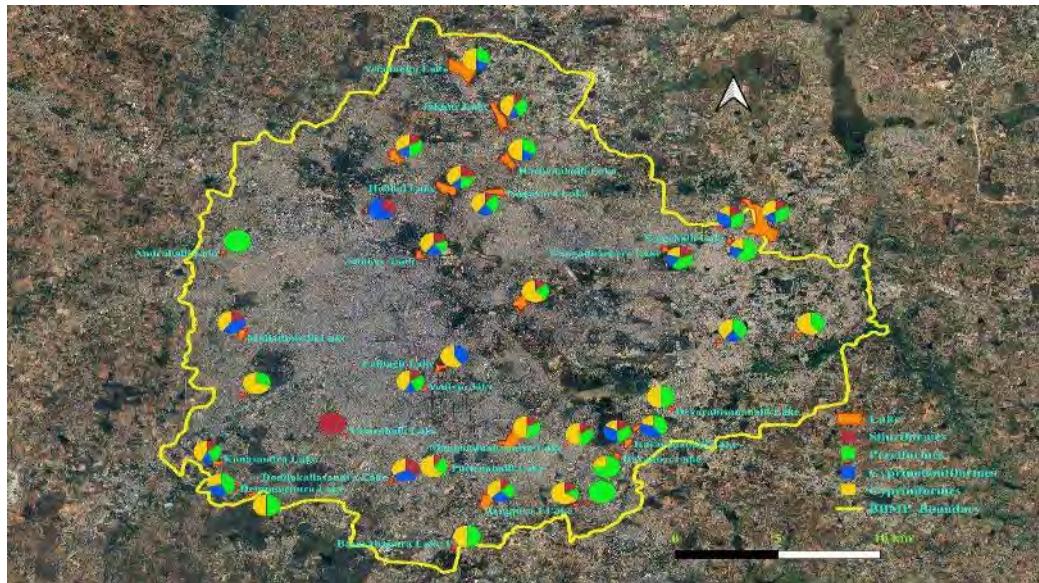
(OP), and nitrate (Nit) were estimated in the EWRG, IISc aquatic laboratory through the standard protocol of APHA (2012).

2.4. Statistical Analysis

Fish assemblages and environmental characteristic linkages were assessed through multivariate Canonical correspondence analysis (CCA) through PAST3 software⁵.

⁵<https://past.en.lo4d.com/download>

Figure 2: Fish Composition (Order Wise) in Urban Lakes of Bangalore City



Source: Authors' Compilation

CCA has been carried out to understand the linkages between species assemblages with the condition of ecosystems. The technique aids in extracting significant environmental gradients from ecological data sets (Soo *et al.*, 2021; Arumugham *et al.*, 2023; Cheng *et al.*, 2019) and the relationship follows Gaussian distribution. Predominant fish orders (Cypriniformes, Perciformes, Cyprinodontiformes, and Siluriformes) and 11 environmental variables (water temperature, total dissolved solids, pH, total alkalinity, total hardness, turbidity, dissolved oxygen, orthophosphate, nitrate, chemical oxygen demand, and biochemical oxygen

demand) of respective habitats were utilized to perform the canonical correspondence analysis.

3. Results and Discussion

3.1. Ichthyofauna Diversity of Lakes

The current study documented a total of eighteen freshwater fish species from four orders, seven families, and fourteen genera in 36 monitored lakes in Bangalore city. Data analyses revealed that Cypriniformes are the most dominant, followed by Perciformes, Cyprinodontiformes, and Siluriformes in the monitored lakes of Bangalore city (Figure 2). The species composition of the order

Cypriniformes is *Catla catla*, *Labeo rohita*, *Ctenopharyngodon idella*, *Cyprinus carpio*, *Cirrhinus mrigala*, *Labeo fimbriatus*, *Puntius ticto*, and *Hypophthalmichthys molitrix*. Cyprinodontiformes include *Gambusia affinis* and *Poecilia reticulata*. Perciformes consist of *Oreochromis mossambicus*, *Oreochromis niloticus*, *Channa punctata*, *Channa striata*, and *Parambassis ranga*, and Siluriformes consist of *Clarias gariepinus*, *Clarias batrachus*, and *Heteropneustes fossilis*.

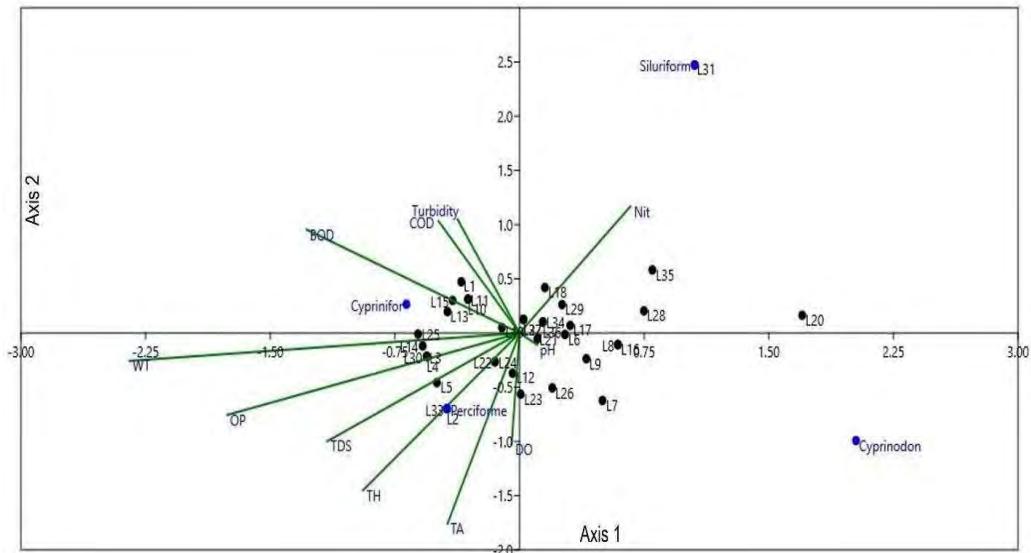
Canonical correspondence analysis (CCA), considering fish assemblages and eleven environmental parameters, highlights that fish distributions and assemblages are influenced by environmental conditions, which include the physical and chemical integrity of habitats. Here, two axes were considered based on eigenvalue and percent of variance. Axis 1 had a 65.02 per cent correlation, while Axis 2 had a 25.24 per cent correlation (Figure 3).

Figure 3 shows the significance of a physicochemical variable, its correlations with the axis, and blue dots indicating fish order in the sampled lakes. Axis 1 is positively correlated with Cyprinodontiformes and negatively correlated with Cypriniformes, water temperature, TDS, BOD, and OP. Axis 2 is positively correlated with Siluriformes, turbidity, COD, and nitrate, while it is negatively correlated with Perciformes, total hardness, total alkalinity, and dissolved oxygen. The turbidity of aquatic ecosystems aids fish in three ways: protecting juvenile fish

from predators, promoting food abundance, and facilitating migration. However, high water turbidity negatively impacts fish egg survival, hatching success, feeding efficiency, growth rate, and population size (Phan *et al.*, 2020). CCA analyses reveal that DO (dissolved oxygen), water velocity and pH significantly impacted the fish assemblage structure in the Mechi River (Adhikari *et al.*, 2021). The physicochemical properties of water, such as temperature, transparency, velocity, pH, DO, CO₂ (carbon dioxide), and hardness, have a substantial impact on the quantity and richness of species (Pokharel *et al.*, 2018).

Fish spawning, growth, metabolism, breeding, and development are all influenced by temperature since they are poikilothermic (Corum *et al.*, 2023), and the ideal pH range is 6.5 to 8.5. The primary factors contributing to pollution and biodiversity loss at Betwa sites were excess nitrite, total hardness, and turbidity (Dubey *et al.*, 2013). Nutrient concentration increases can lead to the growth of phytoplankton, which eventually die and are decomposed by microorganisms, causing anoxia and large fish and aquatic life deaths due to the high rates of organic matter decomposition. Low dissolved oxygen (DO) levels in water induce stress, leading to poor appetite, delayed growth, illness susceptibility, and death in fish species (Abd El-Hack *et al.*, 2022). *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, *Poecilia reticulata*, *Oreochromis mossambicus*, *Oreochromis niloticus*, *Clarias*

Figure 3: The Canonical Correspondence Analysis (CCA) Triplot Between Fish Composition and the Physicochemical Parameters of Urban Lakes



Note: Physicochemical parameters: water temperature (WT), dissolved oxygen (DO), pH, total dissolved solids (TDS), total hardness (TH), total alkalinity (TA), chemical oxygen demand (COD), biochemical oxygen demand (BOD), turbidity, orthophosphate (OP), and nitrate (Nit). Fish orders: Siluriformes (Siluriform), Cyprinodontiformes (Cyprinodon), Perciformes (Perciforme), and Cypriniformes (Cyprinifor). Lake names: Basapura 1 Lake: L1; Basapura 2 Lake: L2; Basavanapura Lake 1: L3; Devarabisanahalli Lake: L4; Haraluru Lake: L5; Hulimavu Lake: L6; Kaikondrahalli Lake: L7; Kasavamahalli Lake: L8; Lalbagh Lake: L9; Madivala Lake: L10; Mangammanapalya Lake: L11; Munnekolala Lake: L12; Puttenahalli Lake: L13; Sheelavanthakere Lake: L14; Ulsoor Lake: L15; Bhattrahalli Lake: L16; Gangadharkere Lake: L17; Hebbal Lake: L18; Jakkur Lake: L19; Mathikere Lake: L20; Nagavara Lake: L21; Rachenahalli Lake: L22; Seegehalli Lake: L23; Yelahanka Lake: L24; Dubasipalya Lake: L25; Hemmigepura Lake: L26; Konasandra Lake: L27; Mallathahalli Lake: L28; Sankey Lake: L29; Sompura Lake: L30; Uttarahalli Lake: L31; Yediyur Lake: L32; Andrahalli Lake: L33; Doddabommasandra Lake: L34; Doddakallasandra Lake: L35; Yele Mallappa Shetty Lake: L36.

Source: Authors' Compilation

gariepinus, *Clarias batrachus*, and *Heteropneustes fossilis* are omnivores. Omnivores have a wide range of diets but primarily rely on detritus. Omnivores, located

at the base of the trophic structure, are most tolerant of degradation or ecosystem dysfunction. As degradation intensifies, it leads to the disappearance of insectivores and

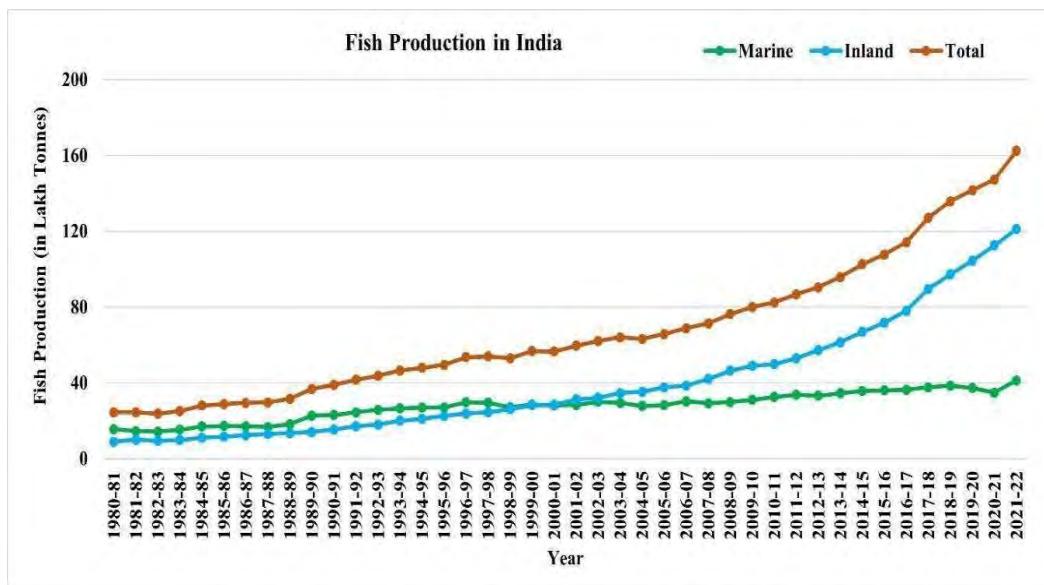
piscivores, followed by benthic insectivores, general insectivores, planktivores, and omnivores (Wichert & Rapport, 1998). The study confirms that environmental parameters, including DO, TDS (total dissolved solids), pH, transparency, nitrate, phosphate, hardness, and alkalinity, influence the fish assemblage pattern (Sarkar *et al.*, 2020).

3.2. Blue Revolution in India

The Indian Blue Revolution is expected to contribute significantly to the Indian economy through the fish and aquaculture

sectors. India is the world's second-largest producer of aquaculture and the third-largest producer of fish, accounting for 8 per cent of fish produced worldwide. The total fish production during 2021–2022 was 16.24 million tons, of which 4.12 million tons are marine fish and 12.12 million tons are aquaculture (the Ministry of Fisheries, Animal Husbandry, and Dairying, 2023). According to an economic survey, the fisheries sector in India provides employment to over 28 million people and generates export earnings of 466 billion rupees in 2019–2020. India's overall fish production was dominated

**Figure 4: The Graph Shows Fish Production in India from 1980 to 2022
(Handbook Fisheries Statistics 2023)**



Source: Authors' Compilation

by marine fish production until 2000 (Department of Fisheries, GoI). A paradigm shift has occurred in Indian fisheries, with inland fisheries taking the lead in contributing to fish production, which increased from 36 per cent in the mid-1980s to 70 per cent in the most recent period (Figure 4).

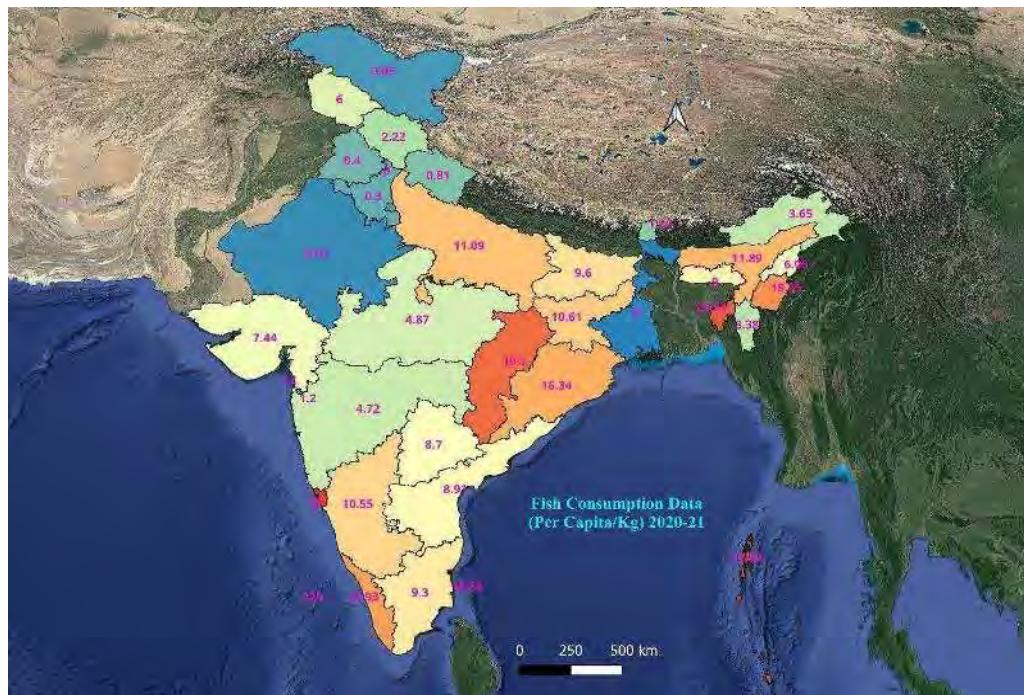
Fish is consumed on average at 6.31 kilograms per person in India. Figure 5 depicts the statistics on fish consumption per capita per kilogram for 2020–21 across many Indian states.

The annual fish consumption accounts

for 10.55 kg per person in Karnataka State.

Poverty in the fishing community is primarily due to large family sizes, a lack of fishing gear, and limited employment opportunities (Kumar *et al.*, 2018). The Pradhan Mantri Matsya Sampada Yojna (PMMSY), approved by the Indian government in May 2020, aims to boost fish production by seven million tonnes, increase aquaculture productivity from 3 tonnes per ha to 5 tons per ha, double exports from Rs. 46,589 crores to Rs. 100,000 crores, create over 55 lakh job opportunities,

Figure 5: Fish Consumption Data (per Capita/Kg) 2020-21 (Handbook Fisheries Statistics, 2023)



and double fishermen and fishing communities' incomes to boost economic growth. The PMMSY, which has invested Rs. 20,050 crores, aims to address productivity gaps, infuse innovation, enhance post harvest infrastructure, modernize the value chain, and establish a framework for effective fisheries management and fishermen's welfare. Fish production has gained impetus with PMMSY evident from a fish production of 162.48 lakh metric tons, compared to 141.64 lakh metric tons in 2019–20 (Ministry of Fisheries, Animal Husbandry, and Dairying, 2023).

3.3. Water Pollution Affects Fish Health and Its Economic Value

Inland water, including ponds, lakes, rivers, streams, canals, and dams, significantly supports the livelihood of people and socio-economic development. Variations in the physical, chemical, and biological integrity of freshwater ecosystems would lead to an unfavourable habitat, impacting the fish life cycle. Freshwater aquatic ecosystems are impacted by different sources of pollutants that come from mining operations, air deposition, land based runoff from urban and agricultural regions, and direct industrial discharges (Arthington *et al.*, 2016).

Conservation planning needs to focus primarily on preserving species diversity and enhancing ecosystem services. The diversity of the ichthyofauna in Bangalore has drastically decreased recently (from 55 species in the 1970s to 18 species in 2020) due to the failing

ecological status of aquatic ecosystems in Bangalore due to unplanned senseless urbanization leading to encroachment of lakes, loss of interconnectivity among lakes, sustained inflow of untreated industrial effluents and domestic wastewater, habitat loss or degradation, introduction of exotic invasive fish species, flooding, and overfishing (Sincy *et al.*, 2022). Fish diversity is threatened by overfishing, climate change effects, siltation, increased agricultural production, natural droughts, urbanization, and water pollution (Pandit *et al.*, 2021).

The fish provide various goods and services, as evident from the annual provisioning service provided by fish from wetlands, which is worth INR 32,175 per hectare (Ramachandra *et al.*, 2021). The rise in pollution and habitat degradation is leading to a decline in the economic worth of freshwater ecosystems, evident from INR 20 per hectare per day in the contaminated Amruthalli Lake in Bangalore and INR 10,435 per hectare per day in the pristine Rachenahalli Lake (Ramachandra *et al.*, 2011). The profuse growth of invasive exotic species led to the decline of native species, resulting in the reduction of the economic worth of fish in Varthur Lake in Bangalore due to the sustained inflow of pollutants and the rapid growth of macrophytes (Ramachandra *et al.*, 2011). In Ulsoor Lake, Devarabisanahalli Lake, and Sankey Lake, a sudden drop in dissolved oxygen levels brought on by sewage inflow led to asphyxiation and, ultimately, fish

death (Ramachandra *et al.*, 2016; Benjamin *et al.*, 1996). The depletion of oxygen caused by the vast proliferation of cyanobacteria was the cause of the significant mortality of fish and other aquatic life (Zhang *et al.*, 2022). Additionally, local fisheries are suffering economically due to the decline of native, diverse fish species and the prevalence of non-native species in lakes (Giannetto & Innal, 2021). Aquatic invasive species outcompete native species, resulting in severe biodiversity loss, health risks, and economic losses, all impacting ecosystem services (Singh, 2021).

Lakes in Bangalore city are consistently undergoing degradation due to the sustained disposal of large volumes of raw or partially treated sewage, municipal solid waste (including construction and demolition debris), untreated industrial effluents, and the encroachment of storm water drains and lake beds, etc. Degradation of ecological conditions in lakes is evident from eutrophication and heavy metal contamination of biota (Ramachandra *et al.*, 2020a). Water pollution significantly impacts wetland goods and services due to declining fish productivity and food quality, impacting the livelihood of dependent populations, which necessitates an immediate restoration of ecological status by decontaminating lakes and regulating pollutants entry to the lake to enhance the ecological quality of lakes and ensure favourable habitat conditions for native aquatic species to maximize aquatic biodiversity and livelihood prospects in fragile

lake ecosystems (Ramachandra *et al.*, 2020b).

4. Conclusion

The fisheries sector is crucial for global food security, nutrition, livelihoods, and promoting economic growth and sustainability. The study documented 18 freshwater fish species from four orders, 07 families, and 14 genera in the monitored 36 urban lakes in Greater Bangalore, with Cypriniformes being the most dominant order, followed by Perciformes, Cyprinodontiformes, and Siluriformes. The sustained inflow of contaminants (untreated sewage and industrial effluents), habitat loss and degradation, the introduction and culture of invasive exotic species, and overexploitation of aquatic resources are the major threats to urban lakes, leading to the decline of the diversity of freshwater fish and productivity. Changes in biotic and abiotic variables have a major impact on the distribution and richness of fish populations in aquatic ecosystems. CCA analyses reveal that declining environmental factors impact fish species and their habitats. Fish production plays a major role in socio economic development. Fish offer food security since they are a great source of animal protein and other nutrients and a significant source of income and employment. Contaminating aquatic ecosystems has contributed to a decrease in ecosystem services. The rapid degradation of freshwater ecosystems, increasing water scarcity in Bangalore, and declining fish biodiversity

necessitate urgent conservation and restoration measures.

Fish are ideal for studying phenotypic differentiation at species and population levels, with ecological diversification, habitat fragmentation, and long term geographical isolation potentially contributing to population differentiation. Lakes in urban areas are undergoing severe stress due to unplanned developmental activities leading to the catchment degradation and sustained inflow of untreated sewage and industrial effluents, which have altered the physical and chemical integrity. In this regard, the current study provides a baseline information for prudent management of aquatic ecosystems to sustain the livelihood of dependent, vulnerable sections of society in Bangalore. However, the limitation of the current study is non-inclusion of all drivers of changes in the physical and chemical integrity with the biological diversity.

Scope for further research includes (a) assessment of heavy metal contamination of water bodies with the disposal of industrial effluents on fish diversity and accumulation of heavy metals in fish tissues, (b) investigations across seasons to understand the seasonal variability of fish diversity, (c) barcoding of fish species to strengthen fish diversity database. The lack of a database on freshwater fish in wetlands and target species (barcode) reference databases has been the major drawback for biodiversity analyses,

necessitating the development of various strategies to overcome these limitations.

Acknowledgements

We thank the EIACP-ENVIS Division, The Ministry of Environment, Forests and Climate Change, the Government of India, and the Indian Institute of Science (IISc) for their sustained support of ecological research. We are grateful to local fishermen for sharing the local use information and for assisting in sampling.

References

Abd El-Hack, M.E., El-Saadony, M.T., Nader, M.M., Salem, H.M., El-Tahan, A.M., Soliman, S.M., & Khafaga, A.F. (2022). Effect of environmental factors on growth performance of Nile tilapia (*Oreochromis niloticus*). *International Journal of Biometeorology*, 66(11), 2183-2194.

Adhikari, A., Limbu, J. H., & Pathak, S. (2021). Fish diversity and water quality parameters of Mechi River, Jhapa, Province No. 1, Nepal. *Borneo Journal of Resource Science and Technology*, 11(1), 24-34.

APHA. (2012). Standard Methods (20 Ed.) for the examination of water and wastewater, APHA, AWWA, WPCE, Washington DC.

Arthington, A.H., Dulvy, N.K., Gladstone, W., & Winfield, I.J. (2016). Fish conservation in freshwater and marine realms: status, threats and management. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 26(5), 838-857.

Arumugham, S., Joseph, S.J.P., Gopinath, P.M., Nooruddin, T., & Subramani, N. (2023). Diversity and ecology of freshwater diatoms as pollution indicators from the freshwater Ponds of Kanyakumari district, Tamilnadu. *Energy Nexus*, 9, 100164.

Beltrán-López, R.G., García-Andrade, A.B., &

Ornelas-García, C.P. (2023). Mexican freshwater fishes in the anthropocene. In *Mexican Fauna in the Anthropocene*, Cham: Springer International Publishing,129-152.

Benjamin, R., Chakrapani, B.K., Devashish, K., Nagarathna, A.V., & Ramachandra, T.V. (1996). Fish mortality in Bangalore lakes, India. *Electronic Green Journal*, 1(6),1-8.

Cheng, D., Zhao, X., Song, J., Sun, H., Wang, S., Bai, H., & Li, Q. (2019). Quantifying the distribution and diversity of fish species along elevational gradients in the Weihe River Basin, Northwest China. *Sustainability*, 11(21),6177.

Corum, O., Uney, K., Terzi, E., Durna Corum, D., Coskun, D., Altan, F., & Elmas, M. (2023). Effects of temperature on the pharmacokinetics, tissue residues, and withdrawal times of doxycycline in rainbow trout (*Oncorhynchus mykiss*) following oral administration. *Veterinary Sciences*, 10(6),401.

Department of Fisheries, GoI. Retrieved from: <https://dof.gov.in/inland-fisheries>

Duarah, J.P., & Mall, M.(2020). Diversified fish farming for sustainable livelihood: A case-based study on small and marginal fish farmers in Cachar district of Assam, India. *Aquaculture*, 529,735569.

Dubey, V.K., Sarkar, U.K., Pandey, A., & Lakra, W.S. (2013). Fish communities and trophic metrics as measures of ecological degradation: a case study in the tributaries of the river Ganga basin, India. *Revista de Biología Tropical*, 61(3),1351-1363.

Economic survey, 2021-22. Government of India, Ministry of Finance, Department of Economic Affairs, Economic Division,North Block,New Delhi.

FishBase 2023.Retrieved from: <http://fishbase.org>

Giannetto, D., & Innal, D. (2021). Status of endemic freshwater fish fauna inhabiting major lakes of Turkey under the threats of climate change and anthropogenic disturbances: A review. *Water*, 13(11),1-17.

Handbook Fisheries Statistics 2023. Retrieved from: <https://dof.gov.in/sites/default/files/2023-08>

Jayaram, K.C. (1999). The freshwater fisheries of the Indian region. New Delhi: Narendra Publishing House.

Kumar, D., Mehta, R., Yadav, R., Kumar, S., & Kumar, M. (2018). Studies on fisheries status and socio-economic conditions of fisher community in Dholi region, Muzaffarpur, Bihar, India. *Journal of Entomology and Zoology Studies*,6(3),76-80.

Mahamood, M., Javed, M., Alhwairini, S.S., Zahir, F., Sah, A.K., & Ahmad, M.I. (2021). *Labeo rohita*, a bioindicator for water quality and associated biomarkers of heavy metal toxicity. *NPJ Clean Water*,4(1),17.

Makki, T., Mostafavi, H., Matkan, A.A., Valavi, R., Hughes, R.M., Shadloo, S., Aghighi, H., Abdoli, A., Teimori, A., Eagderi, S., & Coad, B.W. (2023). Predicting climate heating impacts on riverine fish species diversity in a biodiversity hotspot region. *Scientific Reports*, 13(1),14347.

Maulu, S., Nawanzi, K., Abdel-Tawwab, M., & Khalil, H.S. (2021). Fish nutritional value as an approach to children's nutrition. *Frontiers in Nutrition*, 8,780844.

Menon, S.V., Kumar, A., Middha, S.K., Paital, B., Mathur, S., Johnson, R., Kademan, A., Usha, T., Hemavathi, K.N., Dayal, S. and Ramalingam, N.(2023). Water physicochemical factors and oxidative stress physiology in fish, a review. *Frontiers in Environmental Science*, 11,1240813.

National Fisheries Development Board, 2023. Retrieved from: https://nfdb.gov.in/welcome/about_indian_fisheries#

Pandit, D., Saha, S., Kunda, M.,& Harun-Al-Rashid, A. (2021). Indigenous freshwater ichthyofauna in the Dhanu River and surrounding wetlands of Bangladesh: species diversity, availability, and conservation perspectives. *Conservation*, 1(3), 241-257.

Phan, T.C.T., Manuel, A.V., Tsutsui, N., & Yoshimatsu, T. (2020). Impacts of short-term salinity and turbidity stress on the embryonic stage of red sea bream *Pagrus major*. *Fisheries Science*, 86, 119-125.

Pokharel, K.K., Basnet, K.B., Majupuria, T.C.,& Baniya, C.B. (2018). Correlations between fish assemblage

structure and environmental variables of the Seti Gandaki River Basin, Nepal. *Journal of Freshwater Ecology*, 33(1),31–43.

Ramachandra, T.V., Alakananda, B., Rani, A., & Khan, M.A. (2011). Ecological and socio-economic assessment of Varthur wetland, Bangalore (India). *Journal of Environmental Science & Engineering*, 53(1),101-108.

Ramachandra, T.V., Asulabha, K.S., Sincy, V., & Jaishanker, R. (2024). Wetlands for human well-being (Editorial). *Journal of Environmental Biology*, 42(2).

Ramachandra, T.V., Sincy V., Asulabha K.S., Sudarshan, B., & Rahaman, M.F. (2016). Recurring Fish Mortality Episodes in Bangalore Lakes: Sign of Irresponsible and Fragmented Governance. *ENVIS Technical Report 105, Environmental Information System, Centre for Ecological Sciences (CES), Indian Institute of Science, Bangalore*.

Ramachandra, T.V., Sincy, V., & Asulabha, K.S. (2020b). Efficacy of rejuvenation of lakes in Bengaluru, India. *Green Chemistry & Technology Letters*, 6(1),14-26.

Ramachandra, T.V., Sincy, V., & Asulabha, K.S. (2021). Accounting of ecosystem services of wetlands in Karnataka State, India. *Journal of Resources, Energy and Development*, 18(1-2),1-26.

Ramachandra, T.V., Sincy, V., & Asulabha, K.S. (2022). Natural capital accounting and valuation of lentic aquatic ecosystem services in Karnataka, India. *Strategy Paper – II, Karnataka Science and Technology Academy (KSTA)*.

Ramachandra, T.V., Sudarshan, P., Vinay, S., Asulabha, K.S., & Varghese, S. (2020a). Nutrient and heavy metal composition in select biotic and abiotic components of Varthur wetlands, Bangalore, India. *SN Applied Sciences*, 2,1-14.

Rasyad, M.F.M., Widyanti, A., Pebriani, N., Fadliyah, S., Ainiyah, R.K., Pratama, W.N., Putra, A.J., Wahyunindita, V., Wahyuni, H.I., Dewangga, E.P., & Hayati, A. (2020). Fish diversity as bioindicator of downstream pollution in the Surabaya River and Jagir River. *Ecology, Environment and Conservation*, 26, S69-S76.

Roy, S., Ray, S., & Saikia, S.K. (2021). Indicator environmental variables in regulating the distribution patterns of small freshwater fish *Amblypharyngodon mola* in India and Bangladesh. *Ecological Indicators*, 120, 106906.

Sarkar, U.K., Bakshi, S., Lianthuamluai, L., Mishal, P., Das Ghosh, B., Saha, S., & Karnatak, G. (2020). Understanding enviro-climatological impact on fish biodiversity of the tropical floodplain wetlands for their sustainable management. *Sustainable Water Resources Management*, 6,1-12.

Sincy, V., Asulabha, K.S., Jaishanker, R., & Ramachandra, T.V. (2024). Ecological and economic worth of Bangalore wetlands. *Pollution Research*, 43 (1–2),164-170.

Sincy, V., Jaishanker, R., Asulabha, K.S., & Ramachandra, T.V. (2022). Ichthyofauna diversity in relation to water quality of lakes of Bangalore, Karnataka. *Biodiversity Challenges: a way forward, Daya Publishing House*, New Delhi,115–146.

Singh, A. K. (2021). State of aquatic invasive species in tropical India: An overview. *Aquatic Ecosystem Health & Management*, 24(2),13-23.

Soo, C.L., Nyanti, L., Idris, N.E., Ling, T.Y., Sim, S.F., Grinang, J., Ganyai, T., Lee, K.S.P. (2021). Fish biodiversity and assemblages along the altitudinal gradients of tropical mountainous forest streams. *Scientific Reports*, 11(1),16922.

Svobodova, Z., Loyd, R., Machova, J., & Vykusova, B. (1993). Water quality and fish health. *EIFAC Technical Paper. No. 54, Rome, FAO*,56–57.

Tabrez, S., Zughaiibi, T.A., & Javed, M. (2022). Water quality index, *Labeo rohita*, and *Eichhornia crassipes*: Suitable bio-indicators of river water pollution. *Saudi Journal of Biological Sciences*, 29(1),75-82.

Talwar, P.K., & Jhingram, A.G. (1991). Inland fishes of India and adjacent countries. New Delhi: Oxford and IBH co. Private limited.

The Ministry of Fisheries, Animal Husbandry, and Dairying 2023. Retrieved from: <https://minfahd.gov.in/>

Wichert, G.A.,& Rapport, D.J.(1998). Fish community structure as a measure of degradation and rehabilitation of riparian systems in an agricultural drainage basin. *Environmental Management*, 22(3),425-443.

Zhang, W., Liu, J., Xiao, Y., Zhang, Y., Yu, Y., Zheng, Z., Liu, Y., & Li, Q., (2022). The impact of cyanobacteria blooms on the aquatic environment and human health. *Toxins*, 14(10),658.