LAKE SPONGE EDGE

A Nature-based Blueprint for Urban Lake Revival

BELLANDUR LAKE AS A CASE EXAMPLE

THEME: DESIGN4LAKES
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URBAN LAKE SYSTEMS IN BENGALURU: CONTEXT AND CRISIS

Bengaluru: The City of Lakes

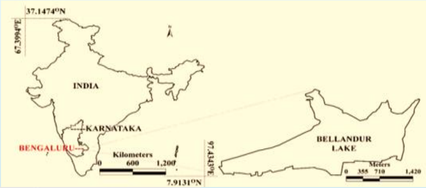
- Historically, Bengaluru functioned as an interconnected tank system supporting water storage, flood control, and groundwater recharge.
- Rapid urbanisation has fragmented and degraded this system.
- Urban lake conservation is now a critical planning challenge.

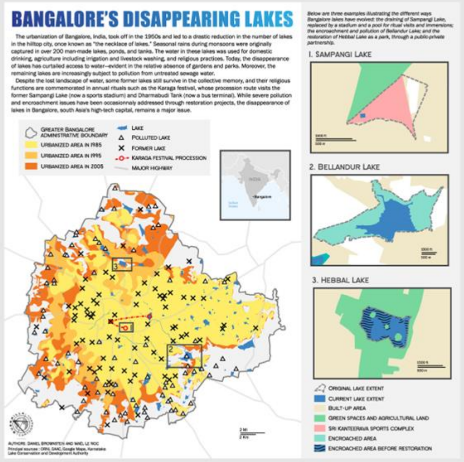
Why Urban Lakes Matter

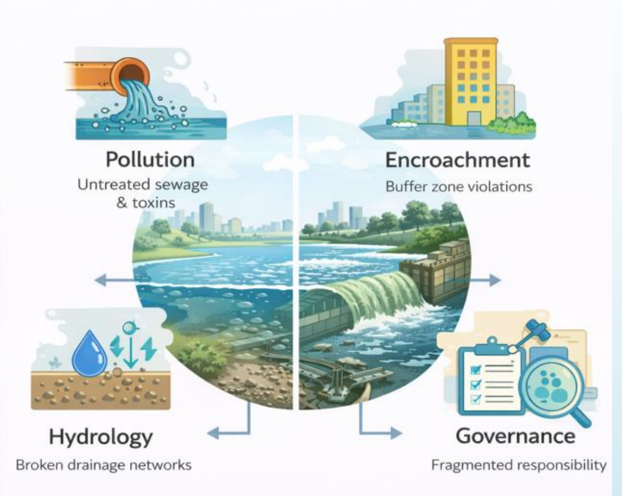
- Flood control & stormwater management
- Groundwater recharge
- Microclimate regulation
- Biodiversity & public value

CASE EXAMPLE: BELLANDUR LAKE

- Largest lake in Bengaluru (~900+ acres)
- Part of the Koramangala–Challaghatta valley system
- Receives untreated sewage from multiple drains
- Downstream link to Varthur Lake → Pennar basin







URBAN LAKE CRISIS DRIVERS

Pollution
- Untreated sewage & industrial effluents
- Chronic frothing and ecological collapse

Encroachment
- Buffer zone violations
- Conversion of lake beds and drains

Hydrology
- Broken rajakaluve networks
- Loss of lake connectivity → flooding

Governance
- Multiple agencies, no single owner
- Reactive monitoring and weak enforcement

SPATIAL & ENVIRONMENTAL MAPPING

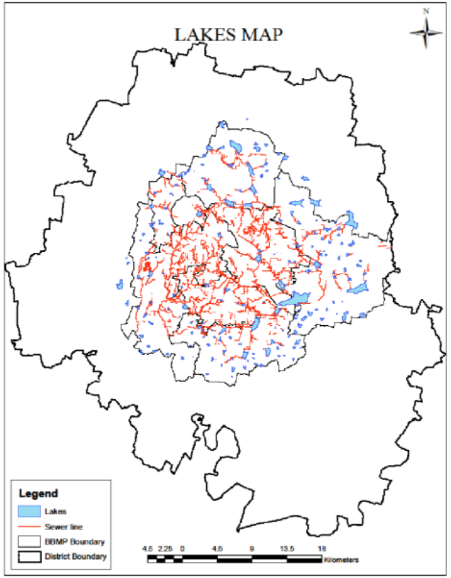


Fig: Lakes Map
Shows the **distribution of lakes** (blue) within the **BBMP area** and the wider **district boundary**

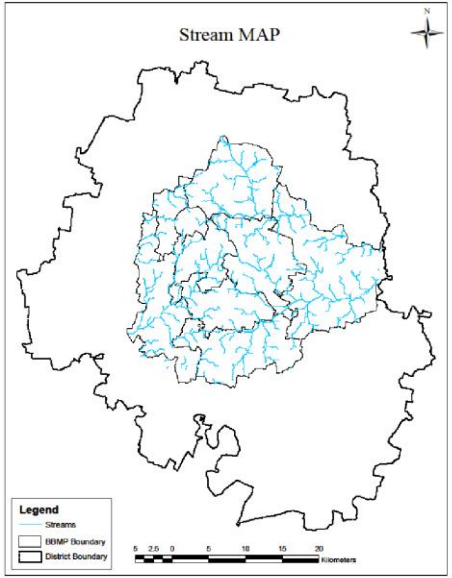
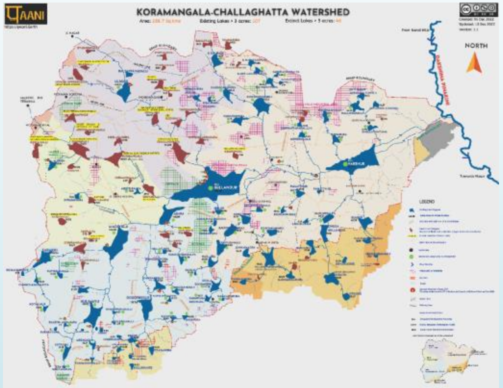


Fig: Stream Map
Depicts the **natural stream and stormwater (rajakaluve) network**

"The maps indicate that Bengaluru's natural lake–stream network has been significantly altered by the expansion of sewer infrastructure, disrupting the original hydrological connectivity."

Fig: Thematic Watershed Map Of The Koramangala–Challaghatta Basin In **Bengaluru**.



Land use type	Area
Built Up	779382
Lake	122078
Vegetation	562109
Barren Land	404567

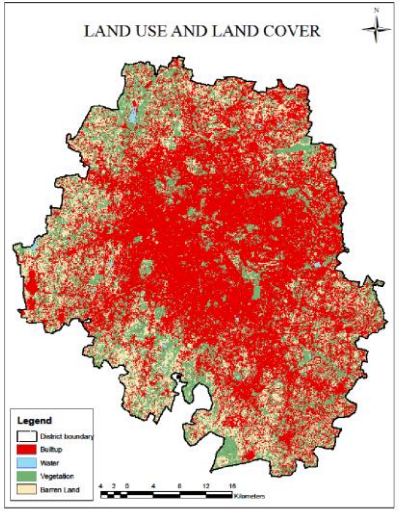


Fig: Land Use and Land Cover (LULC) Map
Clearly shows **intense urbanisation** in the core and rapid outward sprawl

Fig: Land use percentage

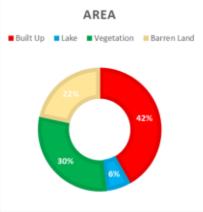


Table: Land Use area

ENVIRONMENTAL INDICATORS

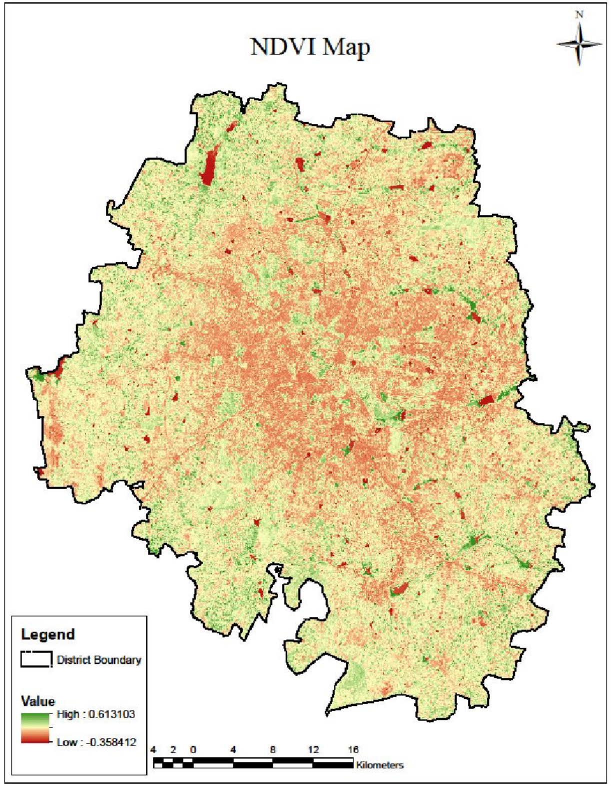


Fig: NDVI Map (Normalized Difference Vegetation Index)
Higher NDVI toward peripheral zones → **remaining vegetation patches**

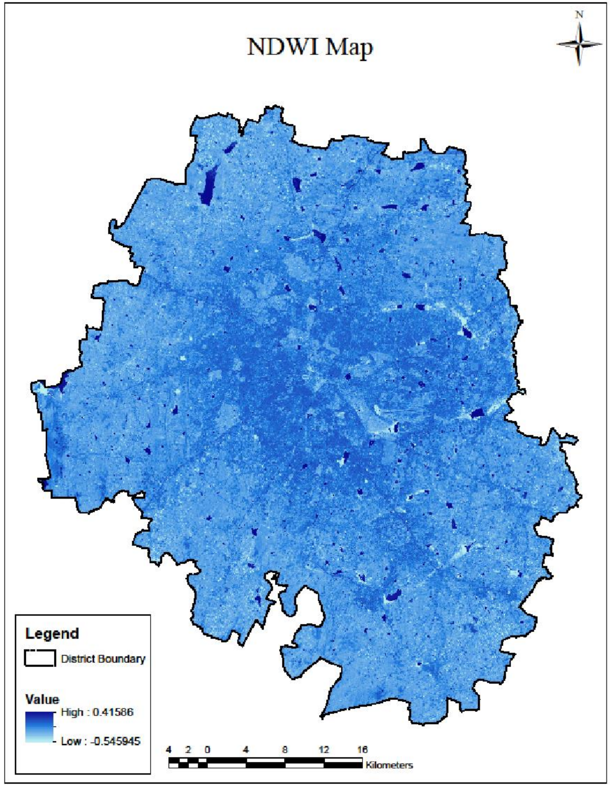


Fig: NDWI Map (Normalized Difference Water Index)
Confirms **fragmentation of lakes** across the city

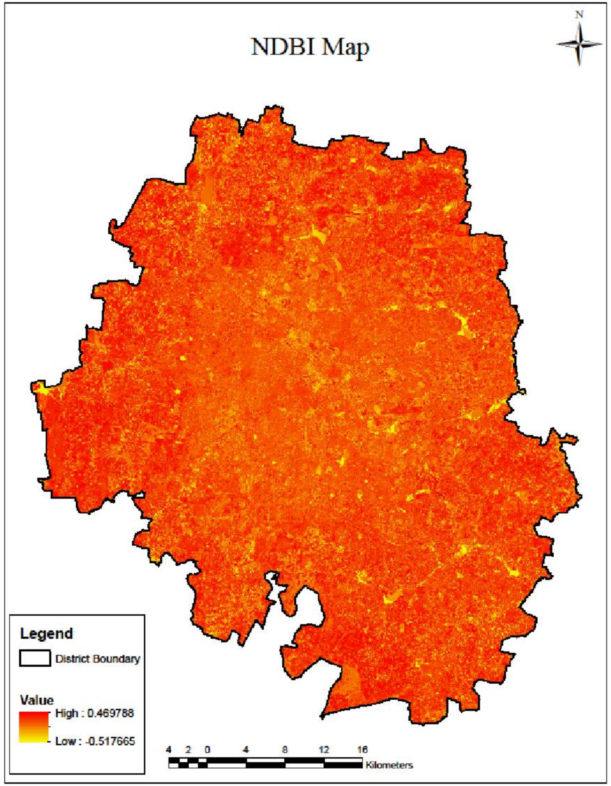


Fig: NDBI Map (Normalized Difference Built-up Index)
Expansion of built-up areas into peripheral zones

SPATIAL & ENVIRONMENTAL MAPPING AND EXISTING SITUATION ANALYSIS

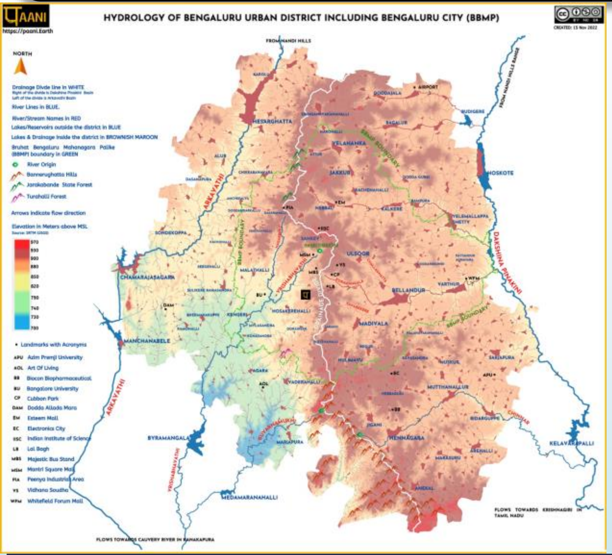


Fig: Hydrological Map Of Bengaluru Urban District (Including BBMP), Showing **How Water Flows, Drains, And Exits The City**.

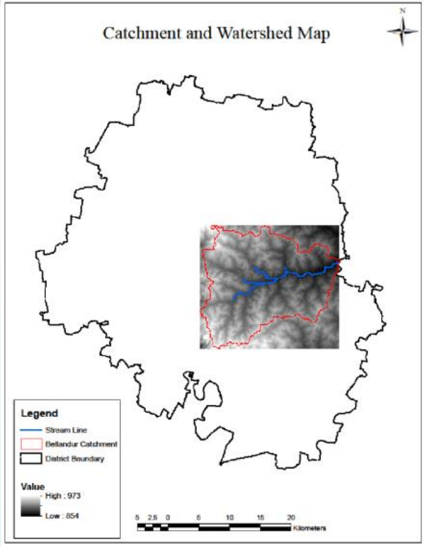


Fig: Bellandur Lake is located in **southeast Bengaluru**

Current Lake Condition

Bellandur wetland is **severely polluted** due to **sustained inflow of untreated and partially treated sewage and industrial effluents for over four decades**.

The lake exhibits hypertrophic conditions, marked by:

- Excessive nutrient enrichment
- Dense growth of aquatic macrophytes such as *Eichhornia crassipes* and *Alternanthera philoxeroides*

Sediment quality is critically degraded:

- Heavy metals including **Zn, Cu, Cr, Pb, Ni, and Cd** exceed permissible and ecological threshold limits in most sampling locations.
- The wetland now functions primarily as a pollutant sink rather than a natural lake ecosystem..

Edge Conditions

- **Shoreline and inlet zones** show the **highest concentration of heavy metals**, indicating direct pollution loading along the lake edges .
- Sediment contamination is highest at **inlets and shoreline zones**, where degraded edges reduce the lake's **self-purification capacity**.

Natural wetland buffers have been compromised due to:

- Encroachment,
- Solid waste dumping,
- Conversion of wetland margins into built-up areas,

PROBLEM IDENTIFICATION

Challenges in Governance and the Environment

- **Large Inflow of Untreated Sewage:** Every day, Bellandur and Varthur lakes receive over 500 million litres of partially treated and untreated sewage, primarily from residential sources. Approximately 40% of Bengaluru’s sewage eventually enters downstream lake systems.

- **Inadequate STP Capacity:** Upstream sewage treatment plants (STPs) are often overloaded or malfunctioning, forcing lakes to act as unintended bioremediation systems and increasing downstream contamination.

- **Inadequate Buffer Enforcement:** Rapid urbanisation has led to encroachment along lake edges. Nearly **90% of remaining water bodies are affected by development pressures**, while **around 79% have already disappeared due to urban expansion.**

- **Siltation and Nutrient Loading:** Continuous inflow of wastewater from households and nearby industries has caused extreme nutrient enrichment in the lake. This accelerates sedimentation and reduces the lake’s average depth, currently estimated between **1.1–2.1 meters**.

- **Multi-Agency Governance Fragmentation:** Multiple agencies manage different aspects of the lake, leading to poor coordination and unclear accountability. Restoration efforts often focus on beautification rather than addressing pollution sources, highlighting the need for a unified lake governance framework.

- **Hydrological Disruption of Lake Networks:** Encroachment and infrastructure development have blocked **rajakaluves (stormwater drains)** connecting Bengaluru’s cascading lake system, disrupting natural water flows and increasing urban flood risk.

BRIDGE BETWEEN ANALYSIS AND PROPOSAL

Fig: A **design-led approach** bridges analytical understanding and implementable urban lake solutions.

Design at the Center
- Spatial structure defines lake performance
- Zonation, edges, buffers and flood spaces shape outcomes

Technology as an Enabler
- Monitoring and data support design decisions
- Enables adaptive and responsive interventions

Policy as Support
- Provides regulatory and institutional backing
- Ensures long-term implementation and management

Analysis informs design; technology enhances responsiveness; policy ensures long-term continuity.

LAKE ZONATION STRATEGY

Proposals & Design Framework

1. Conservation Strategy

Objectives - Safeguard hydrology, biodiversity, and legal lake boundaries.

- Design
- Demarcate and legally enforce 30m–75m buffer zones
- Remove encroachments & restore rajakaluves (stormwater channels)
- Freeze further construction in critical recharge zones.
- Lake boundary fencing using ecological edges (not concrete walls)
- Lake health audit every 6 months

2. Eco-restoration Strategy

Objectives - Improve water quality and revive ecological functions.

- Design
- Constructed Wetlands
- Floating Wetlands
- Floating Solar Platforms (Selective Zones)
- Biodiversity Pockets

3. Public Interface Strategy(People–Lake Relationship)

Objectives - Make lakes inclusive social infrastructure without ecological damage.

- Design
- Permeable pavements
- Elevated wooden boardwalks
- Viewing decks
- Eco-education centers
- Lake interpretation signage
- Cultural Integration Strategy

4. Flood Buffer Strategy

Objectives - Restore lake as urban flood regulator.

- Design
- Stormwater Detention Basins.
- Bio-swales Along Roads
- Cascade Restoration.
- Flood Simulation Mapping
- Blue-Green Corridor Reconnection
- Multi-Tier Flood Storage System

ADAPTIVE LAKE EDGE DESIGN

Proposals & Design Framework

➢ **Seasonal Variation Strategy**

A. Variable Edge Design

- Gentle sloping banks (1:6 to 1:8 gradient)
- No vertical concrete retaining walls
- Allow water spread expansion in monsoon

B. Seasonal Wetland Belts

- Outer ring becomes marsh during monsoon
- Converts to grass meadow during dry season
- Supports birds in winter

➢ Seasonal Lake Edge Adaptation Model

A. Flood Condition (Monsoon Scenario)

- Design Measures:
- Floodable parklands
- Terraced embankments
- Controlled spillways

B. Dry Condition (Summer Scenario)

- Design Measures:
- Shallow recharge pits
- Floating solar clusters (reduce evaporation)
- Aeration fountains
- Sediment exposure management

➢ Human–ecology Balance Strategy

A. Carrying Capacity Assessment

- Limit daily visitor count
- Zoning based on ecological sensitivity
- No access to bird nesting islands

B. Buffer Gradient Model

- Instead of hard separation:

Urban → Recreational → Semi-Natural → Natural Core

Creates smooth transition.

C. Time-Based Access

- Bird breeding season: restricted zones
- Night-time ecological dark zone
- Morning hours: nature trails

Table: Quantifiable Balance Targets

Indicator	Target
Ecological Zone Protection	60% area
Public Access Zone	30%
Restricted Buffer	10%
Visitor Cap	Based on 1 person/10 sqm

➢ **Ecological Buffer Condition (Riparian Edge Scenario)**

A. Design Measures:

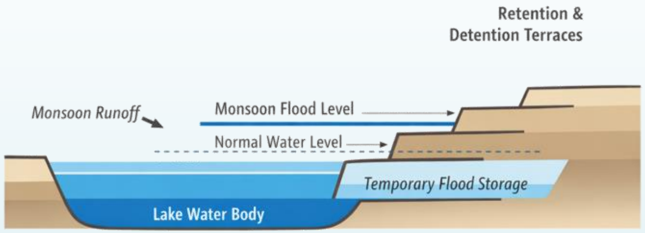
- Native riparian vegetation belts
- Sediment and nutrient filtration zones
- Habitat creation for birds and aquatic species
- Stabilised vegetated slopes to reduce erosion

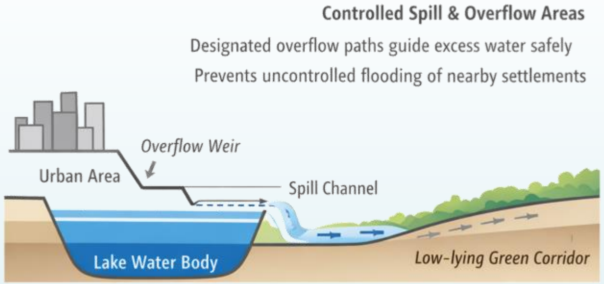
LAKE AS URBAN FLOOD RESILIENCE INFRASTRUCTURE

Urban lakes must function as **active flood-control systems**, not passive water bodies.

Design Logic

- Urban lakes function as integral components of the stormwater network.
- Design interventions can **store, slow, and safely release** excess runoff during extreme rainfall events.
- Flood management is fundamentally a **spatial and landscape design challenge**, not only an engineering task.





Retention & Detention Zones

Terraced lake edges temporarily store excess monsoon runoff and reduce peak flood discharge downstream.

Design elements:

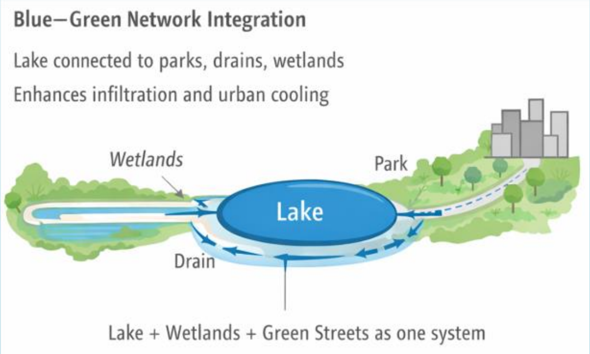
- Landscape terraces
- Floodable parklands
- Seasonal storage zones

Controlled Spill & Overflow Areas

- Designated overflow paths guide excess water safely
- Prevents uncontrolled flooding of nearby settlements

Design Logic:

- Spill channels
- Low-lying green corridors

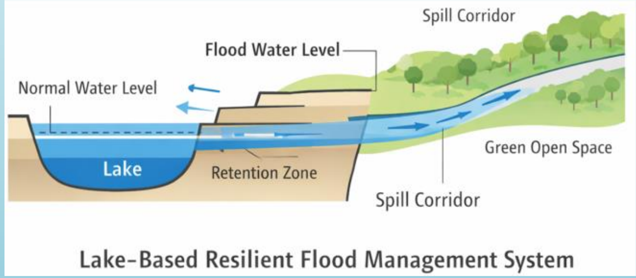


Blue–Green Network Integration

- Lake connected to parks, drains, wetlands
- Enhances infiltration and urban cooling

Design Logic:

- Lake + wetlands + green streets as one system



Designing lakes as flood infrastructure transforms disaster management into landscape planning.

GOVERNANCE AND MANAGEMENT ISSUES

Problem Identification Logic

Structural Fragmentation

Lake management is divided across sectors such as sewage treatment, land administration, and water management, preventing lakes from being governed as integrated ecological systems.

Information Asymmetry

The absence of shared data platforms results in conflicting agency priorities and fragmented decision-making.

Symptom-Level Interventions

Current responses often address visible symptoms (such as frothing or surface pollution) rather than the underlying causes, including untreated sewage inflow.

Governance Failure

The lake crisis reflects a systemic governance issue rather than purely a technical or engineering problem.

Institutional Challenges

Multiple Agencies, Limited Accountability

Key institutions including **BBMP, BDA, BWSSB, and KSPCB** manage different aspects of the lake system without a unified authority or clear accountability.

Data Deficit

Lack of integrated GIS databases and real-time monitoring systems leads to inconsistent records, delays in decision-making, and weak planning coordination.

Reactive Governance

Management actions are often triggered by public crises such as flooding, fires, or pollution events rather than through long-term, catchment-scale maintenance strategies.

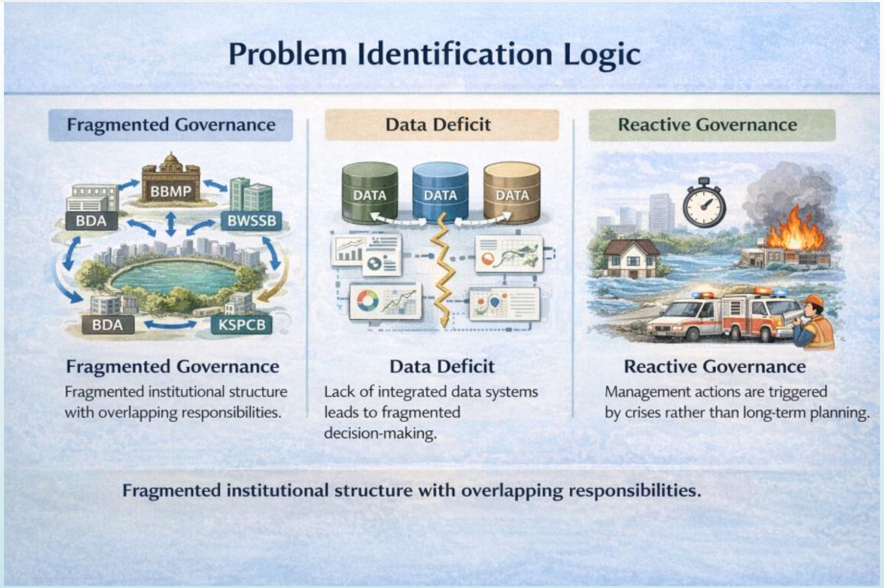


Fig: Problem identification

- Bellandur Lake receives **~500 MLD of sewage inflow daily**
- Bengaluru generates **~1,440 MLD of sewage**
- **80% of historic lakes lost or degraded** due to urbanisation
- Encroachment of **rajakaluves disrupts lake connectivity**
- **Fragmented governance across BBMP, BDA, BWSSB, and KSPCB**

GOVERNANCE & MANAGEMENT ISSUES [PROPOSALS AND DESIGN FRAMEWORK]

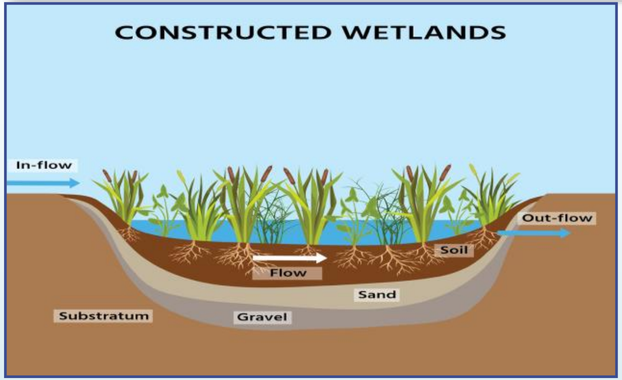
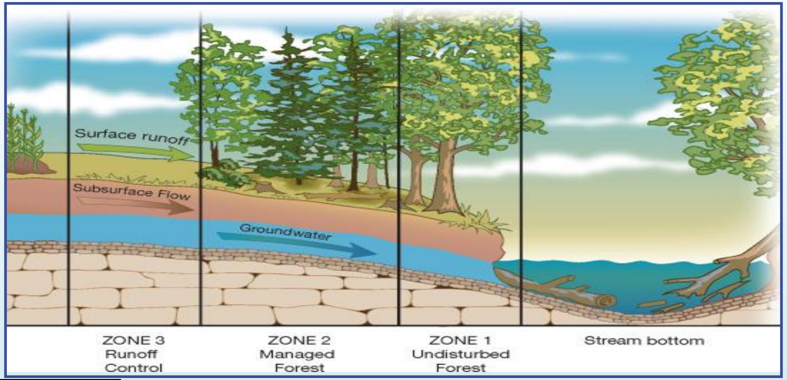


Fig: ECOLOGICAL DESIGN INTERVENTIONS



A. Constructed Wetlands At Major Inlets

- Multi-stage reed bed system
- Sedimentation + gravel filtration + phytoremediation
- Reduces BOD, COD, nutrients, heavy metals
- Acts as pre-treatment before lake entry

C. Soft Lake Edges Nature-Based Buffer

- 5-15 m vegetative riparian buffer
- Gradual slope (1:5)
- Native grasses & emergent plants
- Reduces erosion and surface runoff pollution

INTEGRATED DESIGN FRAMEWORK

Stage 1 Interception	Constructed wetlands at inlets.
Stage 2 - In-Lake Remediation	Floating bio-filters + controlled macrophyte harvesting.
Stage 3 - Edge Restoration	Soft shoreline + buffer zone enforcement.
Stage 4 -Governance Reform	Single Lake Authority + real-time water monitoring.

INTEGRATED ECOLOGICAL TREATMENT FLOW

Urban Sewage → Pre-Treatment Chamber → Constructed Wetland Cells → Lake Body (Floating Bio-Filters) → Soft Vegetated Edge Buffer → Improved Water Quality & Ecological Resilience

B. Floating Bio-Filters In-Lake Remediation

- Floating vegetated rafts
- Root-zone microbial treatment
- Controls eutrophication & algal bloom
- Improves dissolved oxygen

Bellandur's degradation reflects both ecological stress and governance failure. A multi-layered restoration approach combining wetlands, floating bio-filters, and ecological lake edges can restore water quality and system resilience.

POLICY INTEGRATION PROPOSAL

Key Policy Instruments

NGT Regulations (National Green Tribunal)

•Enforce lake buffer zones and wetland protection

•Prevent encroachments and untreated sewage discharge

AMRUT Mission

•Funding support for sewerage infrastructure

•Lake rejuvenation and urban water management

Smart Cities Mission

•Digital monitoring and data-driven lake management

•Integration of technology for environmental governance

Institutional Coordination

Effective implementation requires collaboration among key agencies:

•**BBMP** – Lake maintenance and urban infrastructure

•**BWSSB** – Sewage treatment and diversion systems

•**BDA** – Land use planning and development control

•**KSPCB** – Pollution monitoring and compliance enforcement

Effective lake restoration requires **integration of ecological design strategies with existing policy and institutional mechanisms.**

Implementation Goal

Integrate ecological restoration, infrastructure planning, and governance mechanisms to ensure long-term urban lake sustainability.

National Policies (NGT)

↓

State & Urban Programs (AMRUT / Smart Cities)

↓

Local Agencies (BBMP, BWSSB, BDA, KSPCB)

↓

Lake Restoration Implementation

1. Data-Linked Planning Controls

• GIS boundary validation

• 500m Ecological Sensitivity Zone

• Drone & satellite compliance

2. Three-Tier Buffer Regulation

• 0–30m Core: No construction

• 30–75m Eco: Permeable + low FAR

• 75–150m Urban Interface: Controlled dev + RWH

3. Performance-Based Management

• KPIs: DO, flood retention, biodiversity

• Annual Lake Health Scorecard

• Funding tied to outcomes

Outcome: Flood Resilience | Improved Water Quality | Accountable & Data-Driven Governance

IMPLEMENTATION PHASING

Bellandur Lake is a terminal lake within Bengaluru's urban watershed and receives large volumes of untreated sewage and polluted stormwater runoff from upstream catchments. These conditions have led to recurring environmental problems such as toxic foaming, fire incidents, loss of biodiversity, and periodic flooding in surrounding areas. Addressing these challenges requires a policy-driven and phased rejuvenation approach that integrates ecological restoration, infrastructure improvements, and coordinated governance.

Phased Strategy for Lake Restoration

Effective lake restoration requires a **step-by-step implementation process** that integrates ecological design, infrastructure upgrades, and governance coordination.

Phase 1 — Assessment & Monitoring

Objective: Establish baseline conditions and identify priority interventions.

Design Actions:

- Comprehensive lake health assessment
- Mapping of sewage inflows and drainage networks
- Installation of water quality monitoring systems
- Data integration through GIS platforms

A phased approach ensures that ecological restoration, infrastructure upgrades, and governance reforms progress in a coordinated manner.

Phase 2 — Physical Interventions

Objective: Restore ecological functions and improve water quality.

Design Actions:

- Construction of **wetlands and bio-filtration systems**
- Development of **adaptive lake edges and buffer zones**
- Implementation of **floating bio-filters and aeration systems**
- Diversion of untreated sewage into treatment infrastructure

Phase 3 — Governance & Long-Term Management

Objective: Ensure sustainable operation and monitoring.

Design Actions:

- Establish integrated lake governance framework
- Coordination between BBMP, BWSSB, BDA, and KSPCB
- Continuous monitoring and adaptive management strategies
- Community participation in lake stewardship

Phase 1 Assessment → Phase 2 Physical Restoration → Phase 3 Governance Integration

APPLICABILITY TO ALL URBAN LAKES

While demonstrated through **Bellandur Lake**, the proposed framework is **adaptable and scalable to urban lakes of varying sizes, contexts, and stress levels**.

Scalability Framework

1. Modular Design Toolkit

The spatial design principles—lake zonation, ecological buffers, floodable edges, and public interfaces—can be **reconfigured based on lake size, catchment condition, and urban pressure**.

2. Scalable Technology Layer

Monitoring systems, spatial data, and performance indicators can be **scaled from basic manual monitoring to advanced sensor-based systems**, depending on local capacity and resources.

3. Policy Adaptability

The framework aligns with **existing municipal, state, and national lake protection regulations**, allowing integration into master plans, stormwater policies, and lake management guidelines.

From a site-specific case to a city-wide and national urban lake regeneration approach.

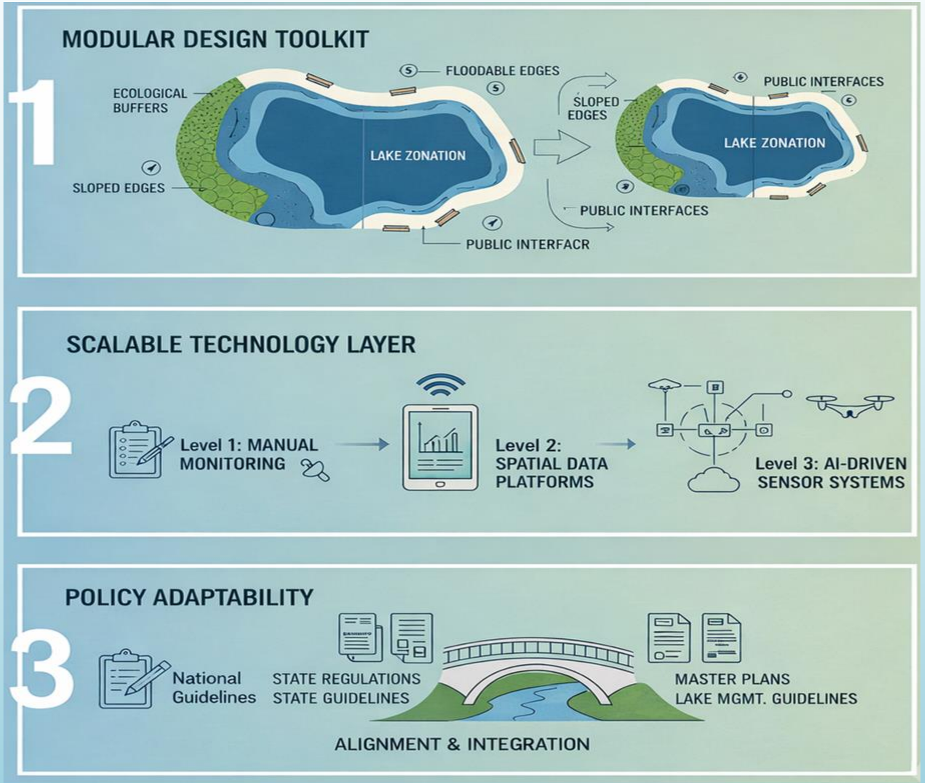


Fig: **Scalability Framework**

CONCLUSION & IMPACT

Reimagining Urban Lakes as Ecological Infrastructure

The **Lake Sponge Edge framework** demonstrates how design-led, nature-based strategies can restore urban lakes as resilient socio-ecological systems. By integrating ecological restoration, hydrological management, and policy coordination, the proposal addresses both environmental degradation and governance challenges in urban lake systems.

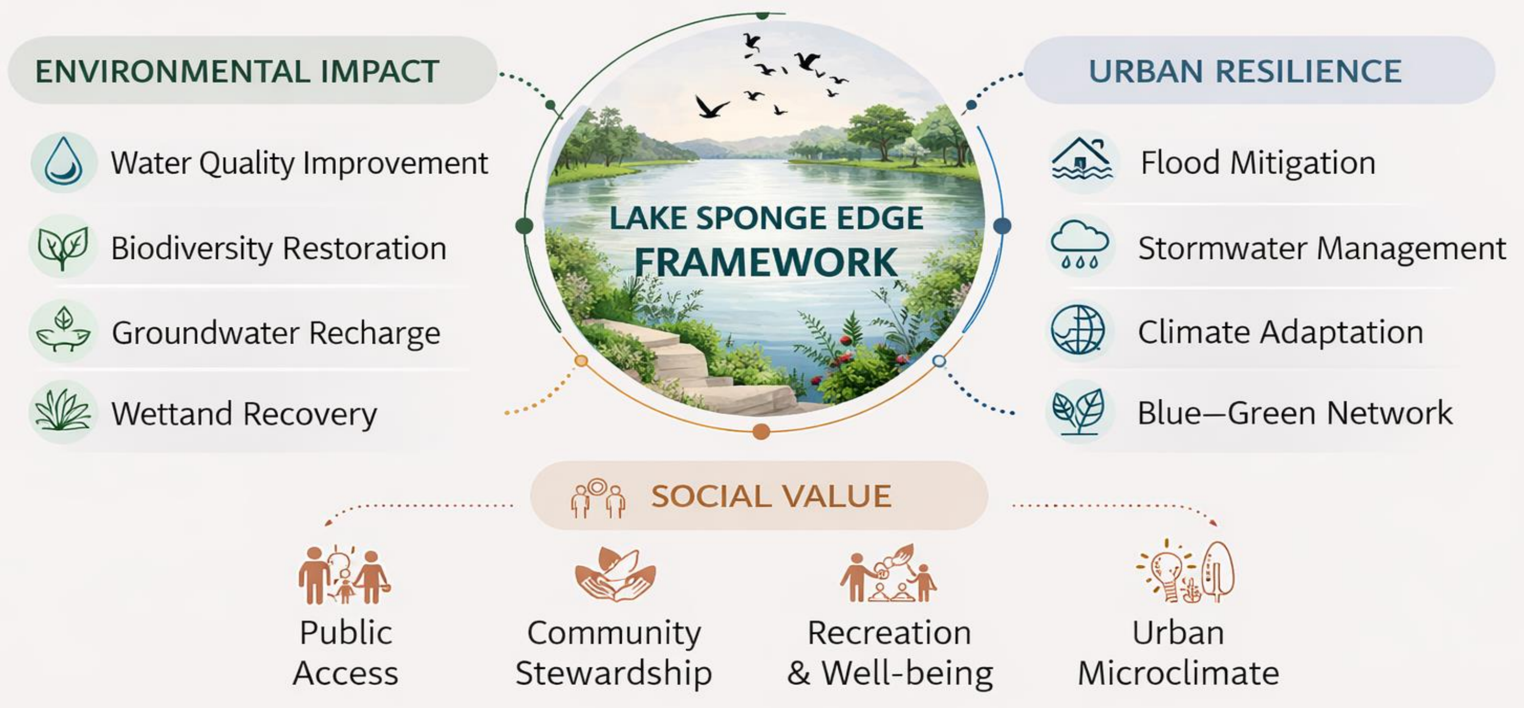


Fig: Lake sponge edge framework

Key Takeaway:
Urban lakes must be planned and managed as living ecological infrastructure. Integrating design, hydrology, and governance restores ecosystem functions, improves water resilience, and supports sustainable cities.

Sources

REFERENCES:

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ISRO Bhuvan; USGS Landsat; OpenStreetMap; Survey of India;
Ramachandra et al. (IISc); Sudhira et al.; Kadlec & Wallace;
NDVI (Tucker, 1979); NDWI (McFeeters, 1996); NDBI (Zha et al., 2003);
NGT Guidelines; MoHUA (AMRUT, Smart Cities); CPCB;
Ramsar Convention; World Bank; UNEP

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