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Rejuvenation of water bodies with recycled water

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ABSTRACT

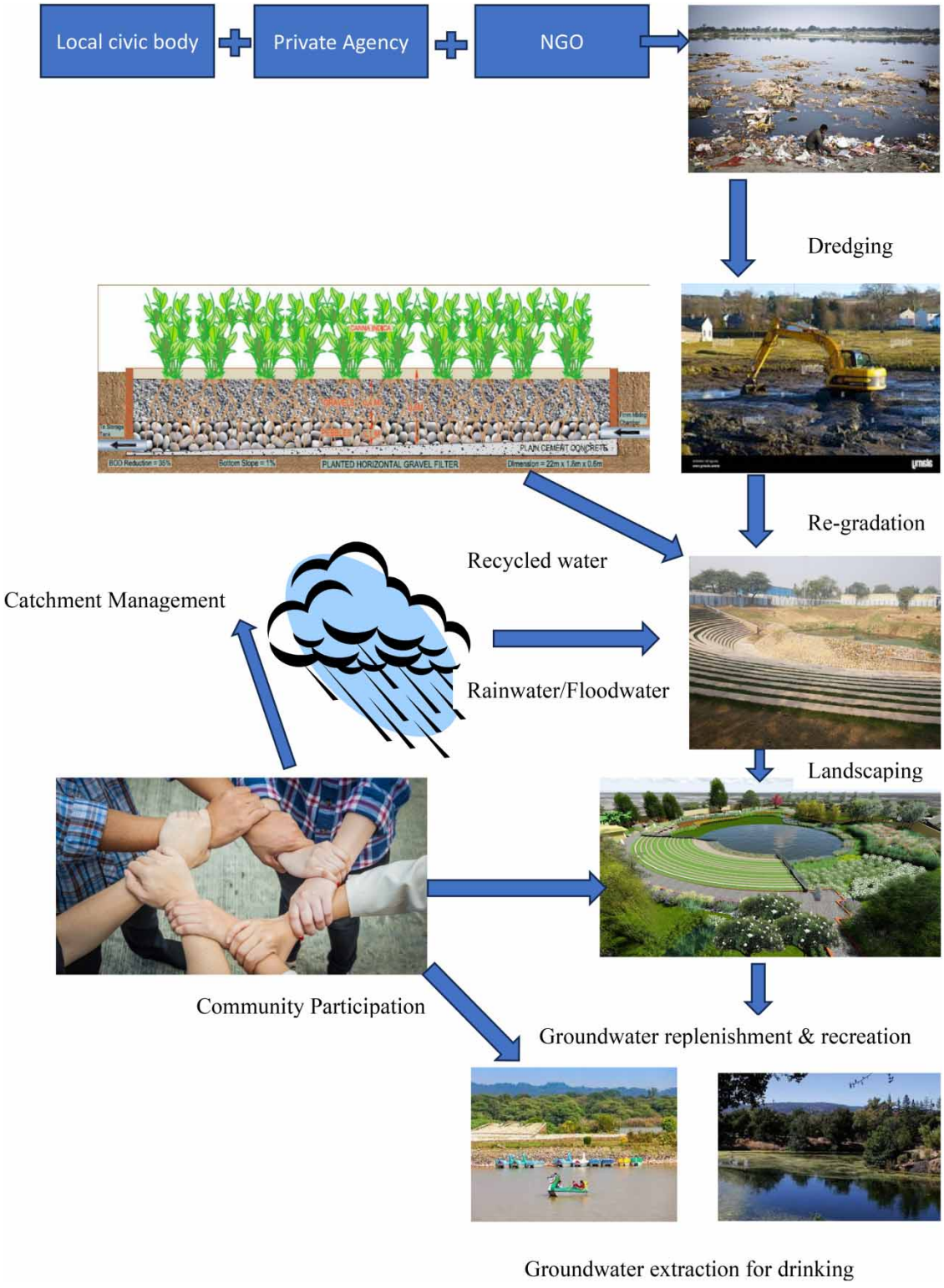
This study investigated the new routes of groundwater replenishment in water-constrained urban communities. Against the present water demand of 1,440 million gallons per day (MGD) in Delhi, 1,000 MGD including 140 MGD groundwater is being supplied. Additionally, residents, institutions and commercial occupants are illegally extracting 250 MGD. This groundwater extraction is enormous in comparison with the water injected into the ground through rain water harvesting, resulting in the tremendous depletion of the groundwater table. The aim of the study is to replenish groundwater with tertiary treated effluent available round the year. The study is conducted on one natural water body rejuvenated in the South and another artificial water body constructed in West Delhi with the objective of determining whether groundwater can be replenished with tertiary treated water with an improved quality, and whether it can be replicated elsewhere. The qualities of the groundwater and water tables were checked before and after rejuvenating the water bodies. The utilization of tertiary treated effluents has resulted in raising the groundwater tables from 5 to 7 m and improved the quality of the groundwater in the past 2 years. This practice can be replicated elsewhere as done in Brisbane (Australia) and Singapore.

Key words: Delhi, groundwater, tertiary treatment, treated effluent, water bodies

HIGHLIGHTS

- Utilize recycled water for replenishment of groundwater in overexploited water zones.
- Treated effluent passes through floating wetlands, surface aerators and filtration.
- Water table increased by 7.0 m at Pappankalan and 5 m at Rajokari.
- Water bodies becoming the place of recreation for surrounding localities.
- These practices can be applied anywhere in India and abroad effectively.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Groundwater is the major freshwater resource that meets around 33% of the global drinking water demand (Li 2016). Most of the water and irrigation demand in India is met from groundwater. Even in the United States, 40% domestic water supply is supplemented through groundwater. Hence, irrespective of whether a country is undeveloped, developed, or developing, groundwater plays a very important role in fulfilling basic

needs (Swain *et al.* 2022). During the last three decades, groundwater exploitation has increased manifold in India due to the growing population and the limited surface water, which has resulted in unexpected groundwater depletion and water quality deterioration, subsequently reducing future water resources for the next generation. This requires a paradigm shift in water policy to recharge groundwater with recycled water that is available round the year (Gdoura *et al.* 2015) and has many advantages, i.e., reducing the disposal of wastewater in rivers and drains, reducing floods, increasing groundwater levels, and establishing water storages for emergency use (Bouwer 1991, 1996). Moreover, recycled water is used to recharge groundwater all over the world (Ghayoumian *et al.* 2005). In the United States as well recycled water is widely used for groundwater recharge as supported by the Environmental Protection Agency (Schmidt *et al.* 2013). This is despite the fact that using recycled water to recharge aquifers invites many controversies, which are largely the result of human mental blocks (Nijhawan *et al.* 2013). The groundwater recharge through the natural process/filtration is far slower than the exploitation of groundwater resulting in the faster depletion of water tables. Hence, Managed Aquifer Recharge (MAR) has become increasingly important (Asano & Cotruvo 2004; Hochstrat *et al.* 2010). In Delhi, more than 400 MGD groundwater is being extracted to supplement the gap between drinking water demand and its supply, resulting in a tremendous drop down in the groundwater table in 9 out of the 11 districts in Delhi. However, the efforts for replenishment of groundwater are not enough. Delhi Government incentivises its customers by reducing water charges by 5% for the installation of Rain Water Harvesting at their premises and 15% if their Sewage Treatment Plant, in addition to Rain Water Harvesting system, is functioning (Delhi Jal Board 2023). Despite this incentive, the consumers' response is very poor.

In ancient times, there were natural water bodies like lakes, johar/pokhars, and so on in villages and even in urban areas to collect rainwater for use by them as a water source round the year. However, then the groundwater was also replenished through that water. With the passage of time, these water bodies were encroached upon and vanished. The remaining water bodies were polluted with sewage, solid, and industrial waste. The people who were connected with these water bodies began moving away from these water bodies owing to the emission of obnoxious gases generated from the wastewater, thereby neglecting them (Brindha & Schneider 2019). Even in Delhi there were around 1,045 water bodies in rural and urban areas that have since been reduced to only 625 (Kumar *et al.* 2022) as of now per the Parks and Garden Society, Government of the National Capital Territory of Delhi (DPGS 2023) report in Table 1. The recycled water is an asset that can reduce the burden on water supply demand by making it usable for non-drinking purposes. Although tertiary treated water can be converted

Table 1 | Current status of static water bodies in the NCT of Delhi (Delhi Parks and Gardens Society 2023)

S. No.	District	Total Nos. of water bodies	Non traceable Water bodies	Water polluted bodies	Encroached water bodies	Water bodies converted into Park	Water bodies near Yamuna	Maintaining agencies				
								DDA	DJB	BDO/ Rev	MCD	Ors
1.	East	52	3	16	3	8	17	46	2	–	2	2
2.	North East	31	2	1	2	8	17	23	2	4	–	2
3.	Shahdara	23	–	–	–	–	–	21	–	–	2	–
4.	North	165	5	14	50	7	21	131	–	27	3	4
5.	North West	164	1	14	28	21	1	143	1	14	2	4
6.	South	142	5	11	29	13	2	98	–	6	3	35
7.	South East	42	9	1	2	2	10	40	–	–	–	2
8.	South West	273	6	30	37	13	0	184	1	78	7	3
9.	West	64	4	16	18	9	4	63	–	–	–	1
10.	New Delhi	60	3	3	8	5	1	53	–	–	3	4
11.	Central	29	2	4	3	3	3	20	–	1	1	7
	Total	**1,045**	**40**	**110**	**180**	**89**	**76**	**822**	**6**	**130**	**23**	**64**

into drinking water, there is a mental block in using the recycled water for drinking. However, this tertiary treated water can be used for the replenishment of groundwater, which in turn can be extracted for drinking purposes directly after disinfection or indirectly for further treatment. In addition, there may be other uses of recycled water for non-drinking purposes, as shown in Figure 1. The addition of surface water for Delhi for the growing population is a remote hope, as the upper dam storages, i.e., Lakhwar Vyasi, Renuka Ji, and Kishau, are under planning and construction stages and may take one or two decades in their commissioning. Delhi can supplement the water supply with groundwater only after replenishment of the groundwater with recycled water, which is also a sustainable source. Hence, groundwater recharge with recycled water is one of the best ways to replenish groundwater and use groundwater as a raw water resource in Delhi. This practice has already been adopted successfully in Singapore, Australia, and the United states, wherein recycled water of tertiary standard is stored in lakes and groundwater is extracted for various purposes (Vanderzalm *et al.* 2015, 2020; Sun *et al.* 2020; Radcliffe 2022).

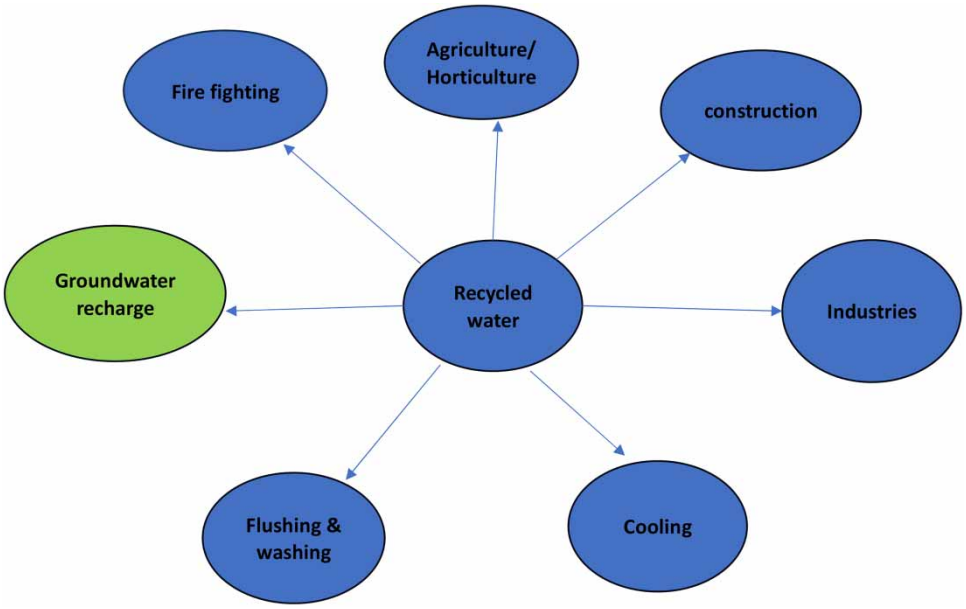


Figure 1 | Use of recycled water for different non-potable uses.

1.1. Study on current status of water bodies

Water bodies, being one of the important water resources, must have water at least of bathing standard (Supplementary material, Table S1). These must have a natural catchment to catch the rainwater during rains. But, due to the fast urbanization and neglected wastewater management, most of the water bodies in Delhi are heavily encroached upon, consequently shrinking the original catchment area and polluting it. The stormwater surface run-off goes back to roads/colonies resulting into water logging, as no water shed management and no well-defined catchment areas of water bodies exist (Brindha & Schneider 2019). The water in the water bodies is highly polluted because of the dumping of solid waste and the inflow of wastewater and industrial effluent (Supplementary material, Figure S1(a)) into these water bodies. Open drains carrying black and gray waters also face anthropogenic activities causing a high risk of infection and communicable diseases. In this regard, microbiology parameters like Escherichia coliform, total coliform, and total aerobic count are important to be investigated and treated suitably before the treated water is collected in water bodies (Giannakis *et al.* 2015; Liang *et al.* 2019; Sharma *et al.* 2020; Yin & Shang 2020; Krishnan *et al.* 2021; Yacouba *et al.* 2021; Bahadur *et al.* 2023).

The residents nearby and passers-by try to keep themselves aloof due to the bad smell resulted from anaerobic reaction in biomass and the dirtiness in and around the water bodies. However, these water bodies would have been very good recreational places. The polluted water collected in the water bodies percolates into the ground and pollutes the groundwater, which becomes irreparable in the long run, thus reducing further the groundwater resource (Jonah & Dawda 2014). The people using this groundwater through tube wells or hand pumps suffer from waterborne diseases when they draw water from the ground and use for their consumption. The flora

and fauna that should have been in natural lakes have disappeared. The birds are flying away from these water bodies instead of toward them. However, thousands of migratory birds as well as aquatic lives can be seen in the rejuvenated lakes or Biodiversity Parks developed by some of the relevant agencies (Supplementary material, Figure S1(b)).

The encroachment of the watershed areas of most of the water bodies has resulted in the accumulation of rainwater in and around the colonies instead of its flowing into the water bodies. Since these slums cropped up in the watershed areas of the water bodies illegally, the government could not provide basic amenities like water and sewerage. Hence, the sewage generated by those residents also discharges into these water bodies through point and non-point sources. The solid waste generated in such slum colonies that have illegally grown in the watersheds of the water bodies is not properly managed. The residents, therefore, throw their solid waste into the nearby water bodies, polluting the freshwater available in these water bodies. The water bodies are generally neglected in metro cities, resulting in their poor maintenance. The residents nearby who are the immediate beneficiaries are also not made aware of the benefits and importance of the proper maintenance of the water bodies. Instead, they consider the water bodies as dumping places for solid waste and sewage disposal.

2. METHODOLOGY FOR REJUVENATION OF WATER BODIES

The objective is to actively rejuvenate existing water bodies by restoring them to their natural original condition and maintaining them properly thereafter, which involves treating the wastewater discharging into the water body to tertiary standard, reusing it for filling the water body, and creating an asset for public recreation and for help in groundwater recharge as a water resource. The treatment plant is designed according to the required quality standards of treated effluent (Kuo & Smith 1998). This will also help in the prevention of water logging during monsoons as the rainwater will flow naturally towards the nearest water bodies. The community participation in planning, implementation, and maintenance of these water bodies must be ensured for the successful commissioning of the project. After rejuvenation of a water body, the residents nearby will be encouraged to participate in related recreational activities, thereby enhancing the value of nearby properties as the social and environmental conditions of the surrounding area will improve. The following are the standard operating procedures for rejuvenating existing water bodies. Figure 2 shows the methodology of the rejuvenation of existing polluted water bodies.

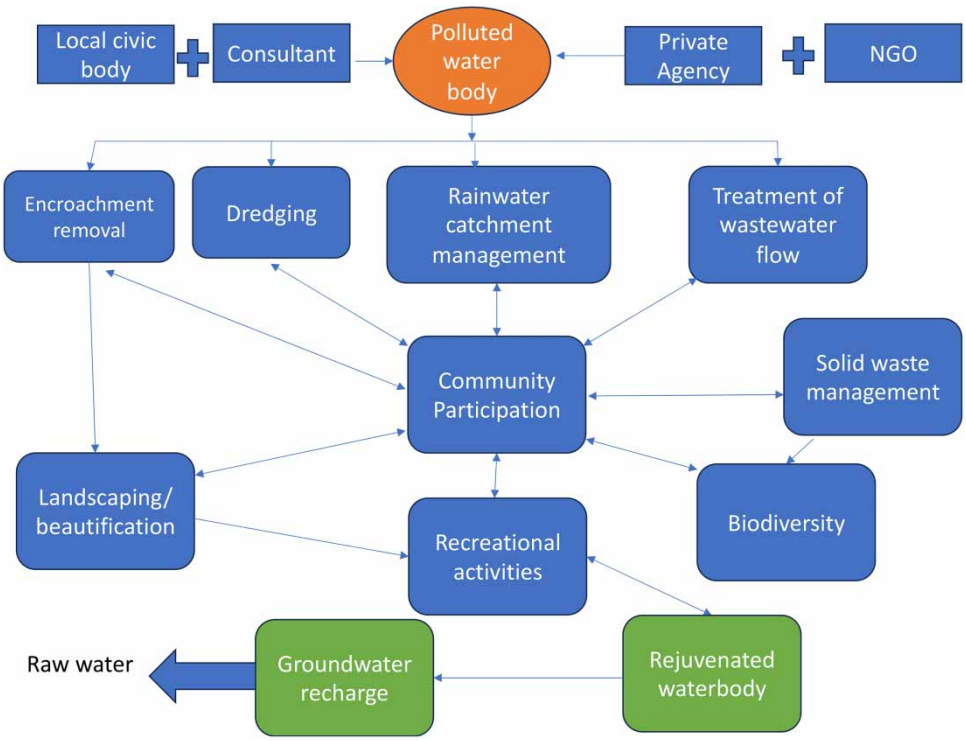


Figure 2 | Methodology of rejuvenation of existing polluted water bodies.

2.1. Restoration of original and natural watershed of water bodies

This study has been conducted in Delhi, with a present population of more than 24 million. Around 45% is unplanned settlement and water supply demand is not met with per the recommendation of the Central Public Health and Environmental Engineering Organisation (CPHEEO). The water supply is supplemented with groundwater extracted through bore wells as well as that delivered by water tankers. The climate of Delhi is varied with a minimum temperature as low as 10 °C in winter and as high as 45 °C in summer. The average annual precipitation is 560 mm. Yamuna River passes across the city for a length of 48 km. However, drinking water available from the river is allocated per the Memorandum of Understanding (MoU) 1993 signed among the basin states. Approximately 30% of the groundwater is extracted legally and illegally to meet the drinking water demand of Delhi. Although there are more than 1,000 water bodies in Delhi, there are only few clean water bodies remaining where the people of Delhi can go to for picnics and for leisure activities for some time on weekdays or weekends. It is therefore essential to work out the robust methodology for the rejuvenation of water bodies for the replenishment of groundwater as well as for the recreation of the people of Delhi. Figure 3 shows the zonal map and the location of water bodies in Delhi.

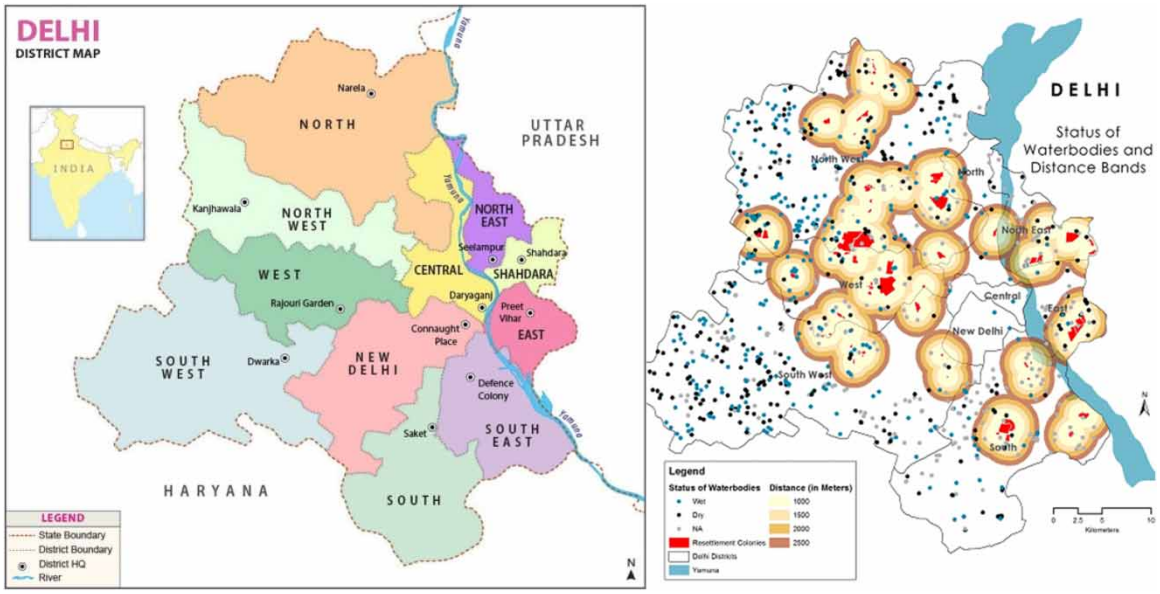


Figure 3 | Delhi's zonal map and locational plan of water bodies.

There is a well-defined catchment area for each water body wherefrom the rainwater as a point or non-point source discharges, is collected in the water body, and infiltrates into the ground. This area is very important for the survival of the water body, which has been encroached upon by the illegal occupants. However, this area is already available in old revenue records of the government, which can be sought and marked on the plan. After mapping the original catchment area of the water body per the revenue record, the entire watershed of the water body should be freed from all types of encroachments. The reduced levels are marked on the plan for re-grading the watershed for the water body so that the entire rainwater flows into the water body. The stormwater drains after isolation from the wastewater are re-graded and the land is surfaced with filter media in such a manner that the entire rain water is diverted towards the centre of the water body (Figure 4).

2.2. Wastewater and solid waste management

All the intakes of the wastewater are identified and marked on the plan. The quality parameters of the wastewater are tested for designing the treatment plant that may deliver the desired quality of treated effluent. The water quality of the water body is intrinsically linked to the quality of the inlets. It is, therefore, essential to trap and clean these before they drain into the water body. A constructed wetland is an appropriate and sustainable solution for this. The natural water treatment arrangements such as wetland systems, soil, filter media, organisms, and so on are used to treat municipal or industrial wastewater, stormwater run-off, and so on. Some of the species of plants

Figure 4 | Re-gardening of watershed of water body and landscaping.

used for root zone treatment in a wetland system are *Eleocharis palustris*, soft stem burus, sweet flag, Narrow leaf cattail, Broad leaf arrowhead, Green Ash, Red Maple, Green arrow arum, and *Spartina altemiflora*. The constructed wetlands of an appropriate capacity should be planned for the site and integrated as part of the larger landscape scheme, as it involves almost zero operational cost and merges with the overall landscape (Simon & Joshi 2021).

A large amount of solid waste is thrown by the residents in and on the banks of drains, rivers, and ponds. In Delhi, the solid waste generation was estimated to be 17,000–25,000 tonnes/day for the anticipated population of 22.4 million by 2021. Despite efforts to decompose the waste by composting, incineration, and so on, a minimum residue of 4,000–5,000 tonnes/day, i.e., 20%, will require a large area of landfills (MoEF GOI 2001). Hence, there will be a lot of pressure on the municipal bodies to manage even the residue of municipal waste in the future. Without an adequate solid waste management infrastructure in Delhi and better awareness programs, the residents will continue throwing their domestic waste in nearby water bodies, i.e., drains and rivers, ultimately increasing pollution in the water bodies. For preventing the dumping of solid waste into water bodies, the concerned municipality must construct proper Dalao (intermediate large dust bin for collecting solid waste temporarily before disposing at sanitary landfills), and place dust bins at regular intervals for the collection of solid waste. Door-to-door collection of solid waste can be implemented in the surrounding areas of a water body so that solid waste is collected and disposed of properly instead of being dumped in the water body.

The wastewater flowing into water bodies carries a lot of sludge that gets deposited on the bed of the water body besides the solid waste dumped by the residents. The organic matter deposited in the beds of the water bodies gets digested due to anaerobic reaction and generates obnoxious gases, i.e., carbon monoxide, methane, and hydrogen sulfide. To prevent such a situation and ensure clean water in water bodies, it is essential to dredge the historical sludge from the beds of water bodies at regular intervals.

2.3. Landscaping of catchment of water body and ecological restoration

The major catchment of a water body must be designed as a wetland park with urban wilderness, attracting butterflies, useful insects, birds, aquatic life, and so on. These wetland parks must be designed to manage stormwater effectively as an integrated part of the landscape. The gardens will also provide high-quality public open spaces for the surrounding communities. These will be pesticide- and herbicide-free zones. This approach would not only enhance the capacity for retention during monsoons but also help reduce pollution load further, increase groundwater recharge, reduce water temperature (as high temperature are unsuitable for certain aquatic life) in extreme summers, enhance the local ecosystems and biodiversity, provide a robust amenity space for the surrounding communities, and facilitate other social needs. Every project of water body restoration will have certain specific site-based requirements that will need to be addressed on a case-by-case basis. In tandem, degraded ecosystems and habitats must be restored where applicable and/or new ecological landscapes created. The natural process of self-revival of water bodies, i.e., wetland systems and ecosystems, must be ensured while rejuvenating water bodies (Mahapatra & Varghese 2017).

2.4. Enhancement of socioeconomic values through community participation

Clean water bodies and restored ecologies and landscapes provide the basis for creating public assets in a city in the form of public spaces, recreational amenities, and enhanced biodiversity. These assets must be incorporated in all restoration initiatives to enable the creation of water-oriented amenities that are robust in the long term, giving rise

to new zones of growth and opportunities. The most important component of the rejuvenation process of water bodies is the proper maintenance, which is possible with the help of community participation during the planning, construction, and any decision-making, and thereafter in the maintenance and monitoring mechanism so that the beneficiaries may feel the ownership of the project and keep the water bodies in proper condition. The community, which is the beneficiary in the future, can prevent encroachments on the watershed, convince residents not to dump solid waste, and keep monitoring for the proper maintenance of the water body. There are many success stories of community participation in water management in India, i.e., Bangalore Lake management.

2.5. Future management standard and monitoring mechanism

The species of plants to further clean treated water are planted near the water body and remaining parts of the residences nearby as mentioned in various studies (Ervin *et al.* 2006; Pollock *et al.* 1998; Olde Venterink *et al.* 2003). The flora and fauna are selected according to the quality of water in the water body and to further the maintenance of the quality of water (Chiarawatchai *et al.* 2008). The proper maintenance of treatment plants, stormwater drains, plants, and shrubs is to be done per the aforementioned Standard Operating Practices. Table 2 summarizes the key aspects of the maintenance and management of water bodies and surrounding parks.

3. NOTABLE CASE STUDIES OF REJUVENATION OF NATURAL AND ARTIFICIAL WATER BODIES

3.1. Pappankalan artificial water body

The Sewage Treatment Plant (STP) at Pappankalan of 20 MGD capacity is producing the tertiary quality standards treated effluent, i.e., biochemical oxygen demand (BOD) < 5, suspended soilds (SS) < 7 PPM, coliforms between 250 and 500 PPM after disinfection. For utilization of the Pappankalan STP-treated effluent, an artificial water body has been constructed in around 25 acres of land (Delhi Jal Board 2023). The water body in the 25 acres of land was excavated for about 7–8 ft deep until the sand strata arrived and the excavated earth was spread around the periphery of the water body. The groundwater table was recorded nearby this artificial lake before filling it with recycled water. The around 1.5 m thick impervious layer of soil at the bed of the drain was replaced with sand and gravel to ensure percolation of water into the ground. Since this artificial water body has been created near Najafgarh drain, previously known as Sahibi River, the soil strata below 4.2 m was found completely sandy. Due to the vicinity of the Najafgarh drain carrying wastewater, it was anticipated that the quality of the groundwater may be poor. The quality of groundwater at the depth of 10 m below the ground was checked and recorded in Table 3. The tertiary treated water of quality standard BOD < 5, SS $<$ 5 PPM, and coliform < 250 ppm was collected in this water body to its brim. The floating wetlands and aerators were also installed within the water body to further improve the quality of water within the water body so that the water percolating into the ground is as good as of bathing quality standard (Figure 5). Since, this water will percolate through various layers of earth before meeting with groundwater, the quality will further improve. The groundwater table has risen by 7 m in the last 18 months. The high rate of percolation and replenishment of the water table is due to the sandy strata and filter media in the bed of the water body. Finally, the quality of the lake water and groundwater table are recorded at periodic intervals and compared to see improvement in the water table as well as the quality of groundwater. Since the water table is now higher than the normal flow water level of the Najafgarh drain, the chances of groundwater contamination are very rare due to the ex-filtration of the groundwater from the water body to the drain.

3.2. Rejuvenation of Rajokari natural water body

The Rakokari water body in South Delhi was heavily encroached upon, polluted, and abandoned (Figure 6(a)). The groundwater table in South Delhi has gone down by 50–15 m. The soil texture in most of the area is alluvial soil with hard rocks. The soil texture in Rajokari was found to be a layer of silty sand up to 2–3 m, alluvial soil below this layer, and hard rock underneath. The water table nearby was 45 m below the ground. After adopting the aformentioned methodology, i.e., removing encroachments, revival of original rainwater catchment to the extent of 70%, setting up of constructed wetland STP at the mouth of incoming drain, and addressing the catchment and landscaping issues, the water body was rejuvenated resulting in the raising of the groundwater table by 5 m during the previous monsoon. The sewage from the surrounding area is being treated by a constructed wetland system and discharged into the water body. The landscaping has been done to uplift the beauty of the surrounding area and to create a recreational space to attract the surrounding community. Since the groundwater has been increased, the energy consumed in extracting water through tube wells is also reduced. This has also

Table 2 | Key aspects of maintenance and management of water bodies and surrounding parks

S. No.	Elements	Details
1.	Active monitoring of water quality	Water quality of the water body and that of the constructed wetland outlet shall be tested weekly. These tests must be carried out by labs certified by the National Accreditation Board for Testing and Calibration Laboratories (NABL)
2.	Solid waste management	Litter and solid waste including leaves, rubbish, paper, bottles, cans, rocks, and gravel shall be removed from all areas on a daily basis. All refuse resulting from the maintenance operation shall be disposed of at locations designated by the Municipal Corporation of Delhi (MCD). All hardscape areas shall be swept or blown free of debris daily. Construction and demolition daste dumping shall be controlled.
3.	Constructed wetland management	• Survey to identify new inlets shall be carried out bi-annually and necessary trapping into the constructed wetland should be undertaken immediately. • Need for replantation shall be assessed in 3 months, and then bi-annually thereafter, with replantation carried out as required. • Cleaning of collection cum sedimentation chamber shall be undertaken once every 4 months. • Need for de-silting shall be assessed bi-annually and de-silting shall be carried out as required (usually once in 2–3 years). • Pruning of overgrown plants from Phytorid Beds shall be carried out on a quarterly basis. • Hydraulic water level checks shall be undertaken bi-annually, and action shall be undertaken as required. • Gravel check of Phytorid Beds and reshuffle shall be undertaken bi-annually. • Routine Pump Maintenance shall be undertaken on a quarterly basis. Bioremediation augmentation by Bio-media application in Phytorid Beds shall be undertaken annually.
4.	Maintenance of landscaped areas	The nature of landscape maintenance should be aligned with the concept of the park. To sustain the quality and health of a wetland garden with urban wilderness, minimal maintenance is required. The following is to be adhered to: • The wetland garden will be a pesticide/herbicide-free zone with only the use of organic manure if necessary. • Pruning of trees, shrubs, ground cover is to be avoided unless carried out to (a) eliminate disease and (b) to keep a 1.5 m zone along pathways free of any obstruction that may cause accident. • Turf areas/Meadows designed as gathering spaces may be mowed if necessary during the growing season to maintain easy access and continued use.
5.	Irrigation	The irrigation shall be operated at an appropriate seasonal schedule, using the least amount of water necessary to maintain the growth, health, and vigour of all landscape plant materials. All necessary actions will be taken to maintain and repair all irrigation systems on the property.
6.	Lighting	Lighting fixtures/systems shall be maintained to ensure peak performance during the life of the project. All fixtures shall be cleaned per requirements specified in the project contract. Replacements of fixtures shall be made to remedy breakage and to maintain appropriate lighting levels.
7.	Replanting and extra work	Plant material that dies through the fault or neglect of the contractor, or because of preventable circumstances, shall be replaced with a specimen of the same species and of equal or similar size as the plant lost.

improved the environmental and social condition of the nearby areas (Figure 6(b)). Therefore, this is one of the best examples of community participation wherein the Residents' Welfare Association was involved from planning to its commissioning.

4. DISCUSSION

The guidelines on replenishment of groundwater were published and welcomed in Australia. These were implemented in the three states, i.e., South Australia, Western Australia, and Victoria. In other states implementation was not progressing, despite the requirement, opportunities, and viability there. These guidelines were reviewed in the last 10 years and risk assessment was also carried out in terms of the quality of waste treatment, soil profiles, and quality of groundwater after its replenishment (Dillon *et al.* 2020). A similar review of the

Table 3 | Groundwater quality before and after the construction of the artificial lake at Pappankalan

S. No.	Parameters	Before C/O lake	After C/O lake	Remarks BIS: 10500 (2012)
1.	pH	8.19	8.00	6.5–8.5
2.	Electrical Conductivity	2,472	2,100	
3.	Ca	38.16	28.18	75
4.	Mg	64.37	45.40	30
5.	Na	424	315	20
6.	K	10	5	10
7.	Cl	424.14	315.10	250
8.	NO_3	83.80	85.00	45
9.	F	1.94	1.65	1
10.	SO_4	37	31	150
11.	NO_2	0.06	0.05	
12.	PO_4	0.05	0.05	
13.	HCO_3	372.55	285.45	244
14.	WQI	215	–	200–300 (very poor)

Figure 5 | Floating wetlands and aerators in the artificial water body at Pappankalan STP.

Figure 6 | Rajokari water body, pre-rejuvenation and post-rejuvenation.

guidelines and the monitoring of the quality of the recycled water and the quality of the replenished groundwater is also essential in Delhi to ensure the improved quality of groundwater in a sustainable manner.

Although proactive measures are required to be taken to preserve these water bodies not only in Delhi but across the country, these require very harsh regulations and enforcement of the environment law, which are

somehow missing. The existing laws related to water bodies can include the polluter pays principle, which must be stringently implemented. These regulations should not be confined to Delhi, but put into action in the whole country without further delay (Kumar *et al.* 2022). According to the report published by Delhi Parks and Gardens Society, most of the ponds in Delhi have been reduced in the area due to encroachment, siltation, dumping of garbage, and depleted sources of water, which calls for the immediate attention of the government to revive these to their original shape and conditions. Similar issues can be identified across the country as most of the cities identified under the Smart City initiative are already experiencing water scarcity. Hence, it is essential to map the coordinates of all water bodies in a single platform to monitor, control, and prevent pollution and in parallel make the people aware of the importance of protecting these water bodies locally from becoming extinct. Healthy water bodies, such as wetlands, help the ecosystem stay rich in biodiversity. Since sewage treatment plants (STPs) are set up for treatment of wastewater flowing into the water bodies, the quality parameters of the wastewater and accordingly the process design of the STP must be done properly to ensure collection of tertiary treated effluent in water bodies. The regulating authority must check the quality of water in water bodies periodically.

5. CONCLUSION

Temporal analysis of water bodies using high-resolution satellite imagery for pre- and post-monsoon surveys can be done to understand the availability of a source of water, its quantity, and quality in tanks, ponds, lakes due to rainfall, or due to some other sources such as flooding water from canals and water from rainwater harvesting channels. In parallel with that, the water quality analysis can be done using a comprehensive field visit. The second step can be to identify the probable source of pollution. This information can be used for prioritising the water bodies for rejuvenation. Public participation by mass awareness campaigns can lead towards behavioural changes in society, and this can be the core of the conservation plan.

It is necessary to use recycled water of bathing standard along with the rainwater to inject into the ground to recoup the drawdown of water table in Delhi. The rejuvenation of water bodies and creation of artificial water bodies are the probable solutions to increase groundwater sources in future. In addition, community level/large-scale rainwater harvesting through stormwater drains, large parks, check dams, ridges, and forests should also be adopted for groundwater recharge at large scale to maintain the balance between extraction of groundwater and its replenishment at the same time. To improve the efficiency of replenishment rate, impervious layers of soil should be replaced with sand or filter media. To avoid the possible contamination of the groundwater in the process of replenishment with recycled water, it is essential to monitor the water quality of the recycled water from STPs as well as in the water bodies regularly so that the quality of water being percolated into the ground is assured. A monitoring bore well should also be installed for regular monitoring of groundwater quality. The enforcement of environmental laws to protect the water bodies must be done diligently by the concerned regulating authorities.

There are two ways to supplement the gap between demand and supply. One is either to use recycled water directly for non-potable purposes or to manage groundwater recharge with rain and recycled water to enhance sustainability of the groundwater source. The Delhi Government should make its best offices use the recycled water for potable and non-potable uses. Thus, if rainwater and recycled water are used for groundwater recharge through static water bodies, the problem of drinking water may be resolved in Delhi to a large extent, as groundwater from the periphery of these rejuvenated water bodies can be further extracted for drinking after proper treatment.

With encouraging results achieved in these two water bodies of Delhi, wherein the water table has risen up to 5–7 m in addition to the improvement in the quality of the groundwater, the water bodies elsewhere in India and abroad can be rejuvenated and the groundwater can be replenished with recycled water in a similar sustainable manner creating additional water resources.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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