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Insights from a fast-growing secondary city of India

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ORIGINAL ARTICLE

Positioning the role of urban ponds in water sensitive cities: insights from a fast-growing secondary city of India

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Urban areas across the world are increasingly facing water scarcity due to population growth and urban expansion, which places significant stress on land use and leads to the depletion of water bodies. In many developing nations, the pursuit of economic gains often takes precedence over environmental concerns, resulting in unsustainable urban development. For rapidly expanding cities in these countries, sustainable urban water management is crucial to balancing economic development with environmental preservation. The concept of "water-sensitive cities" integrates environmental preservation, technological innovation, and community engagement to address these challenges. Urban ponds, especially in cities like India, play a crucial role in this context, providing environmental benefits as well as many ecosystem services. However, urbanization places significant stress on these ponds, causing pollution, deterioration, and disregard. This research conducted in Kozhikode, a fast-growing coastal city in India, aims to highlight the pivotal role of urban ponds in enhancing the city's water sensitivity. The study encompasses comprehensive field surveys to identify and evaluate urban ponds, considering water quality, ecosystem services, and governance dynamics. The results of water quality show that most of the ponds have the potential to act as a decentralised drinking water supply source. The study also revealed the importance of ecosystem services provided by urban ponds, ranging from local benefits to global contributions. Multiple governance challenges for the conservation of urban ponds are also identified. The study highlights the significance of preserving urban ponds while advocating for enhanced management strategies through proper governance mechanisms. Proposed recommendations on governance include policy refinements, community engagement, pollution mitigation, and integrated planning approaches.

Keywords Water-sensitive cities · Urban ponds · Water quality · Ecosystem service · Governance

Introduction

The United Nations (2019) estimates that 55% of the world's population lives in urban areas as of 2018, and that number is expected to rise about 68% by 2050. Urbanization is progressing at a significantly faster pace in developing countries compared to developed countries (Zhang 2016). This accelerated growth places significant pressure on the environment, particularly affecting water sources, and leads to substantial hydrological and ecological disruptions

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(Ahmed et al. 2019). The immense pressure of population density and the backlog of housing and infrastructure placed on rapidly growing urban regions leads to changes in land use and increased demand for natural resources (Mohan et al. 2020). Due to these reasons, the area of water bodies, agricultural land, and open areas is significantly reduced and overexploited, which accelerated water-related issues, including contaminated water sources, lack of potable water supply, stormwater flooding and water-borne diseases in the fast-growing cities (Brown and Mijic 2019; Sreedevi and Harikumar 2023).

Among these, the most pressing issue that cities face today is the water shortage (Hallegatte et al. 2013). The demand for freshwater resources will only increase in urban areas, requiring a major rethinking of urban water management in fast growing cities.

Urban water services are increasingly being highlighted as having a positive impact on a city's viability, sustainability, resilience, and productivity (Rijke et al. 2013). In developing nations, where infrastructure development and economic gain are given priority over environmental concerns, sustainable urban water management is vital for safeguarding water resources and maximising their benefits for current and future generations, as well as for a resilient city (Bulte and Van Soest 2001; Basu and Shaw 2013). To achieve these goals, particularly in light of factors such as climate change (Hoekstra et al. 2012), increasing urbanisation, degradation of ecosystems and aging infrastructure (Vaux 2015), a fundamental change must be made in the way that services provided by water systems are planned, developed, and delivered (Ashley et al. 2013). A paradigm shift is necessary for cities to achieve sustainable development and growth. 'Water-sensitive cities' is a novel idea that has emerged over the past decade. In the wake of a water crisis in Australian cities, the Cooperative Research Centre for Water-Sensitive Cities (CRCWSC) used this word for one of the first times (Rashetnia et al. 2022). Common elements among these definitions include environmental protections, water security, advanced technologies, informed citizens, and stronger institutions. A water-sensitive city is one that is (i) liveable, (ii) resilient, (iii) sustainable, and (iv) productive, according to CRCWSC. The design strategy integrates hydrology, landscape architecture, and sociology to prepare for urban water while integrating the natural environment and sustainable technologies. Communities, authorities, infrastructure, ecosystems, and industry stakeholders work together to build future resilience and empowerment. The WSC vision comprises three fundamental guiding principles for practical application (Rogers et al. 2020). (1) Considering cities as catchments to provide resources for applications at various scales; (2) Cities providing ecosystem services for the seamless integration of urban water management within the urban environment; (3) Water-sensitive communities, where citizens are connected to their water environments and actively involved in water-sensitive behaviours, and collaboratively engage in planning to achieve water-sensitive objectives. Effective management of urban water bodies can play a crucial role in transforming cities into water-sensitive cities. Urban water bodies are essential for the environment, public health, and the liveability of cities (Fletcher et al. 2013).

Among urban waterbodies, ponds have a distinctive and crucial position in the realm of urban ecology. Urban ponds serve several ecological purposes in these settings and act as a buffer against the adverse effects of urbanisation (Malgorzata et al. 2016). They are crucial in preserving groundwater levels and harvesting rainwater, playing a pivotal role in mitigating the effects of climate change and contributing to the global carbon balance (Miracle et al. 2010). They control surface runoff to reduce urban flooding, reduce ambient temperature, and act as a water reserve by taking in more rainwater (Hassall 2014). Ponds contribute to the preservation of freshwater ecology by creating a particular environment that is advantageous for urban biodiversity among concrete landscapes. These water pools are home to a variety of local flora and fauna, both aquatic and terrestrial, making them an important repository for urban biological resources (Fuyuki et al. 2014; Hassall and Anderson 2015). The presence of these urban ponds has been overexploited and threatened despite their paramount value, in part because of growing urbanisation. Without a proper assessment of its benefits, these scattered "blue spaces" in urban areas have repeatedly been eliminated to accommodate the growing demand for human settlements (Kalra 2020). The water that is kept in those ponds has been noticeably contaminated because the existing ones are frequently used as the disposal site for untreated waste and sewage from cities (Konar 2018). The main sources of contaminants in the surface water include municipal waste disposal, applied herbicides and insecticides, industrial effluent, and atmospheric deposition (Ali and Khairy 2016). These ponds are also more prone to contamination than other flowing water bodies since they cannot self-clean (Ghosh et al. 2021). Deterioration of the ponds is faster in fast growing cities, especially in developing countries. In India, the disappearance of 80,128 ponds and tanks during 2006–2007 led to a reduction of irrigation potential by 1.95 million hectares (Yadav and Goyal 2022). For example, Bangalore city in India had 262 lakes in the 1960s, but by 2012, only 10 retained water. Similarly, Ahmedabad city in India saw 137 lakes in 2001, but over 65 were lost to urban development (Sodhi 2020). A study conducted in Delhi city in India highlights that, from 1970 to 2009, approximately 108 lakes were lost, and between 2009 and 2013, about 230 more lakes disappeared, with no chance of revival and in 2010-11 revealed that 21 of 44 lakes had dried up due to urbanisation and depleting water tables (Chaudhuri et al. 2022). Hyderabad city in India has lost 3245 hectares of water bodies since 2000 (Prakash et al. 2014). Several studies carried out in India indicate that ponds are at risk due to pollution, encroachment, and the presence of invasive species, which pose threats to their existence (Goyal et al. 2021; Zimmer et al. 2020). The situation highlights the urgent need for effective conservation measures.

While much research on water-sensitive cities often centres around larger metro cities, this study fills a critical gap by examining fast growing secondary cities like Kozhikode, where traditional water bodies (urban ponds) are being increasingly overlooked in urban planning. Kozhikode's coastal location adds complexity, as it faces not only the typical urban water issues but also the challenges of managing water resources in a coastal (saline-prone) environment.

With this background, a research study was initiated to investigate the status of urban ponds in cities, with a specific focus on Kozhikode, a fast-growing coastal city of India. Its primary goal is to highlight the importance of urban ponds in enhancing the city's water sensitivity and resilience. The research involved a holistic approach with detailed field surveys to identify urban ponds, assess water quality, evaluate ecosystem services in selected ponds, and examine governance structures (since Kerala performs well in the three-tier decentralization approach), policies, and conservation efforts related to these significant water bodies. The study's innovative approach lies in its detailed assessment of urban ponds as decentralised water sources, especially in a region where climate change and increasing water demand further strain the already fragile ecosystem.

Study area and environmental settings

This research focuses on Kozhikode, a coastal city on India's southwest coast, between 11°21'N to 11°9'N latitudes and 75°44'E to 75°51'E longitudes (Fig. 1). Historically known as Calicut, it was a major trading hub from the 12th century, attracting merchants from Arabs, Chinese, Portuguese, Dutch, and Britain (Firoz and Kumar 2017). According to the 2011 Census, Kozhikode has a population of 608,255 across 75 administrative wards, which is about 20% of the district's population. The Kozhikode city covers 118.59 square kilometers, roughly 5% of the district. Kozhikode city and its suburbs lie in the lowlands and midlands of Kerala (Viswanath et al. 2015). The climate shows seasonal variations with temperatures ranging from 17.5 °C to 36.5 °C and

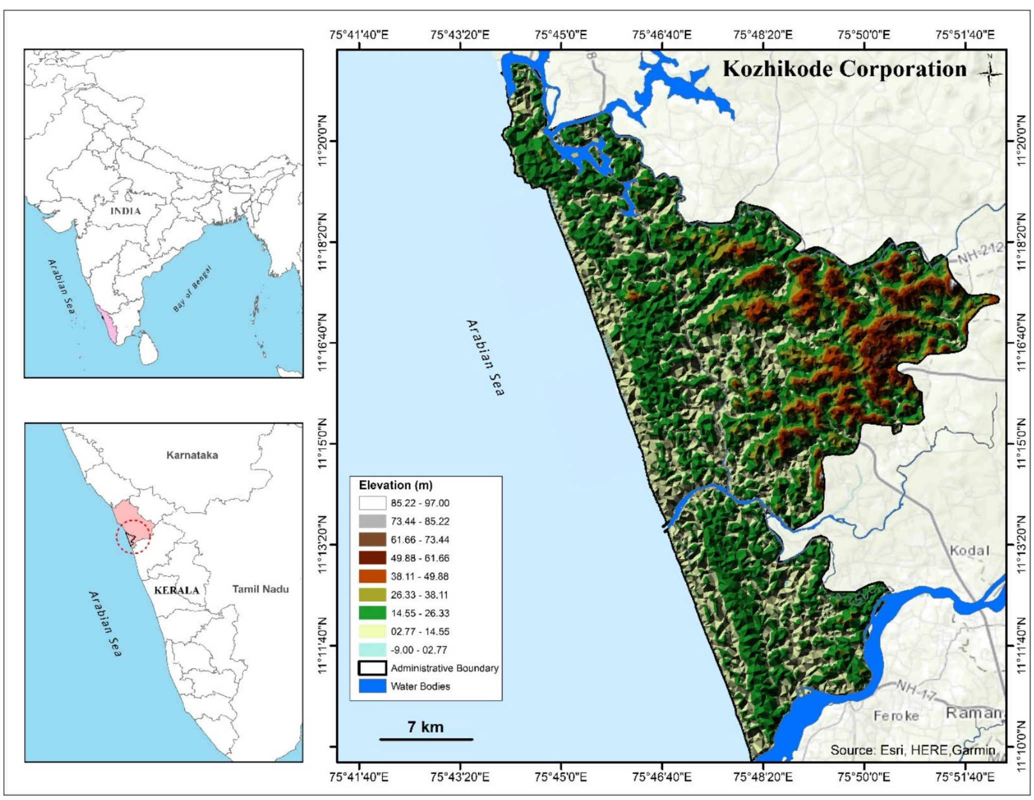

Fig. 1 Map showing location of the Kozhikode city with SRTM DEM showing physiographic setup of the study area

an annual rainfall of 3130 mm over 126 rainy days, mostly from the Southwest and Northeast monsoons (Navaneeth et al. 2024). The 22-kilometer coastline and abundant water resources, including the Korapuzha, Chaliyar, and Kallai rivers, shape Kozhikode's development (Vinod Kumar et al. 2020). The city is rapidly expanding due to intra-state migration and real estate growth (Vadakkuveettil and Grover 2023). A study by the Economist Intelligence Unit (EIU) identified Kozhikode as the fourth most rapidly developing city globally (Navaneeth et al. 2021). Hence, Kozhikode has been selected as the study area to comprehensively examine present status of urban ponds and evaluate its pivotal role within the rapidly expanding coastal urban landscape.

Methodology

The study uses a comprehensive approach to examine the condition of urban ponds within the city of Kozhikode. The study was carried out in several phases. The initial phase involved an extensive field investigation to identify urban ponds in the city, as there is no official record of these ponds in the city. In the second phase, specific ponds of local importance were chosen to evaluate their water quality and ecosystem services. We employed a purposive sampling strategy to ensure a representative selection of ponds based on their geographic distribution and local significance. A total of 24 ponds were chosen, categorized into three distinct groups. The selection process considered factors such as the geographic spread of the ponds across the study area, ensuring that varied ecological conditions were represented. Additionally, local importance was a key criterion, with ponds selected based on their role in community water supply, agricultural irrigation, and biodiversity support. This approach allowed for a more comprehensive understanding of the varying conditions and uses of ponds within the region and allowed us to select ponds that are representative of the broader landscape while ensuring that key sites of local significance were included in the study. Lastly, the study explored the governance status concerning the conservation of these ponds. Further details about the methodology are outlined in the following sections.

Identification and classification of urban ponds

The first phase of the study focused on identification and spatial mapping of urban ponds in Kozhikode, addressing the significant landscape alterations caused by rapid urbanization. Delineating and geographically representing urban ponds is crucial for urban ecology and environmental management, as emphasized by Hassall (2014). We adopted a systematic methodology that integrated remote sensing, GIS, field surveys using handheld GPS devices, and data processing to identify and map these ponds while also documenting their status. The primary objective was to create a comprehensive record and characterization of all existing urban ponds through a detailed transect survey within Kozhikode city on a ward basis, contributing to better environmental planning and management and serving as baseline data for sustaining these urban ponds.

Assessment of water quality

Sample collection and analysis

To evaluate the current water quality conditions of the urban ponds in the city of Kozhikode, water samples were collected from a total of 24 urban ponds in the city. This sampling was carried out during the post-monsoon season, with an equal distribution of eight ponds from each specified category as per Table 3. Sample collection, transport, preservation, and analysis were conducted in strict accordance with the standardised procedures outlined in APHA (2017). A comprehensive range of chemical and bacteriological parameters was analysed that involved 12 physico-chemical parameters, and three bacteriological parameters were estimated according to the standard method (APHA 2017). The results obtained were compared for their suitability with Indian standards (BIS 2012).

Water quality index (WQI)

The water quality index (WQI) serves as a valuable tool to communicate scientific knowledge about water quality to concerned citizens and policymakers and plays a significant role in assessing the characteristics of water (Dendukuri et al. 2017; Marques et al. 2020). Through an integrated approach, WQI simplifies the complex data set of water quality into a single numerical score. Ultimately, this score provides a clear representation of the water quality and offers a comprehensive evaluation of its suitability for various purposes. In this study, we used the weighted arithmetic index method to calculate the WQI (Abbasi and Abbasi 2012). We selected nine water quality parameters to determine the Water Quality Index (WQI); each parameter was assigned a weight (wi) ranging between 1 and 5, depending on how important it is for the overall quality of drinking water. In the next

Table 1 Relative weights of the parameters for the WQI

Parameter	Relative weight	Standard
pH	0.1176	6.5–8.5
Turbidity	0.0588	1 NTU
TDS	0.1176	500 mg/L
Total Hardness	0.1176	200 mg/L
Total Alkalinity	0.0570	200 mg/L
Chloride	0.0570	250 mg/L
Sulphate	0.0588	200 mg/L
Calcium	0.0588	75 mg/L
Magnesium	0.0588	30 mg/L
Iron	0.1176	0.3 mg/L
Nitrate	0.1176	45 mg/L

step, the relative weight (Wi) for each parameter was calculated using Eq. (1)

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \tag{1}$$

Where Wi is the relative weight, wi is the weight assigned for each parameter, and n is the number of parameters used for the study. Table 1 shows the parameters analysed in this study, their standards, and the calculated relative weights. The next step is to calculate the quality rating (qi) according to the following Eq. (2).

$$qi = \frac{Ci}{Si} * 100 \tag{2}$$

Here, Ci is the concentration of parameter in the i^{th} water sample, mgL^{-1} and S_i is the standard for the chemical parameter, mgL^{-1}. In the last stage of our process, we calculated a sub-index (SI) for each of the chosen water quality parameters using Eq. (3). These individual sub-indices were then added, as per Eq. (4), to calculate the overall water quality index (WQI).

$$SIi = Wi * qi \tag{3}$$

$$WQI = \sum SIi \tag{4}$$

Evaluation of Ecosystem services

Urban pond ecosystems are a vital component of the urban environment, offering a wide range of invaluable ecosystem services that are essential for the well-being of urban residents (Zinia and McShane 2021). Although urban ponds are recognized for their importance, their values are often neglected or underestimated. They are least considered in the governance process, leading to the rapid loss and degradation of urban ponds and the ecosystem services they offer (Maitry et al. 2023). In the present study, a detailed investigation was conducted to assess the ecosystem services provided by selected ponds in Kozhikode. We utilized the Rapid Assessment of Wetland Ecosystem Services (RAWES) approach to evaluate these services within the local context and across relevant spatial scales. The RAWES method offers a qualitative assessment, providing a comprehensive overview of the diverse benefits that ecosystem services deliver across a wide geographic area (McInnes and Everard 2017). The study was carried out during the post-monsoon season, and 24 selected ponds from each category are taken according to Table 3 for assessment. We have implemented the assessment of RAWES approach for the ecosystem services and considered 37 ecosystem services categorised into functional groups as per the Millennium Ecosystem Assessment (MEA) 2005. These groups encompass provisioning, regulating, cultural, and supporting services. The Study employed an ethnographic methodology that incorporated a blend of on-site observations and visual cues or indicators. Furthermore, we conducted semi-structured interviews, involving a series of questions, to assess the relative significance of each ecosystem service outlined in the RAWES field assessment sheet. We used a five-point scale (as shown in Table 2) to record the importance of each ecosystem service on standardised field forms and subsequently transferred it to Excel spreadsheets.

Table 2 Five-point scale used to assess the importance of each ecosystem service

Score	Assigned numeric value	Ecosystem service
++	2	Potential significant positive contribution
+	1	Potential positive contribution
0	0	Negligible contribution
-	-1	Potential negative contribution
--	-2	Potential significant negative contribution
?	Remove from analysis	Gaps in evidence

Adapted (McInnes and Everard 2017)

The scores obtained were numerically converted for all 24 selected ponds and assessed ecosystem services separately for each service category (provisioning, regulating, cultural, and supporting). These transformed scores were then used to calculate an Ecosystem Services Index (ESI). The ESI serves as a measure that assesses how much ecosystem services are produced in comparison to their maximum potential production (Maitry et al. 2023). Equation (5) is used for the calculation of ESI.

$$ESI = \frac{\sum (n_{+2.0} + n_{1.0}) + (n_{-2.0} + n_{-1.0})}{\sum n_{total}} \quad (5)$$

Assessment of the governance status of urban ponds

The governance of water systems in urban areas is crucial for ensuring the resilience of cities, particularly in the context of climate change and growing urbanisation (Zimmer et al. 2020). Ponds can play a significant role in the provision and management. Understanding the current governance status of urban ponds and exploring potential governance arrangements for integrating ponds into urban water systems is an important step for a sustainable transition towards water-sensitive cities. This part of the research focused on evaluating the current state of governance and the management approach of urban ponds in the city of Kozhikode. Initially, a detailed examination of the existing literature was conducted, encompassing policy documents. Subsequently, an ethnographic approach was performed to collect data, involving on-site observations in the field and the facilitation of semi structured interviews with stakeholders and experts in the relevant field. Altogether 31 stakeholders engaged in water management within the city were consulted to capture their viewpoints on urban pond management. Before the consultation, all participants were briefed on the study objectives and goals. These stakeholders represent a variety of sectors, including academia, operational departments, local self-government, and non-profit organizations.

Results and discussion

Identification and classification of urban ponds

A total of 268 urban ponds were identified within the city of Kozhikode through geotagging with handheld GPS and spatial analysis in GIS environment. The result of the study revealed that urban ponds cover a total area of 23.07 hectares. This comprehensive study was conducted in each ward of the city, systematically covering the entire city to ensure a thorough assessment of its urban pond inventory. The results of this exhaustive effort are depicted in Fig. 2, which provides a visual representation of the spatial distribution of these urban ponds in the city of Kozhikode. Table 3 shows the classification of urban ponds according to the type of use and ownership. Of the 268 urban ponds in the study area, there are 34 public ponds, 138 private ponds, and 96 recreational ponds. Field observation reveals that a considerable majority of these ponds seem to be in a state of abandonment or are not currently utilised for any specific purpose and are not well maintained, excessive growth of vegetation, including invasive species, is observed. This indicates a potential underuse or neglect of these water bodies in the urban landscape. Many of the ponds are used for occasional bathing and irrigation purposes and a very few of them are used for drinking water purpose (Fig. 3).

Physicochemical characteristics of the urban pond water

The evaluation of a wide array of physicochemical characteristics provided a valuable insight in to the health and sustainability of urban ponds and gave insight on the extent of contamination from diverse sources such as wastewater discharge, runoff, solid waste disposal, and local activities such as bathing and laundry. Figure 4 (a) shows the bar diagram of the pH value obtained from the selected ponds in the study. Public ponds are generally observed to have pH values close to neutral, suggesting balanced water conditions. Private ponds exhibit a wider range of pH values, indicating varying water quality conditions. Recreational ponds also show various pH values, with some ponds exhibiting lower pH values, indicating potential acidity concerns. The variation in pH will be mainly due to the activities such as bathing and laundry in ponds that can introduce detergents and organic matter, which affect the pH of the water. The higher acidic value obtained in the abandoned ponds with higher growth algae and other aquatic plants. Public ponds, private ponds, and recreational ponds exhibit a range of turbidity values ranging from 0.81 NTU to 13.2 NTU (Fig. 4b). Some ponds have relatively clear water, and others show higher levels of suspended particles. In most of the samples, the turbidity exceeded the acceptable limit for drinking water. The higher turbidity is mainly due to the lack of maintenance of urban ponds and the runoff from the surroundings.

The amount of dissolved oxygen (DO) in the water is a crucial indicator of its ability to sustain aquatic life (Shah and Joshi 2017; Sruthi et al. 2023). There is a noticeable variation in DO levels in urban ponds in Kozhikode city. The concentration of DO varies from 0.92 (mg/L) to 8.6 (mg/L) in the urban ponds of the city (Fig. 4(f). Lower DO values are observed for the ponds that are ill maintained and where solid waste dumping is observed. Uncontrolled growth of algae and other invasive species is also observed in certain urban ponds, which may also lead to the decline in dissolved oxygen in the ponds. The levels of DO are observed comparatively lower in private ponds, where the maintenance is found to be minimal and excessive growth of invasive plant species is also observed. The Total Dissolved Solids

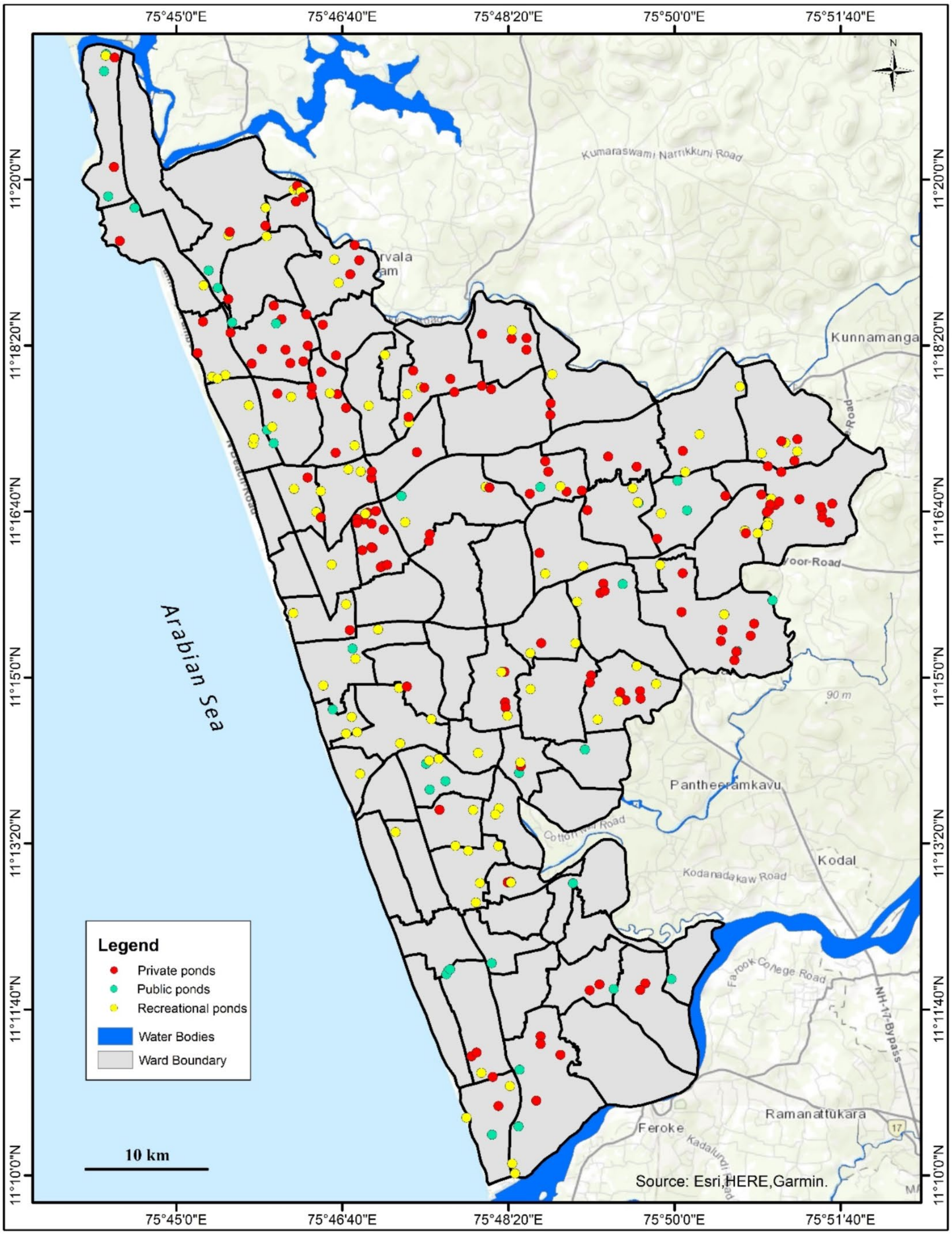

Fig. 2 Location map of the urban ponds identified in Kozhikode city

(TDS) of all water samples collected from urban ponds is found to be within the acceptable limit (Fig. 4 (d). The TDS value ranges from 34.4 mg/L to 370 mg/L. The alkalinity of water signifies its ability to counteract acidity. It arises primarily from the presence of carbonates, bicarbonates, and hydroxides in the water, serving as an indicator of the presence of these components within the water body (Nguyen and Huynh 2022). The alkalinity value of all water samples analysed was found below an acceptable limit and shows the limited influence of carbonates, bicarbonates, and hydroxides in water (Fig. 4(c). Except for one of the public ponds, the values of the total hardness of the all-other water samples are found to be within the acceptable limit. The value ranges from 16 mg/L to 288 mg/L (Fig. 4(e).

Nitrate levels in surface and groundwater are usually present in minimum quantities. However, these levels can

Table 3 Classification of urban ponds in Kozhikode city

Type of ponds	Number of ponds	Type of use	Number of ponds	Area (Acre)	Number of ponds
Public ponds	34	Drinking purpose	6	> 10	1
Private ponds	138	Bathing/Irrigation purpose	179	1–10	11
Recreational Ponds (Temple ponds/ Mosque ponds)	96	Aquaculture purpose	2	0.1-1	61
		Not using/Abandoned	81	< 0.1	195

Adapted (McInnes and Everard 2017)

increase considerably due to factors such as runoff from agriculture activities, leachate from industries, and the release of animal waste(Tamrakar et al. 2022).The nitrate level in the sample varied from 0.05 mg/L to 12.8 mg/L (Figure (g). Higher nitrate levels are detected in abandoned ponds that do not have protective sidewalls or either damaged. These ponds become susceptible to runoff from surrounding areas, which contributes to the increased concentrations within them. Biological Oxygen Demand (BOD) provides insight into the amount of biodegradable organic matter present within an aquatic environment(Saha et al. 2017).The BOD values vary significantly between different types of ponds, with some ponds showing higher levels of organic pollution, while others exhibit better water quality Fig. (4(h). The higher BOD values of certain ponds may be due to pollutants that can originate from various sources, including wastewater discharge, agricultural runoff, urban stormwater runoff, and animal waste. In addition, the accumulation of organic debris, algal blooms.

Bacteriological quality of urban pond water

Microbial contamination is a critical factor that significantly impacts water quality, posing a major health risk on a global scale (Howard et al. 2003). Microbiological analysis is mainly performed to detect the presence of total coliform, *E.coli*, and Faecal coliforms, which serve as a vital indicator for identifying potential faecal contamination in water sources. These indicators play a crucial role in recognizing pollution from human sources, creating a greater risk of pathogenic microorganisms that can lead to various waterborne diseases. The microbiological analysis in this study revealed microbial contamination in all pond water samples, with a significant majority showing a notably high microbial level (Fig. 5). According to the BIS (IS 10500:2012) guidelines, urban pond water is not suitable for consumption without any treatment. The increased bacterial load that was observed can be attributed to surface runoff during the rainy season, which washes away animal excrement, poorly managed sewage, and various domestic waste materials. Furthermore, it is important to highlight that these ponds are in densely populated areas, potentially bringing them in

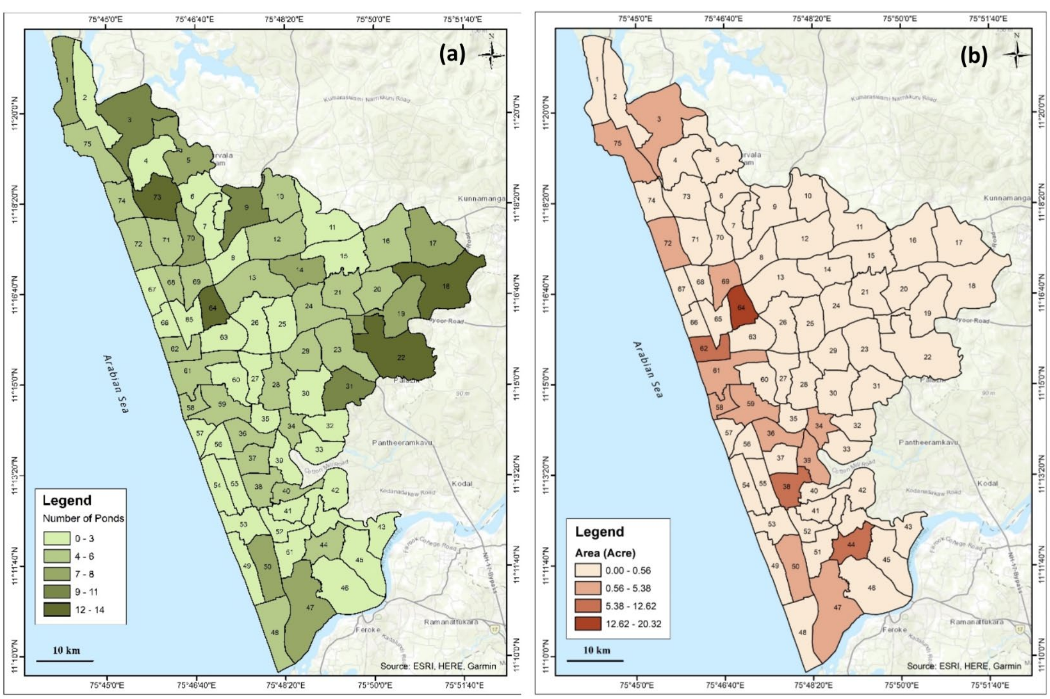

Fig. 3 (a) Ward wise distribution of urban ponds based on number of ponds; (b) Ward wise distribution of ponds based on area covering each pond

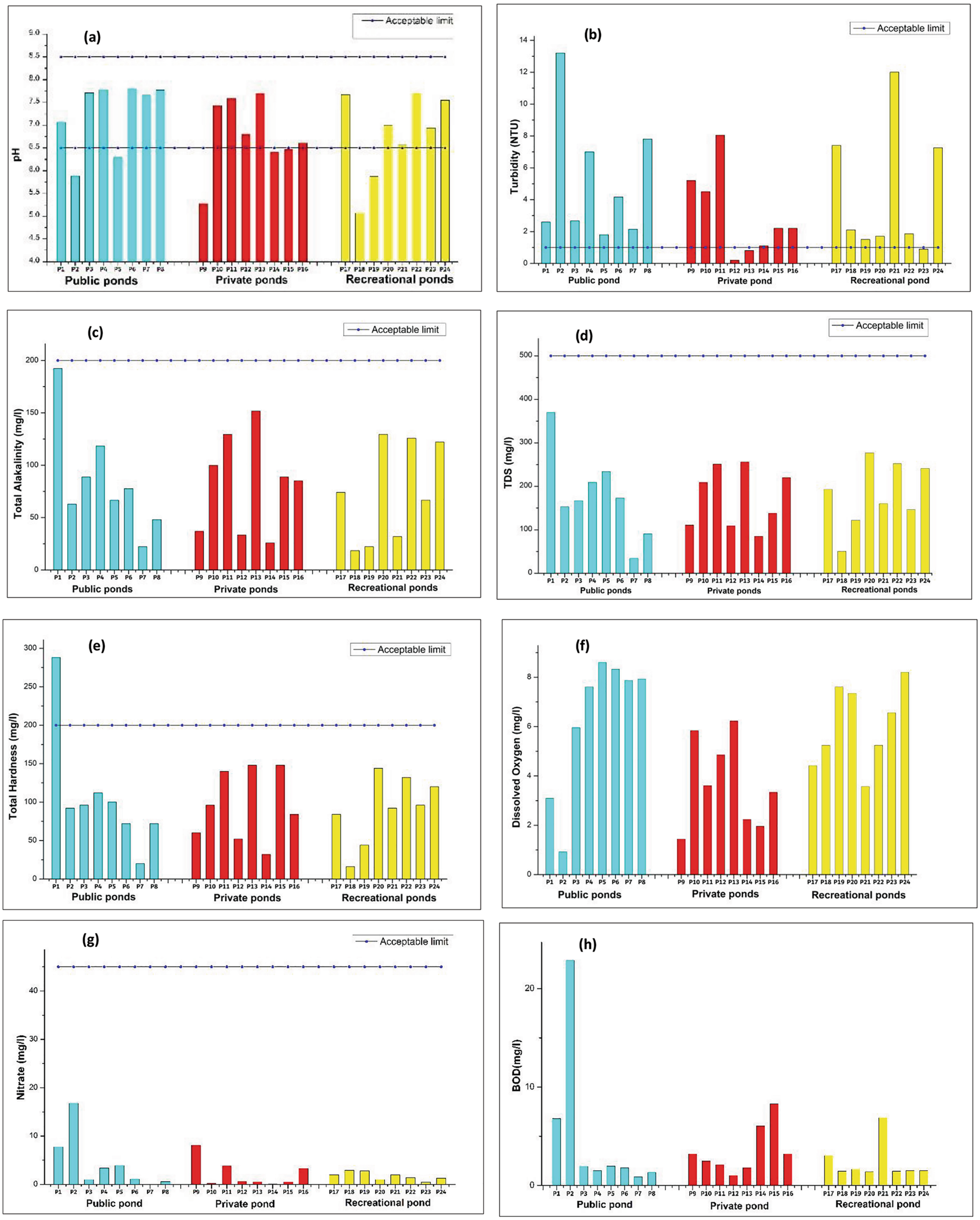

Fig. 4 Water Quality characteristics of (a) pH, (b) Turbidity, (c) Total Alkalinity, (d) Total Dissolved Solids, (e) Total Hardness, (f) Dissolved Oxygen, (g) Nitrate and (h) BOD based on types of ponds in Kozhikode city

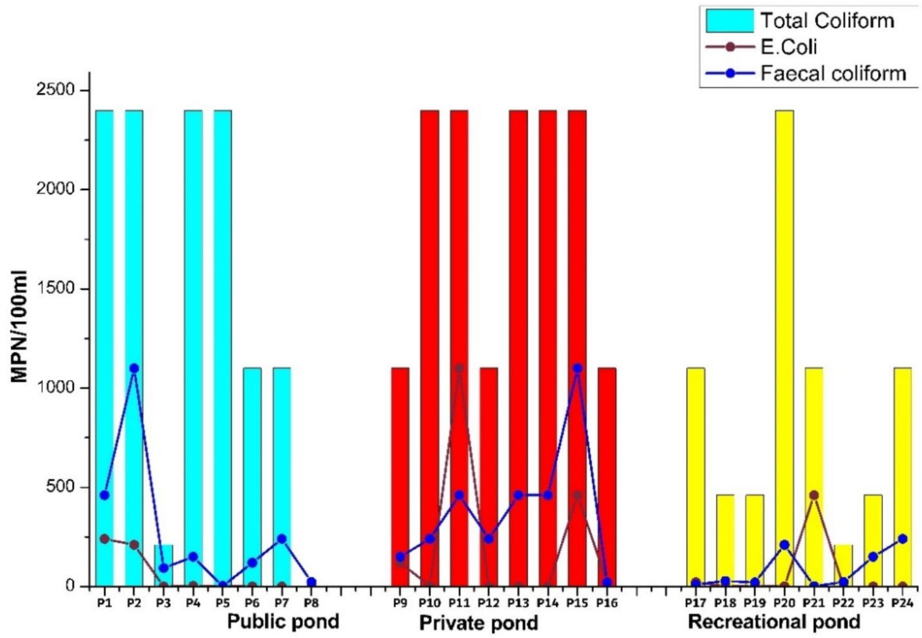

Fig. 5 Distribution of Total Coliform, Faecal Coliform and *E.Coli* of urban ponds

Table 4 Water quality rating as per WQI

SI. No.	WQI range	Water quality status	Number of Ponds
1	< 50	Excellent	10
2	50–100	Good	10
3	100–200	Poor	3
4	200–300	Very poor	1
5	> 300	Water unsuitable for drinking	Nil

close proximity to septic tanks and public sewage infrastructure. Among various types of ponds, private ponds exhibit a higher microbial load compared to public and recreational ponds. This difference may arise from the relatively lower maintenance of private ponds, as is evident from their deteriorated side walls and the dense vegetation in their vicinity. These conditions make it more likely that smaller mammals visit these water bodies for drinking, potentially introducing faecal matter. Furthermore, human activities such as washing and bathing near these private ponds contribute to increased pollutant sources and further increase the risk of microbial contamination.

Water Quality Index

Our analysis reveals that a significant proportion of the examined ponds can be classified as exhibiting excellent to good water quality, with a total of 10 ponds falling within each category (Table 4). However, it is noteworthy that only three ponds have been categorised as exhibiting a "Poor" water quality class, and one of the ponds exhibits a notably high WQI value, thus warranting its placement in the "Very poor" water quality category (Fig. 6). Empirical field observations substantiate that those ponds falling into the "Poor" and "Very poor" categories are consistently characterised by suboptimal maintenance practices. These ponds exhibit a prominent prevalence of excessive algal growth, and lack of adequate protective side walls, and even dumping of solid waste. This phenomenon underscores a direct correlation between deteriorating water quality and the neglect of essential maintenance measures in these aquatic ecosystems.

Field observations reveal a clear distinction in the maintenance and utilisation of various types of ponds. Recreational ponds, particularly those of religious significance, exhibit a relatively higher degree of protection and maintenance when compared to private and public ponds. These religiously significant recreational ponds are often well preserved, contributing to the enhancement of water quality within them. In contrast, most of the private ponds, except for a few, are found to be inadequately maintained and frequently lack any designated purpose or utilisation. Many private ponds have been neglected and remain underutilised, which can significantly impact their overall water quality. In the case of public ponds, the situation is more diverse. Several public ponds are well maintained and serving the essential purposes, including the provision of drinking water. However, there are also instances of public ponds that have been completely neglected, posing concerns for their water quality. In addition, a substantial number of ponds in all categories are

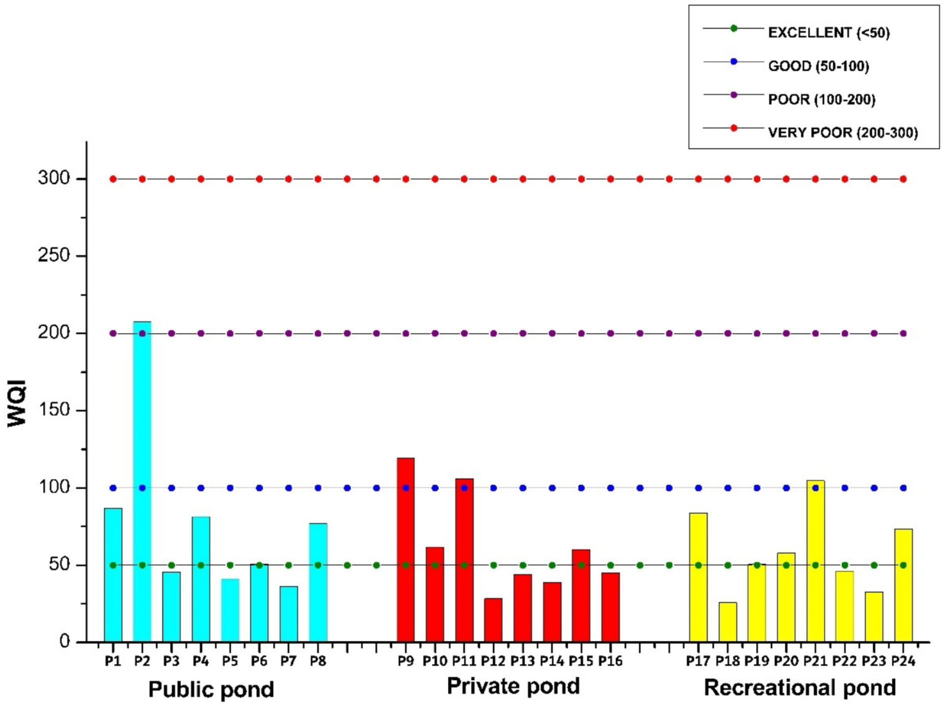

Fig. 6 Distribution of WQI value of urban ponds

primarily used to bathe, which may contribute to the deterioration of the quality of the water due to the associated human activities.

These findings highlight the urgent need for comprehensive management strategies that focus on the maintenance, utilization, and protection of various types of ponds, which hold significant potential as alternative drinking water sources to enhance the city's water security. Currently, Kozhikode city relies primarily on the Peruvannamuzhi reservoir, located 40 km away, for its piped water supply (Navaneeth et al. 2021). This reliance on a distant centralized water supply poses risks in terms of supply disruptions, resource depletion, and rising costs. In contrast, the city's numerous ponds, strategically scattered across different areas, offer a decentralized solution that can reduce the pressure on the reservoir, improve local water access, and enhance overall water security. With proper management and conservation efforts, these ponds could provide a resilient, localized alternative to meet the city's growing water demands, ensuring both water security and environmental sustainability for the future.

Evaluation of ecosystem services

Field observations and subsequent data analysis conducted in the city of Kozhikode have shed light on the substantial ecosystem services offered by urban ponds (Table 5). Our study revealed a notable difference between different types of pond, particularly highlighting that public and recreational ponds consistently scored higher in terms of providing ecosystem services when compared to private ponds (Fig. 7). A discernible pattern emerged from the data, indicating that ecosystem services that contribute significantly were less frequently encountered in contrast to those that produce a positive contibution.

Among the identified ecosystem services, the highest degree of significant positive contribution, denoted as "++" and totalling nine instances, was observed for water regulation within the domain of regulatory services. Following closely behind were cultural and religious values, each receiving an "++" score of eight. Additionally, noise and visual buffering, aesthetic value, recreation and tourism, and cultural services were among the ecosystem services that showed a significant positive contribution in some ponds. In particular, local climate regulation, water purification, and waste treatment were the most frequently occurring ecosystem services, each receiving a positive contribution rating denoted " +" in 20 instances. These were closely followed by the provision of fresh water, the regulation of natural hazards, and primary production, each receiving a positive contribution rating in 18 instances. Other ecosystem services such as air quality regulation, erosion regulation, social relations, and inspiration to art, folklore, and architecture also made valuable positive contributions.

On the otherhand, waste disposal, pest regulation, and disease regulation were the ecosystem services that made

Table 5 Data on the frequency of ecosystem service scores based on counts

Ecosystem services	++	+	0	-	--	L	*R*	G
Provisioning services								
Fresh water	2	18	2	2	0	18	2	0
Food	0	6	18	0	0	6	0	0
Fibre and fuel	0	0	24	0	0	0	0	0
Genetic resources	0	0	24	0	0	0	0	0
Biochemicals, natural medicines, pharmaceuticals	0	0	24	0	0	0	0	0
Ornamental resources	0	0	24	0	0	0	0	0
Clay, mineral, aggregate harvesting	0	0	24	0	0	0	0	0
Waste disposal	0	0	17	4	3	7	0	0
Energy harvesting from natural air and water flows	0	0	0	0	0	0	0	0
Regulating services								
Air quality regulation	1	14	9	0	0	15	0	0
Climate regulation - local	1	20	2	1	0	21	0	0
Climate regulation - global	0	8	16	0	0	0	0	8
Water regulation	9	12	2	1	0	21	0	0
Natural hazard regulation	0	18	6	0	0	18	0	0
Pest regulation	0	0	19	4	1	5	0	0
Disease regulation - human	0	0	20	4	0	4	0	0
Disease regulation - stock	0	0	24	0	0	0	0	0
Erosion regulation	0	8	16	0	0	8	0	0
Water purification and waste treatment	0	20	1	3	0	23	0	0
Pollination	0	4	20	0	0	4	0	0
Salinity regulation, fire regulation	0	8	16	0	0	8	0	0
Noise and visual buffering	4	9	10	1	0	14	0	0
Cultural services								
Cultural heritage	3	3	18	0	0	3	3	0
Recreation and tourism	3	4	17	0	0	2	3	2
Aesthetic value	4	4	15	1	0	6	3	0
Spiritual and religious value	8	2	14	0	0	2	8	0
Inspiration of art, folklore, architecture, etc.	1	10	13	0	0	8	3	0
Social relations	5	8	9	1	1	11	3	0
Educational and research	3	2	19	0	0	3	2	0
Supporting services								
Soil formation	0	0	23	1	0	1	0	0
Primary production	0	18	5	1	0	19	0	0
Nutrient cycling	0	9	13	2	0	11	0	0
Water recycling	0	12	10	2	0	14	2	0
Photosynthesis	0	9	14	1	0	10	0	0
Provision of habitat	3	15	6	1	0	19	0	0

the most negative contributions, each being marked with a '-' in four instances.In total, of the 35 ecosystem services evaluated, 16 of them displayed both positive and negative contributions, 13 exclusively made positive contributions, and six exhibited negligible impacts.

The study identified that ecosystem services are delivered on a different range of scales, ranging from local benefits to global contribution. Apart from global climatic regulation and recreation and tourism, which contribute at a global scale, most ecosystem services were found to primarily provide local benefits. Our approach faced limitations when we lacked enough information to determine how widespread the benefits of certain ecosystem services were. The analysis of benefit scale was not as comprehensive as our evaluation of the significance of individual ecosystem services. Among the 24 urban ponds included in our study, notable findings revealed that Mananchira pond obtained the highest ecosystem service score of '31'. Following closely, the Thali temple pond '29' Fig. 8 (a) provides an image of Mananchira Pond, a well-maintained public pond situated in the heart of the city. Similarly, the Thali Temple Pond, classified as a recreational pond and under the ownership of Thali Temple, also showcased diligent maintenance practices (Fig. 8b). The most substantial negative score of '-16' was recorded for Pashukkulam (Fig. 8d), a public pond that is currently in a state of abandonment and overrun by

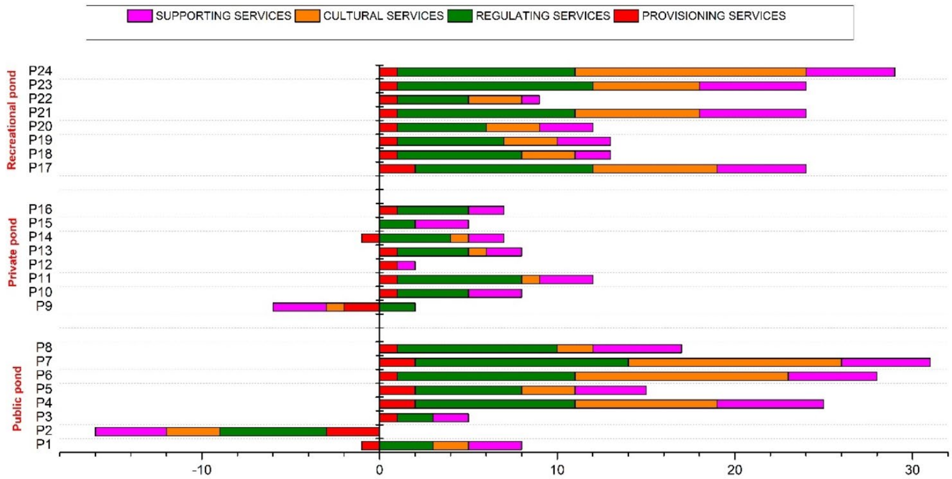

Fig. 7 Graphical representation of the ecosystem service scores of various types of urban ponds in the city of Kozhikode

Fig. 8 Field photograph of urban ponds obtained the highest positive and negative ecosystem service score in the Kozhikode city (a) Mananchira (b) Thali temple pond (c) Varyathukulam (d) Pashukkulam

invasive plant species, along with visible issues of solid waste accumulation. Similarly, Varaythukulam (Fig. 8c), a private pond, exhibited a negative ecosystem service score of '-4'. This pond, too, had fallen into a state of neglect, characterised by substantial algae growth and the proliferation of invasive plant species.

The radar plot depicted in Fig. 9 provides an overview of the evaluation of ecosystem service index for the urban ponds in the city. ESI values are estimated for each type of the ecosystem service as well as for three categories of urban ponds in the study.

1. *Supporting Services*: Supporting services encompass fundamental ecological functions that sustain the overall health of an ecosystem, including processes such as nutrient cycling and habitat provision (Zhao 2013). The higher ESI value for all three categories of ponds shows that urban ponds in this city play a vital role in these foundational ecological processes, contributing to their higher scores in supporting services. This could be due to the positive contribution of urban ponds to factors such as water quality, aquifer recharge, and the presence of aquatic habitats. Among the three category of ponds, public ponds received the highest ESI values, reflecting their extensive role in providing accessible ecological benefits to the broader community, followed by recreational ponds and private ponds.

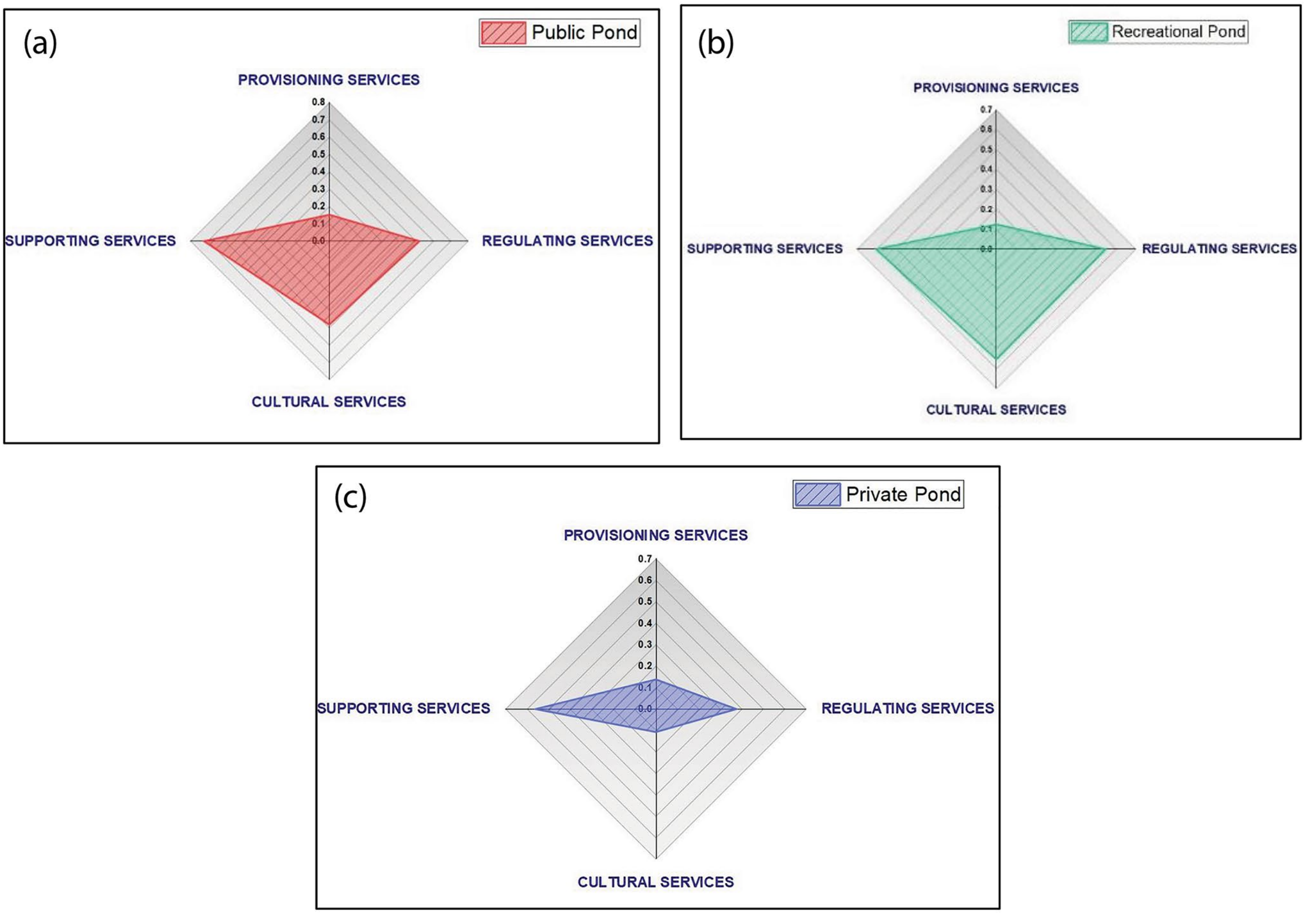

Fig. 9 Radar plot ecosystem service index of (a) public ponds, (b) Recreational ponds, (c) Private ponds

2. *Regulatory Services*: Regulatory services involve functions such as water purification and climate regulation, which are crucial to maintaining the environmental quality of the area (Smith et al. 2013). The design and location of many urban ponds may make them effective in providing essential regulatory services on a local scale, leading to their relatively high scores in this category. Recreational ponds show a comparatively higher ESI value for regulatory services since their regular maintenance and management, Conversely, private ponds tend to have the lowest ESI values, as many suffer from neglect, leading to overgrowth of weeds and vegetation, which diminishes their capacity to deliver these important regulatory functions.
3. *Cultural Services*: Cultural services include aspects such as recreational and aesthetic values, which contribute to the well-being and cultural identity of the community (Oteros-Rozas et al. 2018). The higher ESI value of recreational ponds in cultural services suggests that these ponds in the city show their importance in religious significance. Public ponds also show significant ESI value because some of the ponds like Kuttichira pond and Mananchira pond present in Kozhikode city are central to community life due to their historical significance, aesthetic beauty, or role in local traditions and festivals and are highly valued for their cultural services. Private ponds, though still valuable, scored least due to limited access and use, yet they remain integral to the urban ecosystem.
4. *Provisioning Services*: Provisioning services typically involve the direct supply of resources such as food or water (Mashizi and Sharafatmandrad 2021). The lower ESI value on provisioning services by ponds of all the three categories may indicate that these urban ponds are not used effectively for resource provisioning purposes. Although urban ponds in the city have the potential to become sources of tangible resources like drinking water or fish, they are underutilised and many of the ponds are abandoned and not used for any purpose. This reflects an opportunity to harness the full potential of these ponds for resource provisioning, indicating a need for better management and revitalization efforts to maximize their benefits.The variation in ecosystem service scores among these categories reflects

the diverse roles and conditions of urban ponds within the city. Some ponds excel in fundamental ecological functions and regulatory services, while others may not prioritise resource provisioning or cultural aspects significantly. The condition of the ponds, influenced by factors such as pollution, encroachment, and maintenance practice also play a critical role in determining their ecosystem service scores. Well-maintained ponds with effective conservation practices generally provided higher ecosystem services across all categories. In contrast, neglected or heavily impacted ponds may see diminished ecological, regulatory, and cultural benefits. Thus, the variation in ecosystem service index among urban ponds reflects their unique roles, the pressures they face, and the management practices in place, all of which determine their overall contribution to the urban ecosystem.

Evaluation of the governance of urban ponds urban ponds

Through a comprehensive ethnographic approach encompassing literature review, in-depth interviews with local communities and stakeholders, and extensive field observations, valuable insights into the governance status of urban ponds in our city were obtained. The observational methods employed facilitated a broad understanding of the spatial and temporal dynamics of urban ponds and their associated management practices. Meanwhile, semi-structured interviews were instrumental in capturing diverse individual perspectives on the governance challenges in managing urban ponds and soliciting recommendations for their conservation (Fig. 10). The qualitative and observational data collected underwent a rigorous narrative analysis, which is presented below in three distinct sections.

Legal Landscape and Regulatory Environment

In India, the management and development of water resources fall under the jurisdiction of individual states (Navaneeth et al. 2024). In other words, water management in India is decentralised and controlled at the state level. India has agreed to follow the Ramsar Convention on Wetlands since 1971. Environment Protection Act of 1986, Water (Prevention and Control of Pollution) Act of 1974, and Wetland (Conservation and Management) Rules 2017 are the key legislative frameworks. These rules emphasise the importance of safeguarding waterbodies and strictly prohibit activities such as taking up land, dumping garbage, disposing of untreated waste, expanding industries, changing the purpose of land, and hunting within wetland areas. However, these rules mainly apply to larger natural water bodies with an inundation area greater than 5 hectares; for this reason, smaller water bodies such as ponds are often neglected and lead to their deterioration (Yadav and Goyal 2022).The 2017 National Wetland Inventory, prepared by the Space Applications Centre-ISRO Ahmedabad, only considered wetlands that are 2.25 hectares or larger, underscoring the presence of data gaps in the smaller ponds in the country.

The Central Pollution Control Board (CPCB), State Groundwater Authorities (SGWAs), State Pollution Control Boards (SPCBs) and State Wetland Authority are the principal entities that oversee the regulations at the national and state levels. At the city level, the Municipal Corporation is the major stakeholder, managing and overseeing urban ponds within the city. According to the Kerala Municipality Act of 1994, obtaining approval from the Corporation

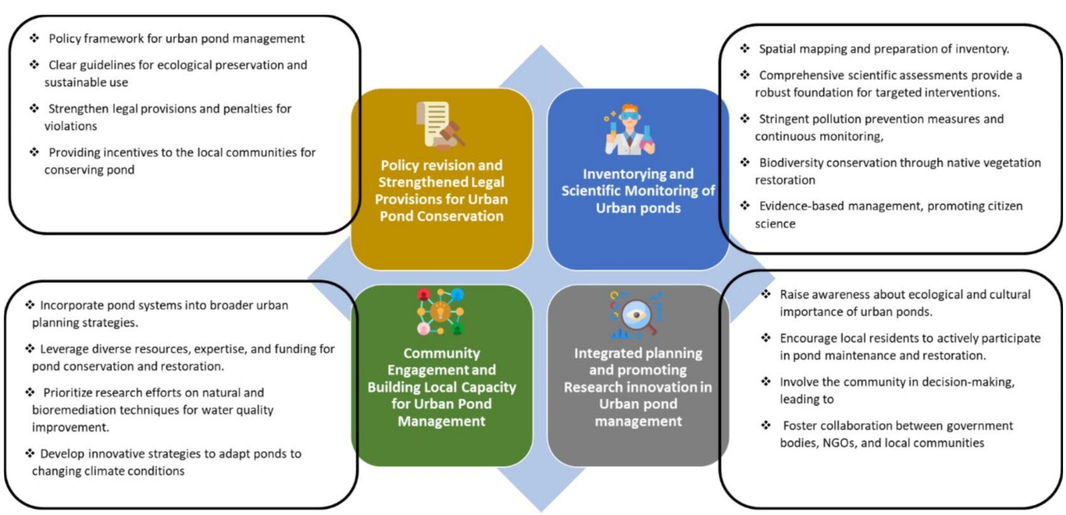

Fig. 10 Pathway for Urban Pond Management

Secretary is mandatory for the construction of a new well or pond, as well as for the demolition of an existing one. As outlined in the Act, the Secretary has the authority to ask for private water source owners to undertake maintenance, cleaning, and protective measures to prevent pollution as deemed necessary. Furthermore, the Act specifies that the Corporation is responsible for the cleanliness and upkeep of public wells, ponds, and reservoirs, ensuring their optimal operation for the public's benefit. Despite the vital nature of this responsibility, there appears to be a discernible deficit in substantial efforts from the Municipal Corporation to fulfil this role effectively. Field observation revealed that many of the public ponds under their purview are observed to suffer from a distinct lack of maintenance, overgrown vegetation, accumulation of debris, and deterioration of the pond's infrastructure and have been left abandoned. Temples and mosques contribute significantly to the conservation of ponds in the city, primarily due to their religious significance. These religious institutions play a crucial role in the conservation and maintenance of ponds, highlighting their cultural and spiritual importance in the city. Numerous private ponds situated on private owned land are notably deteriorating, primarily due to a lack of public awareness, and the transformative shift in land use patterns and agricultural practices has unintentionally led to the neglect and decay of these private ponds. Outlined below are key governance challenges identified for the management of urban ponds, derived from semi-structured interviews conducted with stakeholders.

Governance challenges

1) *Fragmented Responsibility*: Urban pond governance involves multiple authorities and departments, creating fragmented responsibility and coordination challenges. Ownership disputes or unclear ownership complicate maintenance and conservation efforts, particularly when various stakeholders, such as private owners, public authorities, and communities, are involved, each with divergent priorities and interests.
2) *Lack of a Policy and Regulatory Framework*: There is a lack of specific regulations and policies dedicated to urban pond governance, which makes it challenging to enforce rules and guidelines effectively.
3) *Public Participation*: Engagement of the local community in the urban pond management is found limited in the city, may be because residents may not be aware of the importance of these ecosystems and may have competing interests. and lack social platforms for collaborative efforts for pond conservation.
4) *Lack of Interagency Coordination*: Collaboration and coordination between various government agencies responsible for the governance of urban ponds may be lacking, resulting in inefficiencies.
5) *Data and Monitoring Gaps*: Insufficient data collection and monitoring systems hinders the ability to assess the health of urban ponds and make informed decisions about their management.

Recommendations for the Sustainable Management of Urban Ponds in secondary cities

Policy Revision and Strengthened Legal Provisions for Urban Pond Conservation:

The preparation of a cohesive policy framework is crucial for the conservation and management of urban ponds in Cities (Hill et al. 2021). This framework should encompass various aspects of pond management, including ecological preservation, pollution control, community participation, and sustainable development. Within this policy framework, it is essential to establish clear and comprehensive guidelines and standards for urban pond conservation. These guidelines should cover various aspects, such as maintaining water quality, restoring habitat, and sustainable use of pond resources. Having well-defined standards will help to ensure that urban ponds are managed consistently and effectively, regardless of their location. Enforcement and penalties and strengthening legal provisions related to urban pond conservation is a critical step. The existing laws should be amended and reinforced to include stronger penalties for violations. This includes encroachment on pond areas, illegal waste disposal, and any activities that harm the ecological balance of the ponds. Enforcing these laws rigorously will act as a deterrent, discouraging illegal activities and promoting compliance. In parallel with policy uniformity and legal provisions, active engagement with local communities should be encouraged. Payment for Ecosystem Services (PES) needs to be evolved, and that must be integrated into urban planning, in which Kerala can play a lead role since it has a strong three tier Panchayath Raj system. Manoj and Padhy (2015) suggest institutional reform by establishing a Pond Water Development/Regulatory Authority, which should include not only bureaucrats but also water-sensitive citizens. These local communities that live near urban ponds can play a pivotal role in the protection of these water bodies. They can act as root sensors, report violations, and actively participate in conservation efforts. Legal provisions should also include mechanisms to involve communities in decision-making processes related to pond management.

Community Engagement and Building Local Capacity for Urban Pond Management:

Community involvement is an important step for effective urban pond management in Indian cities (Kalra 2020; Berryman et al. 2014). Initiatives should be designed to educate and sensitize local communities about the ecological and cultural importance of urban ponds. This includes raising awareness of the role ponds play in maintaining local biodiversity, acting as natural flood buffers, and contributing to the aesthetic and cultural fabric of the community. Encourage the active participation of residents in the maintenance and restoration of urban ponds can produce transformative changes. Community members can become stewards of these vital ecosystems, taking ownership of their well-being, which will help to build water sensitive communities in the city. Involving them in decision-making processes and management activities not only empowers the community but also leads to more sustainable and locally tailored solutions. Simultaneously, it is essential to build the capacity of local authorities and stakeholders involved in the management of the ponds. This includes providing training and resources for monitoring water quality, habitat restoration, and sustainable landscaping. Research has shown successful pond rejuvenation and management practices through effective community participation in various Indian cities (Sikka et al. 2002; Praharaj 2014; Sen and Nagendra 2020; Sreedharan et al. 2024). Additionally, water quality monitoring programs such as Freshwater Watch (FWW) in Toronto, Canada, have proven successful in engaging citizens in monitoring the pond water quality (Scott and Frost 2017). Citizen science initiatives in the Kozhikode city, such as Water-Folks Kozhikode, which the project team employed in the study area seems to be successful in water data collection and management that involve urban residents can help maintain ponds, and it is the positive outcome from this DST funded Water4 Change project. Collaborative efforts between government bodies, nongovernmental organizations, and local communities can foster a sense of shared responsibility for urban pond conservation. By combining community engagement with capacity building, urban pond management can become a collaborative and holistic endeavour. It not only safeguards these crucial ecosystems but also fosters a sense of environmental stewardship among residents, creating a sustainable and resilient urban landscape.

Pollution Control and Scientific Assessment for Urban Pond Management:

Spatial mapping and effective monitoring of urban ponds are pivotal to sustainable management. Conducting comprehensive scientific assessments provides a solid foundation for decision-making and targeted interventions (Hill et al. 2021). They allow us to understand the specific challenges faced by each pond, such as water quality issues or habitat degradation, and tailor solutions accordingly. Use of remote sensing and in-situ monitoring also helps to track changes over time (Novikmec et al. 2016). Stringent measures must be taken to prevent pollution from entering these water bodies. This involves regulating industrial discharges, ensuring that industries treat wastewater before release, enforcing strict environmental standards, and introducing adequate remedial measures. In Lisbon, Portugal, the introduction of Floating Treatment Wetland (FTW) was found effective in improving the water quality of urban pond (Rodrigues et al. 2022). Similarly, use of Internet of Things (IoT) sensors and Artificial Intelligence (AI) for real-time and smart monitoring and will enhance the prediction of potential threats in water quality such as eutrophication, harmful algal blooms, or pollution spikes, allowing for timely interventions. Promoting biodiversity conservation within urban ponds is also a critical component of sustainable management (Hyseni et al. 2021). This involves the restoration of native vegetation around and within pond areas to recreate a balanced ecosystem and provide crucial habitats. It is essential to promote proper waste management practices in the areas surrounding urban ponds. Communities should be educated and encouraged to dispose of waste responsibly to prevent it from finding its way into these ponds. By combining pollution control measures with rigorous scientific assessments, urban pond management can be evidence-based and proactive. This approach ensures that urban ponds not only survive but thrive, benefiting both the environment and the communities they serve. It is a critical step towards a more sustainable and resilient urban landscape in India.

Integrated Planning and Promoting Research Innovation in Urban Pond Management.

Integrating urban ponds into city planning and development processes is pivotal for their sustainable management in cities (Das and Das 2022). This involves recognising and incorporating their multifaceted roles. First, urban ponds can play a vital role in water management by acting as natural reservoirs, storing and regulating water flow during heavy rainfall and helping mitigate flood risks (Staccione et al. 2021). Recognising this function, city planning should incorporate pond systems into broader urban water management strategies, ensuring that their capacity and health are maintained to fulfil this critical role effectively. Secondly, urban ponds contribute significantly to the aesthetics and quality of urban environments. Their serene waters, lush vegetation, and diverse wildlife can enhance the overall liveability and attractiveness of a city. A study by Sayer (2014) in the aquatic landscape of the United Kingdom highlights the importance of an integrated approach to aquatic conservation, recognising the integrated value of all water bodies. Thus, urban planners should consider ponds as equally important as other water bodies and integral components of urban green spaces and recreational areas, fostering a more sustainable and aesthetically pleasing urban landscape. Moreover, to achieve sustainable pond management, exploring partnerships between government bodies, academia, non-governmental organizations, and the private sector is crucial. Collaboration can help leverage diverse resources, expertise, and funding to support pond conservation and restoration efforts. Non-governmental organisations can bring grassroots involvement and specialised knowledge, while the private sector can contribute technical know-how and financial resources, complementing government initiatives. Such partnerships create a more holistic and robust approach to urban pond management that benefits both the environment and the communities they serve. Lalitha (2022) demonstrates how academia plays a crucial role in this context by building the capacity of local communities to restore and manage ponds effectively, as illustrated in her study on the rejuvenation of Vairakuttai Pond in Katchipattu Village, Tamil Nadu.

Research efforts should prioritise Nature based solutions, focusing on natural and bioremediation techniques to improve water quality without harming ecosystems. Sustainable treatments can mitigate pollution and restore urban ponds to their natural state (Cuenca-Cambronero et al. 2023). This includes the development of sensors and monitoring systems for real-time data on water quality and ecological health. Additionally, the development of mobile apps or online platforms can engage the community in reporting and monitoring pond conditions, creating a more inclusive and informed approach to management. Research should also address the impact of climate change on urban ponds. Innovative strategies for adapting ponds to changing climate conditions, such as increased temperatures and extreme weather events, are essential to maintaining their long-term viability. The recent 2018 and 2019 floods in Kozhikode confirmed that by integrating pond restoration and creation into urban climate adaptation plans, cities can improve their resilience to extreme weather events while enhancing local ecosystems.

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