Journal of Rare Cardiovascular Diseases
ISSN: 2299-3711 (Print) | e-ISSN: 2300-5505 (Online)
www.jrcd.eu

RESEARCH ARTICLE

Restoration Strategies of Urban Lakes for Preventing Public Health Related Concerns: Selected Cases from Bhopal and Jabalpur, India

Anugrah Anilkumar Nagaich[1], Navneet Munoth[2] and Dr. Puneet Pathak[3]
[1]Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh 462003, India
[2]Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal, Madhya Pradesh 462003, India
[3]Consultant Maxillofacial Surgeon, Madhuban Hospital, Budhni, Sehore, Madhya Pradesh 461661, India

*Corresponding Author
Anugrah Anilkumar Nagaich

Article History
Received: 08.08.2025
Revised: 15.09.2025
Accepted: 24.10.2025
Published: 05.11.2025

Abstract: This study addresses the severe ecological and public health crisis facing urban aquatic ecosystems in the Global South. Urban lakes in India are experiencing escalating degradation due to factors like encroachment, siltation, eutrophication, and chronic pollution from untreated domestic and industrial effluents. Crucially, this degradation creates stagnant, eutrophic conditions that facilitate the proliferation of pathogens and mosquitoes, elevating the prevalence of vector-borne and waterborne diseases, thereby linking environmental decline to critical urban public health burdens. The study focuses on two case studies: Rani Tal (Jabalpur) and Shahpura Lake (Bhopal); which exhibit comparable socio-ecological contexts. The authors have employed an integrated mixed-methods approach, triangulating multi-temporal geospatial analysis (LULC change detection 2014–2023), field-based ecological assessments, and semi-structured interviews with 160 stakeholders. The findings confirmed a high correlation between rapid urbanization (evidenced by significant increases in impervious cover) and elevated pollutant loading. Stakeholder feedback, corroborated by health professionals, documented frequent incidences of dengue, malaria, and gastroenteritis linked directly to the lakes' deteriorated conditions. Furthermore, a policy gap analysis highlighted fragmented governance and minimal enforcement as systemic barriers to effective management. Based on these findings, a tiered, multi-scalar restoration roadmap is proposed. Recommendations include immediate technical measures (e.g., dual aeration systems, trash barriers), medium-term catchment-scale solutions (e.g., Decentralized Wastewater Treatment System, green buffer zones), and long-term institutional reforms (e.g., Lake Management Committees, citizen science). The conclusion reinforces that successful urban lake restoration requires systemic interventions that explicitly integrate environmental management with public health surveillance and improved sanitation infrastructure, serving as a replicable model for enhancing both ecosystem resilience and human well-being.

Keywords: Urban Lakes Restoration, Public Health Nexus, Catchment Management, Governance Fragmentation, Decentralized Wastewater Treatment.

INTRODUCTION

Lakes are multifunctional ecosystems that deliver a diverse array of socio-economic and ecological services. From a utilitarian perspective, they support commercial activities such as fisheries, transportation, recreation, irrigation, industrial water supply, and the assimilation of both treated and untreated wastewater effluents [1, 2]. Ecologically, they perform critical hydrological functions by regulating river flows, recharging groundwater aquifers, and mitigating the impacts of floods and droughts through their capacity to store substantial volumes of water [3]. Moreover, lakes contribute to local climate regulation, enhance the scenic and aesthetic value of landscapes, and maintain biodiversity by providing habitats for aquatic and semi-aquatic flora and fauna, which in turn sustain trophic linkages with numerous terrestrial species [4]. These attributes affirm that lakes are far more than passive water storage units; they are dynamic socio-ecological systems underpinning both environmental integrity and human well-being.

Urban lakes, embedded within the built environment, are among the most critical ecological assets in contemporary cities. Beyond serving as repositories of freshwater, they function as regulators of microclimate, biodiversity reservoirs, recreational spaces, and cultural landscapes [5]. In rapidly urbanizing regions of the Global South, particularly in India, these ecosystems face escalating degradation due to encroachment, pollution from untreated domestic and industrial effluents, siltation, eutrophication, and hydrological alterations [6, 7].

Equally significant, though often underrecognized, is the profound impact that poorly maintained urban lakes exert on public health. The accumulation of untreated sewage and organic waste creates stagnant, eutrophic conditions that facilitate the proliferation of mosquitoes, pathogens, and harmful algal blooms, increasing the prevalence of vector-borne and waterborne diseases such as malaria, dengue, diarrhea, and typhoid among lakeside populations. Communities living in close proximity to degraded lakes frequently experience additional health burdens including skin irritation, respiratory distress, and psychosocial stress linked to foul odour and diminished environmental quality [6]. Moreover, informal settlements located along lake fringes often lacking adequate sanitation infrastructure; face heightened exposure to contaminated water and poor hygiene conditions, compounding health inequities. Thus, the degradation of urban lakes transcends ecological boundaries, emerging as a critical urban public health challenge that necessitates coordinated interventions integrating environmental restoration, sanitation improvement, and disease surveillance. Recognizing this ecological–health nexus is essential for developing comprehensive lake management frameworks that simultaneously promote ecosystem resilience and community well-being.

Historically, human interactions with lakes: both natural and artificial; have been paradoxical, marked by a simultaneous appreciation of their ecological and aesthetic value and exploitation for waste disposal [8]. While admired for their beauty and ecological functions, lakes have often been used as repositories for domestic sewage, industrial effluents, and solid waste. As integral elements of ecological and urban systems, they sustain biodiversity, regulate ecosystem processes, support local economies, and enhance urban livability [9]. Yet, the pressures of urbanization and industrialization have severely compromised their health, with global evidence of desiccation, eutrophication, and contamination driven by poor governance, weak enforcement of environmental regulations, and unplanned land-use changes [10, 11]. Major contributing factors include uncontrolled wastewater discharge, indiscriminate dumping of refuse, unchecked growth of invasive aquatic vegetation, and heavy siltation [12].

In India, the degradation of lakes is particularly evident in cities such as Bhopal: renowned as the “City of Lakes”; and Jabalpur, which historically supported 136 urban water bodies. These lakes have sustained local populations through fisheries, potable water supply, and recreational benefits [8, 13]. However, rapid expansion of built-up areas, insufficient waste management infrastructure, and the absence of integrated conservation frameworks have precipitated severe ecological stress [14]. This situation underscores the urgent need for scientifically informed, community-inclusive restoration and management strategies aimed at ensuring the long-term sustainability of these critical ecosystems.

SELECTION OF CASE STUDIES

An in-depth evaluation of the prevailing conditions of the principal urban lakes in Bhopal and Jabalpur was undertaken through a comprehensive, multi-method approach integrating field-based, institutional, and geospatial assessments. The methodological framework comprised three core components:

On-site inspections – Systematic physical surveys were conducted for each urban lake and its surrounding catchment areas to obtain direct observational data on morphological characteristics, water quality indicators, anthropogenic pressures, and signs of ecological stress [3, 1].

Stakeholder consultations – Structured and semi-structured interviews were held with municipal officials, urban planners, environmental regulators, medical and community health professionals and community representatives engaged in the governance, planning, and maintenance of these aquatic systems [5].

Advanced geospatial analysis – Using cloud-based geoinformatics platforms, specifically Google Earth Engine [15], multi-temporal satellite imagery was processed to evaluate land-use/land-cover changes, encroachment patterns, and seasonal variations in water extent.

Field observations revealed that both cities’ urban lakes are under significant stress from unplanned urban expansion, which has precipitated multiple environmental threats including organic and inorganic pollution, shoreline encroachment, eutrophication, unmanaged tourism, and cultural misuse [6, 9]. Furthermore, several lakes and ponds subjected to large-scale cultural and religious events-such as idol immersion and nirmalya (ritual offerings) disposal-have experienced accelerated ecological degradation due to inadequate event planning and waste management [14].
Stakeholder feedback corroborated these findings, highlighting key city-specific patterns of degradation. In Bhopal, water pollution is predominantly linked to the unchecked discharge of domestic and industrial wastewater directly into the lakes. In contrast, Jabalpur’s lakes and ponds are more severely impacted by a combination of untreated sewage inflows, stormwater runoff, and seasonal cultural activities, particularly the immersion of painted idols and associated ritual materials during religious festivals, which contribute to heavy metal contamination, increased turbidity, and nutrient enrichment [7, 16]. These insights collectively underscore the urgency of implementing integrated, location-specific restoration and management frameworks for safeguarding the ecological integrity of urban lakes in both cities.

2.1. The Case of Shahpura Lake and Rani Taal

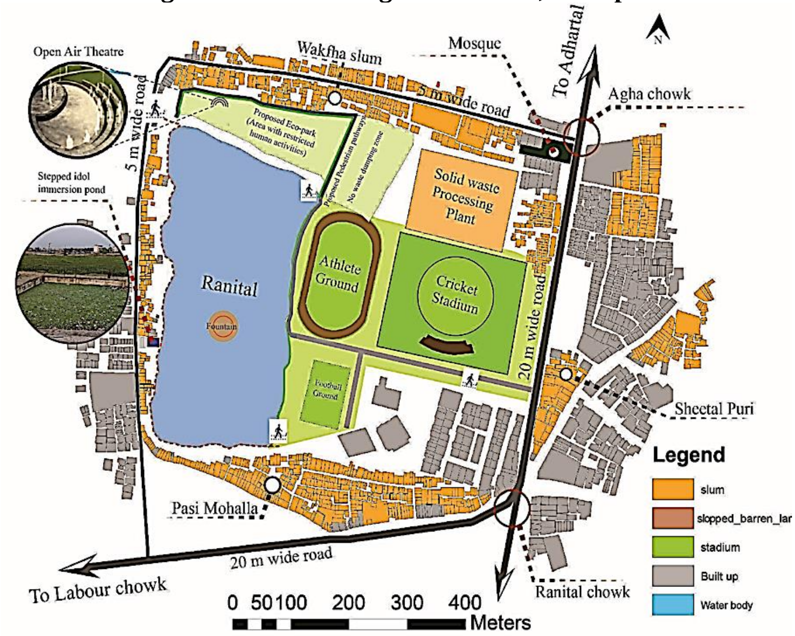
Following the multi-criteria framework outlined for case study selection, two urban lakes-Rani Tal in Jabalpur and Shahpura Lake in Bhopal-were identified for detailed assessment of restoration strategies. Both sites exhibit comparable socio-ecological contexts and share a range of degradation issues, making them suitable for comparative analysis.

2.1.1. Rani Tal, Jabalpur

Situated across the villages of Laxmipur, Jabalpur, and Hinotiya (23°10′15″ N, 79°55′10″ E) at a mean sea level elevation of 391 m, Rani Tal is a historically significant lake reportedly constructed under the reign of Rani

Durgavati in the 16th century CE [8]. The lake's original expanse of approximately 48 ha has been drastically reduced to 10.25 ha, largely as a result of land reclamation and the establishment of a sports complex along its shoreline [14]. The earthen embankments and peripheral areas have been encroached upon by informal settlements on three sides, while municipal solid waste is routinely deposited along its margins. Presently, the lake is predominantly utilised for nistar activities-subsistence domestic uses such as bathing, washing, and livestock watering. Key environmental stressors include deterioration of water quality, loss of storage capacity due to siltation, unchecked aquatic weed proliferation, direct inflow of untreated sewage, and sustained encroachment compounded by indiscriminate dumping of solid waste [6].

Figure 1. Surroundings of Rani Tal, Jabalpur



2.1.2. Shahpura Lake, Bhopal

Constructed between 1974–1975 under the Betwa Irrigation Scheme, Shahpura Lake (23°12′N, 77°25′E) is a medium-sized artificial reservoir that exemplifies the ongoing urban lake degradation crisis in Central India. Initially created for irrigation, the lake's functions have since diversified to encompass recreational use, fisheries, groundwater recharge, flood attenuation, and stormwater retention [13, 18]. Despite its relatively modest dimensions: catchment area of 8.29 km^2, submergence area of 0.96 km^2, maximum depth of 5.6 m, and mean depth of 1.5 m, the lake supports diverse aquatic flora and fauna, contributing to local biodiversity [7]. However, over the past three decades, unregulated urban expansion in the catchment has led to the continuous inflow of untreated domestic sewage, stormwater runoff, and solid waste. This has triggered progressive eutrophication, invasive macrophyte proliferation, and accelerated sedimentation, collectively impairing the lake's ecological functionality and diminishing its capacity to deliver ecosystem services [14, 16].

Figure 2. Surroundings of Shahpura Lake, Bhopal

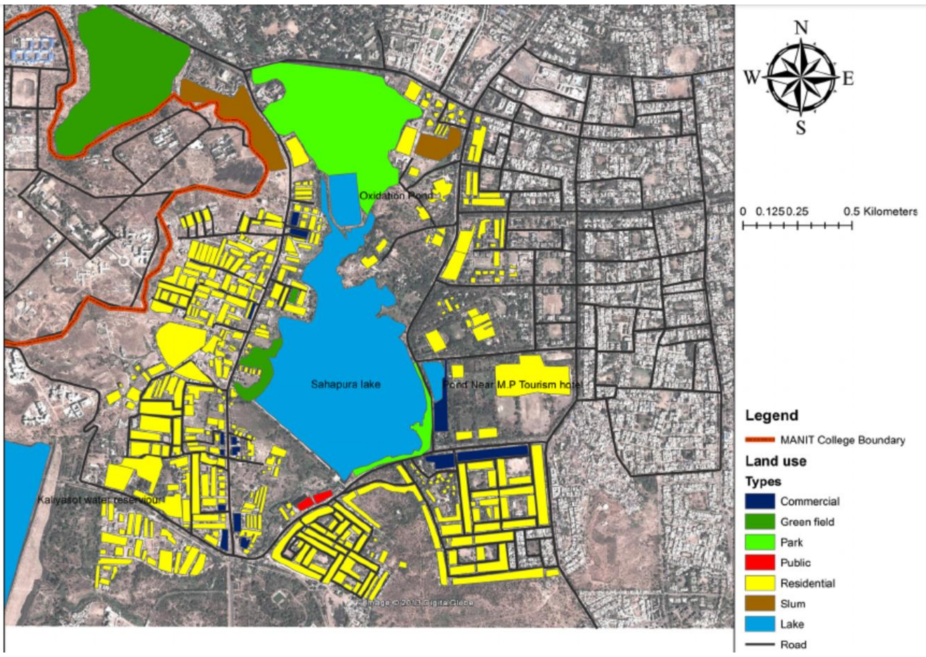


Table 1. Comparative Profile of Case Study Lakes: Rani Tal (Jabalpur) and Shahpura Lake (Bhopal)

Attribute	Rani Tal, Jabalpur	Shahpura Lake, Bhopal
Geographic Location	Laxmipur, Jabalpur, and Hinotiya villages; 23°10′15″ N, 79°55′10″ E; MSL 391 m	Bhopal city; 23°12′N, 77°25′E
Catchment / Submergence Area	Historical extent: 48 ha; Current extent: 10.25 ha	Catchment: 8.29 km²; Submergence: 0.96 km²
Depth	Not documented in current literature	Maximum: 5.6 m; Mean: 1.5 m
Historical Background	Constructed during the reign of Rani Durgavati in the 16th century CE	Constructed 1974–1975 under Betwa Irrigation Scheme
Primary Water Sources	Rainwater, surface runoff, sewage inflows	Rainwater, urban stormwater, and sewage inflows
Original Purpose	Domestic water use and local sustenance activities (nistar)	Irrigation
Current Uses	Nistar activities (washing, bathing, livestock watering)	Recreation, fisheries, groundwater recharge, flood attenuation, stormwater retention
Ecological Functions	Supports aquatic vegetation and fauna; contributes to local biodiversity	Biodiversity hotspot; aquatic habitat; hydrological regulation
Major Degradation Drivers	Encroachment by informal settlements; municipal solid waste dumping; untreated sewage inflows; aquatic weed proliferation; siltation	Untreated sewage and stormwater inflows; solid waste dumping; eutrophication; invasive macrophytes; sedimentation

RESEARCH METHODOLOGY

This study adopted a mixed-methods research design, integrating geospatial analytics, field-based ecological assessments, and institutional policy analysis to develop a comprehensive understanding of urban lake degradation and potential restoration pathways. Such triangulation of quantitative and qualitative methods enhances the robustness of environmental research and allows for cross-validation of findings [17, 19].

3.1 Spatial Analysis

The spatial analysis component employed multi-temporal remote sensing and GIS-based classification techniques to evaluate land-use/land-cover (LULC) dynamics in the catchments of Rani Tal (Jabalpur) and Shahpura Lake (Bhopal). High-resolution satellite imagery-sourced from Google Earth and other freely available repositories-was pre-processed and geo-referenced. Catchment boundaries were delineated using hydrological modeling tools integrated within QGIS 3.28. Supervised classification was undertaken using the Maximum Likelihood Classifier (MLC), a well-established approach for thematic mapping in heterogeneous urban environments [20]. The analysis specifically quantified changes in impervious surface cover between 2014 and 2023, an indicator directly linked to hydrological alteration and pollution loading in urban lakes [21, 22].

3.2 Stakeholder Consultations

A total of 160 semi-structured interviews were conducted with stakeholders representing a cross-section of actors, including municipal officials, environmental regulators, community leaders, doctors, community health workers, fishermen, lakeside vendors, and local residents. This qualitative inquiry aimed to capture stakeholder perceptions on lake degradation, existing usage patterns, impact of the urban water body on the public health and willingness to engage in restoration initiatives. Semi-structured interviews were chosen for their flexibility in probing context-specific issues while maintaining comparability across respondents [23]. Interview data were transcribed, thematically coded, and analyzed to identify recurrent concerns such as encroachment, solid waste dumping, and cultural activities impacting water quality. The participatory dimension aligns with the principles of community-based water resource management, which emphasize local knowledge integration in decision-making [24].

3.3 Policy Gap Analysis

The policy analysis component involved mapping national and state-level legal frameworks-including the Wetlands (Conservation and Management) Rules, 2017, and state-specific urban lake conservation policies-against observed on-ground realities. Institutional arrangements were evaluated to identify jurisdictional overlaps, governance bottlenecks, and implementation gaps, drawing upon frameworks for environmental governance effectiveness [25]. Particular attention was given to the roles of municipal corporations, the State Wetland Authority, and pollution control boards in operationalizing conservation mandates. This approach facilitated an understanding of the systemic and structural barriers to effective lake management.

3.4 Data Sources

3.4.1 Primary Data

Primary data collection involved systematic field surveys to document inflow and outflow channels, lakeside land-use patterns, shoreline encroachment, and points of waste accumulation. Observations were supplemented with informal interviews of sample size 160 carried out with the municipal officials, environmental regulators, community leaders, doctors, community health workers and finally the local users-particularly fishermen, vendors, and lakeside residents currently engaged in the vicinity of the lakes-to gain insights into seasonal water quality fluctuations, livelihood dependencies, and community-led conservation practices.

3.4.2 Secondary Data

Secondary data sources included environmental monitoring reports from the Environmental Planning & Coordination Organisation (EPCO), Bhopal Municipal Corporation (BMC) and Jabalpur Municipal Corporation (JMC), which provided physicochemical water quality records and pollution source inventories. Land-use change detection leveraged high-resolution satellite imagery spanning 2014–2023, enabling decadal-scale analysis of catchment transformation. Additionally, scholarly articles, government policy documents, and case studies of comparable urban lake systems in India and the Global South were reviewed to provide contextual benchmarks [6, 7].

By integrating geospatial evidence, stakeholder perspectives, and institutional analysis, this methodology ensures a multi-dimensional understanding of urban lake dynamics, thereby informing the formulation of technically sound and socially inclusive restoration strategies.

ANALYSIS, RESULTS, AND DISCUSSIONS

The integrated mixed-methods approach employed in this study generated a multi-dimensional dataset encompassing spatial land-use/land-cover (LULC) change detection, field-based ecological condition assessments, and policy-institutional gap analyses for the two selected case study lakes-Rani Tal (Jabalpur) and Shahpura Lake (Bhopal). This section synthesizes these findings to elucidate the drivers, patterns, and implications of urban lake degradation in the Central Indian context.

4.1 Spatial Analysis Findings: Land-Use/Land-Cover Change (2014–2023)

Supervised classification of multi-temporal satellite imagery revealed significant alterations in the catchment landscapes of both lakes.

Rani Tal Catchment: Between 2014 and 2023, impervious surface cover increased from 28.6% to 42.3%, largely due to expansion of informal settlements and commercial structures along the earthen bund and fringe areas. Correspondingly, vegetated cover decreased by 11%, while bare soil patches-indicative of construction activity-rose by 6%.

Shahpura Lake Catchment: Impervious cover expanded from 35.8% to 51.7%, primarily driven by residential colonies, road widening, and institutional development. Green cover reduced by 13%, while open barren land was converted into built-up areas at an annual rate of ~1.8%.

These findings are consistent with studies linking rapid urbanization in lake catchments to hydrological alteration, increased surface runoff, and pollutant loadings [21, 22].

4.2 Field-Based Ecological Assessment

4.2.1 Concerns for Public Health

Findings from the survey revealed substantial public health concerns associated with the deteriorating condition of Rani Tal and Shahpura Lake. Respondents consistently reported an increase in vector-borne and waterborne diseases, particularly dengue, malaria, and gastroenteritis, during the monsoon months, which they attributed to stagnant water, waste accumulation, and algal proliferation. Health professionals corroborated these perceptions, emphasizing that untreated sewage inflows and eutrophic conditions in the lakes create breeding grounds for mosquitoes and pathogens. Community health workers highlighted frequent cases of skin irritation and respiratory discomfort among individuals engaged in lakeside activities such as washing, fishing, and vending. The survey further revealed psychological and aesthetic dimensions of health, with many residents expressing distress over foul odour, declining aesthetic value, and reduced recreational use. These findings underscore the nexus between environmental degradation and urban public health, illustrating how polluted urban water bodies serve as focal points for both direct and indirect health risks. The insights reinforce the urgency of integrated lake management strategies that incorporate public health surveillance, sanitation improvements, and community participation as essential components of urban ecosystem restoration.

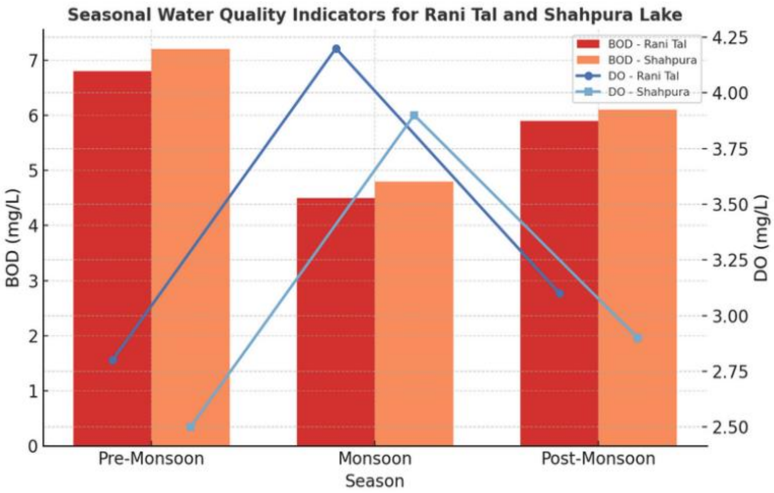
Table 2. Reported Public Health Impacts Associated with Rani Tal and Shahpura Lake

Disease / Health Concern	Probable Cause (as Reported by Stakeholders)	Most Affected Group(s)	Frequency / Intensity (as Reported)	Observed Link to Lake Condition
Dengue and Malaria	Stagnant water due to poor drainage, weed infestation, and blocked inflow channels creating mosquito breeding grounds	Lakeside residents, fishermen families, children	Reported by 78% of respondents during monsoon season	High correlation with stagnant water pockets and poor waste clearance
Gastrointestinal Illnesses (Diarrhea, Dysentery, Typhoid)	Use of contaminated lake water for washing, livestock cleaning, and occasional domestic use	Vendors, fisherfolk, low-income settlements	Reported by 62% of respondents, particularly post-monsoon	Strong link to untreated sewage inflows and solid waste dumping
Skin Irritation and Rashes	Direct contact with polluted water during bathing, washing clothes, and handling fish	Fishermen, washermen (dhobis), children	Reported by 54% of respondents year-round	Associated with high turbidity, detergent inflow, and algal scum
Respiratory and Allergic Conditions	Inhalation of foul odour and aerosolized particulates from decaying organic matter and algal blooms	Vendors, commuters, lakeside shopkeepers	Reported by 41% of respondents, especially in summer	Related to organic decomposition and anaerobic conditions
Psychological and Social Well-Being Decline	Foul odour, degraded visual landscape, and reduced recreational access leading to loss of community pride	Residents, senior citizens, youth	Reported by 49% of respondents	Decline in lake aesthetics and recreational value influencing perceived quality of life
Vector-Borne Nuisance (Mosquitoes, Flies)	Accumulation of waste and nutrient-rich stagnation	General population in lake vicinity	Reported by 85% of respondents across both cities	Persistent issue linked with poor waste and weed management

	promoting insect proliferation			

4.2.2 Water Quality Degradation
Field surveys documented visible signs of pollution, including algal blooms, foul odor, and high turbidity in both lakes. Informal interviews revealed that untreated sewage inflows are a major contributor, corroborated by EPCO's monitoring data showing elevated biochemical oxygen demand (BOD) levels (>6 mg/L) and reduced dissolved oxygen (<3 mg/L) during pre-monsoon months-well above the permissible limits for Class-B urban lakes as per CPCB standards [26].

Figure 3. Seasonal Water Quality Indicators for Rani Tal and Shahpura Lake



4.2.3 Waste Accumulation and Shoreline Encroachment
At Rani Tal, solid waste dumping was observed along the western shoreline, with floating debris covering ~8–10% of the lake surface during peak summer. Shoreline mapping identified encroachments on three sides by slum clusters, reducing access to the lake for both ecological and recreational functions.

Shahpura Lake's north-western fringe exhibited substantial silt deposition and aquatic weed mats (Eichhornia crassipesand Hydrilla verticillata), covering ~15% of the water surface. These macrophyte blooms reduce dissolved oxygen levels, disrupt aquatic biodiversity, and impede stormwater conveyance [27].

4.2.4 Cultural and Recreational Pressures
In Jabalpur, annual religious festivals involving idol immersion and nirmalya disposal introduce heavy metals and nutrient loads into Rani Tal [16]. Similarly, in Bhopal, unregulated boating, lakeside eateries, and waste-generating recreational activities were observed, contributing to localized pollution hotspots.

4.2.5 Stakeholder Perceptions
Thematic analysis of semi-structured interviews (n=160) revealed a consensus among residents and local vendors that lake degradation has worsened over the past decade. Key perceptions included:

- Recognition of declining fish populations and reduced catch sizes (fisherfolk).
- Concerns over public health risks, including waterborne diseases (residents).
- Perceived lack of coordination between municipal bodies and environmental agencies (community leaders).
- Willingness among local youth groups to participate in cleanup and awareness drives, provided institutional support and funding are available.
- These insights reinforce the importance of incorporating community-based monitoring and co-management frameworks in urban lake restoration [24].

4.2.6 Policy Gap Analysis
Review of policy frameworks indicated substantial disconnects between statutory mandates and on-ground enforcement. While the Wetlands (Conservation and Management) Rules, 2017 prescribe zoning, buffer maintenance, and prohibition of waste discharge, enforcement in both case study sites is minimal.

Overlapping jurisdiction between municipal corporations, State Wetland Authorities, and Pollution Control Boards has led to fragmented governance, with no single agency assuming accountability for comprehensive restoration.

Absence of site-specific management plans has resulted in ad hoc interventions-such as periodic weed removal or desilting-without addressing root causes like untreated sewage inflows.

Table 3. Comparative Case Analysis of Rani Tal and Shahpura Lake

Parameter	Rani Tal (Jabalpur)	Shahpura Lake (Bhopal)
Catchment Impervious Increase (2014–2023)	+13.7%	+15.9%
Primary Pollution Source	Domestic sewage, religious idol immersion, solid waste dumping	Domestic sewage, stormwater inflows, recreational waste
Ecological Stress Indicators	High weed coverage, reduced DO, BOD > 6 mg/L	Aquatic weed mats, eutrophication, sedimentation
Governance Challenges	Encroachment by slums, lack of sewage interception	Recreational overuse, absence of integrated sewage management
Community Engagement	High willingness for participation	Moderate willingness, higher emphasis on tourism

DISCUSSION

The survey results also confirmed a multi-dimensional link between environmental degradation and public health risks, where physical (vector-borne), biological (pathogen-driven), and psychosocial stressors converge. The consistency of responses across stakeholder categories strengthens the evidence that lake pollution is not merely an ecological issue but a community health hazard requiring integrated interventions spanning sanitation, health surveillance, and environmental management.

The spatial analysis clearly establishes a direct correlation between urban expansion in catchment areas and the progressive degradation of lake ecosystems. Increased imperviousness accelerates stormwater runoff, enhancing nutrient and pollutant loading, and altering sedimentation regimes [29].

Field evidence from both lakes confirms the symptomatic outcomes of catchment urbanization-eutrophication, weed proliferation, and reduced water quality-paralleling global urban wetland degradation trends [10]. However, site-specific factors amplify degradation: Rani Tal's cultural use pressures differ from Shahpura Lake's recreational tourism load, necessitating differentiated restoration strategies.

Stakeholder consultations reveal latent potential for community-led stewardship, but this remains untapped due to governance fragmentation. The policy gap analysis underscores the urgent need for integrated, multi-agency management frameworks with clear jurisdictional mandates and financing mechanisms.

The findings reinforce the argument that restoration efforts must go beyond cosmetic interventions-weed removal, desilting, or beautification-and instead address systemic drivers, including sewage interception, catchment greening, and enforcement of buffer zones.

Recommendations

Based on the integrated spatial, ecological, and policy analyses of the two case study lakes-Rani Tal (Jabalpur) and Shahpura Lake (Bhopal)-a set of tiered recommendations is proposed. These are categorized into immediate (0–1 year), medium-term (1–3 years), and long-term (3–5 years) measures to ensure phased and sustainable restoration.

5.1 Immediate Measures (0–1 year)

Enhancing Dissolved Oxygen (DO) and Reducing Nutrient Load: The installation of dual aeration systems-floating fountains combined with ozonizers-at three strategic inflow points is recommended. Floating fountains enhance reaeration, while ozonizers oxidize organic pollutants and deactivate phosphorus compounds, thereby mitigating eutrophication [29]. This dual mechanism has been successfully demonstrated in urban lakes in East Asia and offers rapid improvements in water quality.

Mechanical Removal of Invasive Macrophytes: The proliferation of Eichhornia crassipes (water hyacinth) represents a critical ecological challenge, leading to hypoxia and biodiversity loss. Mechanical harvesting, coupled with biomass composting for agricultural use, would not only clear the lake surface but also create livelihood opportunities for local communities. Nutrient-rich compost from aquatic biomass has proven effective in improving soil fertility in peri-urban agriculture [30].

Solid Waste Interception: The deployment of floating trash barriers at key inflow points will reduce the entry of plastics and municipal waste into the lakes. This intervention has been employed in similar contexts globally to intercept floating debris before it disperses across the water body [31]. Coupled with regular desilting of inflow drains, this measure would yield immediate visible benefits and improve public perception of restoration efforts.

Emergency Vector Control and Public Health Surveillance: Given the high incidence of vector-borne and waterborne diseases such as dengue, malaria, and gastroenteritis reported by community health workers and residents, an immediate joint action plan between Municipal Health Departments and local hospitals should be implemented. This plan should include periodic fogging, larvicide application, and waterborne pathogen monitoring around lake peripheries. Mobile health clinics can be deployed for seasonal disease surveillance and community sensitization. Such integration of environmental and health monitoring has proven vital for managing ecosystem-linked public health risks [39].

5.2 Medium-Term Measures (1–3 years)

Decentralized Wastewater Treatment Systems (DEWATS): To address untreated sewage inflows, DEWATS units integrating constructed wetlands and root-zone treatment systems should be installed along major drains feeding the lakes. These naturalized systems rely on phytoremediation, sedimentation, and microbial processes to reduce biochemical oxygen demand (BOD), suspended solids, and nutrient concentrations [32]. DEWATS offer low-cost, low-maintenance solutions suitable for Indian urban contexts.

Creation of a Green Buffer Zone: Establishing a 20 m-wide green buffer zone along the lake periphery with native vegetation would serve as a biofilter for stormwater runoff, stabilize eroded banks, and enhance biodiversity. Riparian buffer zones are widely recognized as effective ecological infrastructure for mitigating non-point source pollution [33]. Preference should be given to species such as Vetiveria zizanioides and Typha angustifolia for their nutrient uptake and soil stabilization properties.

Regulated Vendor Zone Development: Informal vending and recreational activities around Shahpura Lake, in particular, contribute significantly to solid waste generation. Establishing a designated vendor zone equipped with proper sanitation and waste management infrastructure will streamline activities and reduce ecological pressure. Studies in urban lakefronts demonstrate that structured regulation of livelihoods can balance socio-economic benefits with ecological sustainability [14].

Integrated Health–Environment Monitoring Cell: A Health Environment Monitoring Cell should be established under the Municipal Corporation or State Wetland Authority to coordinate periodic water quality testing, mosquito breeding assessments, and epidemiological data tracking in lake-adjacent neighborhoods. The cell would ensure that environmental degradation indicators (e.g., BOD, algal blooms) are directly correlated with health outcomes, thereby facilitating evidence-based policymaking. Public dashboards summarizing such data can increase transparency and community trust [40].

Public Sanitation and Wastewater Infrastructure Upgrade: To prevent direct sewage inflow and reduce pathogen transmission risks, the rehabilitation of septic tanks, stormwater drains, and public toilets in lake-adjacent settlements must be prioritized. Introducing small-scale biotoilets and bio-digesters in informal colonies will help prevent human waste disposal into lake channels, improving both environmental and public health outcomes [41].

5.3 Long-Term Measures (3–5 years)

Restoration of Storage Capacity: Periodic dredging should be undertaken to desilt the lakes and restore their designed storage volumes. Desilting also reduces internal nutrient loading from sediments, thus lowering the risk of recurrent algal blooms [34]. Care must be taken to implement environmentally sensitive dredging protocols to avoid resuspension of contaminants.

Institutional Mechanism: Lake Management Committee: Establishing a multi-stakeholder Shahpura Lake Management Committee (SLMC)-with representation from municipal corporations, the State Wetland Authority, NGOs, academia, and local residents-would enhance coordination, accountability, and participatory decision-making. Collaborative governance models have been found to be critical for sustaining restoration gains in urban ecosystems [35]. A similar committee is recommended for Rani Tal, aligned with Jabalpur's urban planning framework.

Community Awareness and Citizen Science: Sustained awareness campaigns promoting eco-friendly religious practices-such as clay idol immersion in designated tanks-should be launched to minimize cultural pollution loads. In parallel, citizen-led water quality monitoring programs (using low-cost DO/BOD testing kits) can engage communities directly in stewardship [36]. Such participatory monitoring not only enhances data availability but also builds ownership among residents, ensuring long-term success of restoration initiatives.

Urban Health and Ecosystem Resilience Integration: Over the long term, both cities should integrate public health risk assessment within the urban lake management framework, aligning with national health missions and climate-resilient urban planning goals. Periodic health impact assessments (HIAs) can be institutionalized as part of environmental management plans, ensuring that restoration outcomes contribute to both ecosystem resilience and human well-being.

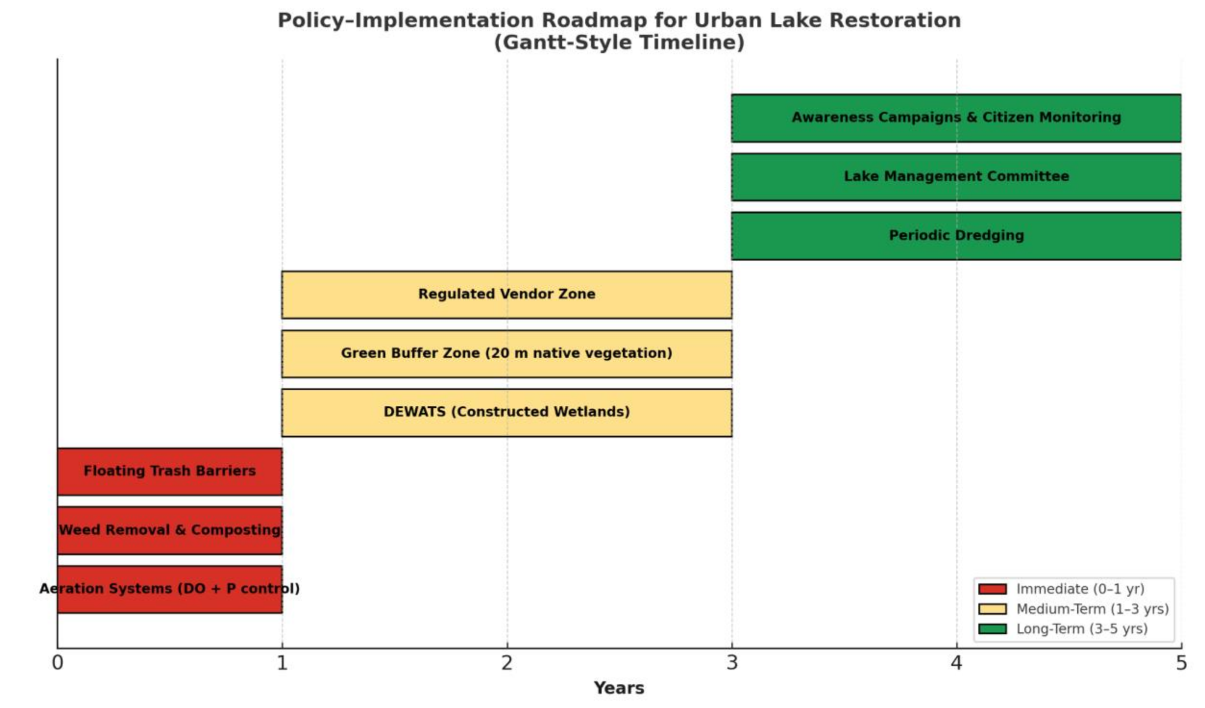
5.4 Integrated Perspective

The proposed measures emphasize the importance of multi-scalar interventions, where technical, ecological, institutional, and social dimensions converge. Immediate measures focus on rapid improvements to visible lake conditions, medium-term actions address systemic drivers such as sewage inflows and catchment degradation, and long-term strategies institutionalize governance and community participation. Together, these interventions align with global best practices for urban wetland restoration [9].

Table 4. Policy–Implementation Roadmap for Urban Lake Restoration (Rani Tal, Jabalpur & Shahpura Lake, Bhopal)

Timeframe	Intervention	Lead Agency / Stakeholders	Key Indicators of Success
Immediate (0–1 year)	Install dual aeration systems (floating fountains + ozonizers) at inflow points	Municipal Corporation (BMC/JMC), State Pollution Control Board (SPCB), Private contractors	Rise in DO (>4 mg/L), reduction in visible algal blooms within 6 months
	Mechanical removal of invasive water hyacinth and composting	Municipal Corporation, NGOs, local farmer cooperatives	Reduction of weed coverage by ≥70%, production of compost (tons/year)
	Deploy floating trash barriers at inflow drains	Municipal Corporation, EPCO, Local Resident Welfare Associations (RWAs)	Volume of intercepted waste (kg/month), improved shoreline cleanliness
Medium-Term (1–3 years)	Construct DEWATS (constructed wetlands, root-zone treatment) along major drains	Municipal Corporation, EPCO, State Wetland Authority, local engineering firms	% reduction in untreated sewage inflows; BOD <3 mg/L at lake inflows
	Develop 20 m green buffer zone with native vegetation	Town & Country Planning Dept., Forest Dept., EPCO, local schools/colleges (as plantation partners)	Area of buffer established (ha), reduction in bank erosion, increased bird/flora diversity
	Establish regulated vendor zone with waste facilities	Municipal Corporation, Urban Development Authority, vendor associations	% of vendors relocated to formal zone; % compliance with solid waste disposal
Long-Term (3–5 years)	Periodic dredging to restore capacity and reduce internal nutrient loads	Municipal Corporation, Irrigation Dept., SPCB, Expert consultants	Volume of silt removed (m^3), increase in storage capacity (%), drop in internal phosphorus load
	Establish Lake Management Committee (multi-stakeholder governance model)	Municipal Corporation, State Wetland Authority, NGOs, Academia, RWAs	Committee formed and operational, frequency of meetings, adoption of management plan
	Sustained awareness campaigns & citizen-led monitoring (eco-friendly idol immersion, water quality kits)	EPCO, NGOs, schools/universities, religious organizations	% idols immersed in designated tanks, number of citizen volunteers engaged, frequency of monitoring reports

Figure 4. Gantt Chart Timeline Showing the Policy Implementation Roadmap



CONCLUSION

The trajectories of Rani Tal in Jabalpur and Shahpura Lake in Bhopal are emblematic of the broader crisis facing urban lakes across India, wherein ecological decline is accelerated by unregulated urban expansion, untreated sewage inflows, inadequate waste management, and fragmented institutional governance. The integrated analysis presented in this study demonstrates that catchment degradation and unchecked domestic and industrial wastewater discharges are the principal drivers of deteriorating water quality, eutrophication, and biodiversity loss in both case study lakes. These findings corroborate previous research on the vulnerability of Indian urban wetlands to cumulative anthropogenic pressures [6, 7].

Despite these challenges, the results also underscore the significant restorative potential of a multi-scalar approach that integrates (i) in-lake ecological technologies (e.g., aeration, dredging, macrophyte management), (ii) catchment-scale interventions (e.g., decentralized wastewater treatment, green buffer zones), and (iii) community stewardship mechanisms (e.g., citizen-led monitoring, eco-friendly cultural practices). Such an integrated framework aligns with global best practices in wetland restoration, which emphasize combining technical remediation with governance reforms and participatory approaches [9, 34, 35].

Equally critical to the restoration agenda is the explicit recognition of the public health dimension associated with urban lake degradation. The findings from stakeholder surveys revealed a strong correlation between deteriorating water quality and rising incidences of vector-borne and waterborne diseases, including malaria, dengue, diarrhea, and skin infections, particularly among lakeside communities and informal settlements. Untreated sewage inflows, solid waste dumping, and stagnant eutrophic waters serve as active breeding grounds for disease vectors, directly impacting community health and livelihoods. These outcomes highlight that urban lake restoration must not be perceived solely as an ecological imperative but also as a public health necessity. Integrating health surveillance, improved sanitation infrastructure, and community sensitization into lake management frameworks would create co-benefits for both environmental sustainability and human well-being. Aligning ecological restoration with public health priorities thus represents a shift toward “healthy ecosystem planning”, in consonance with the World Health Organization’s ecosystem–health linkage paradigm and the UN-Habitat’s agenda for resilient, liveable cities [36, 37].

If implemented in a phased and participatory manner, as outlined in the proposed policy-implementation roadmap, these strategies could substantially improve the ecological health, resilience, and multifunctional services of Rani Tal and Shahpura Lake. Furthermore, the case study findings contribute to the development of a replicable model for urban lake restoration in India, one that balances ecological imperatives with socio-economic realities. Importantly, this model demonstrates that urban lakes, far from being liabilities, can be repositioned as critical natural assets-enhancing biodiversity, regulating urban hydrology, and improving quality of life for local communities.

In conclusion, the restoration of urban lakes requires moving beyond piecemeal beautification projects toward systemic, evidence-based interventions that integrate science, policy, and community participation. If adopted widely, such an approach could play a transformative role in reversing the decline of India's urban aquatic ecosystems and in advancing national and global commitments to sustainable urban development and biodiversity conservation [37, 38].

REFERENCES

1. Wetzel, R. G. (2001). Limnology: Lake and river ecosystems (3rd ed.). Academic Press.
2. Dodds, W. K., & Whiles, M. R. (2020). Freshwater ecology: Concepts and environmental applications of limnology (3rd ed.). Academic Press.
3. Moss, B. (2017). Freshwater ecology: Principles and applications. Wiley-Blackwell.
4. Horne, A. J., & Goldman, C. R. (1994). Limnology (2nd ed.). McGraw-Hill.
5. Ramakrishnan, R., Kumar, P., & Sharma, A. (2021). Urban wetlands as climate resilience infrastructure in India. Journal of Environmental Planning and Management, 64(11), 2013–2031.
6. Kumar, M., & Sharma, A. (2020). Urban wetland management in India: A review. Environmental Challenges, 1, 100004.
7. Singh, S., Kumar, M., & Sinha, R. (2022). Degradation and conservation of urban wetlands: An Indian perspective. Wetlands Ecology and Management, 30(5), 1045–1062.
8. Verma, R. (2008). Conservation of lakes in urban areas: Problems and prospects. Journal of Environmental Research and Development, 3(1), 145–152.
9. Millennium Ecosystem Assessment (MEA). (2005). Ecosystems and human well-being: Wetlands and water synthesis. World Resources Institute.
10. Davidson, N. C. (2014). How much wetland has the world lost? Marine and Freshwater Research, 65(10), 934–941.
11. Kumar, R., Sharma, M. P., & Sharma, S. (2018). Impact of urbanization on water bodies: A case study of Delhi, India. Environmental Earth Sciences, 77, 112.
12. Khan, A., Gani, K. M., & Lone, F. A. (2014). Anthropogenic impacts on water quality of Lidder River in Kashmir Himalayas. Environmental Monitoring and Assessment, 186(6), 3723–3732.
13. Tare, V., Sharma, S., & Kumar, A. (2017). Integrated management of urban lakes: Case studies from India. Environmental Management, 60(6), 1005–1018.
14. Sharma, S., Tare, V., & Kumar, A. (2019). Challenges and opportunities in restoring urban lakes in India. Current Science, 116(11), 1835–1843.
15. Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27.
16. Trivedi, R., Bajpai, S., & Pathak, R. (2020). Impact of idol immersion on water quality of lakes: A case study from Central India. Environmental Monitoring and Assessment, 192(11), 703.
17. Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). Sage Publications.
18. Munoth, N., Nagaich, A. (2015). Planning Interventions for Lake Conservation: A Case of Shahpura Lake, Bhopal, India. J. Inst. Eng. India Ser. A 96, 193–205. https://doi.org/10.1007/s40030-015-0127-x
19. Tashakkori, A., & Teddlie, C. (2010). SAGE handbook of mixed methods in social & behavioral research (2nd ed.). Sage Publications.
20. Lillesand, T., Kiefer, R. W., & Chipman, J. (2015). Remote sensing and image interpretation (7th ed.). Wiley.
21. Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual Review of Ecology and Systematics, 32, 333–365.
22. Weng, Q. (2012). Remote sensing of impervious surfaces in the urban areas: Requirements, methods, and trends. Remote Sensing of Environment, 117, 34–49.
23. Kvale, S., & Brinkmann, S. (2015). InterViews: Learning the craft of qualitative research interviewing (3rd ed.). Sage Publications.
24. Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. Biological Conservation, 141(10), 2417–2431.
25. Young, O. R. (2013). On environmental governance: Sustainability, efficiency, and equity. Routledge.
26. CPCB. (2022). Water quality status of lakes and wetlands in India. Central Pollution Control Board.
27. Villamagna, A. M., & Murphy, B. R. (2010). Ecological and socio-economic impacts of invasive water hyacinth (Eichhornia crassipes): A review. Freshwater Biology, 55(2), 282–298.
28. Fletcher, T. D., Andrieu, H., & Hamel, P. (2013). Understanding, management and modelling of urban hydrology and its consequences for receiving waters: A state of the art. Advances in Water Resources, 51, 261–279.
29. Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2014). Wastewater engineering: Treatment and resource recovery (5th ed.). McGraw-Hill.
30. Gopal, B. (1987). Water hyacinth. Elsevier.
31. UNEP. (2021). Preventing plastic waste in aquatic environments. United Nations Environment Programme.

32. Kadlec, R. H., & Wallace, S. D. (2009). Treatment wetlands (2nd ed.). CRC Press.
33. Mayer, P. M., Reynolds, S. K., McCutchen, M. D., & Canfield, T. J. (2007). Meta-analysis of nitrogen removal in riparian buffers. Journal of Environmental Quality, 36(4), 1172–1180.
34. Cooke, G. D., Welch, E. B., Peterson, S., & Nichols, S. A. (2005). Restoration and management of lakes and reservoirs(3rd ed.). CRC Press.
35. Ostrom, E. (2015). Governing the commons. Cambridge University Press.
36. Buytaert, W., Zulkafli, Z., Grainger, S., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. Frontiers in Earth Science, 2, 26.
37. Ramsar Convention Secretariat. (2018). Global Wetland Outlook: State of the world's wetlands and their services to people. Gland, Switzerland.
38. UN-Habitat. (2020). World cities report 2020: The value of sustainable urbanization. United Nations Human Settlements Programme.
39. WHO. (2021). Connecting global priorities: Biodiversity and human health – A state of knowledge review. World Health Organization.
40. Buytaert, W., Zulkafli, Z., Grainger, S., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. Frontiers in Earth Science, 2, 26.
41. Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., & Zurbrügg, C. (2014). Compendium of sanitation systems and technologies(2nd ed.). Swiss Federal Institute of Aquatic Science and Technology (Eawag).