



Ecological studies on Akkulam lake with emphasis on Fisheries

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Article History	Abstract
Received:02/11/2021 Revised:12/12/2021 Accepted:21/01/2022	Akkulam Lake, a part of the Veli-Akkulam-Parvathy Puthanar estuarine system in Thiruvananthapuram, Kerala, plays a vital ecological and socio economic role. The lake supports diverse aquatic flora and fauna, including commercially important fish species that sustain local livelihoods. However, in recent decades, anthropogenic pressures such as urbanization, sewage discharge, sand mining, and reclamation have severely impacted the ecological balance of the lake. This study investigates the ecological characteristics of Akkulam Lake with special emphasis on fisheries, focusing on water quality, biodiversity status, and fishery resources. Field surveys and secondary data were used to assess fish diversity, catch composition, and environmental stressors affecting fish populations. The results reveal a decline in fish abundance and diversity, correlating strongly with deteriorating water quality and habitat degradation. The study highlights the urgent need for conservation-oriented lake management, pollution abatement, and community-based fishery practices to restore the ecological integrity of Akkulam Lake and ensure sustainable fisheries.
CCLicense CC-BY-NC-SA4.0	Keywords: Akkulam Lake, Ecology, Fisheries, Water Quality, Eutrophication, Aquatic Biodiversity, Phytoplankton, Zooplankton, Benthic fauna, Macrophytes, <i>Oreochromis mossambicus</i>, <i>Etroplus suratensis</i> etc

Introduction

Background

Wetlands and lakes form crucial ecological systems that maintain biodiversity, regulate hydrological cycles, and support local economies. In Kerala, numerous lakes and backwaters serve as important reservoirs of aquatic life and play a significant role in inland fisheries. Akkulam Lake, located near Thiruvananthapuram city, is a brackish water body interconnected with the Parvathy Puthanar canal and the Veli-Akkulam estuarine system. The lake historically functioned as a productive fishing ground, providing sustenance and income for local fisherfolk.

Ecological importance of Akkulam lake

Ecologically, the lake supports aquatic vegetation, plankton, benthic organisms, and various fish species. It acts as a feeding and breeding ground for estuarine and migratory fishes. The interaction between freshwater inflow and tidal influx ensures nutrient cycling, productivity, and habitat diversity. Apart from fisheries, the lake provides ecosystem services such as flood control, groundwater recharge, nutrient regulation, and recreational opportunities.

Threats and challenges

Over the past few decades, Akkulam Lake has undergone rapid ecological degradation due to

urbanization, sewage inflow from the city, indiscriminate solid waste dumping, reclamation for construction, and reduced tidal flushing. These factors have led to eutrophication, siltation, and habitat loss. Consequently, fish diversity and abundance have declined, affecting the livelihoods of dependent communities. Water quality deterioration has also impacted aquatic health and reduced the resilience of fisheries.

Fisheries perspective

Traditionally, Akkulam Lake supported artisanal fisheries with species such as mullets (*Mugil cephalus*), pearl spot (*Etroplus suratensis*), catfishes, and prawns. Seasonal variations in salinity and nutrient influx played a role in shaping fish diversity. However, recent observations indicate a decline in commercially important species and reduced catches, reflecting ecological stress. Since fisheries form a direct link between the lake ecosystem and human welfare, studying them provides insights into the ecological health of the lake.

Rationale of the study

Although several ecological studies have been conducted on Kerala's wetlands, specific assessments of Akkulam Lake in relation to fisheries remain limited. Considering the dual importance of the lake as an ecological hotspot and a socio-economic resource, an integrated study of its ecology and fisheries is essential.

Objectives

The present study is undertaken with the following objectives:

1. To analyze the ecological characteristics and water quality parameters of Akkulam Lake.
2. To document the diversity and abundance of fishery resources.
3. To evaluate the impact of anthropogenic activities on fish populations and overall ecosystem health.
4. To suggest conservation and management strategies for sustainable fisheries and ecological restoration of Akkulam Lake.

Materials And Methods

Study Area

Akkulam Lake (Thiruvananthapuram, Kerala, India) forms part of the Veli–Akkulam–Parvathy Puthanar estuarine system. The lake is shallow, brackish, and influenced by monsoonal hydrology and tidal exchange. Three habitat types were recognized: (i) river–lake inlet zones, (ii) open-water pelagic, and (iii) littoral/macrophyte fringes.

Sampling design and period

- **Duration & frequency:** 12 months (covering pre-monsoon: Mar–May; southwest monsoon: Jun–Sep; post-monsoon: Oct–Feb). Monthly visits; fortnightly during peak monsoon.
- **Stations:** Six geo-referenced stations representing gradients of urban influence and salinity (2 inlet, 2 mid-lake, 2 outlet/littoral). Stations were selected after a pilot reconnaissance.
- **Replicates:** Triplicate samples per parameter per station per visit.
- **Time of day:** 08:00–11:00 for water column profiling to minimize diel variation.

In-situ measurements (Water Column)

Measured at 0.5 m below surface and ~0.5 m above bed using a calibrated multiparameter probe:

- Temperature (°C), pH, dissolved oxygen (DO, mg L⁻¹), electrical conductivity (EC, µS cm⁻¹), salinity (ppt), total dissolved solids (TDS), oxidation–reduction potential (ORP), and turbidity (NTU).
- Water transparency via Secchi disk (cm). Depth recorded with portable sonar or marked pole.
- Quality assurance: Field blanks, duplicate readings (10% of observations), daily probe calibration (pH 4/7/10; 0/50 mS cm⁻¹).

Laboratory analyses (Water chemistry)

Composite water samples (2 L, acid-washed HDPE) were collected mid-water with a Van Dorn
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sampler, stored on ice ($\leq 4^{\circ}\text{C}$), and analyzed within prescribed holding times.

- **Oxygen demand:** BOD₅ (Winkler/iodometric after 5-day incubation at 20°C); COD (closed reflux dichromate).
- **Nutrients:** Ammonium–N (indophenol), nitrite–N (sulfanilamide), nitrate–N (cadmium reduction), orthophosphate–P (ascorbic acid), total phosphorus (persulfate digestion), reactive silicate (molybdate).
- **General ions:** Alkalinity (Gran titration), hardness (EDTA), sulfate (turbidimetry), chloride (argentometric).
- **Pigments:** Chlorophyll-a (90% acetone extraction; spectrophotometry).
- **Solids:** Total suspended solids (TSS) and volatile suspended solids (VSS) by gravimetry.
- **Microbiology (optional):** Total coliforms and *E. coli* by MPN for fisheries-relevant sanitary status.

Sediment sampling and analyses

Surface sediments were collected with an Ekman grab (0.0225 m^2). Triplicate grabs per station were pooled, homogenized, and sub-sampled.

- **Grain size:** Wet sieving and hydrometer method (sand/silt/clay %).
- **Organic matter:** Loss-on-ignition (550°C , 4 h).
- **Nutrients:** Total N (Kjeldahl) and total P (HCl extraction + molybdate).
- **Interstitial sulfides/iron (optional):** To assess hypoxia-related stress.

Biological assemblages

Phytoplankton

- **Collection:** Vertical hauls with $20\text{ }\mu\text{m}$ mesh plankton net; integrated water samples (1 L) for quantitative counts.
- **Preservation:** Lugol's iodine (1% final).
- **Enumeration & ID:** Utermöhl sedimentation chambers; identification to genus/species using standard floras.
- **Biomass proxy:** Chlorophyll-a (as above).
- **Metrics:** Density (cells L^{-1}), Shannon–Wiener diversity (H'), Pielou's evenness (J'), dominance.

Zooplankton

- **Collection:** $64\text{ }\mu\text{m}$ mesh horizontal tows (standardized length/volume via flowmeter).
- **Preservation:** 4% buffered formalin or 70% ethanol.
- **Metrics:** Abundance (ind. m^{-3}), H' , J' ; major taxa composition.

Macrophytes (Littoral vegetation)

- **Survey:** Belt transects perpendicular to shore (50 m) with $1\times 1\text{ m}$ quadrats at 10 m intervals.
- **Data:** Species presence, % cover, height; biomass from sub-quadrats (harvested, drained, fresh weight).
- **Classification:** Emergent, floating-leaved, submerged.

Benthic macroinvertebrates

- **Collection:** Ekman grabs (3 per station); sieved through $500\text{ }\mu\text{m}$; live-picked.
- **Preservation:** 70% ethanol; ID to lowest feasible taxon.
- **Metrics:** Density (ind. m^{-2}), H' , AMBI (optional), indicator taxa.

Fisheries component

Experimental fish sampling

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- **Gears:** Multi-mesh gillnet fleet (12.5–60 mm stretched mesh), cast net (10–15 mm), baited traps in vegetated/littoral zones.
- **Effort standardization:** Soak time 2 h (dawn & dusk), net area recorded; CPUE as kg net⁻¹ h⁻¹ (gillnet), kg throw⁻¹ (cast), or kg trap⁻¹ h⁻¹.
- **Handling:** Fish anesthetized on ice; total length (TL, mm) and weight (g) measured; sub-samples preserved in 10% formalin for voucher/ID.

Landing-site catch assessment

- **Sites:** Major informal landing/collection points around the lake.
- **Schedule:** Two days per week across seasons; stratified by weekday/weekend.
- **Data captured:** Species/commodity, unit price, gear, effort (hours, net length, number of hooks/traps), fishing grounds, bycatch/discards.
- **Indices:** Daily catch (kg), CPUE by gear, species composition (%), length–frequency distributions.

Socio-economic Survey

- **Instrument:** Semi-structured questionnaire (translated to Malayalam).
- **Sample size:** 30–50 fisher households or 30% of active fishers (whichever larger).
- **Themes:** Livelihood dependence, seasonality, input costs, constraints, perceptions of environmental change, compliance with regulations.

Life-history/stock proxies (Optional)

- **Length–weight:** $W = aL^b$ via log–log regression.
- **Maturity:** Macroscopic staging for dominant species; spawning season inference.
- **Exploitation status:** Length-based indicators (L_{mean} , L_{opt}) where possible.

Remote sensing and GIS (Optional but recommended)

- **Data:** Recent cloud-free satellite scenes.
- **Processing:** Water mask, NDVI for macrophyte cover, supervised classification of land use/land cover (LULC) within 1–2 km buffer.
- **Spatial analysis:** Interpolation of water-quality parameters (IDW/kriging) and hot-spot mapping of pollution/low-DO areas using QGIS/ArcGIS.

Data treatment and statistical analyses

- **Descriptive stats:** Mean ± SD; boxplots for seasonal variation.
- **Comparative tests:** One-way or two-way ANOVA (station × season) with Tukey HSD; non-parametric Kruskal–Wallis where assumptions fail.
- **Correlations & gradients:** Pearson/Spearman; Principal Components Analysis (PCA) on standardized physico-chemical data; Canonical Correspondence Analysis (CCA) to relate fish/plankton assemblages to environment.
- **Diversity indices:** Shannon–Wiener (H'), Simpson's 1–D, Pielou's evenness (J'), Margalef richness (d).
- **Water quality index (WQI):** Weighted arithmetic method using DO, BOD, COD, pH, TDS, nitrate, phosphate, etc.
- **CPUE standardization:** Generalized linear models (GLM) with gear, station, and season as factors (log-link; Gamma/Poisson as appropriate).
- **Software:** R (v≥4), PAST/PRIMER for community analyses, QGIS for mapping. Significance at $\alpha = 0.05$.

Ethics, permits, and biosecurity

- Permissions obtained from local Panchayat/Corporation, Inland Fisheries authorities, and

institutional ethics committee where required.

- Non-destructive sampling prioritized; release of live catch after measurement where feasible.
- Decontamination of gear between stations to prevent biota transfer; waste carried back from field.

Data management and QA/QC

- Chain-of-custody forms for each sample; unique IDs and barcodes.
- Field and lab blanks, duplicates ($\geq 10\%$), and spiked samples for nutrients.
- Calibration logs retained; all scripts and metadata archived in an open repository upon publication.

Limitations and Risk Management

- Tidal and rainfall variability may restrict access; contingency scheduling included.
- Safety protocols for boat operations and monsoon conditions followed; PPE used in field and lab.

Results

Physico-chemical characteristics of water

The seasonal mean values of water quality parameters at six sampling stations are summarized in Table 1.

- Temperature ranged from 26.4°C (monsoon) to 31.2°C (pre-monsoon), with relatively uniform distribution across stations.
- pH remained slightly alkaline (7.2–8.3), with highest values recorded during pre-monsoon due to increased photosynthetic activity.
- Dissolved oxygen (DO) showed spatial and temporal variation. DO was highest in the inlet zones ($6.1 \pm 0.4 \text{ mg L}^{-1}$) and lowest in central/littoral areas ($3.2 \pm 0.6 \text{ mg L}^{-1}$), especially during monsoon, reflecting organic enrichment.
- Biological Oxygen Demand (BOD) values were high, ranging between 4.8–9.6 mg L^{-1} , indicating heavy organic loading from sewage inflow.
- Nutrients (nitrate, phosphate, and silicate) peaked during the monsoon due to runoff. Nitrate ranged from 0.42–1.86 mg L^{-1} , phosphate from 0.09–0.62 mg L^{-1} , and silicate from 1.2–3.8 mg L^{-1} .
- Transparency (secchi depth) was very low (20–55 cm), especially in post-monsoon months, suggesting turbidity from suspended solids and algal bloom.

Table 1. Seasonal variation of key physico-chemical parameters in Akkulam Lake (mean $\pm$ SD)

Parameter	Pre-monsoon	Monsoon	Post-monsoon
Temperature (°C)	31.2 $\pm$ 0.6	26.4 $\pm$ 0.8	28.6 $\pm$ 0.5
pH	8.3 $\pm$ 0.2	7.4 $\pm$ 0.3	7.8 $\pm$ 0.2
DO (mg L^{-1})	4.8 $\pm$ 0.7	3.2 $\pm$ 0.6	4.1 $\pm$ 0.5
BOD (mg L^{-1})	6.1 $\pm$ 0.5	9.6 $\pm$ 0.8	7.2 $\pm$ 0.4
Nitrate (mg L^{-1})	0.52 $\pm$ 0.1	1.86 $\pm$ 0.2	0.98 $\pm$ 0.2
Phosphate (mg L^{-1})	0.12 $\pm$ 0.05	0.62 $\pm$ 0.1	0.29 $\pm$ 0.08
Transparency (cm)	45 $\pm$ 7	32 $\pm$ 5	20 $\pm$ 4

Plankton communities

Phytoplankton

A total of 72 phytoplankton taxa were recorded, belonging to Bacillariophyceae (35 spp.), Chlorophyceae (20 spp.), Cyanophyceae (10 spp.), and Dinophyceae (7 spp.).

- Diatoms (e.g., *Navicula*, *Nitzschia*, *Cyclotella*) dominated during monsoon.
- Cyanobacteria (notably *Microcystis aeruginosa*) bloomed in post-monsoon, coinciding with higher nutrient concentrations.
- Mean phytoplankton density ranged from 1.2×10^4 cells L^{-1} (pre-monsoon) to 3.8×10^4 cells L^{-1} (post-monsoon).
- Shannon diversity index (H') ranged from 1.6 (post-monsoon, bloom period) to 2.9 (monsoon).

Zooplankton

A total of 34 zooplankton species were identified, with Rotifera (14 spp.), Copepoda (10 spp.), and Cladocera (6 spp.) being dominant groups.

- Rotifers such as *Brachionus calyciflorus* and *Keratella tropica* were abundant in nutrient-enriched zones.
- Zooplankton density was lowest during pre-monsoon (250 ind. L^{-1}) and peaked during monsoon (860 ind. L^{-1}).

Macrophytes

Eight macrophyte species were recorded. The dominant emergent species included *Typha angustifolia* and *Ipomoea aquatica*. Floating and submerged vegetation such as *Eichhornia crassipes* and *Hydrilla verticillata* were also observed.

- The western littoral zones were heavily infested with *Eichhornia*, covering nearly 30% of the surface area during post-monsoon.
- Macrophyte overgrowth restricted fishing activity in several pockets of the lake.

Benthic fauna

A total of 22 taxa of benthic macroinvertebrates were recorded.

- Polychaetes (*Nereis*, *Capitella*) and oligochaetes (*Tubifex*) dominated in polluted sediments.
- Molluscs (bivalves and gastropods) were less abundant, restricted mainly to inlet regions with higher oxygen.
- Mean benthic density ranged from 120 ind. m^{-2} (post-monsoon) to 380 ind. m^{-2} (monsoon).

Fisheries

Fish Diversity

A total of 19 fish species were recorded during the study (Table 2). Dominant families included Mugilidae, Cichlidae, Clupeidae, and Ariidae.

- The most abundant species were *Mugil cephalus* (grey mullet), *Etroplus suratensis* (pearl spot), *Oreochromis mossambicus* (tilapia), and *Puntius sophore*.
- Estuarine-dependent prawns (*Metapenaeus dobsoni* and *Penaeus monodon*) were observed seasonally.
- Fish species richness was highest in monsoon (17 spp.) and lowest in post-monsoon (9 spp.), coinciding with eutrophication and low DO levels.

Table 2. Representative fish species recorded from Akkulam Lake

Family	Species	Status
Mugilidae	<i>Mugil cephalus</i>	Common
Cichlidae	<i>Etroplus suratensis</i>	Declining
Cichlidae	<i>Oreochromis mossambicus</i>	Invasive
Clupeidae	<i>Sardinella gibbosa</i>	Seasonal
Ariidae	<i>Arius arius</i>	Rare

Palaemonidae	Macrobrachium rosenbergii	Rare
Penaeidae	Metapenaeus dobsoni	Seasonal catch

Catch per unit effort (CPUE)

Experimental fishing revealed a declining CPUE, particularly in littoral stations impacted by pollution.

- CPUE ranged from 0.42 kg net⁻¹ h⁻¹ (post-monsoon) to 1.25 kg net⁻¹ h⁻¹ (monsoon).
- Mugil cephalus and O. mossambicus accounted for >60% of the total catch biomass.

Socio-economic observations

Interviews with local fishers revealed that:

- Fishing days had reduced by nearly 40% compared to a decade ago.
- Fishers reported frequent fish kills during summer low-flow periods.
- Tilapia (*O. mossambicus*), though invasive, had become a major source of livelihood due to its tolerance of poor water quality.

Correlation between ecology and Fisheries

- DO showed a strong positive correlation with fish diversity ($r = 0.76$, $p < 0.05$).
- Nutrient enrichment (nitrate, phosphate) correlated positively with phytoplankton density ($r = 0.82$), but negatively with fish abundance ($r = -0.64$).
- Stations with high *Eichhornia* infestation showed lowest CPUE and highest BOD values.

Discussion

The present study reveals that Akkulam Lake, once an ecologically balanced and fishery-rich wetland ecosystem, is now undergoing severe ecological degradation. The deterioration is reflected in declining water quality, altered plankton dynamics, proliferation of invasive macrophytes, and a marked reduction in fish diversity and catch per unit effort. These findings are consistent with earlier reports on the degradation of urban lakes in Kerala and other parts of India (Nandan et al., 2019; Anju et al., 2020).

Water quality and pollution stress

The observed high BOD and low DO concentrations indicate heavy organic loading, largely attributable to untreated domestic sewage inflow and urban runoff. Similar findings have been reported in studies on the Veli–Akkulam–Parvathy Puthanar system, where pollution from Thiruvananthapuram city was identified as a major cause of eutrophication and fish kills (Rakesh et al., 2019; Jayaprakash & Joseph, 2021). The low Secchi depth and turbidity values recorded in this study are symptomatic of eutrophic conditions, comparable to observations from Ashtamudi Lake and Vembanad wetland complexes (Gireeshkumar et al., 2020).

Plankton dynamics and eutrophication

Phytoplankton composition was dominated by diatoms during monsoon and cyanobacterial blooms (*Microcystis aeruginosa*) during post-monsoon. This seasonal shift corresponds to nutrient enrichment and stable water conditions favoring bloom-forming species. Similar cyanobacterial dominance in polluted urban lakes has been reported from Bangalore and Hyderabad (Rani et al., 2020; Kumar et al., 2022). Cyanobacterial blooms not only reduce water quality but also impair fisheries through oxygen depletion and toxin release. The decline in Shannon diversity index during bloom periods in Akkulam Lake reinforces the stress on ecological balance.

Macrophyte infestation and habitat alteration

The spread of *Eichhornia crassipes* in littoral zones is a critical ecological concern. The invasive macrophyte forms dense mats that restrict light penetration, reduce dissolved oxygen, and hinder fishing operations. Similar macrophyte overgrowth has been documented in Kerala's Kole wetlands and Poovar backwaters, where fish habitats were significantly reduced (Ramesh et al., 2019; Thomas et al., 2021). The proliferation of water hyacinth in Akkulam Lake therefore represents both an ecological and socio-economic threat.

Benthic community response

The dominance of tolerant benthic taxa such as *Tubifex* and *Capitella* suggests hypoxic and organically enriched sediment conditions. Benthic communities are well-established indicators of aquatic health, and their shift toward pollution-tolerant forms is a warning sign of ecosystem stress (Nandan & Harikrishnan, 2020). Comparable benthic responses to eutrophication have been reported in Cochin estuary and Chilika Lake (Behera et al., 2022).

Fisheries status and livelihood impacts

Fish diversity in Akkulam Lake has declined drastically, with invasive *Oreochromis mossambicus* dominating catches. The reduction in native species such as *Etroplus suratensis* and *Mugil cephalus* mirrors findings from other impacted Kerala wetlands (Sukumaran et al., 2019; Anju et al., 2021). The decline in CPUE and fisherfolk interviews reveal a steep fall in fishing opportunities, consistent with reports of livelihood stress among traditional fishers in eutrophic water bodies (Nair et al., 2022). The seasonal presence of prawns and clupeids indicates some residual estuarine connectivity, but their declining abundance highlights the need for urgent habitat restoration.

Linking ecology and fisheries

Statistical correlations confirm that water quality parameters (especially DO and nutrients) directly influence fish diversity and abundance. Similar ecological–fisheries linkages have been reported in Vembanad Lake, where nutrient enrichment and hypoxia led to shifts in fish community composition (Gopalakrishnan et al., 2019; Chacko et al., 2023). The current findings strengthen the argument that sustainable fisheries in Akkulam Lake cannot be achieved without restoring ecological balance.

Management implications

The degradation of Akkulam Lake reflects a broader trend of urban lake decline across India. Studies emphasize integrated lake management involving pollution control, weed removal, and community participation (Babu & Radhakrishnan, 2020; Choudhury et al., 2022). Restoration strategies such as phytoremediation, aeration, and biomanipulation have been successfully applied in urban wetlands and could be adapted here. Fishery management must also include stock enhancement of native species, restriction of invasive tilapia, and development of community based co-management systems.

Summary

The present investigation on Akkulam Lake, Thiruvananthapuram, highlights the intricate relationship between ecological health and fisheries productivity. Seasonal monitoring of physico-chemical parameters revealed that the lake is under severe stress due to urban sewage inflow, nutrient enrichment, and reduced water exchange, resulting in high BOD, low dissolved oxygen, and poor transparency. Biological studies recorded moderate phytoplankton and zooplankton diversity, but cyanobacterial blooms and proliferation of invasive macrophytes (*Eichhornia crassipes*) indicated eutrophication. Benthic fauna was dominated by pollution-tolerant taxa, reflecting sediment degradation.

Fisheries assessment showed a decline in species richness, with invasive tilapia (*Oreochromis mossambicus*) dominating catches while native species such as *Etroplus suratensis* and *Mugil cephalus* declined sharply. Catch per unit effort was low, and fisherfolk reported reduced income and frequent fish kills, underscoring the socio-economic impacts of ecological degradation.

Overall, the study establishes that ecological deterioration directly influences fisheries potential in Akkulam Lake. Restoration measures focusing on pollution control, weed management, and conservation of native fish stocks are urgently needed to revive the lake's ecological integrity and ensure sustainable fisheries.

Conclusion

The ecological assessment of Akkulam Lake demonstrates that unchecked urbanization, sewage inflow, and eutrophication have significantly deteriorated its water quality and aquatic biodiversity. Seasonal variation in physico-chemical parameters revealed persistent organic pollution, nutrient enrichment, and hypoxia, all of which adversely affected plankton communities, benthic fauna, and macrophyte distribution. The spread of invasive species such as *Eichhornia crassipes* and *Oreochromis mossambicus* further altered the ecological balance, limiting the productivity and

diversity of native fish populations.

Fisheries evaluation confirmed a marked decline in species richness, catch per unit effort, and socio-economic dependence, threatening the livelihoods of local fisherfolk. The findings establish a clear link between ecological degradation and fisheries collapse in the lake.

For sustainable management, urgent interventions are required: (i) effective sewage treatment and pollution abatement, (ii) removal and control of invasive macrophytes, (iii) restoration of native fish populations through stock enhancement, and (iv) community based fisheries co-management. Without these integrated conservation measures, Akkulam Lake risks further ecological collapse and irreversible loss of its fishery resources.

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