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URBAN WATER BODY RESTORATION FOR DELHI-NCT A REVIEW OF DECLINE TO REVIVAL

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Abstract

Water bodies play a very crucial role in urban ecosystems. They are used to replenish the groundwater, control the microclimate, and sustain biodiversity and are used in social and cultural environments. In NCT of Delhi, numerous traditional lakes, ponds, and wetlands have been degraded over the last decades. This has mostly been a result of urbanization, sewage discharges, and the fact that institutions have not made efforts to restore it. This review examines the previous research available with field observations and geospatial analysis to examine the challenges and opportunities in the restoration of these water bodies. It brings out three general categories of interventions. The first is engineered measures through desilting and wastewater diversion. The second is concerned with ecological approaches, such as bioremediation and rejuvenation of wetlands. The third focuses on the practices of community-related practices, which are based on local involvement. The paper also focuses on governance and policy issues besides technical solutions. It also consists of duplication of duties between agencies and lax enforcement in Delhi. The research proposes better legislative clarity, institutional collaboration, participation in governance, and climate-sensitive planning. It concludes that managing the water bodies of Delhi would continue to be a challenge unless the ecological processes, the modern technology, and reforms in governance are integrated. A community-based framework is suggested as an effective measure to coordinate local restoration with larger Sustainable Development Goals.

***Keywords**: Wetlands; Geographic Information Systems (GIS); Remote sensing; Decision Support Systems; Water governance; Urban Lake management*

Introduction

Urban water bodies (e.g., lakes, ponds, wetlands, tanks, and reservoirs) are an integral part of urban ecosystems, which provide important ecosystem services such as groundwater recharge, flood mitigation, microclimate regulation, sustaining biodiversity, and being used as social and cultural environments [1], [2]. Due to anthropogenic activity, this ecosystem has declined globally. Rapid urbanization, pollution, and hydrological change [3], [4] result in the loss of more than 60% of wetlands since 1900. Increased wetland loss results in ecological problems for cities such as São Paulo, Lagos, and Beijing, which include more frequent flooding, heat islands, and water shortages [5], [6]. These patterns highlight the importance of restoration of these ecosystems on the global scale. In many developing countries, water bodies also serve as dumping grounds for untreated sewage, industrial effluents, and solid waste [7], [8], [9]. This has turned urban lakes into pollution

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sinks, reducing their ecological services and exposing residents to health risks [10]. In Bengaluru, lakes such as Bellandur and Varthur have become a symbol of environmental mismanagement, producing highly toxic froth and even catching fire [11], [12].

Delhi-NCT (National Capital Territory) is experiencing this challenge in a very severe form. Official records list more than 1,000 water bodies in Delhi. However, 40% are encroached upon, polluted by sewage, or converted into parks and other non-functional land uses. Its increasing dependence on Yamuna, Delhi's main source of surface water, increased pressure on the system [13]. Much of the flow of water in the river during dry months consists of untreated or very lightly treated wastewater [7]. At the same time, fast urban development, indiscriminate use of land, and overexploitation of groundwater have disturbed natural hydrology. Fragmented governance prevents restoration efforts from moving at an effective pace and being consistent. All these factors combined make Delhi an important case for looking at models of restoration, connecting engineering solutions, ecological approaches, and community involvement in a stronger and more coherent policy framework [14], [15].

Considerable research has been carried out on urban water bodies in Delhi, but most studies focus on isolated issues rather than the restoration process. There is limited literature that combines engineering solutions, ecological restoration, geospatial technologies, governance, and decision-support methods within a single framework. This review brings these different aspects together to provide a comprehensive understanding of urban water body restoration and to support sustainable management in Delhi-NCT.

Area of Study

The area of study involves the National Capital Territory (NCT) of Delhi. Fig. 1 draws attention to the administrative boundary of the NCT of Delhi and the spatial presence of water bodies for the area of study.

The NCT of Delhi has an area of around 1,483 km² [13]. The study area is under a semi-arid climate, extremely hot in summer, cold in winter, and the normal rainfall in monsoon is 600–700 mm per year [13], [14]. Delhi has two rivers, Yamuna and Sahibi, where the Yamuna River forms the main surface water system [15]. There are several lakes, ponds, wetlands, and stepwells, including Najafgarh Jheel, Bhalswa Lake, Hauz Khas Lake, and Sanjay Lake, which are important ecological and cultural assets [16]. However, rapid growth of population, unplanned growth of urban areas, industrial effluents, and encroachment have caused severe deterioration of many of these water bodies [12], [17]. This makes Delhi-NCT an ideal case for analyzing the challenges for the restoration and rejuvenation of urban water bodies. For this study, urban water with at least 0.1 ha area and greater than 1-meter depth supporting hydrological and ecological functions has been considered. This comprises lakes, ponds, wetlands, tanks, and reservoirs in the Delhi-NCT region. The primary source of water to these water bodies is water from rainfall and wastewater treated in some cases [18]. Groundwater plays a major role in floodplain wetlands such as Najafgarh Jheel; upland lakes such as Hauz Khas, however, depend primarily on monsoon and man-made channels to get their water. This classification, as illustrated in Table 1, is helpful in defining the nature of the water bodies under study and ensuring that restoration strategies are understood in their appropriate hydrological setting.

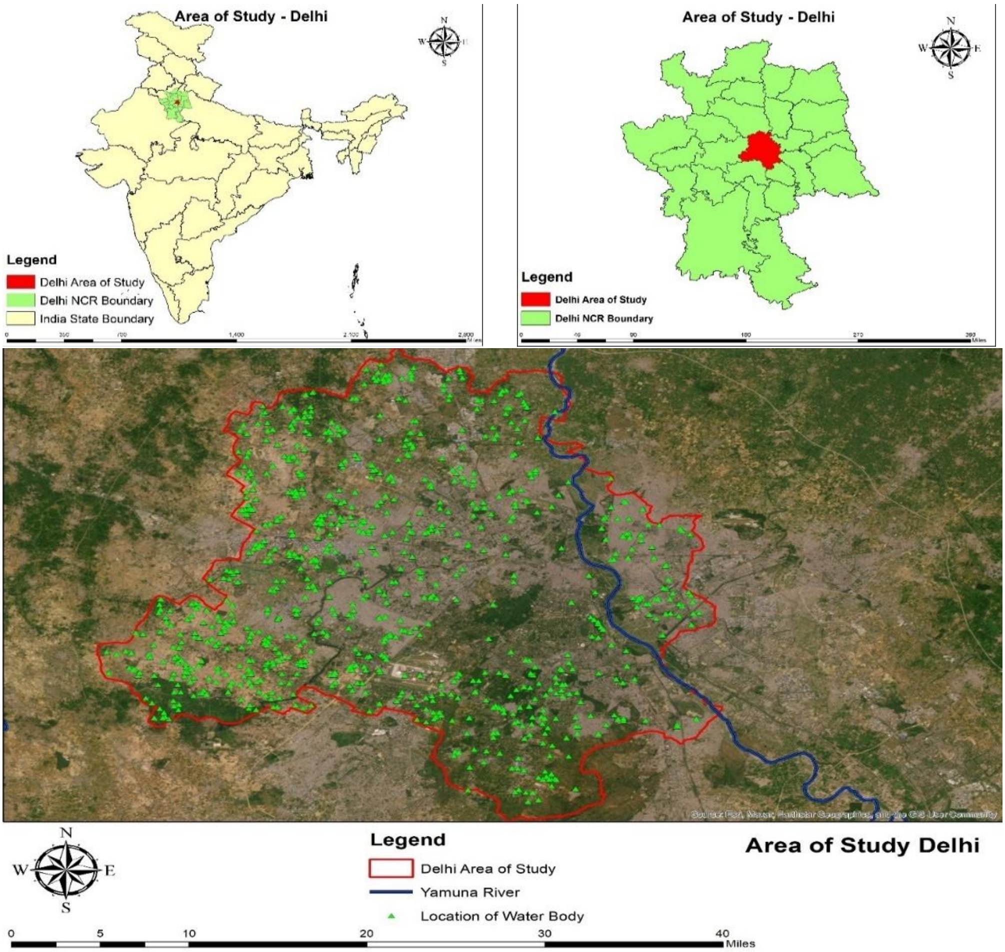

Fig. 1. Area of Interest – Delhi showing listed water bodies on Satellite Imagery

Table 1. Classification of Urban Water Bodies in Delhi-NCT Based on Hydrologic Connectivity, Dominant Drivers, and Restoration Priority

Type of Water Body	Connectivity	Dominant Hydrologic Driver	Restoration Priority
Isolated urban pond	None	Rainfall	Medium
Semi-connected wetland	Stormwater drains	Rainfall + treated wastewater	High
Floodplain wetland	Groundwater-linked	Rainfall + aquifer interaction	High
Heritage stepwell (Baoli)	Groundwater recharge	Aquifer + occasional rainfall	Medium

Methodology

The research design comprises literature review, policy documents, and GIS information to grasp the situation regarding the restoration of urban water bodies. All articles were incorporated in which they were talking about degrading, restoring, or monitoring of urban water bodies from global or Indian perspectives. The chosen literature was further classified into four overriding themes:

- Approaches based on engineering,
- Ecological and naturalistic measures
- Community and governance models, and
- Remote sensing, GIS, dashboards, and Multi-Criteria Decision Analysis (MCDA) for monitoring and decision support.

The water bodies were categorized according to the hydrological connectivity as the following:

- Isolated ponds, which rely solely on rainfall.
- Wetlands connected to the stormwater drains.
- Basins affected by groundwater are found in floodplain regions.

This classification gave a clear-cut idea to find the right approach to the restoration of each type of water bodies. The use of isolated ponds was observed to necessitate the following steps: harvesting of rainwater and building of buffer zones. Although semi-connected wetlands received the advantage of better inlet-outlet control and avoidance of wastewater in their catchments. Connected basins, on the contrary, necessitated interventions that would stimulate the recharge of aquifers and reduce pollution. The priorities on restoration were then set by evaluating the socio-ecological importance and susceptibility of every water body. The research proposed the analysis of the inventory of 1,009 water bodies observed by the Delhi Parks and Gardens Society in 2020–2024 [19] and the determinations of the Central Pollution Control Board [20] and Central Ground Water Board [21] regarding the quality and depletion of groundwater [22]. There are also case studies describing restoration projects in places like Hauz Khas Lake, Najafgarh Jheel, Prasad Nagar Lake, and some parts of the Yamuna floodplain that were analyzed [23], [24], [25]. Besides this, a policy analysis was also done to trace the current legal framework in India to its more detailed international counterparts [26], [27]. This research is based on secondary data; the combination of different sources and the use of geospatial analysis provide a general and policy-applicable insight on the restoration of urban water bodies in Delhi NCT.

Status and Challenges of Urban Water Bodies

Delhi has a unique urban water crisis wherein the water bodies are dried for water in summer and are flooded in Monsoon [28], [29]. The Yamuna River supplies most of the water into the region, with the river bringing 76% of the yearly water during the monsoon period [30]. The flow of the river is, however, very seasonal. Eighty percent of the Delhi stretch is comprised of untreated or partly treated wastewater in dry season [20]. There is a list of 1,009 water bodies in the city (according to the Delhi Parks and Gardens Society, 2020–2024). Among them, about 18% are fully or partly encroached, 11% comprise polluted or stagnant water, 9% have been turned into parks, and 4% are non-traceable, which remains 58% with defined catchments [19]. The groundwater situation in Delhi is also disturbing. In Delhi, there are over 4,200 tube wells and over 12 Ranney wells in operation [31]. This has caused a reduction in the water level in the whole city, down to 2 m bgl in the Yamuna floodplain to about 70 m bgl in south and central Delhi [21]. Moreover, it is also worsened by salinity and high concentrations of fluoride, nitrate, heavy metals, and uranium in deeper aquifers [32].

Rapid urbanization and encroachment have changed the pattern of land use of catchment areas that resulted in reduced water inflows and shrunk water bodies [2], [5], [28]. The pollution load from the discharge of untreated sewage and industrial waste, along with solid waste disposal into lakes and rivers, has severely degraded water quality [7], [29]. Over-extraction of groundwater for irrigation and domestic purposes has lowered aquifer levels, resulting in an imbalance between recharge and extraction [17], [22]. Water body recharge is mostly dependent upon the rainfall only [3], [30]. Changing climate results in erratic monsoons that have reduced natural recharge [4], [22].

Deterioration of the urban water bodies in Delhi has resulted in ecological, hydrological, socio-economic, and cultural impacts. Ecologically, the shrinking of the lakes and wetlands has subdivided migratory birds, fish, and aquatic vegetation habitats, leading to a quantifiable decline in biodiversity [5], [31]. The hydrological aspect of the loss of recharge areas has reduced the supply of groundwater and increased the risk of flooding in periods of heavy rainfall [2], [22]. This has impacted public health since there is an increased risk of waterborne diseases since the contamination of surface and groundwater sources increases the risk [9], [29]. The loss of traditional water structures, lakes, and stepwells also marks a real loss of cultural heritage that previously served to root the life of the community [1], [32]. In economic terms, diminishing water resources have undermined semi-urban agricultural benefits and ecotourism and associated livelihood prospects [2], [33]. These problems must be incorporated to restore and have stronger governance [8], [27].

Best Practices of Restoration

Most water bodies in the urban areas are prone to various problems such as siltation, encroachment, and pollution in the fast-developing urban areas [5], [12]. Consequently, restoration and rejuvenation have become a key aspect of the current environmental governance [8], [18], [27]. The process of restoration is aimed at restoring ecosystems to their original state, whereas the rejuvenation process is aimed at restoring the lost functions with the help of engineering, ecological, and social means. The achievement of effective restoration is also implied by case studies that propose the efficiency of engineering-based, ecological, and community-driven approaches [10], [12].

Engineering Approaches

De-silting and De-weeding

In lakes and ponds, accumulation of sediment and growth of weeds results in reduction of storage capacity and water quality. Regular desilting at continuous intervals improves the water retention capacity and water quality [23]. Removal of floating vegetation enhances the oxygenation process and prevents eutrophication [23], [34]. These combined efforts are important for maintaining healthy aquatic systems [23]. For example, in the Hauz Khas Lake in Delhi, de-silting and specific eradication of invasive species like water hyacinth improved the water flow and enhanced the overall ecological performance [35]. Eradication of algal blooms is a regular activity for sustaining the dissolved oxygen concentration of Hauz Khas Lake, as depicted in Fig. 2.

Fig. 2. Prevention of Algal bloom that covers the surface of Hauz Khas Lake, New Delhi, indicating nutrient enrichment and eutrophication, 2025

Hydraulic Interventions and Inlet/Outlet Management

The water bodies in the urban areas of Delhi lack the natural inflows and outflows, which cause stagnant water and eutrophication. Constructing inlet and outlet channels, diversion structures to supply treated water, and other engineering solutions are useful towards restoration of hydrological connectivity and stability. Fig. 3 shows that a lack of outlet channels that are designed in the urban water body of Delhi will lead to overflow water that is bigger than the catchment area. Recent articles indicate that engineered water diversion and ecological design are associated with better water quality and greater resilience to pollution and climate variability [23], [36]. Such methods are being incorporated into the process of restoring the water bodies within the Indian cities, such as Delhi [12]. One of the keys to rejuvenation can be regulation of entry of wastewater into the water bodies by means of ensuring that there are treated inflows [36].

Fig. 3. Field Verification: Water body before and after flooding

Wastewater Treatment and Diversion

A large portion of the water flowing to lakes and other water bodies in Delhi comes from untreated sewage. This worsens the quality of water. Biodigesters, constructed wetlands, and decentralized wastewater treatment systems (DEWATS) are acknowledged as the sustainable means of solving this issue. These systems treat sewage during its generation and contribute to preventing nutrients prior to the wastewater entering the natural water bodies [36], [37], [38]. They lower key pollution indicators such as biochemical oxygen demand (BOD) and suspended solids using nature-based or hybrid technologies [36], [37]. They help in enhancing larger ecological roles, as well. The latest strategies in the restoration of the Yamuna floodplain in Delhi are more focused on the reuse of treated wastewater. These involve groundwater recharge and irrigation using treated wastewater, which reduces the pollutant load entering the Yamuna while supporting the water demands of peri-urban agriculture [39].

Aeration and Circulation Devices

Diffused air systems, surface fountains, and circulation pumps are artificial aeration technologies that have been demonstrated to enhance the proportion of dissolved oxygen in stagnant urban lakes. They are applicable to restrict algal growth and foul odors, which is why these methods could be effective means of lake restoration [12], [40]. Aeration facilitates better oxygen delivery and water mixing, through which healthy aquatic ecosystems are favored, and organic matters are faster to break down [40]. Such interventions have been successfully done in Delhi. As an illustration, water quality has improved (measurably) in the case of installing floating aerators (Fig. 4) in Prasad Nagar Lake. This has also enhanced trust in local restoration efforts by the communities [21].

Fig. 4. Floating Aerator, Prasad Nagar Lake, New Delhi, 2025

Ecological and Nature-Based Approaches

Wetland Development and Bioremediation

Constructed wetlands are being considered as a viable, nature-based remedy, which depicts a natural process. They utilize aquatic vegetation, soil–water interactions, and microbial ecosystems in the treatment of wastewater and ecological restoration [35], [36]. In addition to enhancing water quality, they recharge groundwater, reduce flooding, and provide habitats for flora and fauna, thereby increasing urban resilience [35], [36]. In Delhi, the creation of wetlands such as the Yamuna Biodiversity Park demonstrates how wetland creation can be integrated with ecological restoration. It also improves water quality, supports migratory bird habitats, and strengthens community participation [41].

Plantation and Buffer Zone Creation

The use of green belts and vegetated buffer zones around catchments of lakes is a known nature intervention strategy used to prevent soil erosion. It removes nutrients and heavy metal pollutants and controls the microclimates on the local level [42], [43]. The buffers also promote carbon sequestration, reduce urban heat island effects, and provide ecological corridors that aid biodiversity conservation in urban landscapes [2], [31], [42]. Analysis of Delhi restoration work around Sanjay Lake and Hauz Khas Lake is an example of how vegetated buffers not only enhance water quality and habitat conditions of migratory species but also improve the cultural and recreational value of the lakes, thereby contributing to community well-being.

Bio-remediation Techniques

Bioremediation is quite an economical and sustainable means of eliminating nutrients and reducing heavy metals in the polluted urban water bodies [44]. These biological processes are based on synergistic reactions of bacteria and other organisms, such as fungi, algae, and aquatic macrophytes, to disintegrate organic matter. It immobilizes toxic metals and restores dissolved oxygen concentration [44]. In Delhi, bioremediation has been suggested to be used in Yamuna tributaries by microbiological means to decrease biochemical oxygen demand (BOD) and increase self-purification capacity [20], [38]. In this case phytoremediation with Phragmites australis and Eichhornia crassipes species has demonstrated good performance in the extraction of heavy metals and surplus nutrients in the lakes fed with wastewater [45].

Linking Water Bodies for Hydrological Continuity

One of the most useful interventions in the restoration of water bodies in the city is hydrological connectivity between isolated ponds and lakes [46]. These types of interconnections can restore natural hydrological processes, enable water flows, and prevent stagnation and eutrophication [40], [46]. The fact that the connection between stagnant ponds and Yamuna tributaries and stormwater channels could ensure a perennial water supply, groundwater recharge, and seasonal drying inhibition has been emphasized by drainage mapping of the area using GIS [28], [46]. Re-establishment of hydrological connectivity in other cities in the world, e.g., Shanghai and Bangkok, has demonstrated that restoring connectivity improves water quality, flood management, and biodiversity conservation [47].

Community-Based and Participatory Approaches

Public participation is one of the keys to successful execution of ecological restoration projects [49]. In Delhi, local villagers from Pochanpur support the Delhi Development Authority for effective restoration of water bodies [12]. This was done by rainwater harvesting, planting trees, and community-led cleanup drives. Environmental awareness campaigns during cultural events, including idol immersion during festivals, have helped to reduce activities that can potentially harm water bodies [49]. NGOs across Delhi-NCT—including the Indian National Trust for Art and Cultural Heritage

(INTACH)—have launched efforts supported by residents to clear silt, manage solid waste, and protect regional flora and fauna. This type of local event brings lasting impact that emerges more often when community leaders and governance support the same [49]. Traditional water bodies such as stepwells (baolis), Johads (village ponds), and tanks are common in villages across Delhi [1]. Restoration and rejuvenation of these traditional water bodies bring affordable and environmentally friendly solutions for residents [1], [26]. By reviving these structures, two objectives can be achieved: bringing the Baoli back to its functioning and preserving its heritage value [1].

Case Studies of Restoration Efforts

In Delhi, the restoration of Hauz Khas Lake serves as an example of planned restoration that can help to revive the water body. The project activity included desilting, an inlet for treated water, buffer vegetation planting, and the installation of aeration systems. As a result of the interventions, there was improvement in water quality and its circulation. They also improved bird diversity and enhanced the recreational value of the lake [50]. Najafgarh Jheel is one of the largest wetlands in Delhi, where a similar approach was adopted. Restoration efforts were focused on diverting untreated sewage and designing controlled inflow channels [51]. This case highlights the importance of integrating hydrological improvement with community engagement to promote long-term ecological resilience [48].

Globally, the Cheonggyecheon Stream restoration in Seoul, South Korea, is widely regarded as a benchmark restoration project. In this project concrete barriers were removed, native riparian vegetation was replanted, and accessible green space was created, which improved biodiversity and helped mitigate the urban heat island effect [52].

A similar rejuvenation project was executed for Bellandur Lake in Bengaluru. It does not meet its restoration objectives despite the installation of sewage treatment plants and aeration systems. The lake is severely polluted and exhibits toxic foaming on the water surface [53]. Hence, learning from successful similar projects, continuous monitoring by nodal agencies along with support from residents is needed to make this project a key example of success.

Best Practices and Lessons Learned

According to research conducted in cities around the world, including Delhi, fragmented restoration efforts or poorly coordinated efforts usually do not yield any type of outstanding result [12], [48]. For example, supplemental work done on siltation alone would only provide short-term relief without having attached ecological buffers to remediation efforts [34], [42]. However, successful restoration projects have combined engineered solutions with ecological restoration and active community participation [35], [49]. An example of this would be the use of Decentralized Wastewater Treatment Systems (DEWATS) used near water bodies, which have been shown to reduce the inflow of untreated sewage to receiving bodies, leading to decreased organic and nutrient loadings, subsequently producing healthy aquatic ecosystems [37], [39]. Similarly, local communities can provide the most benefit by being involved in long-term monitoring and protection of restored sites [48], [49].

Long-term sustained efforts will occur when the public has been engaged and properly empowered through ownership of the restoration process [49]. One additional thing that should be done to ensure the restoration initiative will succeed is that initiatives should be embedded within an overall coherent policy and governance framework to facilitate inter-agency coordination and to help avoid any conflicts created by overlapping mandates [8], [18]. In addition, for restoration outcomes to last long-term, it is critical to continuously monitor and adaptively manage restoration projects. Some of the tools can be used to effectively track restoration projects, including GIS, remote sensing, and IoT (sensors) for real-time tracking of water quality [28], [54]. These technologies support informed decision-making and help ensure the long-term viability of restoration efforts [54].

Monitoring and Assessment Frameworks

Monitoring structures play an important role in monitoring the efficiency of restoration activities and their sustainability in the future [49]. Historically, the monitoring of urban water bodies has been maintaining manual surveys and periodic sampling of water quality [29]. On the one hand, these methods are quite handy, but in most cases, they lack scale, frequency, and objectivity. The recent developments in remote sensing, geographic information systems, and spatial analytics present a scalable and replicable framework for monitoring urban water bodies on a large-scale basis [28], [55].

Conventional Monitoring Approaches

Traditional evaluation of both urban lakes and ponds is done using the three primary categories of parameters: physical, chemical, and biological [29], [56]. Surface area, depth, and rate of sedimentation are physical parameters. Such measurements are used to determine the structural condition of the water body [40]. Chemical indicators used to measure water quality and pollution include dissolved oxygen (DO), biochemical oxygen demand (BOD), and nutrients (nitrates and phosphates) [7], [9]. The biological metrics employed are phytoplankton density, fish diversity, and the abundance of aquatic macrophytes [31], [34]. The Yamuna River in Delhi is one example where the Central Pollution Control Board (CPCB) monitors the river. It checks the concentration of DO, BOD, and coliforms at key sites according to national monitoring protocols [7]. These efforts, however, often produce fragmented and site-specific datasets, making comprehensive analysis difficult [28], [55]. This should be improved in a more integrated manner. Monitoring and management can be made easier through a geospatial structure that integrates the physical, chemical, and biological data [28], [56]. It can also improve policymaking in restoration of water bodies in urban areas [56].

Remote Sensing and Geographical Information System Based Monitoring

Geographic Information Systems (GIS) and remote sensing have become indispensable tools for monitoring urban hydrological properties. Their ability to provide sustained, synoptic, and temporally resolved process information about water extent, quality, and catchment processes makes them invaluable in modern-day city water management [28], [55]. In the National Capital Territory of Delhi, the remotely sensed data collected on the Landsat, Cartosat, and Sentinel platforms have been used with significant regularity to record the changes in surface water distribution, turbidity, vegetative cover, and catchment characteristics [57]. Spectral indices like the Normalized Difference Water Index (NDWI) and the Modified Normalized Difference Water Index (MNDWI) are normally used to map the water extent and surface dynamics based on their ability to support accurate differentiation of aquatic surfaces from built-up and vegetated areas [58], [59].

A multi-temporal study of the ponds in the city of Delhi between 2000 and 2025 has shown severe shrinkage due to intrusion, sediment deposition, and changes in hydrological connectivity. In addition to simple mapping of water extent, remote sensing provides robust proxies for evaluating water-quality parameters. Spectral reflectance allows estimation of chlorophyll-a, suspended sediment concentration, and algal bloom intensity, enabling monitoring where field sampling is difficult [55], [57]. These methodologies are increasingly useful for identifying eutrophication hotspots and prioritizing restoration interventions in urban lacustrine systems.

Like spectral monitoring, GIS analyses of catchments and land-use/land-cover (LULC) patterns complement the understanding of anthropogenic pressures [28], [57]. In places like Dwarka, overlay studies have revealed large proportions of impervious surfaces, reduced infiltration rates, and consequently increased hydrological pressure on urban water bodies. Together, remote sensing and GIS represent an integrated monitoring system incorporating hydrological, ecological, and socio-spatial perspectives [55], [57]. Their integration is crucial for sustainable rehabilitation of urban aquatic ecosystems and evidence-based policymaking. The monsoon floods the water bodies at Dwarka, Sector 23, as presented in Fig. 5. This can be monitored using satellite imagery and verified in the field. The concerned authorities can use pre- and post-monsoon images to regulate water inlets and outlets and thus reduce the likelihood of flooding.

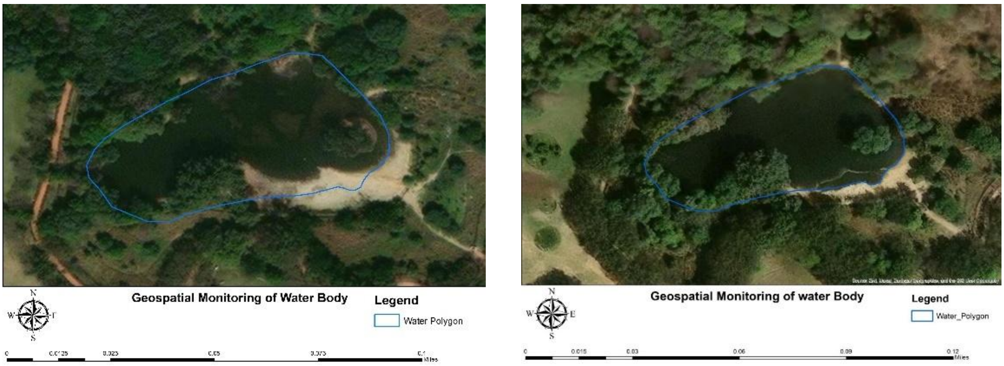

Fig. 5. Geospatial Monitoring of Water Body Using High-Resolution Satellite Imagery (Before and After Monsoon)

Multi-Temporal Change Detection

Change detection methods are an instrument that has gained significant use in urban environmental science to assess degradation and restoration of urban water bodies through time-series analysis [28], [60]. Temporal satellite archives enable accurate determination of long-term ecological shifts. A good example is the Roshanara Lake in Delhi, which was totally dried up between 2000 and 2020, indicating the rapid loss of urban wetlands. On the same note, the encroachment of built-up areas into the Yamuna floodplains has significantly reduced vital buffer zones during recent decades [19], [20]. The seasonal changes in lake volumes, which are closely associated with monsoon cycles, also contribute to the vulnerability of these ecosystems to climate variability and anthropogenic pressures [4], [30].

The methodological developments that have taken place in the recent past have significantly increased the accuracy of change detection in water bodies. Classical machine-learning models such as Random Forest (RF) and Support Vector Machine (SVM) are more effective than conventional pixel-based classification approaches, especially in complex urban environments [61]. In research carried out in the Marmara Lake area (Türkiye), it was established that RF applied to Sentinel-2 imagery resulted in the highest classification accuracy even with limited training samples [62]. These methods not only improve spatial accuracy but also provide effective frameworks for monitoring urban water bodies under increasing anthropogenic and climatic pressures [55], [61].

Restoration Effectiveness Evaluation

The assessment of restoration initiatives requires a pre- and post-restoration comparison of the conditions using indicators that can be measured and compared in a systematic manner [29], [31]. The important parameters include the surface area (since desilting increases storage capacity) and the improvement in water quality, as demonstrated by increased dissolved oxygen and reduced nutrient loads [7], [29]. Biodiversity restoration is also observed, for example, through the return of migratory birds or the reappearance of native fish [31]. One such case is the Hauz Khas Lake, where collaborative use of satellite-based analyses and field sampling showed that surface area and vegetative health improved after restoration [50]. Equally, in Najafgarh Jheel (Fig. 6), wastewater diversion and treatment led to increased wetland vegetation, demonstrating the ecological advantages of the management interventions [51]. These cases highlight that the combination of remote sensing and ground-based ecological surveillance provides a powerful framework for evaluating restoration effectiveness and guiding future restoration efforts [28], [55].

Recent developments in remote sensing have further strengthened restoration monitoring. Integrated assessment frameworks combining spatial and temporal indicators have enabled comprehensive evaluation of physical structure, water quality, shoreline processes, watershed characteristics, and ecosystem services [28], [55]. Furthermore, advances in machine learning, deep learning, and GIS have significantly improved the accuracy and efficiency of spatial data analysis [61], [62]. These computational approaches reduce the challenges associated with high-dimensional datasets, improve pattern recognition, and enable more responsive, accurate, and scalable restoration monitoring systems [61], [62].

Fig. 6. Najafgarh Jheel, Enhanced wetland vegetation and supporting Biodiversity, 2025

Decision-Support Systems

The most promising development in urban water management has been the integration of GIS-based decision support tools that enable evidence-based prioritization of restoration efforts [63]. Based on multi-criteria decision analysis (MCDA), these tools combine ecological, hydrological, and socio-economic parameters for evaluating water bodies [63]. Ecological parameters such as biodiversity richness, vegetation cover, and habitat value are integrated with hydrological parameters including catchment area, inflow–outflow processes, and groundwater recharge capacity. Socio-economic determinants such as community dependence, recreational amenities, and cultural significance are also incorporated because they directly influence the long-term sustainability of restoration projects [48], [63]. Hierarchical weighting methods such as the Analytic Hierarchy Process (AHP) enable decision-makers to prioritize water bodies for restoration in a transparent, evidence-based, and impact-oriented manner [64]. This integrative approach not only reduces subjective decision-making but also improves accountability and cross-sectoral coordination in urban water governance [8], [27], [64].

Validation and Ground Truthing

As well known in current remote-sensing literature, satellite-based indices are among the most effective tools for observing hydrological characteristics at large spatial scales [55], [58], [59]. Their usefulness, however, depends on rigorous field validation to determine accuracy and reliability [65]. The traditional method of ground-truthing is through accurate GPS mapping whereby the spatial extents of aquatic features are measured and compared against satellite-derived polygons [65]. An expanding alternative is based on unmanned aerial vehicles (UAVs), which provide high-resolution spatial and temporal data that are especially useful in otherwise inaccessible landscapes [65]. Field validation also requires systematic sampling of aquatic chemistry, including measurements of pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), and trace metal concentrations, as these are primary indicators of water quality [7], [9], [29]. When combined with satellite observations, these empirical measurements provide a robust geospatial analytical framework for scientifically based decision-support models, thereby improving the management of urban water bodies [28], [55], [65].

Towards a Digital Dashboard for Stakeholders

A digital geospatial dashboard can be used as a dynamic central repository that integrates different sets of datasets [28], [55]. It can include real-time water-quality measurements, temporal maps showing changes in water bodies, and restoration indicators [55], [65]. These platforms have already been successfully implemented in European cities as pilot projects for wetland and urban water management [27], [33]. This demonstrates that Information and Communication Technology (ICT)-enabled tools can bridge scientific information with public participation [48], [49]. Dashboards can enhance transparency and citizen participation by providing easily accessible visualizations and open data [48]. They enable communities to monitor restoration outcomes and promote environmental stewardship [49]. Adapting this model to the Delhi-NCT context would align with the Smart Cities Mission in India by promoting technology-enabled environmental governance and participatory planning [19], [26].

Policy and Governance Dimensions

The process of restoration of water bodies is not merely a technical activity but requires sound policy support and effective governance mechanisms [8], [26]. Although engineering and ecological interventions may deliver immediate benefits, their long-term sustainability depends on clear regulations, institutional coordination, and active community participation [49], [63]. Water management in the National Capital Territory of Delhi is often constrained by fragmented legislation, overlapping institutional mandates, and limited enforcement capacity [19], [25].

In India, environmental legislation indirectly addresses water bodies and does not provide a dedicated legal framework for regulating wetlands [8], [26]. The Water (Prevention and Control of Pollution) Act, 1974, primarily focuses on regulating industrial and municipal wastewater. The Act does not contain specific provisions for the conservation or management of ponds and lakes. The Environment Protection Act 1986 serves as umbrella legislation for environmental protection, although its application to water bodies depends on subordinate rules and notifications. The Forest (Conservation) Act, 1980, and the Wildlife (Protection) Act, 1972, provide protection for wetlands located within forests and protected areas but do not adequately address urban water bodies.

This gap was recognized in the National Environment Policy, 2006, which recommended the establishment of an appropriate legal framework for the management of lakes and wetlands. Consequently, the Wetlands (Conservation and Management) Rules, 2017, were notified under the Environment Protection Act [18]. These Rules define wetlands, prohibit activities such as reclamation, waste dumping, and discharge of untreated effluents, and require State Wetland Authorities to prepare wise-use management plans [18]. However, the 2017 Rules have been criticized for excluding many small wetlands, privately owned water bodies, ponds, and urban lakes from their scope of protection [8]. This limited coverage leaves several ecologically important urban water bodies outside the formal conservation framework. Therefore, there is a need for a comprehensive wetland law that provides a stronger legal basis for the protection, restoration, and sustainable management of all categories of wetlands. In Delhi, jurisdiction over the 1,009 inventoried water bodies is shared among multiple agencies, including the Delhi Development Authority (DDA), Municipal Corporations, the Archaeological Survey of India (ASI), Forest Department, and the Delhi Jal Board, highlighting the need for an integrated institutional framework (Table 2) [16], [19], [21], [25].

Table 2. Water body of Delhi under ownership of different agencies

Authority	DDA	BDO/Rev	MCD	DJB	ASI	Forest	Wakf Board	DUSIB	DSIIDC	JNU	IIT	Total Count
Count	801	132	21	12	16	18	1	1	3	3	1	1009

Such overlapping mandates diluting accountability and often leads to conflicts of responsibility. Scholars have highlighted that the absence of a single consolidated piece of legislation continues to be one of the biggest obstacles to effective urban water governance in India.

Role of National Green Tribunal (NGT)

The National Green Tribunal (NGT), since its establishment in 2010, has become one of the principal judicial institutions for environmental governance in India and has significantly influenced water resource management [25]. It has issued a series of landmark orders relating to the restoration of the Yamuna River, groundwater recharge, and wetland conservation [25]. For example, in 2015, the NGT directed the Delhi Jal Board (DJB) to systematically identify groundwater-contaminated areas and restrict the drilling of new borewells in vulnerable zones. It also mandated rainwater harvesting systems in new buildings with roof areas exceeding 500 m^2, thereby integrating water conservation measures into urban planning [25], [26]. Another important directive encouraged the use of treated wastewater for groundwater recharge, horticulture, and other non-potable purposes, thereby reducing direct discharge into rivers and promoting circular water management practices [20], [21], [25].

However, despite these strong legal and policy measures, implementation on the ground remains a major challenge. Weak political commitment, fragmented institutional responsibilities, inadequate financial resources, and insufficient monitoring mechanisms have often limited the effectiveness of NGT directives [8], [19], [25]. Consequently, although the Tribunal has established high standards for sustainable water governance, the practical ecological outcomes for Delhi's urban water bodies have often lagged policy objectives [19], [25].

Institutional Challenges in Delhi-NCT

Governance of urban water bodies in Delhi is fragmented across state, central, and municipal agencies. This overlapping jurisdiction weakens institutional accountability [19], [21], [25] (Table 2). Another noticeable hindrance is the conflicting authority among the Delhi Development Authority (DDA), Municipal Corporations (MCDs), and the Delhi Jal Board (DJB), which frequently leads to disputes over ownership, maintenance, and restoration responsibilities [19], [21, [25]. This institutional fragmentation often results in administrative delays, while encroachment issues are further aggravated by political interference and prolonged litigation, despite clear identification of violations [8], [25].

Public Participation and Co-Governance

The involvement of communities is increasingly recognized as a key component of the sustainable management of urban water bodies. International frameworks have consistently emphasized this principle. The Rio Declaration on Environment and Development (1992) specifically advocates public participation in environmental decision-making [52]. In Delhi, community participation in lake and wetland restoration has been observed through project-based initiatives involving Resident Welfare Associations (RWAs), local communities, and non-governmental organizations, particularly in activities such as rainwater harvesting, lake clean-up campaigns, plantation drives, and awareness programs [46], [49]. However, broader public participation is often constrained by limited environmental awareness, inadequate institutional support, and competing land-use demands associated with urban expansion and infrastructure development [8], [19].

International experience demonstrates that community-based governance systems can improve ecological outcomes, strengthen institutional accountability, and enhance the long-term sustainability of restoration programs [49], [52]. Studies from India similarly emphasize that co-management approaches integrating local knowledge with scientific expertise provide more context-specific and sustainable restoration outcomes [46], [48]. Although Delhi has witnessed encouraging examples of community participation, these initiatives remain fragmented and project specific. Strengthening institutional support, policy incentives, environmental education, and public awareness programs can transform citizen participation from an optional activity into an integral component of urban water governance and ecological restoration [48], [49].

International Policy Comparisons

An analysis of international models provides valuable insights into how the legal framework governing urban water body restoration in Delhi can be strengthened. In the United States, the Clean Water Act establishes a comprehensive legal framework for regulating pollutant discharges into surface waters and protecting wetlands, thereby safeguarding ecological integrity and public health [54]. Similarly, the European Union Water Framework Directive (2000) requires Member States to achieve and maintain good ecological and chemical status for all surface waters through legally binding environmental objectives [27]. In contrast, India does not yet have comprehensive legislation dedicated specifically to wetlands and urban lakes, relying instead on a combination of environmental statutes, policy instruments, and judicial interventions by the National Green Tribunal and the Supreme Court [8, [18], [25], [26]. Consequently, governance remains fragmented, resulting in overlapping institutional responsibilities, inconsistent implementation, and project-based restoration efforts. Delhi exemplifies these challenges, where the absence of a unified statutory framework and integrated governance mechanism often delays restoration projects and limits their long-term effectiveness [19], [21], [25].

Way Forward: Strengthening Governance

The policy and governance shortcomings in Delhi must be addressed through structural reforms that move beyond isolated interventions towards comprehensive institutional change [8], [25], [26]. India needs a dedicated Wetland and Urban Lake Law that clearly defines jurisdictional responsibilities, mandates periodic monitoring, and imposes stringent penalties for encroachment and pollution [8], [18], [26]. Furthermore, accountability should be strengthened by establishing a nodal management authority responsible for coordinating the ownership, restoration, and long-term management of water bodies in Delhi, thereby reducing inter-agency conflicts [19], [21], [25]. Urban development policies, particularly the Smart Cities Mission and the Delhi Master Plan, should explicitly incorporate water body restoration so that ecological objectives become an integral component of urban infrastructure planning [19]. Participatory governance should also be strengthened by formally recognizing the role of non-governmental organizations (NGOs), civil society organizations, and Resident Welfare Associations (RWAs) as co-managers of local water bodies [46], [48], [49]. At the same time, the Polluter Pays Principle should be more rigorously enforced to ensure that domestic and industrial polluters bear the financial responsibility for environmental damage and restoration [27]. Technological monitoring frameworks, including remote sensing, GIS-based decision support systems, and Internet of Things (IoT)-based water quality sensors, should complement these governance reforms to improve transparency, accountability, and the long-term sustainability of restoration programs [28], [54], [55].

Decision-Support Models for Prioritizing Restoration

Since the extent of degradation has been experienced in all the 1,009 water bodies in Delhi, they cannot all be restored simultaneously. Financial and institutional resources are limited, making it essential to establish restoration priorities based on objective criteria [16], [19], [25]. One systematic and transparent approach for prioritizing restoration interventions is the use of Decision Support Models (DSMs) based on Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA) (Fig. 7) [28], [63].

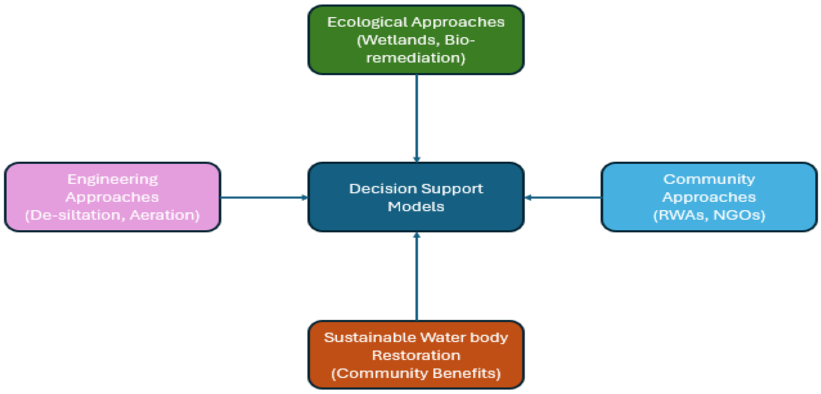

Fig. 7. High-level diagram for Decision support Model

Concept of Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis (MCDA) is particularly valuable in urban water restoration because it integrates diverse types of information into a single decision-making framework [63]. It combines ecological, hydrological, socio-economic, and vulnerability-related factors into an integrated assessment, making it more comprehensive than single-parameter evaluations. MCDA enables a balanced assessment of multiple criteria, including biodiversity, riparian vegetation, groundwater recharge potential, cultural and recreational value, and threats such as sewage inflow and land encroachment [48], [63]. Among the available methods, the Analytic Hierarchy Process (AHP) is one of the most widely used techniques in environmental decision-making. AHP compares individual criteria in a pairwise manner to assign relative weights based on expert judgement and stakeholder preferences [64]. The assessment process is further strengthened when MCDA is integrated with Geographic Information Systems (GIS), enabling spatial analysis to support transparent and evidence-based restoration planning [28], [63].

GIS enables multiple spatial datasets to be integrated and analyzed simultaneously. These include remotely sensed maps depicting the spatial extent of water using indices such as the Normalized Difference Water Index (NDWI) and the Modified Normalized Difference Water Index (MNDWI) [58], [59]. Other important spatial layers include land use and land cover (LULC), comprising built-up areas, agricultural land, and green spaces, together with proximity to pollution sources such as drains and landfill sites and socio-cultural features including heritage sites, schools, and parks [28], [55]. When these datasets are integrated within a GIS environment, they facilitate the development of a Restoration Priority Index (RPI), which classifies water bodies into high-, medium-, and low-priority categories for restoration [63].

Application in Delhi-NCT

As part of the Multi-Criteria Decision Analysis (MCDA) framework, a Geospatial Restoration Index (GRI) was developed for the Delhi-NCT region using a weighted overlay approach implemented in a Geographic Information System (GIS) environment. The framework follows a systematic procedure for evaluating and prioritizing urban water bodies for restoration. The first step involves identifying evaluation criteria under four major dimensions: ecological (30%), hydrological (30%), socio-economic (20%), and vulnerability (20%). Subsequently, weights are assigned to each criterion using the Analytic Hierarchy Process (AHP) together with expert consultation, thereby improving transparency and minimizing subjective bias [63], [64]. The indicators are then normalized to a common scale (0–1), allowing datasets with different units to be compared consistently. Finally, the weighted spatial layers are integrated to generate a composite restoration index [28], [63].

Based on the resulting Geospatial Restoration Index (GRI), water bodies are classified into high-, medium-, and low-priority categories for restoration. Initial application of the framework in the Dwarka and Najafgarh regions demonstrated that water bodies located near densely populated areas received higher restoration priority despite greater pollution exposure because of their significant socio-economic importance and high community dependence [19], [46]. Such geospatial decision-support models provide policymakers with a practical, transparent, and evidence-based framework for prioritizing restoration investments when financial and institutional resources are limited [63].

Advantages and challenges

One of the key strengths of Decision Support Models (DSMs) is their ability to make restoration planning more transparent and evidence based. These models help ensure that limited financial and institutional resources are directed towards water bodies where the ecological and socio-economic benefits of restoration are the greatest [28], [63]. They are also sufficiently flexible to incorporate new datasets, such as climate projections, land-use changes, and updated environmental information, as these become available [4], [28]. However, several challenges remain. Data gaps, subjective weighting of evaluation criteria, and institutional resistance can limit the practical application of these models. Although structured approaches such as the Analytic Hierarchy Process (AHP) improve transparency and consistency, expert judgment inevitably introduces a degree of subjectivity [64]. In many instances, urban agencies continue to face shortages of trained personnel, technical expertise, and digital infrastructure required for the effective implementation of GIS-based decision support systems [19], [63].

Decision-Support Dashboard for Delhi-NCT

One of the potential solutions is the creation of a web-based Restoration Dashboard, which will integrate the numerous outputs of the decision support models with real-time-series monitoring data. And the same platforms are implemented and experimented with in other regions of Europe, and within the confines of Delhi, they can be adapted to the Smart Cities Mission. This kind of dashboard would make essential information like rankings on the priorities of restorations, water quality information, and progress information easily accessible to policymakers and the general population. Such openness would assist in rendering things more responsible. It is also able to reinforce more participatory and inclusive urban water management governance.

Conclusion

Historically, Delhi flourished along the river Yamuna and on a dense network of ponds, baolis, tanks, lakes, and wetlands. These water bodies supported agriculture, community needs, and cultural life. Today, these water assets are at high risk of depletion. According to official surveys by the Delhi Parks and Gardens Society, more than 40 percent of Delhi's 1,009 listed water bodies have either disappeared or survived only as dumping grounds or encroached land parcels [16].

The review shows that most restoration attempts have focused on beautification, desilting, fencing, or conversion of water bodies into parks, while the actual causes of degradation, including catchment degradation, pollution, encroachment, and fragmented governance, remain insufficiently addressed. Long-term restoration therefore requires a multidimensional approach combining hydrological and ecological restoration, catchment protection, community participation, and stronger institutional coordination.

GIS, remote sensing, and advanced monitoring technologies can further support the identification, assessment, and management of water bodies. Reviving Delhi's ponds, lakes, and wetlands can contribute to water security, climate resilience, biodiversity conservation, and improved quality of life, while supporting the Sustainable Development Goals (SDGs). The restoration and decision-support approaches discussed in this review can also be adapted to other rapidly urbanizing cities facing similar challenges.

Recommendations

For effective management and restoration of water bodies, stronger institutional coordination, community participation, appropriate legal frameworks, and the use of modern technologies are required. Restoration efforts should address the actual causes of degradation rather than focusing only on beautification. Hydrological and ecological restoration, protection of catchments and recharge zones, control of sewage inflows, and appropriate buffer zones should be incorporated into restoration planning.

Decision-making on water bodies should be strengthened through better coordination among the Delhi Development Authority (DDA), Municipal Corporation(s), Forest Department, Delhi Jal Board, and other concerned authorities. Identification of a nodal authority responsible for the inventory, monitoring, and coordinated management of water bodies can help overcome communication and coordination gaps among various agencies.

Community participation should be an important component of restoration programmes. Local communities, NGOs, research institutions, and citizen groups can contribute to monitoring, awareness, maintenance, and protection of restored water bodies. Community-driven approaches can strengthen the sense of ownership and reduce the potential for encroachment or inappropriate land-use change.

Restoration of urban water bodies in Delhi also helps meet global commitments under the United Nations Sustainable Development Goals (SDGs).

- SDG 6 (Clean Water and Sanitation): Healthy wetlands can naturally recharge groundwater and filter wastewater. This directly supports SDG 6 by reducing pollution, improving water quality, and ensuring water availability.
- SDG 11 (Sustainable Cities and Communities): focuses on making cities inclusive and resilient. When water bodies are part of urban infrastructure, they can help reduce flooding, offer recreational spaces, and protect cultural heritage linked to historic lakes and tanks.
- SDG 13 (Climate Action): highlights the role of wetlands in managing extreme weather. Wetlands can absorb heavy rainfall and function as carbon sinks. In Delhi, where heat stress and urban flooding are increasing, this function is especially important.
- SDG 15 (Life on Land): promotes biodiversity. Revived wetlands can support migratory birds along the Central Asian Flyway, improve fish habitats, and enhance urban biodiversity. Najafgarh Jheel already shows this potential, attracting large bird populations during winter.
- Finally, SDG 17 (Partnerships for the Goals) stresses the need for collaboration.

Restoration efforts are successful not only through the government, but they can also happen with strong partnerships. These include partnerships with NGOs, research institutions, and citizen groups. For long-term effect, restoration will have to be supported by changing legal frameworks, good institutions, active participation of communities, and the use of modern technology.

This change in perspective can help the city build its resilience and move closer to reaching its sustainable development goals. While this review focuses on Delhi-NCT, the principles of restoration and decision support approaches discussed here are highly transferable to other fast urbanizing cities in India and in the Global South. Many metropolitan regions like Bengaluru, Mumbai, Nairobi, Sao Paulo, etc. are confronting similar issues of encroachment of wetlands, untreatable sewage inflows, and fragmented governance. The combination of engineering, ecological, and participatory strategies, facilitated by GIS-based monitoring and multi-criteria decision models, provides a template that is scalable for urban water management. Adapting these approaches to the socio-ecological contexts of the local area can increase resilience and water security and make progress towards reaching global Sustainable Development Goals (SDGs).

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