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Bridging global knowledge and local action: Urban river restoration in India- Lessons from global river restoration projects

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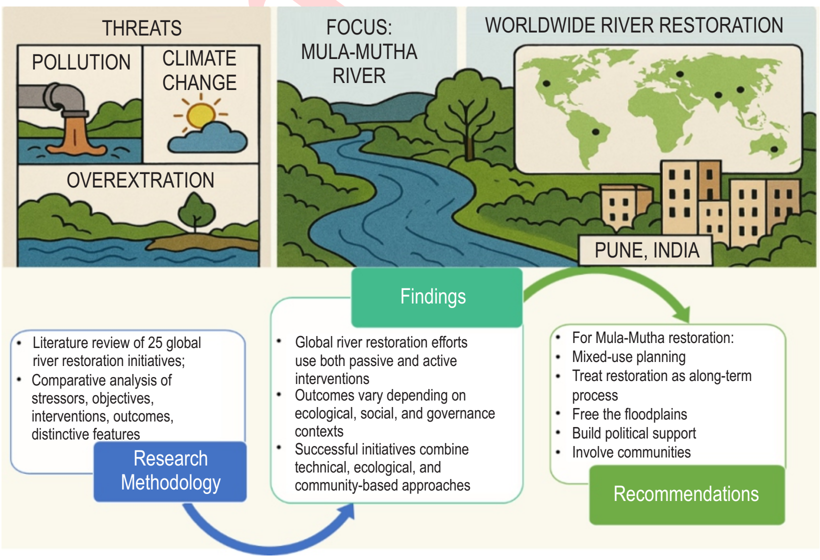
Abstract

Rivers worldwide play a crucial role in supplying freshwater, regulating local climates, conserving biodiversity, and supporting the agriculture and economic growth of nations. However, rivers across the world are threatened by increasing pollution, climate change and excessive water extraction. In 2022, the Central Pollution Control Board of India declared that more than 50% of India's 605 rivers were polluted.

Since urban rivers are more vulnerable to pollution, this study focuses on restoring a severely polluted urban river in India, the Mula-Mutha River flowing through Pune, Maharashtra, India. To develop restoration strategies for Mula-Mutha, this study examined river restoration efforts across the globe. Based on the literature review, we identified river restoration initiatives for 25 rivers across the world, and collected and analysed information regarding the stressors, objectives, interventions (both passive and active), outcomes, and distinctive features of each restoration initiative.

Based on the analysis, this study suggests five restoration strategies for rivers Mula-Mutha including: adopting a mixed-use planning approach for river restoration, accepting river restoration as a multi-year, continuous process, freeing the flood plains, political support for river restoration projects and involving communities in planning and implementation of restoration projects.

Key words: Mula-Mutha River, River restoration, Riverine pollution, Urban river



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Introduction

Freshwater is a finite and increasingly scarce natural resource, necessitating its effective national and international management. Only 0.0001% of the Earth's water is found in rivers and streams, underscoring the fragility of accessible freshwater resources (Shiklomanov, 2000). Alarmingly, Earth's freshwater supply has decreased abruptly since 2014 and has remained low ever sincethen (Rodell *et al.,* 2024). During 2000–2021, the global freshwater withdrawals increased by 14%, accounting for an average growth rate of 0.7% per year, according to the UN World Water Development Report 2025. The increased use of freshwater and its declining availability has resulted in qualitative and quantitative stress on surface and groundwater resources. Needless to say, managing water quality is equally essential for future generations. Sustainable Development Goal 6 (SDG 6) seeks to ensure water availability and sustainable management of water and sanitation for all. However, it is alarming that none of the SDG 6 targets appear to be on track, as noted in the United Nations SDG Report 2025.

Global riverine pollution is intensifying due to plastic waste, nutrient overload, and emerging contaminants. Nitrogen runoff from agriculture worsens this crisis. According to the 'State of Global Water Resources Report 2023' published by the World Meteorological Organisation, the year 2023 marked the driest year for the world's rivers in more than three decades. Almost a quarter of freshwater species are threatened due to pollution and habitat loss. Endangered rivers not only pollute aquatic ecosystems, but also contribute to global warming through methane emissions, spread waterborne diseases to millions and reduce food security for communities that rely on river-based agriculture, states the UN World Water Development Report 2025.

The present state of rivers across the globe and their restoration: Rivers are crucial freshwater sources but are increasingly degraded by urbanisation, industrialisation, pollution, hydrological imbalance, and climate change (Islam *et al.,* 2024; Mehta and Jade, 2024). Major affected rivers include the Yangtze, Nile, Mississippi, Ganga, Brahmaputra, Mekong, Thames, Niger, Congo, Murray-Darling, and Waikato. Global river restoration efforts aim to restore natural functions, biodiversity, and flood protection (Speed *et al.,* 2016). However, a universal approach to river restoration is unfeasible due to diverse contexts. Challenges such as weak regulations, poor planning, and limited public participation persist worldwide (Wohl *et al.,* 2015), hindering effective restoration and sustainable river management outcomes. Table 1 presents select examples of severely degraded rivers and restoration projects adopted to address their issues.

Rivers in India: Current status, challenges and opportunities: India, one of Asia's fastest-growing economies, faces severe water stress. Most rivers are contaminated due to industrial effluents, untreated sewage, encroachments and excessive water abstraction. Maharashtra, particularly Pune district, has the highest number of polluted river stretches, as per a CPCB 2022 Report. The Central Pollution Control Board (CPCB) defines polluted stretches as river segments where water quality consistently falls below standards, primarily due to high BOD levels. Rivers with BOD above 6 mg l^{-1} are polluted, above 8 mg l^{-1} are severely polluted, and within 1–2 mg l^{-1} are considered pristine, according to the CPCB 2025 report. Other indicators include low DO, low nutrients, heavy metals, and high TDS (Sharma *et al*., 2026; Kumar and Singh, 2023; Mishra *et al*., 2024).

As the world's most populous country, India supports 18 per cent of the global population, but is bestowed with only four per cent of the Earth's freshwater, as reported by a World Bank brief titled 'How is India addressing its water needs?', (dated 17 March 2023). Besides this, there are some alarming facts about the present and future intensity of water crisis in India. As one of the fastest-growing economies, India will experience high levels of water stress by 2025. According to NITI Aayog, water demand would increase twice as compared to supply, not only causing severe water scarcity, but it would adversely impact the gross domestic product. In addition to the quantitative water stress, the increasing incidence of water pollution in the country is acting as a 'ticking time bomb'. Around 70 percent of India's water is polluted (Mukherjee and Bhowmick, 2024). Between 1951 and 2024, there has been a decline of 73 per cent in per capita surface water availability in the country. The per capita freshwater availability is now lesser than 1,700 m^3, making India a 'water-stressed' country, states a report by the Centre for Science and Environment published in 2024. The country is ranked 143 out of 180 for sanitation safety and drinking water quality (Block *et al.,* 2024), which could largely be attributed to the dumping of untreated sewage in water bodies. Indian rivers are severely polluted, as around 72 per cent of India's wastewater goes untreated, polluting nearby rivers, lakes and groundwater aquifers, and degrading the water quality. To address this, the CPCB has identified 311 polluted river stretches for restoration across 279 rivers in 30 states and union territories, wherein the BOD level exceeds its permissible limit. This indicates that organic pollution continues to be the major water quality threat for Indian rivers.

Freshwater availability in India: The average annual per capita water availability has drastically decreased over the past decades. In 2001, with 1029 million population, the average annual per capita water availability was 1820 (cubic meter)-1, which then dropped to 1545 (cubic meter)-1 in 2011 with a population of 1210 million, and 1340 (cubic meter)-1 in 2025 with a projected population of 1394 million. This has been further projected to decrease by 1140 (cubic meters)-1in 2050 with the projected population of 1649 million according to the'Per Capita Water Availability Dashboard' developed by NITI Aayog.

The present status of rivers in Maharashtra with specific reference to Mula-Mutha: Maharashtra has the highest number of polluted river stretches in India, as indicated by multiple reports of CPCB. Despite major rivers like Godavari, Krishna, Tapi and Narmada, the state faces severe pollution, with about 3000 MLD

Table 1: Polluted rivers across the globe and their restoration projects

Rivers	Issues	Restoration Programs/ projects	References
Yangtze (China)	Industrial pollution, sewage, plastics, habitat loss	Yangtze River Protection Law (2021); Eco-restoration zones; dam operation regulation.	Wu and Ju (2021)
Nile (Egypt)	Sewage discharge, agricultural runoff, plastic pollution	National Water Resources Plan 2037; wastewater treatment expansion; Nile Basin Initiative	Wolanski *et al.* (2024)
Mississippi (USA)	Nutrient pollution (nitrates, phosphates), Gulf hypoxia	Mississippi River/Gulf of Mexico Watershed Nutrient Task Force; wetland restoration	Hearst *et al.* (2025)
Ganga (India)	Sewage, industrial effluents, religious waste	NamamiGange Mission, riverfront redevelopment, upgradation of sewage treatment capacity	Balkrishna *et al.* (2024)
Mekong (Southeast Asia)	Dam construction, sediment loss, fisheries decline, agrochemicals	Mekong River Commission; transboundary monitoring; community-based conservation programs	Haefner (2024)
Brahmaputra (India)	Erosion, sedimentation, untreated waste, hydropower impact	Brahmaputra River Basin Management Plan; afforestation and floodplain restoration	Pradhan *et al.* (2021)
Colorado (USA)	Overuse, salinity, agricultural runoff, drought	Colorado River Basin Drought Contingency Plan; water -sharing agreements; habitat restoration	Pitt *et al.* (2017)
Thames (UK)	Urban runoff, combined sewer overflows, microplastics	Thames Tideway Tunnel ('Super Sewer'); Thames River Clean-up projects	Shubhankar *et al.*, (2025)
Niger (West Africa)	Oil pollution, sewage, solid waste, agricultural runoff	Niger Basin Water Charter; international collaboration via Niger Basin Authority (NBA)	Adebangbe *et al.*, (2025)
Congo (Central Africa)	Mining runoff, deforestation, sewage pollution	Congo Basin Forest Partnership; water governance frameworks; limited large-scale intervention	Muvundja *et al.*, 2025
Murray-Darling (Australia)	Salinity, over-extraction, algal blooms, agricultural waste	Murray-Darling Basin Plan; environmental flow allocation; Sustainable Diversion Limit (SDL) enforcement	Athukoralalage *et al.* (2025)
Waikato (New Zealand)	Dairy runoff, sedimentation, nitrogen loading	Waikato River Authority; riparian planting and wetland restoration	West *et al.* (2025)

of untreated sewage discharged daily, states a report by South Asia Network on Dams, Rivers and People (SANDRP) - 2018. Polluted stretches total 2095 km—17% of India's total—with the Godavari being the most affected (Table 2). Restoring these rivers is vital, as they sustain urban growth and hold deep cultural and spiritual significance for Maharashtra's people.

Rivers Mula-Mutha: Multiple CPCB reports warn that Pune district has the highest number of polluted river stretches in Maharashtra. The Mula and Mutha rivers, forming the Mula-Mutha, are highly polluted, with BOD levels of 13–18 mg l^{-1}, falling in the Priority III category, according to an action plan for the clean-up of the polluted stretch of the Mula-Mutha River published by the Maharashtra Pollution Control Board in 2019. Over the past few decades, the water quality of Mula-Mutha has progressively deteriorated, hampering its ecological or recreational potential. The physico-chemical and biological water quality parameters of Mula-Mutha rivers have been studied by researchers and the Maharashtra Pollution Control Board indicates that the water quality of Mula and Mutha rivers meets the standards prescribed by CPCB before entering the city limits of Pune. However, as these rivers flow through various areas in the city, the water quality deteriorates, making it unfit for domestic or any other use (Jadhav and Jadhav, 2020; Patil *et al.*, 2020; Deshpande *et al.*, 2026). Not only the water is unfit for use, but the microbial contamination is a health hazard as microbial pathogens exhibit multiple drug resistance. The total length of these rivers is 44 km, largely flowing through urban areas. Both rivers are dammed upstream, according to the Pune Municipal Corporation. The Mula-Mutha River supports Pune's agricultural, residential, and industrial growth. Despite substantial government funding for restoration, it remains one of Maharashtra's most polluted urban rivers, contributing to increased waterborne diseases and severe pollution (Patil *et al.*, 2020; Deshpande *et al.,* 2026; Kulkarni *et al.*, 2024).

Table 2: River Pollution in Maharashtra

Rivers	Approx. length of polluted river stretches (km.)	% to the total length of polluted stretches in Maharashtra
Godavari	300	14.32
Bhima	200	9.55
Krishna	200	9.55
Tapi	150	7.16
Other rivers	1245	59.43
Total	2095	100

About the present study: Given that urban rivers are one of the most valuable but threatened ecosystems in the world, there is a paucity of studies focusing on their restoration specially in developing countries, the present study has three-pronged objectives: To assess the existing restoration programs for Mula-Mutha; To identify the best river restoration strategies for guiding Mula-Mutha's ongoing restoration projects, based on a comprehensive analysis of global river restoration projects; To provide suggestions to urban river authorities and river stakeholders in India. This study offers practical insights not only for Mula-Mutha but also for urban river restoration projects in India and other developing countries experiencing similar pressures and geomorphological conditions. Based on the study of restoration efforts of 25 rivers across the world, this article proposes five restoration strategies for restoring rivers Mula-Mutha, including: Adopting a mixed-use planning approach for river restoration, Accepting river restoration as a multi-year, continuous Process, Developing innovative solutions, Ensuring political support for river restoration and Involving communities in planning and implementing restoration projects.

Research methodology: In this study, a set of 25 rivers across the world was identified for studying their restoration efforts. The following criteria guided the selection of rivers or restoration projects for this study: restoration projects that addressed riverine issues, including organic pollution, flooding, damming, and encroachment; and rivers with sufficient published information and problems similar to those of Mula-Mutha. Table 3 presents the list of 25 rivers selected for this study.

Global river restoration projects: In the USA, early river restoration efforts focused on improving water quality, leading to the enactment of the 1972 Clean Water Act (Wohl *et al.,* 2015). Large-scale river restoration work has been carried out throughout the United States. There is adequate documentation of significant initiatives on rivers such as the Glen Canyon and the Kissimmee (Bernhardt and Palmer, 2007). However, there are a few smaller restoration projects whose restoration methods and outcomes had been under-researched. This motivated Bernhard and Palmer (2007) to develop a database on river restoration initiatives in all the 50 states of the USA, regardless of their size. Consequently, the National River Restoration Science Synthesis (NRRSS) database was developed, which includes information about around 37,000 river restoration projects. It was observed that river restoration projects in the USA have well-defined objectives such as: improving water quality, restoring riparian zones, enhancing in-stream habitat, clearing fish passage, bank stabilisation, etc. Common restoration methods include connecting food plains, stream modification, and creating recreational provisions. Exceptionally, there are also projects which include the removal of existing dams. The scale of river restoration initiatives in the United States varies, from massive dam removal to restoration of small streams. Another key feature of projects in the USA has been the participation of local communities and NGOs. River restoration in Europe has emerged through several major initiatives, notably the European Union Water Framework Directive (WFD) and the EU Biodiversity Strategy, as presented in the 'Yale Environment 360' Report by the Yale School of the Environment. The WFD aims to achieve a 'good status' for all European rivers, while the EU Biodiversity Strategy targets restoring 25,000 km of rivers by 2030 (Schmidt *et al.*, 2025, Fischer *et al.*, 2025) .

Europe's restoration experience reflects diverse techniques and approaches. Examples include dam removals on the Duero (Spain) and Loire (France) Rivers; floodplain marshland development along the Skjern River (Denmark); and the Netherlands' innovative 'Room for the River' programme, which involved relocating dikes up to 350 m inland to restore natural flow, as per the 'Yale Environment 360' Report (Van Stokkom *et al.*, 2015; Schmidt *et al.*, 2025). Zurich implemented the 'Stream Daylighting Programme', which addressed stormwater and wastewater management (Conradin and Buchli, 2004). Similarly, according to a report by European Environmental Agency, titled 'Rivers and Lakes in European Cities', published in 2016, Oslo adopted a 'de-culverting' approach for reopening buried streams to improve ecological integrity and water quality. Other restoration actions across Europe include introducing felled trees in rivers to reduce flow velocity and erosion (Sweden), re-establishing riverine forests along the upper Danube, connecting settlements to sewer networks, and enhancing wastewater treatment infrastructure. In 2024, the European Parliament adopted the European Nature Restoration Law, which aimed to restore 20% of EU land and sea areas, and ensure 25,000 km of free-flowing rivers by 2030. These efforts are underpinned by the European Water Framework Directive and the Habitats Directive, both of which aim to enhance the natural habitats and support species conservation (Pröbstl *et al.,* 2025).

In Australia, the deteriorated river water quality is an outcome of agricultural activities (Speed et al., 2016) and the non-perennial nature of its rivers (Shanafield *et al.,* 2024). For this region, we included the restoration of Murray-Darling, Snow, and Glenelg rivers in our analysis. Organisations such as the Australian River Restoration Centre and the Society for Ecological Restoration Australasia (SERA) are active stakeholders in restoring rivers in Australia. River restoration in Australia has emerged as an effective strategy for reversing the ecological degradation caused by decades of intensive water use, land clearing, and urban development. Restoration efforts in Australia aim to restore natural flow regimes, rehabilitate riparian vegetation, and improve habitat connectivity to support native biodiversity and ecosystem services. Key initiatives, such as the Murray-Darling Basin Plan, emphasize on sustainable water management and ecological resilience across one of the country's most critical river systems. Projects have included reintroducing environmental flows, removing barriers to fish migration, and controlling invasive species (Kingsford *et al.,* 2017). While progress has been made, challenges remain in balancing environmental objectives with agricultural and urban demands, particularly under the pressures of climate change. Therefore, effective river restoration in Australia requires an integrated, adaptive management approach underpinned by scientific research, community engagement, and long-term funding commitments (Pittock and Finlayson, 2011).

Latin American cities have witnessed a significant transition in the perception, utilisation and integration of river spaces (Pradilla and Hack, 2024). Latin America is rich in water resources, home to four of the world's major rivers—the Amazon, Paraná, Orinoco, and Magdalena—and accounts for

Table 3: Rivers selected for the present study

Geographic area	River/ name
USA	Guadalupe, Mississippi, Missouri, Colorado
Europe	Thames, Rhine, Danube, Waal
Australiaand New Zealand	Murray-Darling, Glenelg, Snow, Waikato
LatinAmerica	Bogota, Magdalena,
Asia	Singapore, Cheonggyecheon, Yangtze, Yellow River, Tama, Ganga, Brahmaputra, Mekong
Africa	Nile, Niger, Congo

approximately 31% of the planet's freshwater reserves, as per the World Bank. Despite this abundance, water quality in the region has deteriorated due to unsustainable agricultural practices, human-induced salinisation, unregulated industrial activities, and ongoing challenges related to poverty and population growth (Barlow and Clarke, 2004). Mondragón-Monroy and Honey-Rosés (2016) discuss four river restoration initiatives in Latin America, focusing on the Bogotá, Medellín and Magdalena rivers in Colombia, and the Rímacriver in Peru. River restoration efforts in the region began as early as in the 1970s, driven by public demand to reclaim river spaces and improve sanitation. The goals of these initiatives have been wide-ranging, spanning environmental enhancement, landscape improvement, better fluvial transportation, and fostering connectivity between riverfront neighbourhoods. Common restoration strategies include the development of ecological corridors, parks, greenways and revitalised urban spaces with amenities such as recreational areas and bicycle paths.

The relevance of river restoration initiatives in Japan, China, and Singapore to India's National River Conservation Plan (NRCP) is particularly notable due to shared characteristics such as similar geomorphological features, high population growth and density, and common stressors—including excessive water extraction, discharge of inadequately treated domestic and industrial waste, insufficient wastewater treatment infrastructure, and extensive river damming. Regional networks like the Asian River Restoration Network (ARRN) and the Japan River Restoration Network (JRRN) have also documented restoration efforts in other Asian countries, including Taiwan, Singapore, and South Korea. Our analysis focuses on five key rivers in Asia: the Singapore River, Cheonggyecheon Stream (South Korea), Yangtze River (China), Yellow River (China), and Tama River (Japan).

Japan has a long tradition of river restoration, beginning with continuous water quality monitoring and wastewater treatment development since the 1950s. Beyond improving water quality, efforts also enhance public river access and urban aesthetics (Nakamura *et al.,* 2005). A major milestone was the 1990s 'Nature-Oriented River Works' program, focused on conserving river biodiversity. Success has been driven by revised river legislation and strong involvement of local communities and NGOs. China's earlier focus on engineered river management, including dams and concrete banks, has shifted toward ecological restoration. Current strategies emphasise on riparian vegetation recovery, water quality improvement, and ecosystem restoration, tailored to regional catchment needs (Speed *et al.,* 2016). A recent study by Van Eerd and Banerjee (2025) points out that restoration of Asian urban rivers is intertwined with issues regarding urban citizenship, breach of global housing rights, poverty and vulnerability, livelihood and use of common property resources. It examines the social dimensions of renowned instances and examples of river restoration initiatives in Asian megacities like Lahore, Dhaka, Chennai, Ahmedabad, Bangkok, Manila and secondary Indian cities. It shines light on social concerns of river restoration such as displacement, land and water contestations, the right to housing and the interdependent rights to livelihoods, health and food security.

Studying restoration efforts of these twenty-five rivers helped us identify suitable best restoration practices for Indian river restoration projects. To cite a few examples, for implementing any intervention for the River Missouri (USA), it is a legal obligation for the Implementing Agency to obtain a biological opinion on the impact of the intervention. Mississippi River restoration is unique example as the first environmental restoration and monitoring program undertaken on a large river system in the USA, and has adopted a continuous approach for restoration, based on 30+ years of data through extensive monitoring. Restoration of the Rhine river is characterised by adopting a comprehensive approach aiming to achieve a good ecological and chemical state in the watershed. Some restoration experiences in Africa and Asia highlight nature-based solutions and community-led initiatives to combat land degradation, water pollution, and biodiversity loss caused by rapid population growth and climate change. Restoration of the Murray-Darling (Australia) emphasises on maintaining environmental flow in the river. River restoration programs in India can draw insights from such global river restoration efforts and incorporate some of these suitable best restoration practices in planning and implementation.

River restoration projects in India: Quantitative and qualitative pressures on rivers demand effective restoration to improve water quality and ecosystem resilience. India has invested substantially in two major initiatives—the National Mission for Clean Ganga and the National River Conservation Plan (NRCP). Launched in 1995, the NRCP aims to reduce river pollution through abatement measures. It has covered polluted stretches of 34 rivers across 77 towns in 16 states, with a sanctioned cost of INR 5,870.54 Crore and a central share of INR 2,510.63 Crore, creating 2,522.03

MLD sewage treatment capacity nationwide.

The pollution abatement works taken up under the NRCP include:Interception and diversion works, laying of sewerage systems to capture raw sewage flowing into the rivers through open drains and diverting them for treatment; building STPs for treating the diverted sewage; construction of low-cost sanitation toilets, preventing open defecation on river banks; construction of electric crematoria and improved wood crematoria to conserve the use of wood; river front development works and public participation, awareness and capacity building. However, the success of such projects has been limited and some river conservation projects have faced strong criticism (Mathur, 2012; Desai, 2012; Bedarkar and Mishra, 2021; Blair, 2023). The ongoing river restoration projects in India are criticised for a continued increase in riverine pollution, a greater focus on beautification than pollution abatement, poor settlement of project-affected people, and a lack of community support, among other issues. More importantly, Indian river clean-up projects have mainly focused on major rivers, ignoring the minor rivers that feed them (Manoj *et al.,* 2026), underscoring the importance of restoring minor rivers. Given the urgency of abating riverine pollution and the criticism of current river restoration projects, it is imperative to explore best practices from global river restoration projects and assess their suitability for adoption in Indian rivers.

Mula-Mutha restoration projects aiming at waste reduction and recycling: There are two projects relating to the restoration of river Mula-Mutha: Pollution abatement project and river front development project.

Pollution abatement project: The NRCP, under the Ministry of Environment, Forest and Climate Change (MoEFCC), with Pune Municipal Corporation (PMC) as the implementing authority, aims to improve the water quality of the Mula, Mutha, and Mula-Mutha rivers by expanding sewage treatment capacity from 477 to 873 MLD—adequate until 2027. The project involves constructing new STPs, laying sewer lines, rehabilitating four pumping stations, implementing centralised STP monitoring, improving sanitation in slums, training municipal staff, and launching public awareness initiatives. According to a Press Information Bureau (Government of India) Release on the JICA loan agreement for the Mula-Mutha river pollution abatement project, the project is funded through a soft loan (0.3% interest) from the Japan International Cooperation Agency (JICA), shared 85:15 between the Centre and PMC. The initial cost of the project was estimated to be around INR 990.26 Crore.

Pune river rejuvenation project: Proposed in 2018 with an initial estimated cost of INR 2,619 Crore, the project spans 768 ha along the river. Its scope and cost have expanded. As per Impact Assessment Report by Pune Municipal Corporation, the key components include flood-protection embankments, removal of flow obstructions, interceptor sewers, enhanced connectivity, and public amenities. However, several newspaper and magazine articles highlight that this project received a strong opposition from local communities and environmental activists due to the planned felling of over 7,000 trees and concerns over adverse impacts on the river's riparian ecosystem.

Suggestive measures for restoring rivers Mula and Mutha: Although our review covers restoration efforts for approximately 25 rivers worldwide, we finally selected six urban river restoration cases because these rivers experience stressors closely aligned with those affecting the Mula-Mutha River in Pune, underscoring their relevance to developing restoration strategies for Indian urban rivers. Table 4 presents the issues, details of restoration projects, outcomes and identified best practices for six rivers.

Adopting a mixed-use planning approach for river restoration: We recommend this approach to enhance the ecological health and functionality of degraded river systems. Mixed-use planning integrates habitat restoration, urban green spaces, controlled recreational access, and ecologically sustainable infrastructure, providing both environmental and community benefits. This approach balances ecological, social, and economic objectives by restoring or enhancing environmental functions alongside land use and urban development.A successful example is the Guadalupe River in California, which transformed from a heavily modified, urbanised channel into a revitalised ecological corridor through an integrated river management strategy. The Guadalupe River Park and Gardens project exemplifies this model, combining flood management, habitat restoration, and community amenities within a multi-functional green space. Native vegetation was restored in riparian zones, improving habitat for local and migratory fish species, including Chinook salmon. Moreover, the incorporation of pedestrian and bike trails, wetlands, and educational spaces has fostered public engagement, enhancing community connection with the river and awareness of environmental issues.This holistic planning model demonstrates how multi-use design can restore natural river processes, enhance biodiversity, and improve resilience to climate-related stressors while promoting sustainable urban living. For the Mula-Mutha rivers, a similar mixed-use approach could be adopted, emphasising ecological restoration while also reconnecting the local community to the river through accessible, inclusive, and ecologically sound design. Such an approach would ensure the Mula-Mutha's restoration aligns with environmental sustainability, urban livability, and long-term community stewardship.

Accepting river restoration as a Multi-year, continuous process: River restoration should be viewed as a continuous, multi-year process rather than a time-bound project, given pressures from urbanisation, climate change, and population growth. Thames River, once biologically dead due to industrial pollution, has seen major ecological recovery through wastewater treatment, habitat restoration, and species reintroduction. However, it remains stressed by runoff, temperature rise, and land-use changes. Thames Tideway Tunnel, operational since May 2025, diverts 34 sewage outflows, preventing 95% of spills. Similar long-term interventions could address untreated sewage,

Table 4: Selected cases of urban river restoration programme across the globe

River/ Country/ Reference	Issues	Restoration Programme/ details of restoration work	Restoration objectives	Outcome of the restoration project	Best practices identified
Guadalupe, the USA, Gole (2014)	Flooding	Guadalupe River Project; Guadalupe Creek Restoration Project	Flood protection; Habitat restoration; The community's desire for open spaces	Flood protection, Habitat restoration, Recreational amenities	Adoption of mixed -use planning
Thames, the U.K., Speed *et al.* (2016)	Deteriorated water quality due to industrialisation and anthropogenic activities; Outbreak of waterborne diseases, floods	Investment in sewage treatment plants, Construction of the London Tideway Tunnel	Improvement in water quality, habitat restoration	Considered one of the cleanest rivers in the world, supports the widest biodiversity; however, water quality issues persist	Multi-decade effort; Strong community participation
Waal, Netherland, Welsch *et al.* (2025)	Frequent floods	'Room for the river', repositioning of a dyke inwards	Giving more space to the river to accommodate higher water levels	Flood Control, Creation of public space	Innovative solution to flood protection
Cheonggyecheon, S. Korea, Lah *et al.* (2015)	Buried river, poor quality of water, and natural environment	Cheonggyecheon River restoration through the demolition of an expressway built on the river	Urban renewal through river rejuvenation	Urban renewal, improved access to the river	A radical yet effective approach to restoring flow by demolishing obstacles
Singapore, Singapore, Savage *et al.* (2004)	Water security, flood control	ABC Waters Programme	Water security, Flood control	Cleaner River offering high quality living	Harvesting stormwater at a larger scale Citizen Science
Genbee, Japan, Nakamura *et al.* (2005)	Deteriorated waterfront	Regular clean-ups, Releasing nymphs of fireflies in water	Cleaning the river, improving the recreational waterfront	Creation of a beautiful waterfront bestowed with nature	Participation of citizens, corporations, and government

Based on the analysis of river restoration projects presented in the above table, we suggest the following restoration strategies for rivers Mula-Mutha

Mula-Mutha River's major stressor, through sustained restoration and adaptive management. At present, the approach to Mula-Mutha restoration is largely ad hoc, project-based, and highly oriented towards beautification. Rather, what is needed is adopting a multi-year, continuous approach guided by data, utilising various types of data to monitor water quality, identify pollution sources, and guide restoration efforts.

Freeing the floodplains: The 'Room for the River' program along the River Waal in the Netherlands is a novel flood protection method. Traditionally, flood protection involved engineering solutions such as raising the height of dikes. The Room for the River program represents a more adaptive, nature-based approach that allows the river to have more room to spill over safely during high discharge. For the river Waal, dikes have been relocated so that they are set back further inland, leading to the expansion of floodplains. Ultimately, the 'Room for the River' program not only entails better protection from flooding, but it also means better local ecological and community resilience, improving habitat conditions for wildlife, improving water quality, creating opportunities for recreation and aesthetic enjoyment and enhancing the setting for local communities. The transformation of the River Waal demonstrates how an integrated, innovative approach to flooding can protect and restore river ecosystems and urban areas simultaneously. During monsoon season, the rivers Mula-Mutha also flood largely due to illegal construction in its floodplains and encroached banks. Therefore, it is strongly recommended that the floodplains of the river Mula-Mutha be restored to their natural state, allowing the rivers to flow freely, resulting in several benefits for the rivers and the community.

Ensuring political support for river restoration: Political will is essential for the success of large-scale restoration projects, as demonstrated by the Cheonggyecheon Stream restoration in Seoul, South Korea. Once a polluted, buried stream beneath a highway, it was transformed into an accessible green corridor integrating ecological education and public spaces. Led by Mayor Lee Myung-bak as part of his vision for a 'green city', the project initially faced resistance due to traffic congestion but succeeded through continuous stakeholder dialogue. The restoration reduced urban heat, improved air quality, boosted the local economy, and influenced sustainable urban development patterns, becoming a global model for urban stream restoration. The Cheonggyecheon case underscores that strong political will aligned with public interest drives transformative outcomes. Similarly, restoring the Mula-Mutha rivers requires firm political commitment focused on ecological recovery rather than beautification, achievable through resolutions or notifications issued by state or regional authorities, such as PMC, PCMC, or PMRDA.

Involving communities in planning and implementing restoration projects: Community engagement in river restoration is essential for fostering long-term public commitment and stewardship of restored ecosystems. Singapore's 'Transforming Our Canals' initiative, part of the Active, Beautiful, Clean Waters (ABC Waters) Programme, successfully converted neglected utilitarian canals into vibrant community spaces through extensive public participation. Schools, NGOs, and local groups were involved in the design and implementation process. During the Kallang River redesign, community workshops with stakeholders and residents helped in developing a plan balancing ecological restoration with the creation of public amenities, fostering a strong sense of ownership among the community members, similarly, Japan's Genbee River restoration project exemplifies meaningful community involvement, engaging local farmers, residents, and schoolchildren in river monitoring, planting, and riverbank maintenance. This inclusive process improved ecological outcomes while strengthening local identity and environmental awareness. Such participatory approaches demonstrate that when communities contribute to restoring river corridors, restoration efforts benefit from revived ecological knowledge, stronger community support, and culturally connected, resilient ecosystems. For the Mula-Mutha River restoration, meaningful community participation is critical, as the ongoing riverfront project currently faces opposition from local residents. Incorporating participatory frameworks—such as those seen in citizen science initiatives in Singapore and the Thames—could help bridge gaps between authorities and communities. In these models, citizens assist in monitoring water quality, studying ecosystem health, and raising awareness about conservation issues. Such involvement not only enhances scientific data collection but also promotes shared responsibility, transparency, and sustainable river governance.

The implementing agencies would benefit by extending this exercise of identifying best practices to a few more cases of urban river restoration. They should look into restoration efforts undertaken in Asian countries, such as Singapore (River Singapore), China (River Yangtze), Japan, and South Korea (River Cheonggyecheon), as they share identical climatic, geographic, morphologic and demographic conditions (Moore and Rutherfurd, 2017).

Perspective: This study highlights significant concerns related to river restoration initiatives in India, specifically the Mula-Mutha, and exposes deficiencies, including faulty design, over emphasis on aesthetics and beautification, and a lack of public involvement. Notwithstanding significant investments, the condition of numerous rivers in India continues to deteriorate. To tackle these issues, the river restoration program in India must define explicit objectives, implement thorough pre- and post-impact evaluations, and enhance local community engagement.

This engagement is essential for maintaining rehabilitated rivers and guaranteeing they fulfil both ecological roles and human requirements. Although it is crucial to learn from global river restoration experiences, successful outcomes depend not just on replication from similar projects elsewhere, but also on building a science-policy interfacethrough scientific adaptation of these solutions to India's distinct socio-economic, topographical, and hydrological settings. The emphasis should not only transcend mere surface renovations or commercial utilisation of floodplains, but prioritise quantifiable advancements in ecological integrity and community welfare. Restoring degraded rivers to their 'near-natural state' presents considerable obstacles, particularly for developing nations facing financial limitations. As 'water-wise' communities, we ensure that future generations inherit pristine and flourishing rivers. Though the study provides recommendations for the effective restoration of the Mula-Mutha rivers, it also has implications for urban rivers, especially in developing countries.

The study has limitations, as it is based on the analysis of twenty five river restoration experiences through a literature review and supplementary sources. Future studies can draw inspiration from this paper and adopt other research approaches. Similarly, future studies can include more case studies of river restoration, especially in urban contexts.

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