Supplementary Issue
Rethinking Urban Rivers

URBAN INDIA

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Nature-based Solutions in Urban River Management

Blue Green Infrastructure Planning

Revival of Urban Waterbodies and Groundwater

Pollution Abatement in Rivers

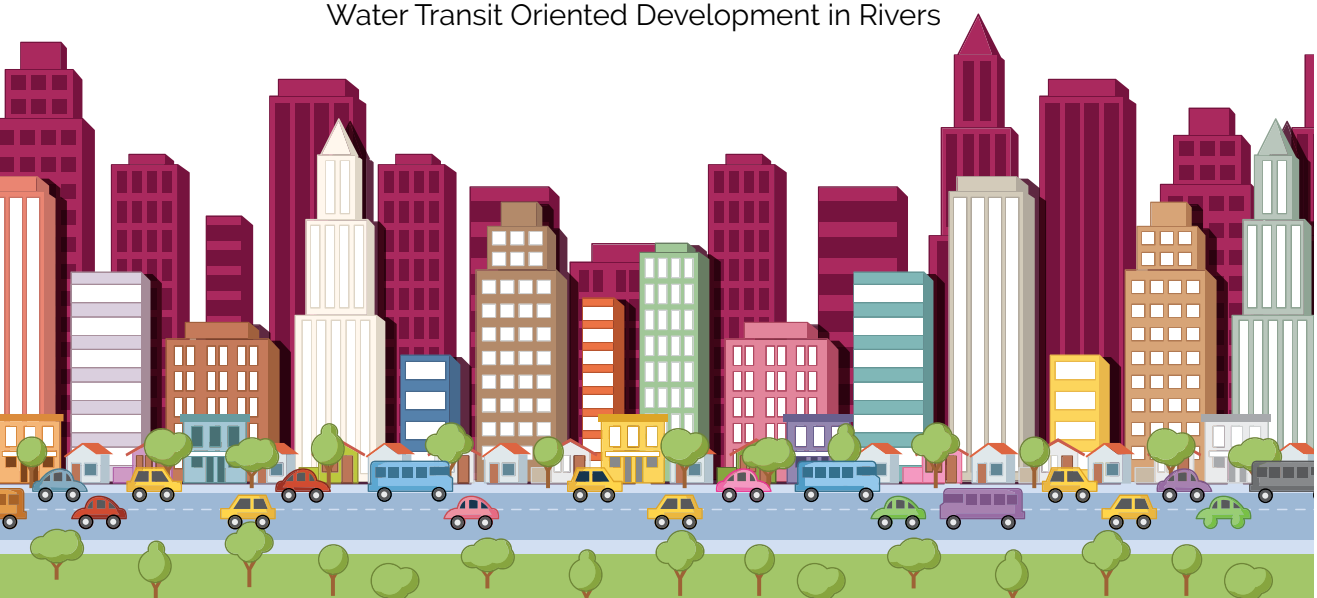
River Sensitive Development

Technology and Urban Rivers

Spatial Planning and Ecosystem Services

Wastewater Pollution and Socio-Economic Impact in Rivers

Water Transit Oriented Development in Rivers



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The National Institute of Urban Affairs (NIUA) is a
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URBAN INDIA

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Editorial

As the climate crisis intensifies, it magnifies the inherent challenges within India's urban landscape. To address these escalating issues, especially concerning water security, it is crucial to take appropriate actions. Urban water management stands out as a pivotal area for intervention, essential for realizing the vision of sustainable urban futures in India. In this agenda, the National Institute of Urban Affairs (NIUA) has recognised the critical role of integrated urban water management practices in achieving water-secure urban communities. Importantly, innovative thinking and research are instrumental in accelerating progress toward this goal.

This special issue of the Urban India journal is dedicated to exploring and unlocking the potential of contemporary concepts and innovative ideas to address the diverse challenges facing rivers and waterbodies in Indian cities. The articles in this special issue offer a range of perspectives and solutions, contributing to the broader dialogue on urban water management.

The first article, authored by Ambika Malhotra-Kothari and I, advocates for the integration of Nature-based Solutions (NbS) in urban river management. The authors explore how overcoming barriers to effective NbS deployment can enhance resilience against climate-induced extremes. They argue for holistic planning to make the benefits of NbS more visible and attractive to stakeholders and investors, thereby advancing water security.

Karpagavalli S, Subrata Chattopadhyay, and Visakha Jha focus on blue-green infrastructure (BGI) in Tirunelveli, Tamil Nadu. Their article examines how incorporating BGI elements—such as enhanced street design, stormwater management channels, retention basins, and constructed wetlands—can address environmental strategy gaps and improve water infrastructure services and amenities.

Pranav Varshney, Meenakshi Dhote, Bidisha Chattopadhyay, and Nikita Madan investigate the historical and current status of Aligarh's waterbodies. By analyzing the interconnectedness of ponds, natural drains, and groundwater, and highlighting the ecosystem services provided by the 'Sheka Jheel' wetland, their study offers a method for prioritizing the rejuvenation of the city's water resources.

Shivalika Arora, Chetan R. Patil, and Jyoti Verma tackle pollution issues in the Ganga river basin using a Fuzzy Analytical Hierarchical Process (FAHP) technique. Their study compares pollution drivers with the Urban River Management Plan of Kanpur and proposes a 'Riparian Zone Policy Framework' to restore the river's self-cleansing capabilities.

Shakchi Singh, Nilanjana Das Sur, Utsav Choudhury, and Kanika Bansal conduct a multi-level assessment of pollution in the Ganga, Varuna, and Assi rivers in Varanasi. Their recommendations include removing encroachments, developing riverfronts, reusing treated wastewater, and reassessing the Urban River Management Index to reflect these changes.

Mrignayani Chandra, Madhuri Kumari, Ravinder Kumar Tomar, and Jyoti Verma explore the role of community involvement in managing pollution in the Dakshineswar stretch of the Hooghly River. Their proposed solutions include a GIS-integrated app for waste management, bioremediation techniques, and clean energy options for boats to improve water quality.

Arunima KT, Mohammed Firoz C, AK Kasthurba, and Peeyush Gupta focus on spatial planning within watershed regions. They stress that Ecosystem Services (ES)—including provisioning (such as food, water, energy), regulating (like air quality and climate stability), cultural (aesthetic, recreational, spiritual), and support services—should be central to planning strategies. The goal is to harness and protect these services to benefit both ecosystems and human populations.

Rupal Srivastava, Rajeev Malhotra, and Rahul Sachdeva advocate for interdisciplinary collaboration to address wastewater management challenges. They highlight innovative methods such as decentralized wastewater treatment systems and Nature-based Solutions. These approaches aim to improve water quality and enhance community well-being, showing that combining expertise from social and environmental sectors can lead to more sustainable solutions.

Daman Dogra, Kshama Puntambekar, Gaurav Vaidya, and Sarika Chakravarty discuss the concept of a water-centric city, where urban planning integrates water transit terminals with other transportation infrastructure like roadways and railways. This approach aims to promote inland water transportation, making urban transportation systems more sustainable and efficient.

This supplementary issue of Urban India aims to present unique case studies of urban water bodies and suggest innovative approaches to resolving urban river and waterbody management issues. I hope this collection of research articles will provide evidence based policy inputs to all stakeholders engaged in promoting the sustainable development of cities wherein rivers and waterbodies form an integral part of the ecosystem.

Dr. Victor Rana Shinde
Special Editor &
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From the Editor's Desk

Urban India, home to 487 million people, accounts for 35.19 per cent of the total population[1]. It is projected that 50 per cent of India's population will live in urban areas by 2047[2]. India is also committed to becoming a developed nation with a 30 trillion-dollar economy by 2047. Urban areas will play a crucial role in realising this vision, with associated opportunities and challenges. With the climate crisis becoming widespread, one of the primary challenges would be to balance economic growth with environmental sustainability.

NIUA's mandate, since its establishment in 1976, has been to provide contemporary state-of-the-art research, knowledge and capacity development support to cities as they define their development trajectories. Over the last few years, our focus has been to promote sustainable and integrated solutions to cities optimising the use of natural resources that are environmentally friendly. By prioritising ecologically friendly practices, we strive to create urban environments that are not only resource-efficient but also minimise their ecological footprint.

Since the last five years, in association with the National Mission for Clean Ganga, we have been striving to address a vital aspect of overall river management – 'the urban element'. This focus is critical despite cities accounting for only a small portion of the country's river basins, because they significantly contribute to the undesirable state of rivers. Our narrative is that **since cities have contributed to the problem, they must also be part of the solution.**

The concerns for environmental conservation and demands for sustainable development, starting with the Stockholm Conference of Environment (1992) and the UN Earth Summit (1992), are new if compared to the age-old cultural and traditional practices of environmental conservation which are present in India. As far back as the Atharva Veda, the spirit of harmony with nature and

[1] Ministry of Health and Family Welfare (2020), Report of the Technical Group on Population Projections *for the period of 2011-36.*

[2] *United Nations, Department of Economic and Social Affairs, Population Division (2019). World Urbanization Prospects: The 2018 Revision.*

preserving the environment for future generations was taught as a way of life. ***"mātā bhūmih putruahan pṛthivyā:"*** **Translation –** "Do not harm the environment, do not harm the water and the flora…"

We must recognise the interdependence between cities and rivers, and take proactive measures to preserve and restore river ecosystems. It is important to acknowledge that river management today is a vastly different process compared to the past. The challenges we face now are more complex and require a multifaceted approach. Effective river management today demands transdisciplinary thinking and action, encompassing fields such as hydrology, engineering, landscape architecture, economics, social sciences, urban planning, and more. This comprehensive approach is essential to address the diverse and interconnected issues affecting our rivers and adjoining habitations to develop sustainable solutions for their conservation and revitalisation.

In this context, I am happy to introduce this issue of *Urban India* on 'Re-imagining Urban Rivers'. It is supplementary to the main volume 43.2 and brings forth the multi-dimensional challenges that our river cities are facing in recent times. It is likely to be a good reference for professionals working on urban river management and is intended to cater to the needs of the research communities, students, planners and policy makers.

I am delighted to have Dr Victor R. Shinde as special editor and Dr. Biswajit Kar as guest editor of this issue. I would especially like to appreciate the effort of Mr. Lovlesh Sharma for conceptualising this volume. I also thank Ms. Manju Rajeev Kanchan, Mr. Berjis Driver and the design team of NIUA for extending their support in bringing out this supplementary issue of the journal.

Dr. Debolina Kundu
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Embracing Nature-based Solutions in Urban River Management

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Abstract

The relationship between river and land has been forgotten within the urban fabric. With climate stresses becoming common in the form of cyclones, unpredictable intense rainfalls, and extreme heat coupled with water insecurity, Indian cities are struggling to keep up. Nature-based Solutions (NbS) are a response in which green-blue infrastructure reduces the pressures of urbanisation on the river and the strain of flooding on cities, while at the same time, reinforces economic and social growth. It also creates public spaces for communities, generates job opportunities, and safeguards the larger environmental ecosystem.

This paper analyses the role of Nature-based Solutions on urban rivers through case studies and breaks down four key under-explored aspects that prevent the scaling-up of NbS in India. NbS projects lack funds for planning, implementation, O&M, and long-term management. The paper zooms into standards, regulatory and participatory methods, and financing mechanisms that help in scaling up NbS, attract investments, develop contextual solutions, and provide clarity to all stakeholders. The objective of the paper is to present the value of NbS for urban rivers and climate stresses through holistic planning for clarity on benefits to stakeholders and potential investors to enable implementation and uptake.

Keywords: Urban River Management, Nature-based Solutions, Urban Planning, Urban Flooding, Private Sector Financing, Standardisation of NbS

The Urban Paradigm

With climate extremities becoming more common each year, heavy rainfalls and cyclones coupled with insufficient drainage systems and incapacity of rivers have often brought Indian cities to their knees or rather floating in sewage water. This not only brings loss and damage to life and property but also increases infectious diseases, destroys crops, damages public infrastructure, reduces mobility, and adversely affects the local and regional economy. Unplanned rapid urbanisation has led to loss of natural drainage networks, reduction of floodplains and river capacity, and increase in unnatural catchments within the grey infrastructures of the city. Within the urban fabric, the relationship between a river and land has been forgotten in the last 100 years.

In 2018, flooding was responsible for global economic losses of more than 37 billion dollars (USD), while drought caused losses worth approximately 28 billion dollars (Podlaha, Lörinc, Bowen, & Bhattacharya, 2018). If humans did not intervene, would it be called flooding or erosion or just the nature of a river? We draw a line on a paper defining the edges, floodplains, or water levels. Without the line, the river does not flood, it just flows naturally.

As most cities are developed along rivers, one must find ways of living with them. Additionally, extreme climate stresses further add to the pressures felt by cities. The cities that experienced three to four months of monsoon, are now breaking under high intensity rains that are funnelled into just one month. As floods are becoming more prevalent and recurrent in many Indian cities, there are elevated impacts on life, property, and economy, and cities need to take an action-based approach.

Immediate Need for Combined Effort

Nature has many functions and advantages in urban rivers and waterbody management. Some of these are:

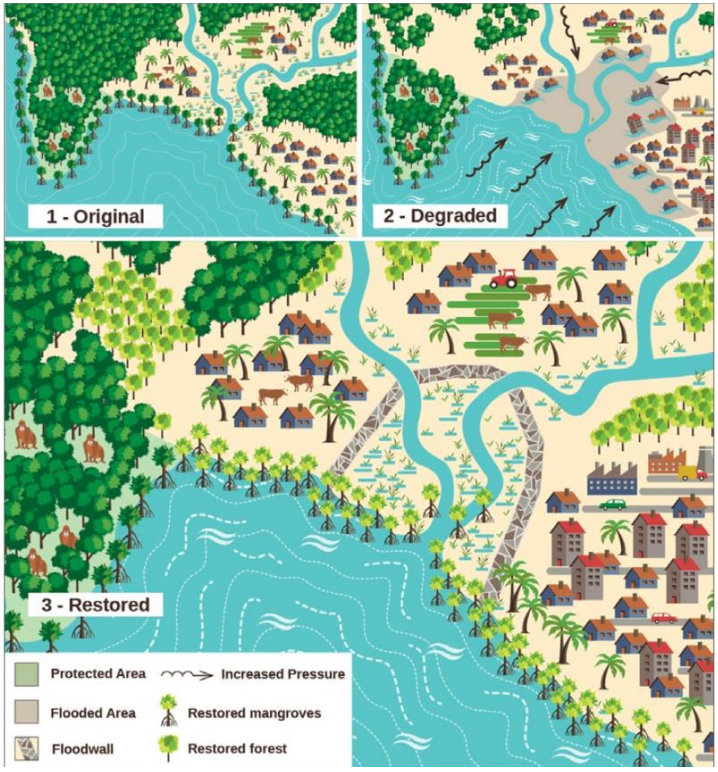
- Wetlands have a high carrying capacity, thus making them important elements in reducing the pressure of high-intensity rains.
- Floodplains store large volumes of water during extreme events, thereby delaying or buffering the downstream impacts (IUCN, UN Environment, & UN Environment-DHI, 2018). They also provide reduced flood risks, groundwater recharge, and extremely fertile land.
- Maintenance of natural drainage systems in a city helps in eliminating urban flooding.
- Mangroves are like walls which reduce high waves from reaching land. They are also breeding grounds for many types of fish and organisms.
- Restoration or rejuvenation of upstream river ecosystems provides a new source of income as well as cleaner water for downstream communities.
- Large green covers along the rivers act as riparian buffers that support in cooling cities, and improve air quality. According to the India State of Forests Report (Ministry of Environment Forest and Climate Change, 2019), the carbon stock from forests (including plantations) in 2019 was estimated at 26.12 billion tonnes of CO2 equivalent.
- Appropriate grasses with wide root networks increase the stability of floodplains and prevents erosion.

The use of nature for simultaneous benefits towards biodiversity and societal well-being was defined for the first time at the 2016 World Conservation Congress by the International Union for Conservation of Nature (IUCN). Here, Nature-based Solutions (NbS) was defined as - actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, UN Environment, & UN Environment-DHI, 2018).

Nature-based Solutions (NbS) are where green-blue infrastructure can reduce the pressures of urbanisation on the river, and flooding of the river on cities. It also supports creating spaces for communities and reduces the burdens of climate change and water scarcity while complementing the existing grey infrastructure to build resilience in a city.

Sponge cities are a type of NbS that helps to passively clean, absorb, and store water. The Atal Mission for Rejuvenation and Urban Transformation (AMRUT) 2.0 launched in October 2021 in selected 500 cities and towns, featured a holistic approach towards urban aquifers by using the strategy of sponge basins to effectively turn cities into sponge cities (Thara, 2023).

Figure 1: Hypothetical Scenario of NbS Along Urban Rivers



Source: E Cohen-Shacham, 2016

While NbS cannot be a siloed approach for river management, it brings great value within a holistic plan. It can support disaster management in terms of river-edge and floodplain protection; restore base flow and groundwater levels; reduce stormwater run-off and unplanned water collection; and help in wastewater clean-up to increase reuse and return flow to the rivers. In the last 10 years, water hazards have been among the top five risks in the likelihood and severity of impacts, as per the World Economic Forum's global risk assessment (World Economic Forum, 2019). As seen in Figure 1, using NbS along with grey infrastructure can help in safeguarding communities, essential services, environmental ecosystems, and investments.

Good Practices

Many indigenous practices are also various types of Nature-based Solutions where the community lives with the rivers by safeguarding the ecology. For example, in the Netherlands, permeable dams are a mesh of wooden logs where the water and sedimentation go through but cuts down the waves that erode the edges (Winterwerp, 2020). At a larger scale, the East Kolkata Wetlands (Figure 2), made up of 12,500 hectares that were initially salt marshes, were later transformed into fish farms and paddy fields. Surrounded by the city, it is one of the main discharge sites for Kolkata's sewage, but using NbS, it produces much of the city's fish, vegetables, and flowers under community ownership. The site supports the livelihood of nearly 74 percent of the working population from the adjoining areas. It recycles 750 million litres of municipal wastewater (including domestic and some industrial effluent) and generates 22 tonnes of fish and 150 tonnes of vegetables per day (Mukherjee & Sen, 2020).

Figure 2: East Kolkata Wetlands in the Middle of Densely Populated Kolkata

Source: Google Earth Pro, accessed on 17th June 2023.

From a climate action lens, NbS is a technology that undertakes both adaptation and mitigation practices. Circular models of water management using Nature-based solutions have emerged as effective in minimising water extraction from rivers and waterbodies, conserving resources, increasing return flow to the rivers, and helping cities in generating revenue. By emphasising the recovery, treatment, and reuse of water in a circular approach, India can alleviate its water stress and pave the way for a greener and more resilient future.

In 2011, Bengaluru decided to recharge the Amani Doddakere Tank (ADT) in Haskote, which had been completely dry for 18 years (Danso, Naidu, & Drechsel, n. d.). The wastewater from the city to the lake flowed through an unlined natural canal which automatically treated the wastewater in the process. The groundwater started recharging in the region, and farmers began tapping into the canal, thus preventing the water from reaching the tank. The intent of the project failed as very little water reached the tank, but using NbS of an unlined canal helped in reusing the wastewater to rejuvenate and support the social and economic factors of the region (Danso, Naidu, & Drechsel, n. d.).

Benefits and Initiatives of NbS

With an investment of 4.5 billion US dollars under the Namami Gange Programme (Press Information Bureau, 2023), a number of initiatives have emerged for rivers. However, many of these initiatives are limited to pollution abatement and covering infrastructure gaps, not considering the social, economic, and environmental value of the rivers and water bodies.

In June 2019, 12 percent of India's population was already living in a 'Day Zero' scenario due to excess ground water extraction, key reservoirs' reduced capacity, inefficient water management, and weak monsoons (Matto, 2019). With extreme climate and water stress being experienced by many Indian cities, there is an immediate need to look at the issues holistically with collaboration across all stakeholders to plan for sustainable urban river management with appropriate monitoring and financing mechanisms.

Some of the social, economic, and environmental benefits of Nature-based Solutions for cities include:

- Tourism
- Livelihood generation
- Carbon sequestration
- Temperature reduction in place of Urban Heat Island Effect
- Real estate growth due to proximity to Blue-Green Infrastructure (BGI)
- Municipal revenue generation
- Enhanced health and well-being in nearby communities

As often seen, many jump onto the NbS train but lack the scientific mapping to contextualise the solutions. Trade-offs occur if maladaptation of NbS is undertaken. For example, certain climate change mitigation policies or climate action plans encourage NbS with low biodiversity value, such as afforestation with non-native monoculture (Seddon et al., 2020). Other challenges of ill-

informed NbS includes land degradation, food security, loss of livelihood, increase in pollen or pests, water availability, and rapid gentrification of the urban region. Selection of the right site with appropriate conditions along with scientifically selected NbS technology and long-term monitoring mechanisms, is the way forward.

With persistent innovation in understanding methods of urban river management, especially from an NbS lens, currently four key aspects lack research and strategies in the Indian context. This paper will detail the landscape of NbS in relation to the four under-strategised sections and present entry points to reduce obstacles for cities.

Stakeholder Engagement

One reason Nature-based Solutions are not fully exploited is because of the complexity of multiple jurisdictions and stakeholders that need to be engaged in implementing them (IUCN, UN Environment, & UN Environment-DHI, 2018). After all, in India, water is a state subject and implementation is funded by a central scheme, while the true benefits might be local to the city or the neighbourhood. Beneficiaries can be located across geographic and administrative boundaries. This makes it quite a task in collecting, collaborating, and convincing all stakeholders. Since NbS is a type of infrastructure that needs firm operations and management instruments post-implementation, stakeholder ownership is critical. Therefore, it is necessary to cut across this institutional complexity to plan, finance, and implement NbS in a coordinated manner.

For example, Aurangabad Municipal Corporation with other key government stakeholders and solution providers worked to restore a seven kilometre stretch of the Kham River. The dying seasonal river had turned into a nalla (a sewage and solid waste carrying drain). Through NbS, the riparian edges were restored using eighty-six native plant species, and the groundwater fed natural springs and wells were rejuvenated to enhance the base flow. The compelling part of the river restoration was the behavioural change activities and community participation. Through a citizen survey, it was clear that 40 percent of the city was unaware of the existence of a river in their city. Citizen-led plogging drives helped in collecting 300 kilogrammes of waste from the river, and using the waste, playful public spaces and signages were created.

From a ground-up approach, the city and other non-government organisations can help in bringing awareness to the waste choking stormwater drains, thereby adding to the city's reaction to excess water. Often, citizens are found engaging in poor practices that lead to pollutants entering the drains and rivers at both small and large scales. This includes disposal of daily household waste, raw sewage, synthetic fertilisers, and construction debris that block the flow of water in narrow channels. Thus, behavioural change is one of the primary strategies that influence citizens to refrain from such practices.

Another method of engagement can be to generate livelihood opportunities for the local communities through NbS. This entails charging a small fee for entering the area, job generation for maintenance, creating public spaces, or strategically placing kiosks or commercial activities within the site. Cities can run programs similar to the Ganga Praharis (Guardians of the Ganga), where the community becomes the eyes and ears in managing the river edge and floodplains from

encroachment and pollution. To achieve this, the traditional methods of disseminating knowledge must complement the strategies that are rooted in behavioural change.

Land Allocation

For urban NbS, land allocation is a big crisis as real estate values in cities are lucrative. It can take years, even decades, for ecosystems to deliver a full suite of benefits, whereas grey solutions can immediately produce anticipated results. Land allocation becomes a tedious process where real estate moguls present more revenue generation from the land for the city. However, this does not take ecosystem services into account. The Millennium Ecosystem Assessment Report (2005) defined Ecosystem Services as "the benefits people derive from ecosystems". The report (Millennium Ecosystem Assessment, 2005) further divides it into four categories - provisioning services such as food and water; regulating services such as flood and disease control; cultural services such as spiritual, recreational, and cultural benefits; and supporting services, such as nutrient cycling, that maintain the conditions for life on Earth.

If certain green-blue areas are not conserved for their larger benefit to the city and its people, even unrelated profit-making economies and systems will struggle. The balance between immediate returns from economic growth and long-term returns from environmental protection needs to be balanced.

Standards, Regulations, and Scaling-up

Fundamentally, criticisms of the NbS concept stem from lack of globally recognised standards and principles that guide its implementation. This vacuum opens NbS up for harmful interpretations and misguided applications (Qi, Terton, & Vaughan, 2021).

In India, many cities are initiating tree planting drives in the name of climate action and Nature-based Solutions. However, without proper analysis of site conditions, indigenous plants and O&M practices, these methods lead to the misuse of the term NbS, thereby overselling the idea and reducing its value. Furthermore, without proper standards, the private sector utilises NbS for greenwashing or advertising carbon neutrality without changing their ecologically unfriendly practices.

For standardisation of NbS, the value of ecology within the rivers and their waterbodies needs to be measured. Thus, improved valuation first requires an understanding of how key river processes create significant improvements in the measurement of water flows, watershed conditions, and a range of biophysical processes, such as sediment transport, as well as social, economic, and cultural dependencies on rivers (Opperman, et al., 2018). But how does one identify and quantify these intangible benefits? Due to its large variety of social, economic, and environmental benefits, it is evident that the value of NbS is hard to quantify. It is also arduous to manage natural infrastructure when Nature-based Solutions are an entire ecosystem in comparison to grey infrastructure that is essentially a closed system.

In the case of Coimbatore, Tamil Nadu, the city decided to revitalise eight lakes that were connected to the Noyyal River by creating recreational facilities for the neighbouring communities. A mix

of NbS was designed to increase both the quantity and quality of wastewater that was entering the lakes (United Nations Environment Programme, 2022). No-go zones were designated to allow nature to thrive without human disturbance. A detailed environmental and social impact assessment was undertaken along with a management plan to facilitate adherence to the regulations under state and national policies and guidelines. Additionally, a dedicated institute, The Coimbatore Lakes and Catchment Management Authority, was proposed to ensure O&M during and post-completion were to be sustained along with an assigned fund.

Like the long-term planning in Coimbatore, other cities can also create regulatory bodies that oversee and prevent harm to the ecological systems that are important for the health of the city like acting as carbon sequestration hubs, and reducing the effects of climate change and water pressures. Further, city authorities can also focus on regular monitoring of activities around the ecological site. These activities include construction and its waste, prevention of commercial sand mining, and regular maintenance of existing natural and manmade canals. Collaborative efforts with local communities will help to keep the waterbodies, rivers, and their ecosystems clean and healthy for a long time. Standardisation and regulatory frameworks can improve and evolve the applications of NbS, help plan a consistent approach, and verify solution-oriented outcomes, which will lead to greater confidence in NbS among decision-makers, financiers, and communities.

Financing Nature-based Solutions

Urban flooding is significantly different from rural flooding as urbanisation and concrete cities lead to unnatural catchments, thus increasing the floods from 1.8 to 8 times and flood volumes by up to six times (National Disaster Management Authority, n. d.). Urban flooding affects livelihoods, mobility, economic activities, and services. It also affects commercial activities of big companies like Uber, Amazon, and Zomato, thereby making NbS a collective solution with respect to river and water management. As per Sheccid Gómez, et al. (2023), most NbS projects are financed either by the public sector or philanthropic funds, with only 14% being provided by the private sector. Some of the barriers in investing into the sector include:

- The length of time for Nature-based Solutions to provide a return on investment as it can take years for the solution to reach its full capacity
- Lacking proof of concept, especially from a climate action lens
- Lacking tax cuts or benefits from the city or state authorities
- Not being included in the larger schemes and policies at the centre thus preventing large investments
- Lack of clarity in contextualising the solutions to the geo-climate and local pain points
- Complex implementation methodology as multiple stakeholder groups are required
- Inadequate research on quantification of distribution of social and economic gains across stakeholders

Public funding cannot cover the gaps in protecting the river and its ecosystem. It is imperative to attract and include private capital in NbS projects. But with its current complexity, how does one make it straightforward and structured to not scare away funding? The costs and benefits of NbS need to be clear to the stakeholders and potential investors to increase uptake.

New financial tools like Green Bonds, Carbon Credits, or even simple decision-making tools can help in simplifying the sector for ease of investment. Decision making tools can be designed for different participants. For example, one can be for the private banking sector to understand, identify, measure, and assess their dependence and impact on natural capital (Sheccid Gómez, 2023), while another can be for city officials to select the right type of NbS for their designated sites with the exact issues to be addressed and the amount of funding required.

In July 2023, Junagarh applied and succeeded to become the first civic body in Asia to trade water credits. The program run by UNFCCC since 2014 allows projects or civic agencies to earn credits for water conservation (Khakhariya, 2023). The program addresses the water crisis that is experienced in many cities and also helps incentivise rainwater harvesting and groundwater recharge. Junagarh won nine million water credits for saving 10 million litres of water through the Hasnapur reservoir conservation project. The municipal corporation of the city can convert the water credits into financial instruments, thereby attracting finance from the private sector, banks, and impact funds for further development in the city.

Blended financing or co-financing tools can quickly add investment security and thereby increase the funds that are available for NbS. This is a strategic mix of public sector and philanthropic investment which will reduce the investment risk and increase project bankability, thus attracting large amounts of private capital (Sheccid Gómez, 2023). However, these investment strategies work best only when the risk is lower.

Lastly, it is also important to note which phase of the NbS project is lacking funds, whether it is in planning the project, implementation, or O&M, and long-term management. The post-completion operations and management section lacks funds significantly. Maybe this is because of the difficulty in identifying all direct and indirect benefits. The communities have to own the project, which is the key to the success or failure of a project. This will happen only if there is economic benefit for them. However, looking from another lens, is it fair to put the ownership and management on the community? The city can create financing mechanisms along with a MEL (Monitoring, Evaluation and Learning) system with ecological and social feedback systems built into it. The O&M (Operations & Maintenance) can be used as a selling point for NbS where the government can create roles for small service providers who can be within the regulatory framework of municipalities. These service providers or vendors can then be accountable for the NbS project in maintaining its performance and restoration and continue to be paid for their services.

Conclusion

In cities, especially dense informal housing in climate-vulnerable areas close to the river, many suffer increasingly due to flooding, extreme water shortage, or climate stress. This results in loss of life, livelihood, and the willpower to hustle each day. Nandini, having lived and worked in

Chennai in the care economy for five years with her family, had access to very little support after the floods or during intense heat waves with almost no water. Being in the care economy, she was not provided health or life insurance, nor was she given any formal support that is predominant in white- and blue-collar jobs.

Restoring the riparian buffer, a NbS strategy, along the floodplains would help in flood control, give cover from extreme heat, and restore the groundwater table. It might also help Nandini's family with a secondary source of income. Nature-based Solutions can change our ways of living with nature, supporting harmonious, healthy co-living.

With integration of differently scaled solutions into the larger water management of a city through master plans, policies, acts, implementation, and by-laws, NbS has the potential to make cities resilient, inclusive, and healthy.

Conflict of Interest

The authors declare no conflict of interest.

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Blue-Green Infrastructure Planning for a Sustainable Development: A Case of Tirunelveli

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Abstract
Globally, numerous urban centres are transitioning their planning methodologies towards nature-centric strategies as alternatives to conventional grey infrastructure solutions. This paradigm shift incorporates both green and blue elements which is driven by heightened environmental consciousness, particularly regarding climate change. This study investigates the emerging concept of "Blue-Green Infrastructure" (BGI), analysing the ongoing initiatives in India and internationally. Furthermore, it proposes prospective measures to foster sustainable urban development, mitigate urban river pollution, and enhance overall urban functionality, with a specific focus on Tirunelveli. Informed by global and domestic case studies, this paper aims to reconcile the divergence between traditional urban planning frameworks that are typically characterized by either Green Infrastructure or Water Sensitive Planning, by advocating for integration of BGI as an innovative urban strategy.

Keywords: Blue-Green Infrastructure (BGI), Water-sensitive Planning, Nature-based Solutions

Introduction
In the aftermath of the COVID-19 pandemic, numerous nations formulated economic recovery plans. However, there was also widespread recognition globally of the importance of sustainable resurgence, with focus on mitigating climate change impacts and undertaking long-term rehabilitation efforts in urban areas (Chandra, 2022). Due to urbanization, cities, the major contributors to climate change, are experiencing significant loss of green and blue elements across India.

For instance, studies have revealed alarming transformations in cities like Bengaluru, where urban areas have expanded by over 900 percent in just four decades, leading to depletion of green spaces and waterbodies (Ramachandra, 2017). Similarly, Mumbai has witnessed a decline of 60-65 percent in biodiversity and waterbodies due to urbanization (Fermades & Chatterjee, 2017). This has been the scenario of many metropolitan and large cities, thus making long-term sustainable development all but impossible.

This significant depletion in the environment has been unintentionally caused by incompetency to proficiently streamline, govern, and oversee the urban infrastructure and planning processes. Of the four threats that are anticipated to adversely affect countries due to climate change, only one pertains to governmental inadequacy in implementing sufficient measures to mitigate climate change. The remaining three threats are environmental in nature and largely stem from unplanned and negligent urban development practices (World Economic Forum, 2020).

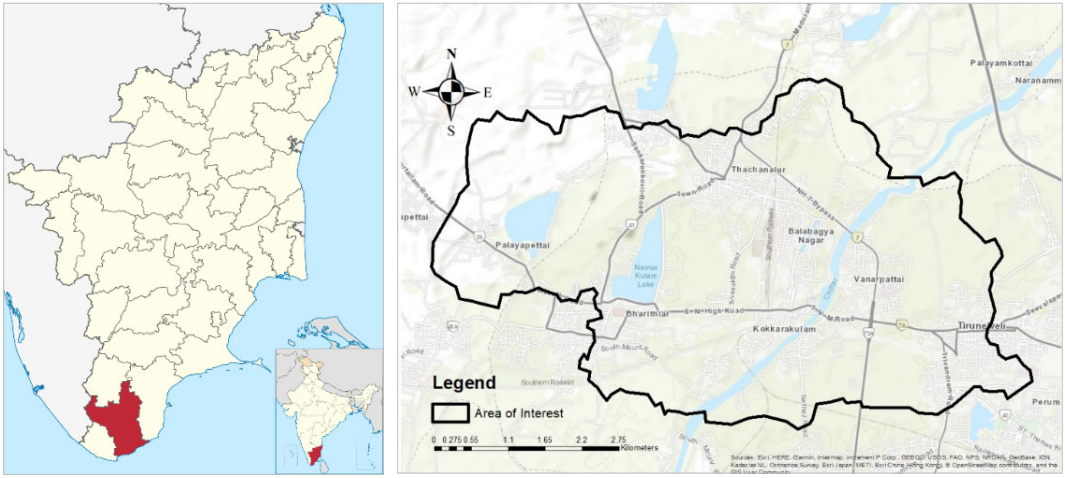
Hence, it is imperative for governments to prioritize their actions which are aimed at climate-proofing cities and promoting sustainable urban growth. But, previous attempts to address climate-related environmental problems by adapting conventional "grey infrastructures" have fallen short of providing long-term sustainable solutions, because they were temporary technological fixes. Instead, they should be more ecologically conscious by implementing and adhering to nature-driven approaches, a purpose purely offered by development of 'Blue-Green Infrastructure'.

Study Area

Urbanization comes at the cost of diminishing greenery and waterbodies in cities, which result in significant environmental challenges. The city of Tirunelveli in Tamil Nadu, though still in its developmental phase, is not immune to this trend. Even though we have seen many cities reach a point of overcrowding and diminished resources, Tirunelveli is still in its developmental period. As such, it presents us with the opportunity to restore its balance with nature and prevent further loss of the blue-green elements.

Situated within the urban cluster of Tirunelveli District, the study area spans 29.18 square kilometres and is defined by contours and hydrological catchments. Central to this area is the Thamirabharani River, the only perennial river in Tamil Nadu, that flows from the Western Ghats to the Bay of Bengal, traversing Tirunelveli and Tuticorin districts.

Figure 1: Location of the Study Area: Tirunelveli



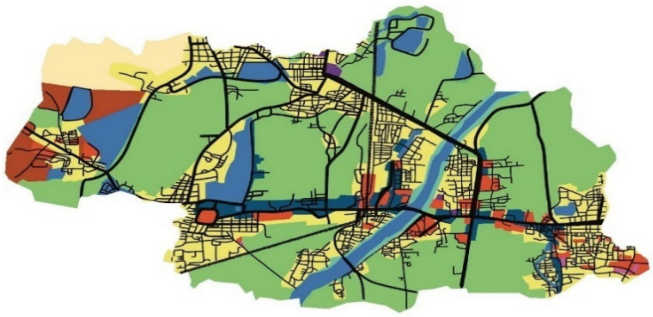
Source: Using base map sourced from ESRI

Figure 2: Water Network in Tirunelveli

Source: Using Secondary water resources data from Nellai Neervalam, on the base map sourced from ESRI

A comprehensive analysis of the study region reveals the presence of thirteen water tank pits that are interconnected by two channels. This interconnectedness presents the potential for establishing a network between the blue and green infrastructures which are crucial for sustainable urban development. The site area comprises 11% waterbodies and 52% green spaces. Over the years, the amount of blue and green components in the city has decreased drastically. Unfortunately, waterbodies which are a vital part of human settlements, have begun to lose their importance in the process of urbanization and there is an urgent need to address this issue via conscious urban planning.

Figure 3: Land Use Distribution in Tirunelveli



Landuse Category	%
Residential	15.23
Commericial	1.55
Public/Semi-Public	1.43
Industrial	0.77
Transport	15.33
Utilities & Services	1.65
Open & Green space	51.71
Waterbodies	11.28
Wetlands	0.90
Total	100.00

Source: Secondary Data from Tirunelveli Municipality

With an integrated network of blue-green spaces, it is possible to address the environmental issues that are present in the urban areas while also providing value and connection with society. This not only helps in reviving the environment but also enhances and protects the overall functioning of urban areas.

Objectives

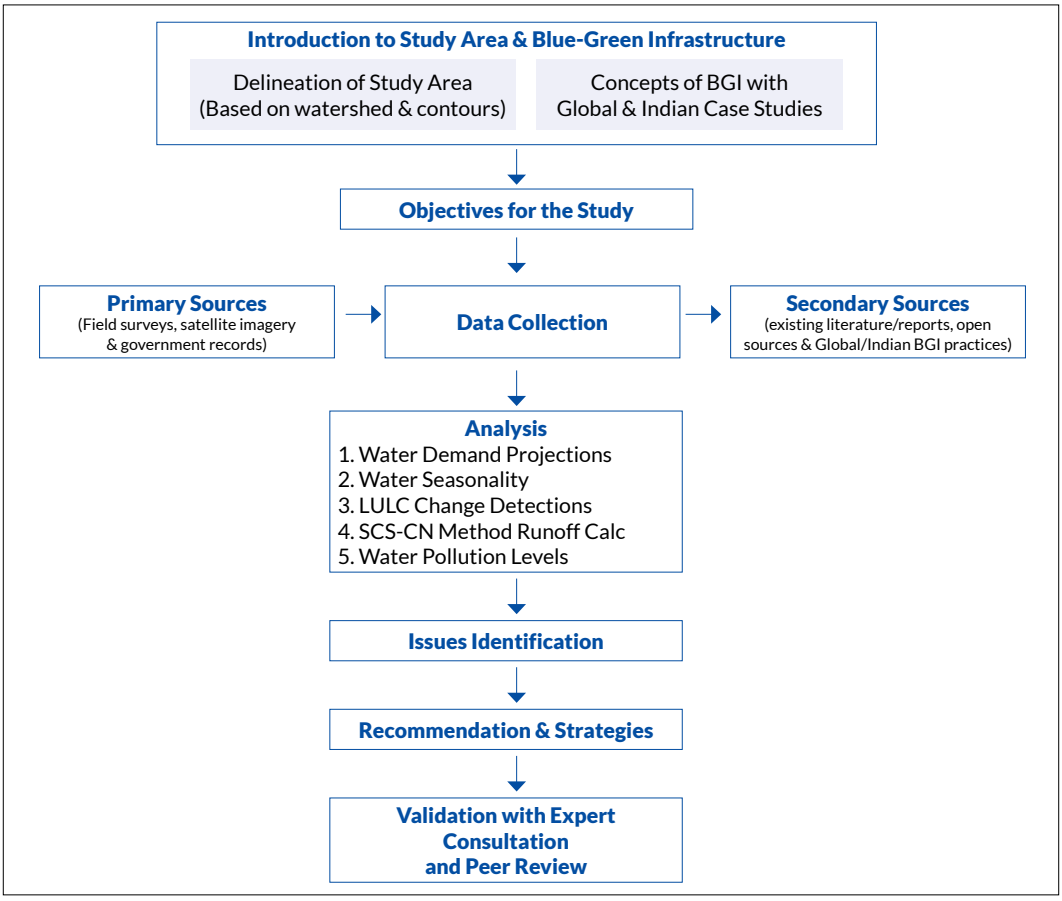
The objectives of this study are:

- To enhance the functionality of the city through blue and green networks.
- To future-proof and increase water availability of the city.
- To reduce water pollution and rejuvenate the waterbodies.
- To provide year-round recreation to strengthen the connections between society and nature as well as protect urban biodiversity.

Methodology of the Study

The methodology employed in this study involved a multi-faceted approach to assess the current state of the Blue-Green Infrastructure (BGI) and address the associated challenges in the study area. The following steps were undertaken:

Flow Chart 1: Methodology



- **Data Collection:** Comprehensive data collection was conducted to gather information on land use/land cover, surface temperatures, water demand, availability projections, sewage outfalls, and contamination levels. Primary data sources included field surveys, satellite imagery, and government records. Secondary data sources comprised of existing literature, reports, online open sources, and databases related to BGI global practices and in India.

- **Analysis:** By correlating the following analyses, the study attempted to provide a holistic understanding of the blue-green resource management in the study area, encompassing both quantitative assessments of water availability and qualitative evaluations of water quality and environmental health.

  - The **water demand and availability projections** data for the year 2040 were analyzed to gain insights into the future water requirements and potential challenges that are associated in meeting them.

- The **seasonal patterns and trends of water availability** were analyzed to understand the fluctuations that take place throughout the year, and which are crucial for effective water resource management.
- The **detection of land use/land cover changes** were performed and correlated with the surface temperature data to identify the relationships between land use changes, availability of green areas, and temperature variations within the urban clusters.
- **The SCS-CN method** was then employed to assess the impact of land use changes on **water runoff**, aiding in the evaluation of the effects of urbanization and land development on hydrological processes.
- Evaluation of **water pollution in the river** including sewage outfalls and contamination levels, was conducted to assess the water quality and environmental impact which helped in guiding strategies for improvement of water quality and leading to environmental protection.

- **Issues Identification:** Following the analysis, the issues of the study area were identified, which encompassed land use conversions, urban heat islands, water network system challenges, poor drainage systems, sewage contaminations, and encroachments on waterbodies.

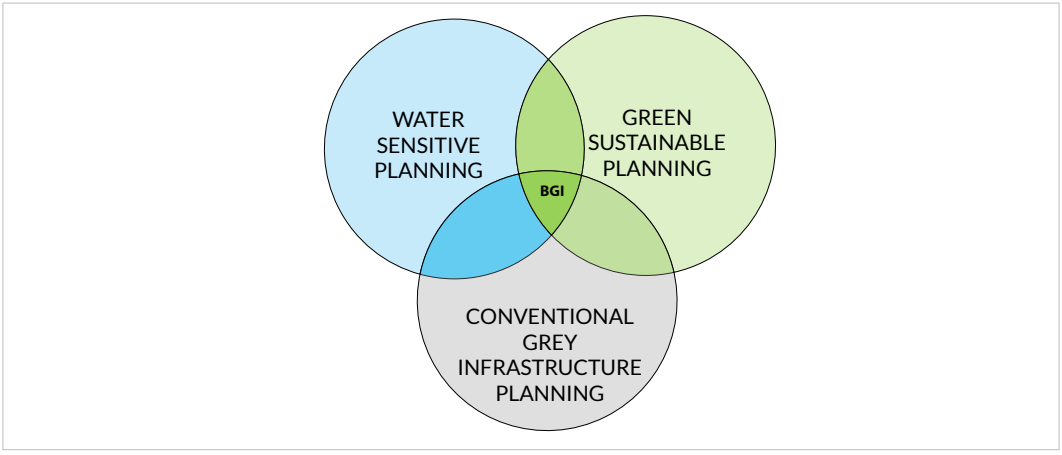
- **Recommendations and strategies** were developed to address these issues.

Methodology and findings were then validated through peer reviews, expert consultations, and comparison with existing studies and best practices in Blue-Green Infrastructure (BGI).

Blue-Green Infrastructure (BGI): An Urban Solution

Blue-Green Infrastructure (BGI) is a holistic urban planning approach that is aimed at creating interconnected networks of green and blue spaces within urban areas. These spaces are strategically planned and managed which provide a range of ecosystem services and other benefits to the environment, economy, and society.

Figure 4: Concept of Blue-Green Infrastructure (BGI)



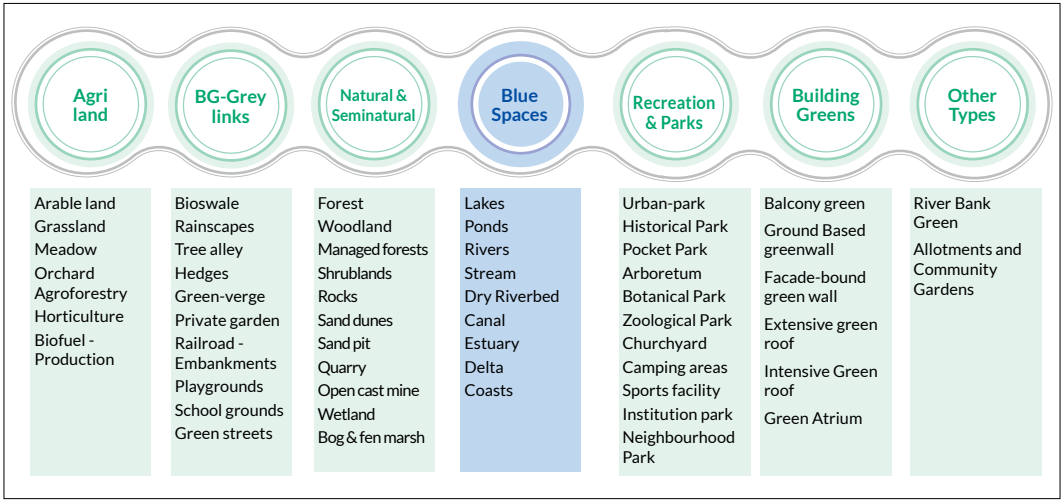
While there is no universally accepted definition of BGI, it is used interchangeably with Green Infrastructure. However, it is important to acknowledge that Green Infrastructure includes blue components as well. Thus, BGI emphasizes the integration of both green (land) and blue (water) spaces to improve environmental conditions and enhance the well-being of citizens.

"Green Infrastructure is a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation, and climate mitigation and adaptation. This network of green (land) and blue (water) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities, and enhances biodiversity", as defined by the European Commission (2013).

Addressing the Gap Between Blue and Green Initiatives

Despite the recognition of the importance of BGI, there exists a gap in its implementation at the administrative level. Initiatives focus on single objectives that are related to either green or blue components of the environment, such as water-sensitive planning, green infrastructure, stormwater management, flood management etc. (E2Designlab, 2017). BGI aims to bridge this gap by coordinating with the greening and water management efforts to achieve complementary results.

Figure 5: List of Blue and Green Spaces in the Paradigm

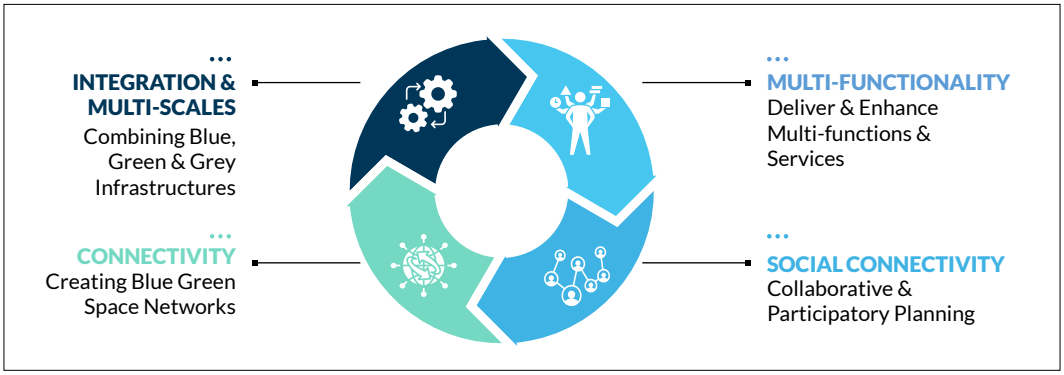


Core Principles of BGI

Effective planning of BGI requires the consideration of various operational scales, from local to city-wide or watershed levels, as well as their long-term effects. The four core principles of Blue-Green infrastructure were identified after a thorough understanding of its functions and benefits. These principles emphasize the importance of coordinating urban blue and green areas, establishing interconnected networks, maximizing benefits, and engaging diverse stakeholders in the planning process. The core principles of BGI are:

- **Integration of infrastructures at different scales**: To integrate and coordinate urban blue and green areas at multiple scales ranging from meso, through nano, micro, and macro scales of perspectives.
- **Connectivity of spaces:** To establish a blue-green network that helps to enhance and safeguard the multi-functions of the network components which an isolated space cannot deliver on its own.
- **Multi-functionality:** To consolidate the various initiatives and enhance the potential of urban blue-green spaces, thereby enabling them to offer numerous advantages and benefits.
- **Social connectivity:** To ensure implementations and solutions that actively involve participation from a diverse range of stakeholders which foster social inclusivity.

Figure 6: Core Principles of BGI



Global Blue-Green Infrastructure Practices

Blue-green initiatives, also known as nature-driven solutions, have been implemented globally over the past two decades to address a range of urban challenges. While these initiatives differ in characteristics and objectives depending on the specific issues they aim to tackle, the knowledge gained from these actions informs the development of Blue-Green Infrastructure methodologies for urban problem-solving. Table 1 provides an overview of these measures:

Table 1: Learnings from Global Blue-Green Strategies

Location	Strategy	Motivation for BGI	Intent/Outcome
Singapore	Active, Beautiful, Clean (ABC) Water Program	Adaptation to climate change	To fully harness the potential of the extensive network of drains, canals, and rivers, the development of 17 reservoirs, and other drainage systems over time has been planned to boost tourism and improve water quality. (Dreiseitl, 2016)
		Flood prevention, groundwater level	
		Water pollution, water Recycling	
		Increasing biodiversity	
		Increasing permeability	

Location	Strategy	Motivation for BGI	Intent/Outcome
Gorla Magiore Waterpark, Milano	Wetland Constructed System	Decrease in floods	Constructed wetlands outperform the grey infrastructure treatment plants for water treatment and flood mitigation. Despite having comparable expenses, constructed wetlands offer additional benefits such as wildlife support and recreation, which are highly valued by neighbouring communities.
		Decrease in river pollution	
		Ecosystem services	
		Increase in Biodiversity	
		Carbon sequestration	
		Sustainable urbanisation	
Wuhan, China	Sponge City Program	Lake rejuvenations	The city has set annual stormwater retention goals by zoning certain land areas and ensuring that urban infrastructure can absorb the run-off. This is achieved by allocating 20% of the land to absorbent blue-green elements. (Jing, 2019)
		Stormwater management	
		Water sensitive planning	
		Flood management	
		Reduced water pollution	
Hannover, Germany	Sustainable Housing Community	Rainwater management	With the concept of "every single drop matters" in mind, rainwater harvesting has been prioritized, along with a semi-natural run-off strategy. There is also emphasis on maintaining a constant status of the aquifer in the local area. (Dreiseitl, 2016)
		Increasing permeability	
		Renaturation	
		Natural Recreation in Dense Settlements	
Philadelphia	Green City Clean Water Plan	Stormwater management	Embracing the five paradigms of infrastructure systems, the city successfully renovated its century-old drainage system. It implemented rainwater harvesting management throughout the city by incorporating bioswales, retention tanks, and drainage channels to enhance water resilience.
		Flood management	
		Sustainable urbanisation	
		Groundwater recharge	
		Decrease in pollution	
		Permeability	
		Carbon sequestration	

Indian Practices of Blue-Green Infrastructure

Indian cities like Delhi, Bhopal, Madurai, and Bengaluru are increasingly incorporating the Blue-Green Infrastructure into their development plans to enhance environmental resilience of urban areas, despite the concept being relatively new to the Indian context. The primary aim of these plans is to enhance the city's natural blue network system and adjacent public spaces through strategic and intentional interventions.

However, implementing such approaches in Indian cities presents significant challenges. These cities are already densely inhabited and are facing multiple development issues such as mixed land use, imbricating responsibilities of different institutions, distorted urban growth, technological challenges etc. With limited space for blue-green facilities within these densely built environments, any new Blue-Green Infrastructure initiative must demonstrate high efficiency and adaptability to ensure sustainable development outcomes.

Table 2: Learnings from Blue-Green Initiatives in India

Location	Strategy	Motivation for BGI	Intent/Outcome
Delhi	Blue-Green Master Plan of Delhi 2040	Flood Prevention	For preservation of the environment and enhancement of urban development, an integrated network of BGI has been envisaged to be provided throughout the city to ensure the city's resilience against major future shocks and calamities. A "Blue-Green Policy" has been drafted and introduced for the country. (DDA, 2021)
		Decrease in pollution	
		Aquifer Recharge	
		Rising permeability	
		Increase in Biodiversity	
		Green corridors	
		Afforestation	
		Natural recreation space and values	
Bhopal	Blue-Green Master Plan of Bhopal 2021	Lake rejuvenation	To enhance, preserve, and develop the green elements and build a sustainable urban environment. (NIUA, 2016)
		Sustainable Urbanisation	
		Water management	
		Water recycling	
		Waste management	
		To increase green spaces	

Analyses

Water Demand & Availability Projection for 2040

As per data from the Public Works Department (PWD), the overall quantity of water obtainable in the Thamirabarani River basin including surface water, groundwater, recycled, and de-silted water is estimated to be 1740 MCM (Million Cubic Meters). The projected data shows that in 2040, the amount of water available for urban sectors is only 135 MCM, which means that by then the water demand will be equal to or higher than the current availability which demonstrates the need to increase the amount of water available.

Seasonality Occurrence Analysis

The JRC (Joint Research Centre) Global Water Data has been utilized to assess the seasonal occurrence of waterbodies. The results of the study demonstrate that the majority of waterbodies in the area retain water for only 4-6 months, while a few can last the year. This indicates that there is an imperative need to boost the availability of water throughout the year.

Figure 7: Seasonal Water Occurrence of Waterbodies in Tirunelveli

Figure 7 (a): Water Availability in the Waterbodies from January-February (Winter)

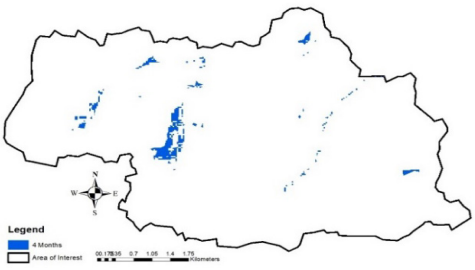


Figure 7 (b): Water Availability in the Waterbodies from March-May (Summer)

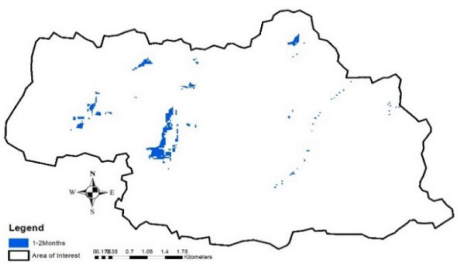


Figure 7 (c): Water Availability in the Waterbodies from June-October (Pre-Monsoon)

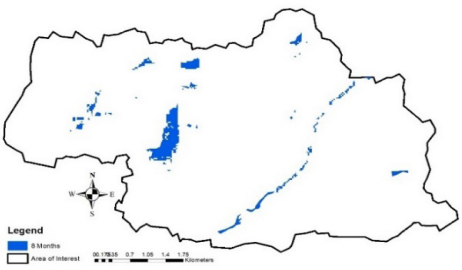
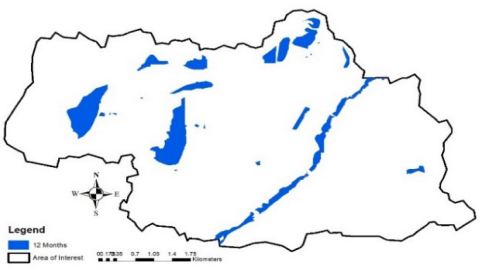


Figure 7 (d): Water Availability in the Waterbodies from October to January (Post-Monsoon)

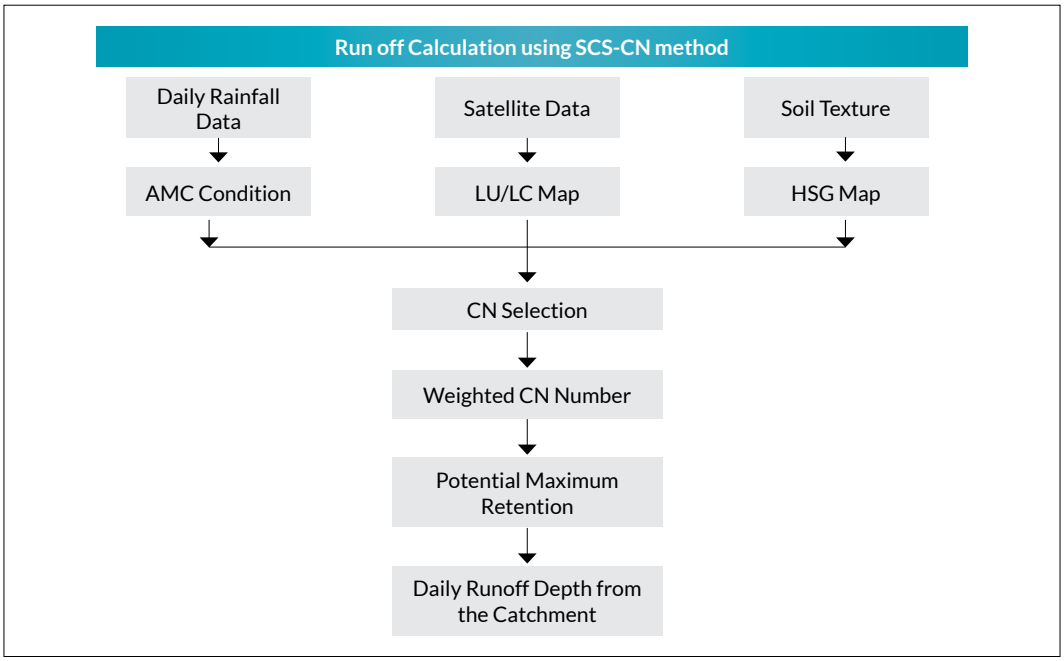


Source: Analysis using secondary resources from JRC Global Water Data Archive

Run-Off Calculation Using SCS-CN Method

The annual run off from the catchment area was calculated using the Soil Conservation Service – Curve Number (SCS-CN) method as demonstrated in Figure 8 to better understand its potentiality.

Figure 8: Method Used to Calculate the Annual Run off Using SCS-CN Method



Source: Dhawale, A.W. (2013)

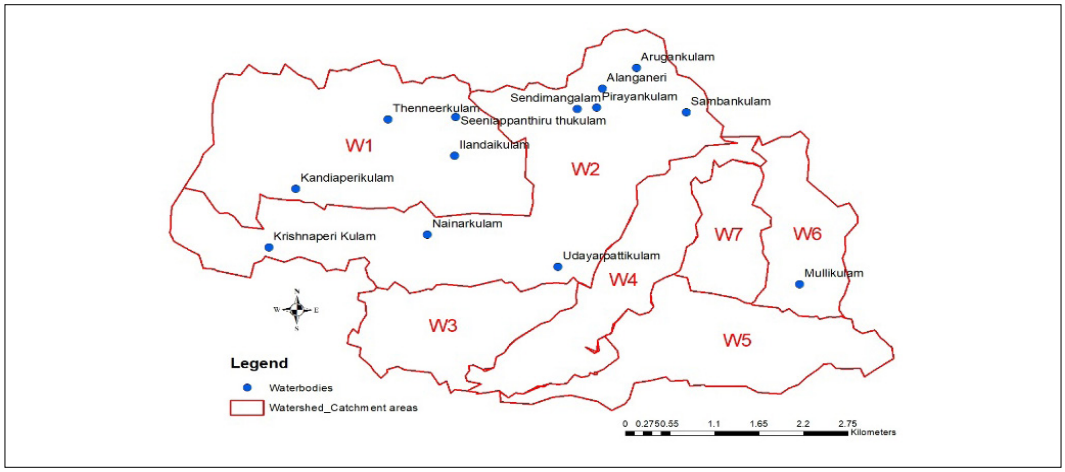
Table 3: Findings of Run Off Calculation for the Whole Watershed

Total Rainfall in the Year	1555.56 mm	**Total Run Off in the Year**	526.78 mm
Total Rainfall Volume in the Year	46.14 MCM	**Total Run Off Volume in the Year**	15.63 MCM
Percentage of Run Off from Rainwater		34%	

According to the analysis, 46.14 MCM of rainfall was recorded in the entire study area, out of which 34% was in the form of run off (15.63 MCM). This run off either drains into the rivers or gets wasted along with sewers.

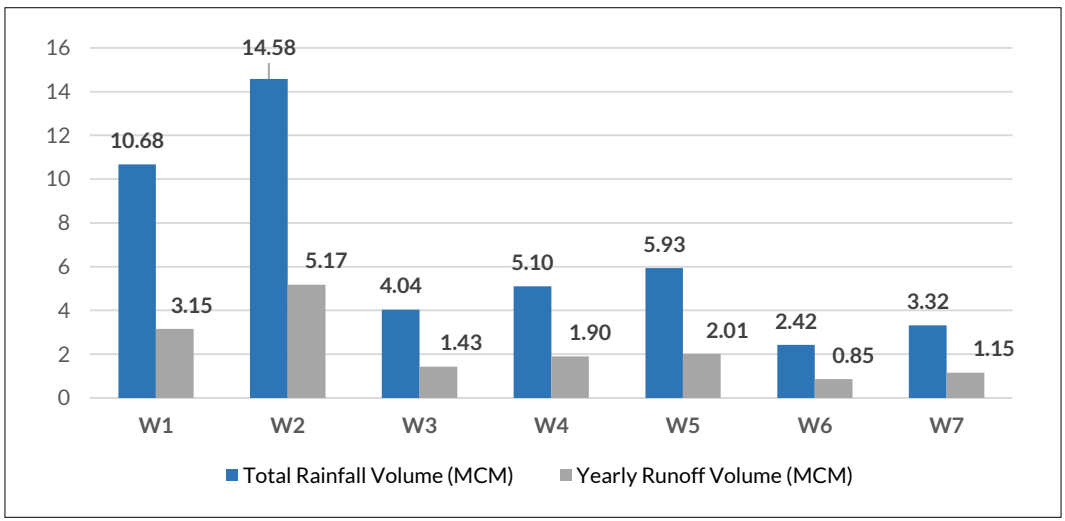
In addition, the entire watershed has been divided into seven distinct catchment zones as shown in Figure 9. With similar methodology, their individual run off volume and depth have been computed as well. Consequently, the run off percentages for smaller catchments/watersheds range from 30-35% which presents great opportunities to improve the water supply through storage or infiltration systems in the areas.

Figure 9: Smaller Catchment Areas Inside the Watershed Along with Placement of Waterbodies in Tirunelveli



Source: Delineation using Digital Elevation Model (DEM) in GIS

Figure 10: Comparison of Total Rainfall Volume and Run Off Volume in Tirunelveli



Potential to Increase Water Availability

After considering the run off depth and the storage capacity of the existing waterbodies in watersheds, it was calculated that 11.89 MCM of water can be augmented for the study zone, apart from the watershed with a river. Despite that the Watershed W2 has several waterbodies, it is still capable of storing an additional 4.34 MCM of water.

Table 4: Potential of Increased Water Availability from Run Off Volume in Tirunelveli

	Name of Tank	Tankpit Area/ Ayacut in Ha	Water Capacity of Tankpits in MCM	(Existing) Watershed's Total Water Storage Capacity in MCM	Watershed ID	Run Off Volume in that Watershed area (MCM)	Potential to Increase Water Availability = Run Off Capacity (MCM)
1	Kandiaperikulam	161.81	0.947	1.0426	W1	3.15	2.1100
2	Seeniappanthiru thukulam	30.4	0.0125				
3	Ilandaikulam	30.42	0.0782				
4	Thenneerkulam	10.715	0.0049				
5	Krishnaperikulam	178.87	0.0127	0.833	W2	5.17	4.3407
6	Nainarkulam	148.11	0.3797				
7	Udayarpattikulam	27.96	0.0365				
8	Sendimangalam	54.18	0.0642				
9	Pirayankulam	18.46	0.0952				
10	Alanganeri	20.77	0.0809				
11	Sambankulam	15.18	0.0256				
12	Arugankulam	33.24	0.1382				
13	Mullikulam	94.01	0.0092	0.0092	W6	0.85	0.8456
No waterbodies in these catchment areas (W3, W5, W7) 0.00 0.00		0.00	0.00	0.00	W3	1.43	1.43
		0.00	0.00	W5	2.01	2.01	
		0.00	0.00	W7	1.15	1.15	
Total Capacity of all Waterbodies = MCM			1.8848 MCM	Potential to Increase Water Availability			11.89

Source: Analysis using secondary water resources data from Nellai Neervalam

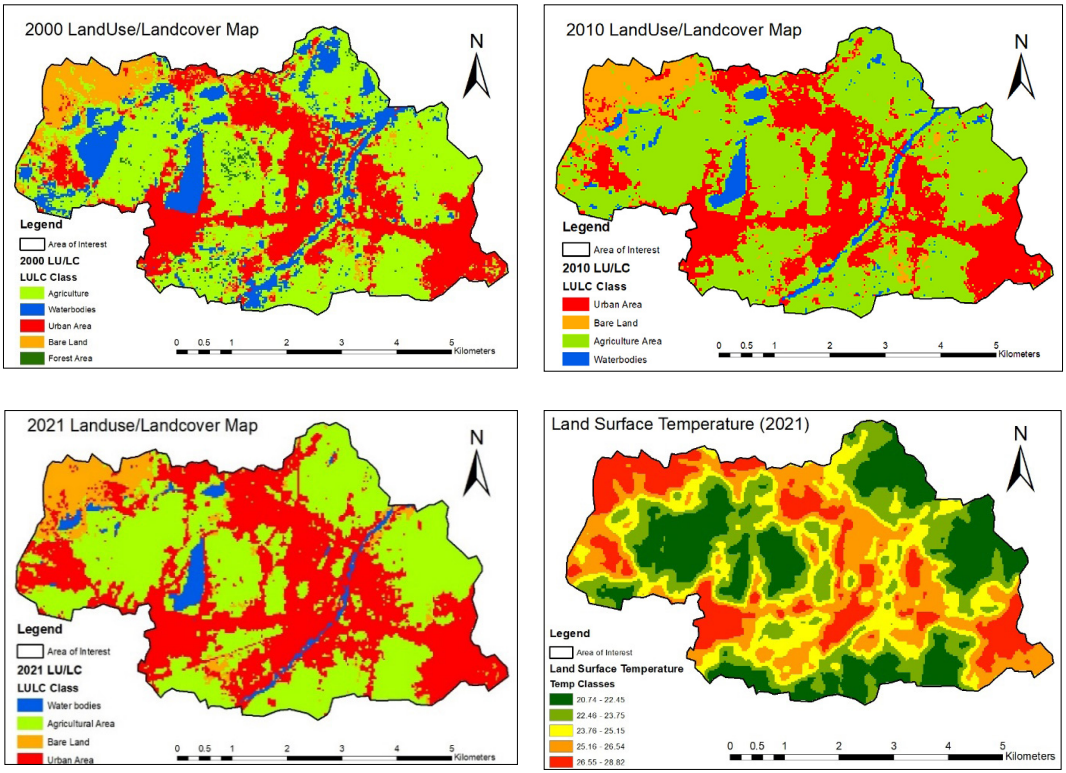
LU/LC Change Detection and Comparison with Surface Temperature

Land use/Land cover analysis was conducted for the years 2000, 2010, and 2021 which revealed that there is a gradual decline of waterbodies and forest areas over this period. The study area experienced rapid urbanisation which resulted in the transformation of small ponds and creeks into other land uses such as barren land and urban areas.

The development was along one of the major transit lines that connects the CBD (Central Business District) to the suburbs. Between the city and the suburbs, there is a significant difference in surface temperature. The urban heat effect is seen in highly populated areas such as the city centre near the temple, or the older settlements close to the river. Areas with large waterbodies and vegetation typically remain relatively cooler.

Since 2010, there has been an increase of more than two degrees in the temperature of urban zones which suggests the formation of a heat island. To counter this effect, green policies must be implemented and embraced for better results.

Figure 11: LU/LC Classification of 2000, 2010, and 2021 and LST Map of 2021, Tirunelveli



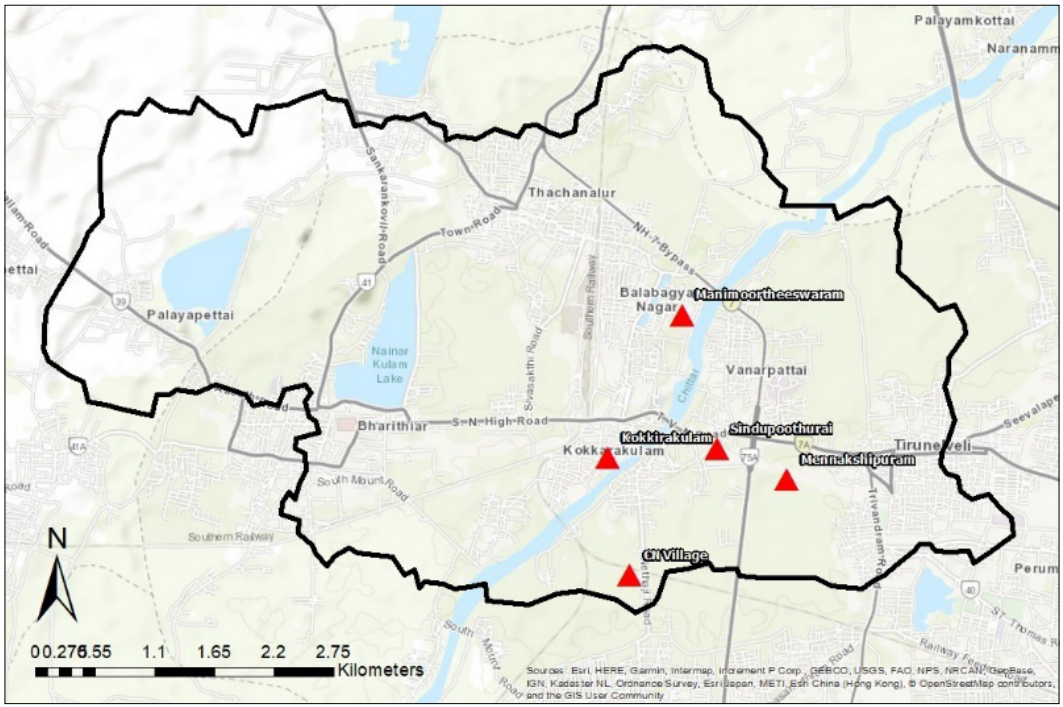
Note: Methodology for LST adopted based on Ugur & Gordana, 2016.

Source: Author using GIS Software

Sewage Outfall and Contamination Level Analysis

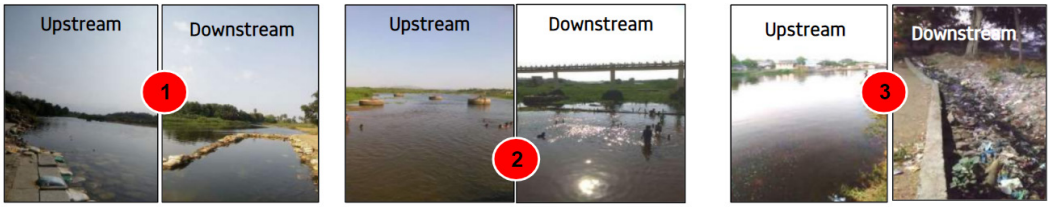
There are five sewage outfall points in the study area. As per CPCB (Central Pollution Control Board) Tirunelveli, the quality of water at these outfall spots satisfies both class-B and Class-C standards. There is a 7.77 MLD gap between the water generated and the sewage water that gets treated. This is discharged directly into the river through these outfall intrusion points. This gap needs to be addressed and using Nature-based Solutions could provide more benefits to the environment than any conventional treatment plant.

Figure 12: Sewage Outfall Spots in Tirunelveli



Source: Secondary Data from CPCB, Tirunelveli

Figure 13: Reconnaissance Survey Pictures Showing Condition of Sewage Outfall Spots along the Thamirabarani River



Source: Pictures taken by Author on 12.01.2022

Table 5: Showing Sewage Treatment Gaps in the Municipal Corporation, Tirunelveli

Urban Area	Total Amount of Sewage Produced	Total Amount of Sewage Fed into the Treatment Plant
Tirunelveli M. Corp	31.97 MLD	24.2 MLD

Source: Secondary Data from CPCB, Tirunelveli

Issues Identified

The following issues were identified from the comprehensive analysis conducted in the study area:

- Conversions of land use from blue to green to urban areas.
- Rapid urbanization led to the emergence of Urban Heat Islands in densely populated settlements.
- There is potential for improving the existing water network system.
- Many areas suffer from poor drainage systems and impermeability.
- Most tank pits have surface water availability for only 4-6 months per year.
- In two decades, water availability balances out with demand, leaving little surplus for use.
- Approximately 34% of rainwater is converted into run off, resulting in wastage.
- There is potential to increase water availability in the watershed by 11.89 MCM through various means.
- Quality of discharge water into the river requires improvement.
- It is necessary to address the 7.77 MLD gap between sewage generated and treated in the city.
- Lack of recreational spaces and encroachments in floodplains is evident from people's perceptions and expert opinions.
- Dumping of waste/construction materials into waterbodies is a significant concern.
- Inadequate leisure facilities around waterbodies hinder the social connectivity with nature.

Recommendations and Strategies

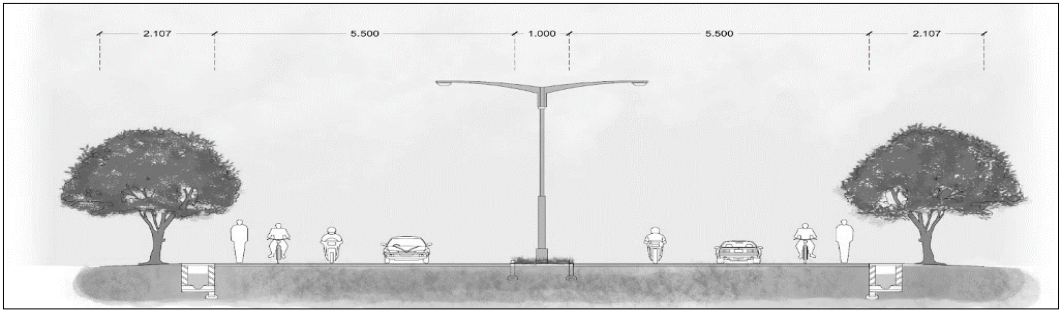
This section outlines the proactive measures that are aimed at addressing the identified issues and promoting sustainable management of water resources and environmental conservation in the study area. With focus on improvising and integrating Blue-Green infrastructure, the proposals include:

- Improvisation and integration of Blue-Green infrastructure, such as roads and water channels, is proposed with the main aim of managing stormwater at its source and redirecting it to the available water resources and to the ground.
- It is recommended to construct two retention basins, with a total volume of approximately 11,500 cubic meters, on the same land where two waterbodies were converted into green spaces, as per the land use/land cover analysis. This is correlated with the potential to hold more water based on the SCS-CN method that was used to calculate the watershed run off.
- To mitigate the existing sewage treatment gap, constructed wetlands with vertical subsurface systems have been suggested to treat the quantity of discharge water that is effectively flowing into the river.
- Riparian region regulations and development initiatives are advocated to prevent encroachments, foster social connectivity with nature, establish green corridors, and promote river-centric planning, thus ensuring sustainable management of river ecosystems.

Road Improvisation with Blue and Green Elements

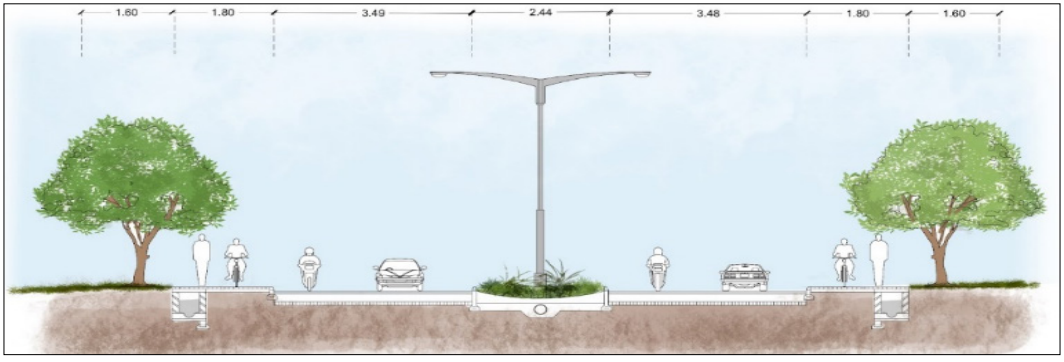
Retention boulevards include a green, slightly sunken median that transports and slowly absorbs rainwater through infiltration while still enabling ordinary vehicles to use the street. They involve reducing the capacity of existing highways; therefore, this kind of initiatives can be highly useful along major, underused metropolitan networks. *Example: S.A. Plads, Copenhagen.*

Figure 14: Existing Road Section of Arterial Roads



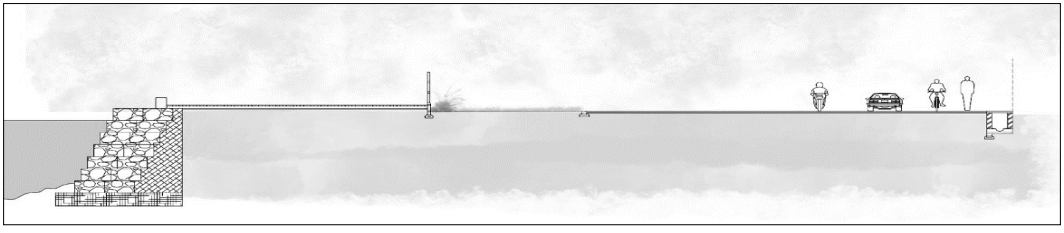
Source: Author

Figure 15: Proposal of Retention Boulevards - Roads Section



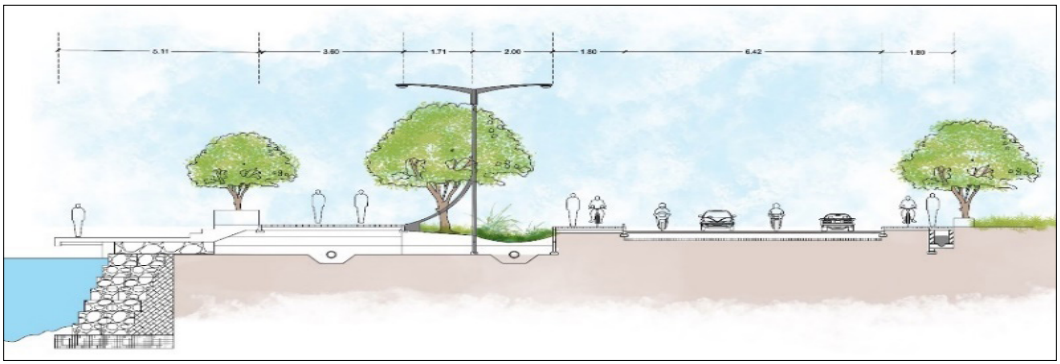
Source: Author

Figure 16: Existing Road Section of Collector Roads



Source: Author

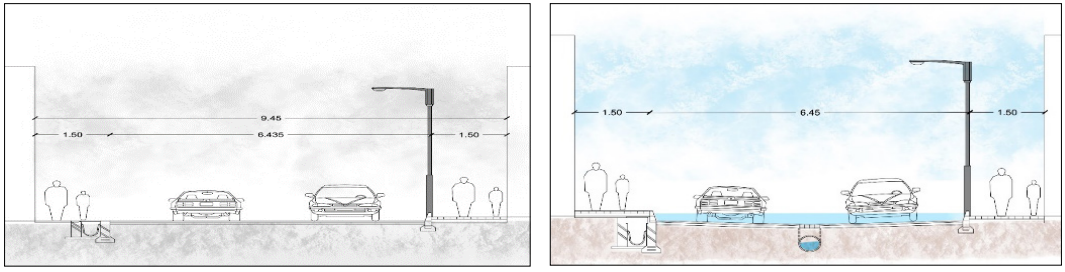
Figure 17: Proposal of Green Streets - Road Section



Source: Author

Green streets are recommended to have linkages with cloudburst roads. The infiltration planters and porous surfaces should be used in conjunction with the nearby waterways to create green streets. *Eg: Watts Branch, DC.*

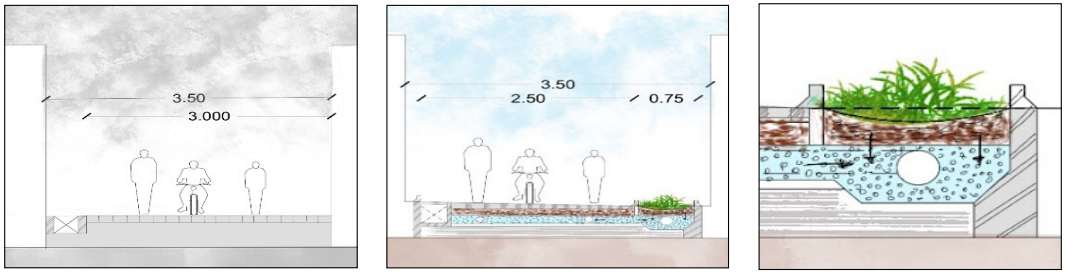
Figure 18: Existing Road Section of Sub-Arterial Roads (Left Image) & Proposed Road Sections for Burst Pipe Road (Right Image)



Source: Author

To ensure connectivity and not hinder the busy traffic on the road, pipes are positioned just under street level to collect and convey water to the nearby waterways. The cases where there is not enough room for above-ground transportation, burst pipe road proposals are recommended and built with a V-shaped profile. *For example: Cloud Burst pipe roads in the Pladds area, Copenhagen.*

Figure 19: Existing Road Section of Local Roads (Left Image), Proposed Road Sections for Retention Alley (Middle Image), and Bioswale Detail Section (Right Image)



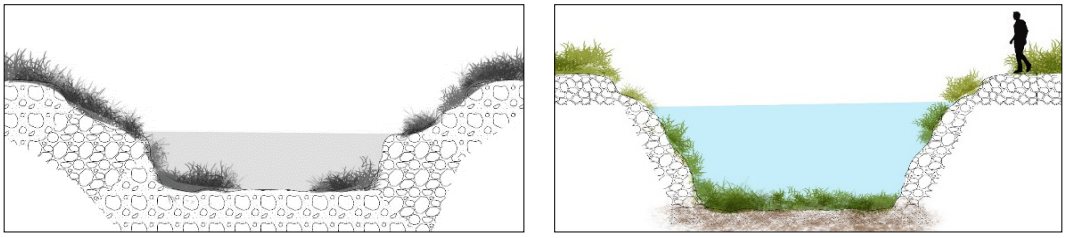
Source: Author

Normally, retention alleys are in areas which lead to vulnerable low-lying regions. Through sponge planters, bioswales, and filtrating surfaces, retention alleys provide delayed transit of stormwater and potential detention of the same. *For example: Hans Tavsens Park, Copenhagen.*

Water Channel Improvisation with Blue and Green Elements

Urban creeks involve old streams that serve as transportation links between other waterbodies. Urban streams, which are smaller in size, can restore or build stronger neighbourhood character and social areas. *For instance: Creeks or streams in Arkadien Asperg, Stuttgart, Germany, etc.*

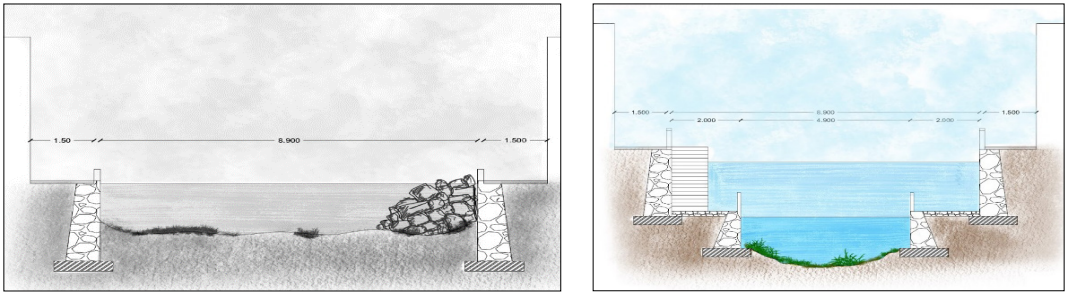
Figure 20: Existing Road Section of Urban Creeks (Left Image), Proposed Road Sections for Urban Creeks (Right Image)



Source: Author

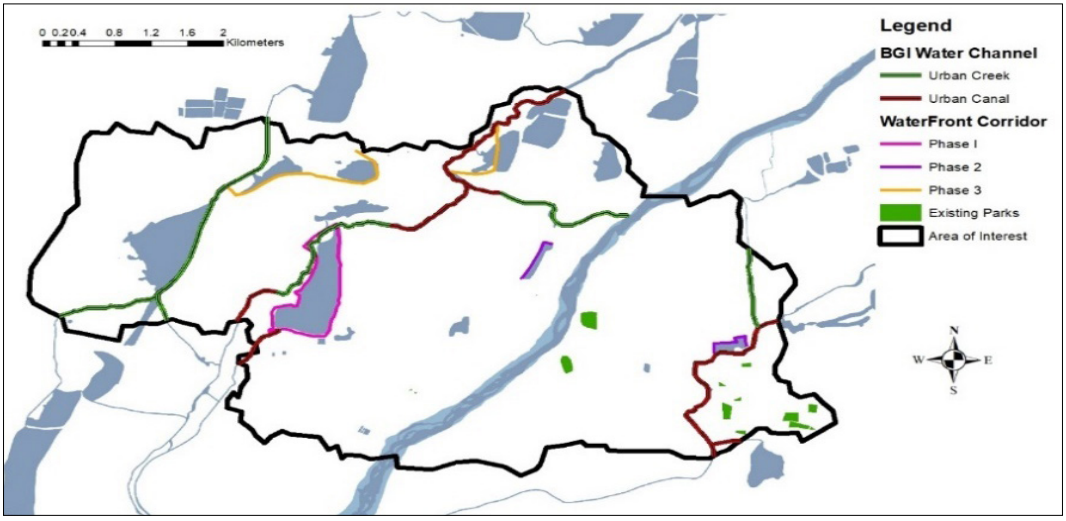
Urban canals entail water channels within a congested urban environment. They can be created to add fresh, healthy respite to the city while boosting biodiversity and the potential for stormwater run off. *For example: Cheonggyecheon Canal in South Korea.*

Figure 21: Existing Road Section of Urban Canals (Left Image), Proposed Road Sections for Urban Canals (Right Image)



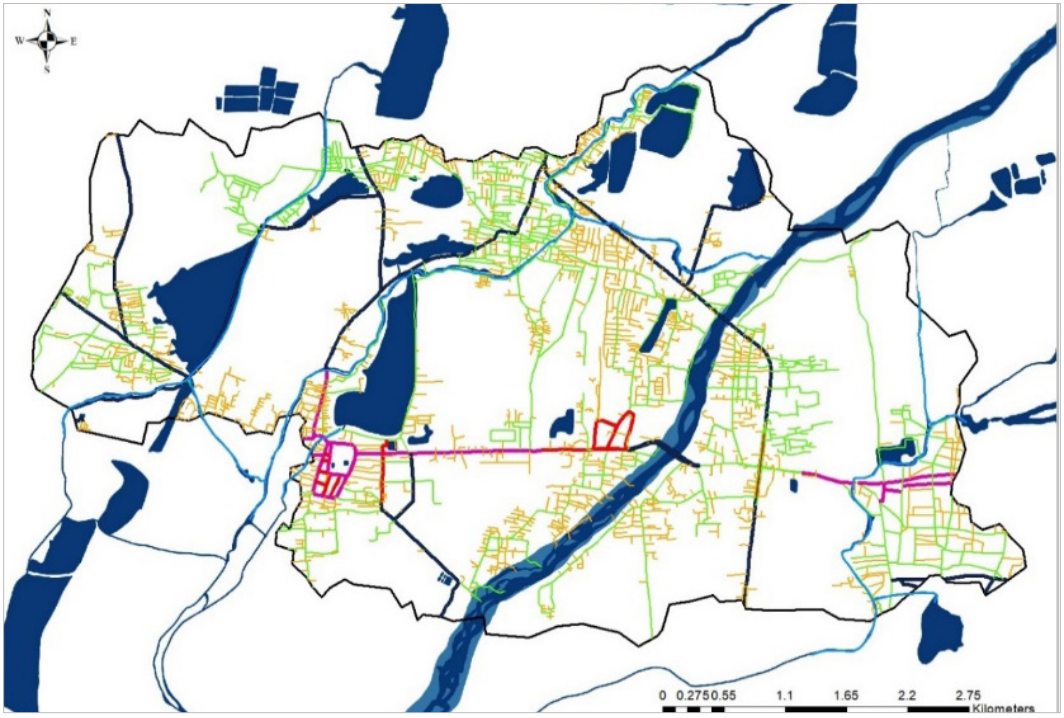
Source: Author

Figure 22: Proposed Urban Creeks and Urban Canals with Waterfront Corridors, Tirunelveli



Source: Author

Figure 23: Proposed Roads Connected with nearby Waterbody for Drainage of Stormwater, Tirunelveli



Source: Author

Table 6: Length of the Proposed Roads and Water Channels

Road/Street Type	Length (km)	Water Channel Type	Length (km)
Cloudburst Roads	4.30	Urban Canals	8.350
Cloudburst Pipe Roads	6.73	Urban Creeks	9.146
Retention Boulevards	22.3		
Green Streets	105.72		
Retention Alleys	112.90		

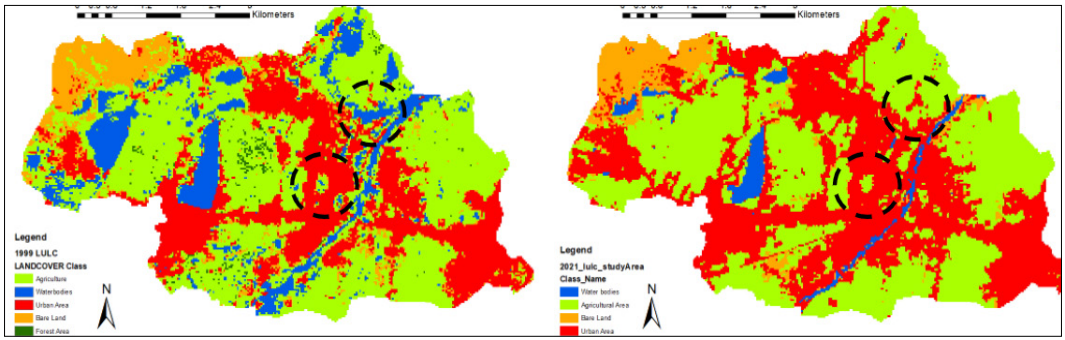
Source: Author

The BGI Road Typologies are put forward in the area under consideration following alignment with the contour. Furthermore, they are proposed as per the inclination so that stormwater can be effectively guided towards any nearby waterbodies and channels. It is recommended to designate waterfront corridors to facilitate the connection between people and waterbodies, thus helping in cultivating a bond with the natural surroundings.

Retention Basins

With 11.89 MCM of run off available from rainwater, so to increase the water availability, two retention basins have been proposed in the low-lying elevations in the middle of urban settlement. The area is in catchment W2. In comparison to LULC of the years 2000 and 2020, two waterbodies have disappeared over this time period due to the effects of urbanization.

Figure 24: LULC Maps of 2000 and 2020 Showing the Disappearance of Two Waterbodies in Tirunelveli



Source: Author

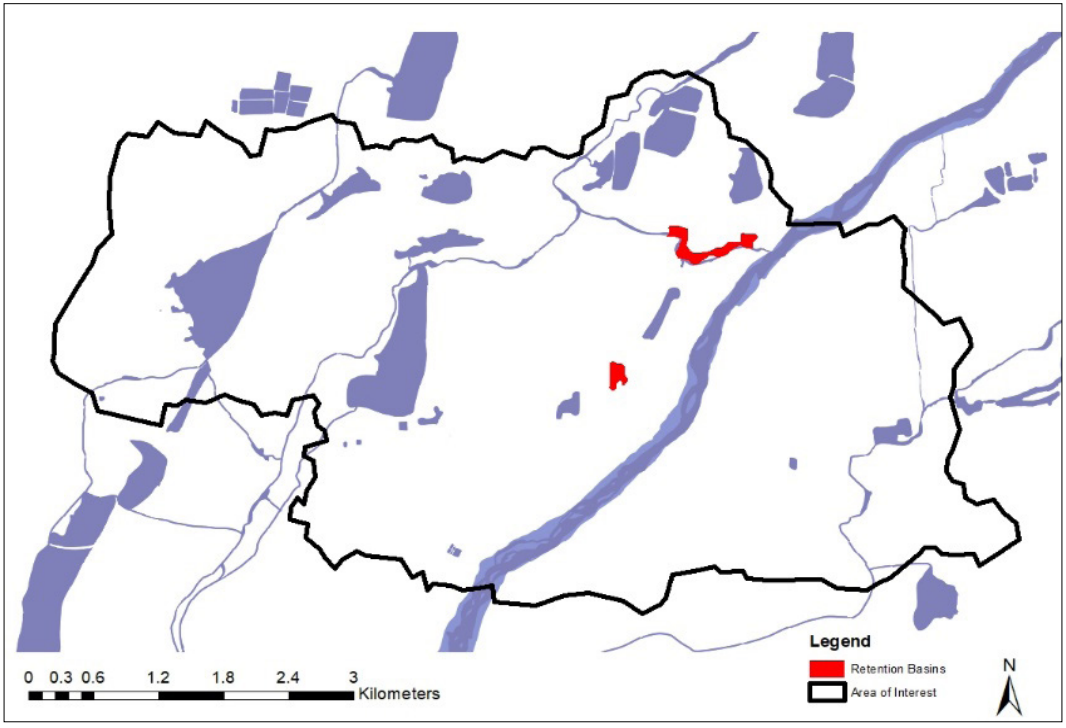
These retention basins were aligned with the contours to find that they were in the low-lying areas of the elevation in the study area, therefore feasibility of accumulating stormwater was possible, thus making it suitable for the proposal.

Table 7: Volume, Area, Depth, and Cost Estimate of the Retention Basin

Retention Basin	Volume (cu.m)	Area (sq.m)	Depth (m)	Approximate Cost Estimated for the River Basin (Rs crore)
1	191436	31906	~6.00	10.6
2	143577	93508	~4.50	9
Total	335013			20

Source: Author

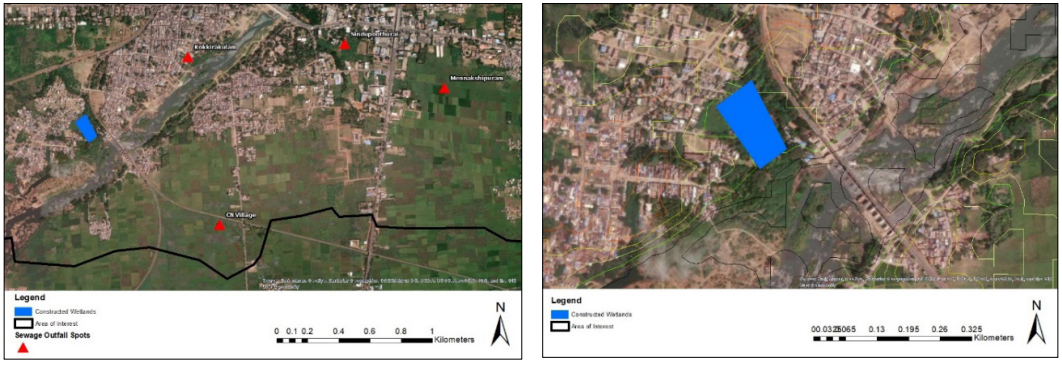
Figure 25: Placement of the Retention Basin in Tirunelveli



Source: Author

Constructed Wetlands with Vertical Subsurface Flow

Figure 26: Satellite Image of Placement of Constructed Wetlands Adjacent to Thamirabharani River in the Study Area



Source: Author

By implementing the method recommended in the UN-Habitat manual for calculation of areas in the Constructed Wetlands (CW), we get an area of 95444.18 sqm for the vertical flow bed.

A single CW with 600 KLD capacity is recommended, therefore we need a set of 6 units of VF-CW each with 7320 sqm area. Implementation can be done in two phases with units of two CWs in phase 1 and units of four CWs in phase 2.

Table 8: Area Requirement of All Units in Constructed Wetland

Area of VF Bed	~95,500 sqm
Settler/Primary Anaerobic Settling Tank	~3,850 sqm
Polishing Pond	~7,770 sqm
Total Area Needed	~111000 sqm

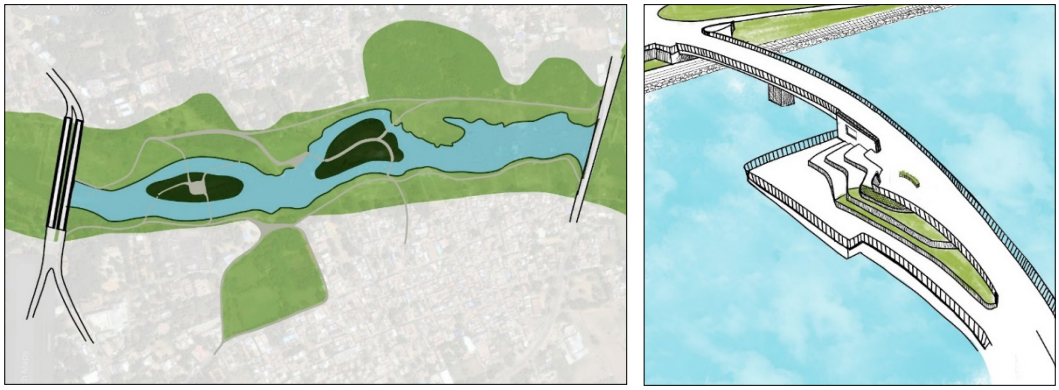
Source: Author

The use of Napier grass (Pennisetum purpureum) in VF-CWs has been recommended for the treatment of greywater in India *(Pillai & Vijayan 2013)*. It is suitable for growing in Tirunelveli, Tamil Nadu.

Riparian Region Regulation & Development

The Riparian Region can align with the "Blue-Green Policy of Delhi Master Plan 2041" with focus on the following regarding the river and waterbodies:

Figure 27: Provision of Nature Trails in the Riparian Region and 300m Green Buffer Around the Flood Plains and Provision of Recreational Spaces



Source: Author

Recommendations to Enhance the Value of Rivers

- Species that degrade the riparian region are recommended to be restored with native flora and fauna
- Tree Planting and Reforestation along the banks of the river are recommended to enhance the rich biodiversity of the environments

- Through the Constructed Wetland (VSSF – Vertical Sub-Surface Flow) management, sewage outflows into rivers were carefully scrutinized and biological purification of rainwater from the storms through CW is ensured

Recommendations to Strengthen the Bond Between Society and Nature

- Nature Trails during low river water level are provided in places with Nature-based Solutions to enhance the relationship between the community and the river.
- Increased recreational provision along the flood plains with greenways and cycle tracks are recommended.
- "Active and passive recreational activities" such as educational nature trips, wildlife tours, camping, etc., in the parks and service areas to be carried out for effective awareness.
- Wetlands to have "No public access" to the fragile areas of the ecosystems.
- The existing parks near the river to be a part of the recreation program to increase footfalls and generate more revenue.

Interventions for Green Elements

- A 300m buffer to be provided and greened to preserve the river.
- To strengthen the bond between people and the river, a green corridor of two hundred meters is to be provided.
- Proper re-stilting of the "wetland" to be done and planting of trees to ensure the debris from being fed into the river and to control contamination; ultimately "restoring the ecosystem".
- Green roofing of government buildings and temples.

Recommendations of River Bank Design Checklist for Riverfront Projects

A river bank design checklist is advised to ensure consistency across all riverfront projects by minimising encroachment, fostering social connectivity with rivers, and improving biodiversity along the river bank. It is also recommended to include: A multi-use pedestrian pathway with a minimum width of 10 feet, 12 feet for segregated cycling and pedestrian lanes, and a combined Bicycle-pedestrian pathway of 16 feet are advised. Additionally, it is suggested to provide seating with tree covers and permeable pavers (as permitted materials). For a secure urban facility, proper lighting and signage guidelines for the riverfront projects are also necessary.

Recommendations for an Exhaustive List of Riparian Vegetation

It is important to promote landscaping initiatives that include bioswales, stormwater planters, and green standards. It is advised to compile a comprehensive inventory of all the benefits of riparian plants and those that are suitable to the Tirunelveli climate and region.

Policy Recommendations for Tirunelveli

- **Infrastructure-related policies**
  - Zero Tolerance Policy for Combined Sewer Overflows (CSOs)
  - Water quality milestones of river discharges

- **Planning related policies**
  - River Bank Protection Policies on:
    - Encroachment
    - Foreign species
    - Non-naturalised shorelines
    - Direct waste discharge
    - Dumping of wastes
  - Preservation of wetlands under the National River Conservation Plan
  - Alignment with "Blue-Green Policy of Delhi Master Plan 2041"
  - Permeable Streets Policy
- **Green norms**
  - Promotion of Green Norms in Building Construction through FSI incentives
  - Tax Exemptions for Green Roofing (70% or 500 sqm) of buildings
  - Special tax incentives for solar proofing rooftops
  - Compulsory Green/Solar Proofing of every government building and temple structures
  - Mandatory/Strict Regulations for Rainwater Harvesting
- **Citizen engagement norms**
  - River Protection Community under the Nellai Neervalam Plan
  - Zero Plastic Pollution norms
  - Overflow Action Days Ordinance

Suggestions, Conclusion, and Way Forward

In conclusion, this paper addresses a range of critical issues that concern urban rivers and waterbodies, particularly in the context of Tirunelveli, by advocating for interventions that integrate both blue and green elements of cities. It tackles challenges such as water pollution, flood risks, water availability, urban biodiversity degradation, neglect of the importance of waterbodies, and lack of citizen engagement with urban rivers, along with floodplain encroachments.

The proposed strategies rejuvenate the entire water network system through an integrated Blue-Green network and aims to protect and enhance the hydrological and ecological values, future-proof the environment for climate change adaptation, and prevent further loss of waterbodies and vegetation. They enable long-term environmental sustainability by strengthening the green elements and help them to flourish.

Moving forward, it is imperative for the government and the stakeholders to take decisive steps towards implementing these recommendations, thereby ensuring the protection and revitalization of waterbodies and urban ecosystems for the benefit of current and future generations.

Acknowledgements

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Conflicts of Interest

The authors declare no conflict of interest.

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Reinventing the Lost Trilogy of Ponds, Natural Drains, and Groundwater with Focus on Shekha Jheel: A Case Study of Aligarh

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Abstract
Water is essential for all life forms on Earth but never has our planet's water been under such pressure as today. Climate changes, loss of biodiversity, and pollution are some of the most common and interconnected challenges that concern water and its ecosystems. Different forms of water which includes water bodies (ponds, drains) and groundwater, form a hydrological cycle which offer critical opportunities to reduce the stresses from anthropogenic activities. In the present study on Aligarh, a city located in the Ganga-Yamuna Doab, an area historically rich in water resources but now home to degraded water resources; ponds and drains in urban Aligarh and Shekha Jheel wetland have been inventoried and assessed. Disruption in the trilogy of ponds, drains, and groundwater and its manifestations were studied. A methodology to prioritize ponds has also been suggested. Findings reveal that the interconnectedness between ponds, drains, and groundwater has been completely disrupted that has resulted in environmental degradation, taking the city away from resilience and sustainability. Recommendations encompassing regional level strategies, master plan interventions, Nature-based Solutions, people's involvement etc were suggested.

Keywords: Aligarh, Waterbody, Pond, Groundwater, Drain, Interconnectedness, Trilogy

Introduction

Globally, two billion (26%) people lack access to safe drinking water and 3.6 billion (46%) do not have access to safe sanitation. Furthermore, the global urban population facing water scarcity is expected to double from 930 million in 2016 to 1.7-2.4 billion people in 2050 (United Nations, 2023). Water scarcity, primarily of clean freshwater, and the associated vulnerabilities are further exacerbated by climate change with an increase in incidences of extreme events, heat waves, droughts, and floods (United Nations, n.d.). The Dublin Conference on Water and Environment, 1992, Rio conference, Millenium Development Goals 2015, and at present, the Sustainable Development Goals 2030, have paved the way for revisiting water related policies and practices.

In this context, the significance of holistic approaches such as the integrated approach, systems approach, ecosystem approach, and cybernetics in the conservation of sources of water viz. waterbodies, rivers, and groundwater, has increased manifold. In the global discourse, blue-green infrastructure and the provision for ecosystem services has evolved as key elements in urban adaptation strategies to enhance resilience to climate changes and disasters. While knowledge regarding the linkage between waterbodies, rivers, and groundwater has existed for a long time, it has emerged as critical in the present journey towards climate resilience and reduction in disaster risks. The trilogy as described in the present paper is based on the systems approach and focuses on the linkages between the sources of water and its association with human settlements and their activities. The need to view water as a part of the larger natural and anthropogenic ecosystem has been reiterated in this paper and was studied in the context of Aligarh, a city sitting amidst aplenty yet experiencing water stress.

Aligarh city with a population of 8.74 lakh (Census of India, 2011), lies 130 km South of the National Capital Territory of Delhi in the Ganga-Yamuna Doab. It is the district headquarter of Aligarh district which has the famous Aligarh Muslim University (AMU), established in 1875 by Sir Syed Ahmed. It is believed that Aligarh was chosen for setting up AMU due to good *'aab-o-hawa'* (roughly translated to water and air) in the area (Khalil, 2021). The city is also famous for Aligarh locks. It lies in the humid sub-tropical climatic zone (Koppen's Classification). The average annual rainfall is 754mm with 80 percent of it concentrated in the four months of June, July, August, and September.

Aligarh and its immediate surrounding areas are characterized by high groundwater table, gentle slope, fertile soil, good connectivity, and being rich in water resources. The city lies in the command area of the Upper Ganga Canal with Shekha Bird Sanctuary, an important bird area that abuts the canal. Aligarh is home to more than a hundred waterbodies of various sizes, but most of them are in dismal conditions and the city falls under the overexploited category[1] of groundwater (CGWB, Block wise Categorization, 2022), with an extraction rate of around 343% observed in the 2017 assessment (Sinha, 2021). A few of these waterbodies like Achal taal not

[1]*As per CPCB, 'Over-exploited' areas, where there should be intensive monitoring and evaluation and future ground development should be linked with water conservation measures.*

only have local cultural and religious significance but are also visited by people from nearby areas. The Comprehensive Environmental Pollution Index (CEPI) has identified Talanagari and Chherat Industrial area as severely polluted areas. The water resources of the city are under extreme stress due to anthropogenic activities and need to be judiciously managed and protected at the earliest.

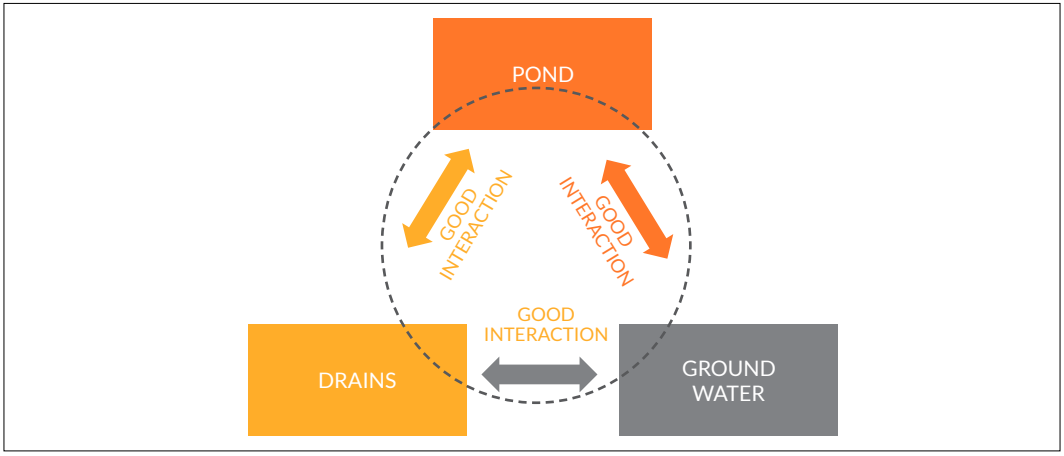
The authors argue that the disruption in the interconnectedness between the waterbodies, drains, and groundwater is one of the key factors of environmental degradation in the city and the solution to reclaiming the lost *"aab-o-hawa"* lies in re-establishing the interconnectedness. The present research is focused on studying the disruption in the trilogy of ponds, natural drains, and groundwater in Aligarh city, and the causes, processes, and manifestations thereof. A methodology for prioritization of waterbodies and stretches of drains has also been evolved to select the waterbodies and drains for rejuvenation. This shall assist the service provisioning agencies in sustainable management and conservation of aquifers and surface waterbodies within Aligarh and in other similar cities. At present, efforts by city authorities are underway in the city for conservation of select ponds but in an isolated manner.

Trilogy of Ponds, Natural Drains, and Groundwater: A Holistic Approach

The Concept of Interconnectedness

The concept of the trilogy was based on the idea of a series of three musical compositions that are closely related and are part of a single theme. The authors argue that ponds, drains, and groundwater management, each forms a part of this trilogy, thus leading up to a broader theme of water resource management. So, all three elements need to be considered in a holistic manner. While studies (Thomas C. Winter, 1998), (Cherepansky M.M), (Gelt, 1994), and (Geiger, 2018) in the past have discussed this interconnectedness theoretically, very few have been able to explain its working on the ground.

Figure 1: Representation of Trilogy



Source: Author, 2022

The interconnection between surface water and groundwater in areas with different natural conditions determines the regime and dynamics of water exchanges between them (Cherepansky M.M) and (Gelt, 1994), (Geiger, 2018). While natural processes impact surface-water/ groundwater interactions; anthropogenic actions like water pumping and untreated waste water discharge also have a direct impact on this process. Complex factors like natural geology, local aquifer conditions, and human activities related to land use also affect the quality of groundwater which further affects its connection with the surface water. Thus, in human settlements, efforts to rejuvenate waterbodies or drains need to adopt a systems approach and consider all natural and anthropogenic causes.

Approaches and Initiatives for Waterbody Rejuvenation and Groundwater Management in Urban Areas

Water Management has taken centre-stage in the global resource management discourse that is propelled by increasing water stress, exacerbated by climate changes in different regions of the world. Globally and in India, various approaches towards judicious and efficient water resource management are Integrated Water Resource Management (IWRM), Integrated Urban Water Management (IUWM), Water Sensitive Nature Based Solution Approaches such as Sustainable Urban Drainage System (SuDS), sponge cities, and water sensitive urban design and planning are also being adopted in cities. In India, some of these have translated directly or indirectly into water and sanitation programmes and schemes.

Several of the central and state programmes and schemes related to water and sanitation are being implemented in Aligarh. Rejuvenation of two waterbodies in the city has been undertaken under the Smart City Mission. Recently, five urban ponds were identified by the municipal corporation under the Amrit Sarovar Scheme. Polluted water from the drains is being treated under a pilot scheme using Phyto-remediation technology under the Namami Gange Programme. The water supply and sanitation are being improved under the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) and AMRUT 2.0 and the Swachh Bharat Mission.

Methods

The study was conducted as part of the Master's thesis program from November 2021–June 2022. The urban water bodies in Aligarh city and the Shekha Jheel wetland in the rural hinterland were the two major parts of the study. There were three core objectives of the study–first, to study the interconnectedness between the ponds, drains, and groundwater in urban Aligarh; second, to evolve a methodology for prioritization of ponds and drains in a holistic manner; and third, to study the Shekha Jheel in context of Aligarh.

There was a clear need to prepare an inventory of the water bodies in Aligarh due to the absence of any comprehensive study on it. The secondary data was collected from published and unpublished sources which included gazetteers, reports, statistical records, and other resources that were available in the public domain. The primary data for the waterbodies and Shekha Jheel was collected through site visits. People's perception was captured through surveys and stakeholder interviews. Maps and inventories were prepared by visiting the accessible ponds/drains and

referring to the maps that were available in the public domain; land use and activities within a 100m buffer of the waterbody were recorded. Stakeholder consultations were conducted with district level officers, municipal level officers, local NGOs, institutions, and environmentalists. Surface water and groundwater samples were collected and the water quality assessment was done from a NABET (National Accreditation Board for Education and Training) accredited lab. Ponds and waterbodies have been used interchangeably in the paper.

Software like Microsoft Excel, ArcGIS 10.8, and Google maps were used for quantitative and spatial assessment, respectively. Google Earth was used to compare the areas and development around the waterbodies from 2003 to 2022, during the post-monsoon period.

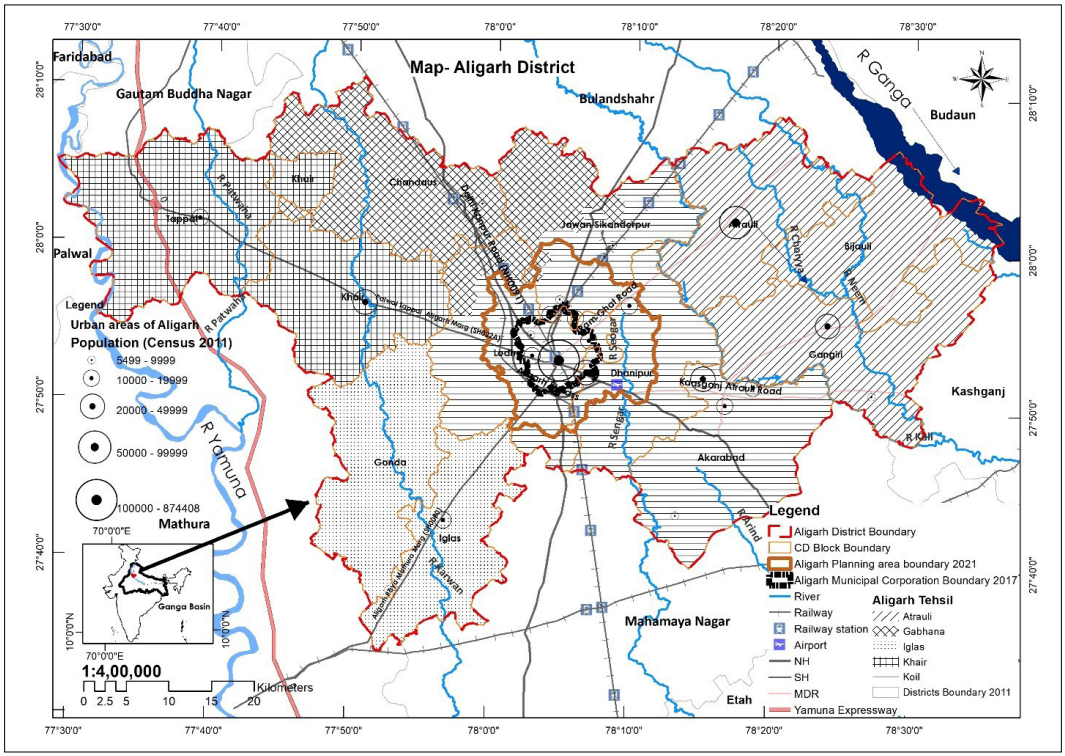
The Lost Trilogy: A Case of Aligarh City

Regional Context

Aligarh city is located in Koil tehsil and is almost the geographical centre of Aligarh district and nearly equidistant from River Ganga and River Yamuna in the Ganga-Yamuna Doab. The district has a population of nearly 37 lakh and 33 percent of the population resides in urban areas (Census of India, 2011). The city is well connected to the National Capital Region (NCR) and other cities of India through National Highway-91, National Highway-93, State Highway-22A and State Highway-80. The district is bounded by the Ganga River on the north-eastern side and Yamuna River on the north-western side. The district is drained by Rivers Kali, Sengar, Karwan, Patwaha, and Neem among others. The Upper Ganga Canal and its various distributaries pass through the district. Shekha Bird Sanctuary, an Important Bird Area (IBA) of Uttar Pradesh adjoins the Upper Ganga Canal near Aligarh city.

A little more than 900 wetlands have been identified within the district, out of which Koil tehsil has nearly one-third of the wetlands (Hussain, Ilyas, & Imam, 2022). River Kali flowing in the eastern part of the district carries sewage, chemical laced agricultural runoff, and industrial effluents from the upstream areas which contribute to the toxic waste of the environment (Ajmal et.al, 1988, CPCB, 2013, Sirohi et. al 2014). Recent studies have suggested that River Kali has contaminated the groundwater with heavy metals along the river (Khan & Khan, 2019). Though, overall, the stage of groundwater extraction is 78 percent (CGWB, Dynamic Ground Water Resources of India 2022, 2022) in the district, Aligarh city has been categorised as over-exploited.

Map 1: Aligarh District and Other Various Features



Source: Survey of India's 14 Toposheets (H43X8, H43X12, H43X16, H44S4, H44S8, H44S12, G43F9, G43F13, G44A1, G44A5, G44A9, G43F14, G44A2, G44A6), Census of India (2011), Aligarh Municipal Corporation's GIS webpage

A Brief History of Aligarh

Historically, Aligarh has been known as Allygurh, Coel, Kol, Koil (Hutchinson, 1856) and also as Muhammadgarh, Sabitgarh, and Ramgarh. (Siddiqi, 1981) In 1342, Koil was described by Ibn Battuta in his memoir Rihla, as "a lovely town surrounded by mango groves." Owing to the green environment, the area also acquired the name of Sabzabad (District Administration NIC, 2022). The area was once covered by forest, thickets, and groves. There are villages which are named after the *jungle* trees for example *Jau*, *Dhak*, *Mahua*, and *Imli* etc. (Siddiqi, 1981). The area had several ponds including rain-fed, temporary, and stagnant. Inns were constructed around Bain/ Baolies where travellers could rest. It was a custom that villagers (Aligarh city to Shekha Jheel) would construct ponds to collect rainwater. Some of the places bear resemblance to local names for ponds viz. *pokhar*, *kunda*, *dig*, *dabha*, *daha*, *nimna*, *dariya*, *tal*, *kachhar*, and *jal* (Final Report on the Revision of Settlement in the District of Aligarh, 1982).

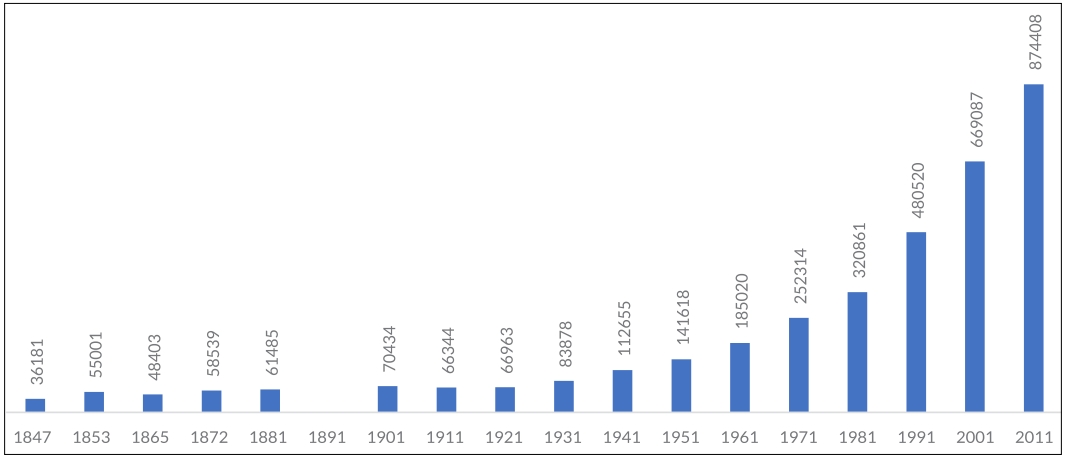
Around 1724-28, the Upper kot *Jama Masjid* was built on an elevated ground since the surrounding area was prone to waterlogging. The city also had tanks such as Sabit Khan's tank which acted as water reservoirs for the summer months. Waterbodies such as Adhawan *jheels* close to River Sengar's source, as well as moderately large *jheels* at Gopi, Bhawan Grahi, Shaikha, Ikri, and Gursikaran were present here. The area had plenty of black bucks/antelopes. The Upper Ganga Canal was built in 1852 (Atkinson, 1875). It changed the hydrological character of the area which resulted in a rise in the groundwater level along the canal and led to waterlogging conditions in the adjoining areas. Shekha Jheel was formed around this time (Kalpavriksh, 2009).

Earlier, there were areas in the north-eastern part of the city which were poorly drained that also gave rise to the growth of deep morass, resolved through excavation of the Aligarh drain. The main source of irrigation were the wells and rivers along with ponds, lakes, and water reservoirs. (Siddiqi, 1981). During 1875, Sir Syed selected Aligarh as the site for AMU stating that Aligarh's *"aab-o-hawa"* was "perfectly suitable" for the intellectual and physical well-being of an individual. (Khalil, 2021). From 1800 onwards, increase in village population and growing value of agricultural land led to a sharp decline of the groves and forest area (Siddiqi, 1981, Mann, 1995).

Aligarh City Profile

In 2021, the Aligarh city area was 63.82 sq km and the estimated population was 13,21,579 (AMC, 2021). It is a highly dense urban settlement with 22,545 persons per sq km, a typical characteristic of urban centres in the fertile Ganga plains (Census of India, 2011). The city is divided into two distinct halves on either side of the railway line. The western side houses the old city and is densely populated while the eastern side has relatively new development. The most prevalent settlement typologies in the city include planned development, unplanned development, old city area, and privately owned developed colonies. There has been a sharp increase in the slum population between 2001 to 2011 (Census of India, 2001, 2011) from 1,74,300 (26%) to 3,67,134 (44%).

Figure 2: Urban Population Growth in Aligarh

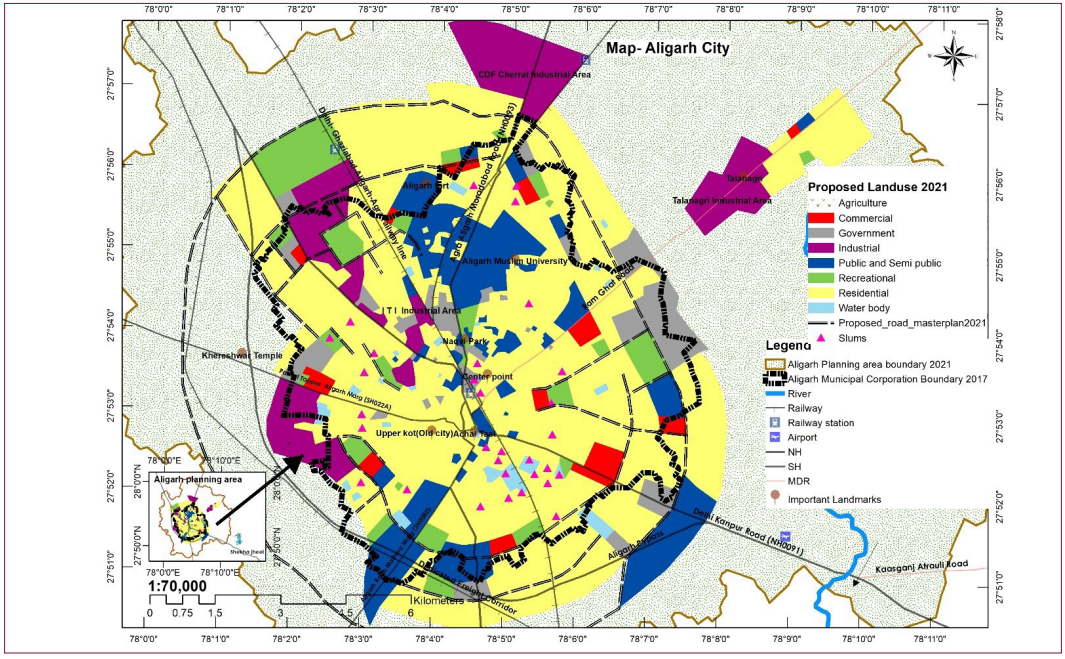


Source: Hutchinson, 1856; NEVILL, 1909; and Census of India, 2011

The built-up area in Aligarh municipal limits and the surrounding areas increased by 16 percent, from 61 sq km in 2005-2006 to 71 sq km in 2015-16 (NRSC, n.d.). In 1975, Aligarh was declared as Aligarh Regulated Area which comprised Aligarh Municipality and 110 villages. This was done to control the unplanned and uncontrolled development in Aligarh city and to speed up the planned development (Aligarh Development Authority, 2003). Aligarh has had two Master Plans, 2001 and 2021, the third (2031) is in the draft stage. The delineated planning area for 2021 is 11,470 ha that is proposed to increase to 20,986 ha in the Master Plan 2031 (Draft). Shekha Jheel has been included in the latter plan. Aligarh has only 0.37 sq m per capita of open space, much below the recommended 10-12 sq m per capita (URDPFI guidelines, 2014). As per Master Plan 2021, water bodies/Nallahs/Ponds comprise 1.33 percent of the total area (152.85 ha), while parks and open spaces comprise 9.67 percent (1109.3 ha).

According to Master Plan 2021, no other land use is allowed on the water bodies other than the 'water bodies and ponds', as listed in the Master Plan. The Master Plan also mentions that any 'layout plan above 20 acres should have 5 percent of the land reserved for ponds and water bodies, which has a minimum area of 1-acre and 6-m depth', and any 'layout plan less than 20 acres should have a recharge well'. Additionally, Percolation Pits for groundwater recharge from rain is mandatory in all plots of 1000 sq m and above area. This is not only mandatory for plots but is also applicable for all existing and new government buildings. Also, 15m around the main nallahs should be left for green areas.

Map 2: Proposed Land Use Plan 2021 and Location of Slums in Aligarh



Source: Aligarh Master Plan 2021, Municipal Corporation GIS webpage (https://gis.nnaligarh.in/GIS/Home/GISPortal), and City Sanitation Plan 2014

Aligarh has three industrial areas, ITI Industrial Area, UPSIDC Industrial Area sectors I and II (Tala Nagri), and Chherat Industrial area; the latter two are outside the municipal limits but are part of the planning area. There are 4673 small scale units and 11 large scale units, employing nearly 24,000 and 1900 workers, respectively (Personal Interview, March 2022). Many of these industries viz. locks, brassware, zinc dye, metal-based steel fabrication are Red industries (CPCB, Final Document on revised classification of Industrial Sectors under Red, Orange, Green and White Categories, 2016) with high pollution potential.

As per the Central Pollution Control Board (CPCB), Aligarh is also a Severely Polluted Area (SPA) and its CEPI[2] (Comprehensive Environmental Pollution Index) score has risen sharply from 48 to 61.88 (neutral to critical), in the water category from the year 2009 to 2018. The Shakti Nagar area in the city is a probable contaminated site[3] for lead contamination. There is no CETP but ETPs are installed in all the water polluting industries in the cluster (UPPCB, 2022). Aligarh drain and Cherrat drain receive effluents from the industrial areas (UPPCB, n.d.).

Since 1975, the city has been served by a piped water supply system from groundwater sources. To make matters worse, the water supply of the city is well below the Service Level Benchmarks (erstwhile MoUD, 2011), with water supply connections being present in only 82,326 households (31.1%). The demand for water is 205 million litres per day (MLD) however, the supply is only 120 MLD, and the per capita per day supply is only 90 litres compared to the recommended 135 LPCD (Open data Platform: India smart cities, 2019) implying that most of the households are dependent on individual private borewells in their premises. There are about 18 locations in AMU and a few government buildings in Aligarh where Rain Water Harvesting Systems (RWH) have been installed (AMU, n.d and Amar Ujala, 2021).

The city received ODF++[4] (Open Defecation Free) certification in 2020. Only 3.10 percent of the city's area and almost 20 percent of the city's population is connected to the sewerage network while the rest are dependent on on-site sanitation systems like septic tanks (Open data Platform: India smart cities, 2019). A MLD Sewage Treatment Plant is insufficient in capacity, as the sewage generation is much higher at 79.08 MLD as of May 2022. The faecal sludge treatment plant (32 MLD) is in place however it was not in a working state when visited by the author in February 2022. There are no monitoring stations for checking the quality of the surface water in the city (2022).

[2]*CEPI is the Comprehensive Environmental Pollution Index. CPCB developed CEPI to find an Index value to characterize the quality of the environment in the industrial cluster. CEPI scores of 70 and above are identified as Critically Polluted Areas (CPAs) and CEPI scores between 60 and below 70 are categorized as Severely Polluted Areas (SPAs).*

[3]*Contaminated sites are delineated areas in which the constituents and characteristics of the toxic and hazardous substances, caused by humans, exist at different levels and in conditions which pose existing or imminent threats to human health and/or the environment.*

[4] *The Swachh Bharat Mission-Urban aims to fulfil the objective of 100 percent Open Defecation Free (ODF) status in all Urban Local Bodies (ULBs) in the country by 2019. This will entail providing access to clean and usable toilet facilities for the citizens. In larger prospects, ODF flagship is taken ahead by ODF+ and ODF++.*

The official statistics for solid waste management indicate that the city (3star GFC[5] certified) is performing well as the rank has gone up from 173 in 2018 to 34 in 2022, but in reality, there is still a lot of scope for improvement. Nearly 545 Tonnes Per Day (TPD) is generated and only 435 TPD (79.8%) is collected. (Solid Waste Management City Profile : Aligarh India, 2018). Out of 80 wards, door to door collection is practiced partially in 70 wards, and as of May 2022 (Amar Ujala, n.d.) 10 wards have 100 percent door to door collection facility. The rest of the solid waste is dumped either into the open areas, roadsides, or into the water bodies.

Various urban local agencies are working in siloes for the conservation of water resources in Aligarh. The Aligarh Municipal Corporation is responsible for water supply, rejuvenation of ponds, upgradation of new infrastructure, and implementation of policies. The Irrigation department is responsible for the cleaning of drains, Upper Ganga Canal, minor canals, and ensuring availability of water, while the Forest Department is responsible for plantation of trees, and management of the Shekha Jheel. The Aligarh Development Authority (ADA) is responsible for preparation and implementation of the Master Plan. Responsibilities of rejuvenation of rural ponds and AMRIT Sarovar are in the hands of the Block Development Officers. Uttar Pradesh Pollution Control Board (UPPCB) is responsible for abating and monitoring pollution, while groundwater is managed by the Central Ground Water Board (CGWB).

Degraded Water Systems: Ponds, Natural Drains, and Groundwater

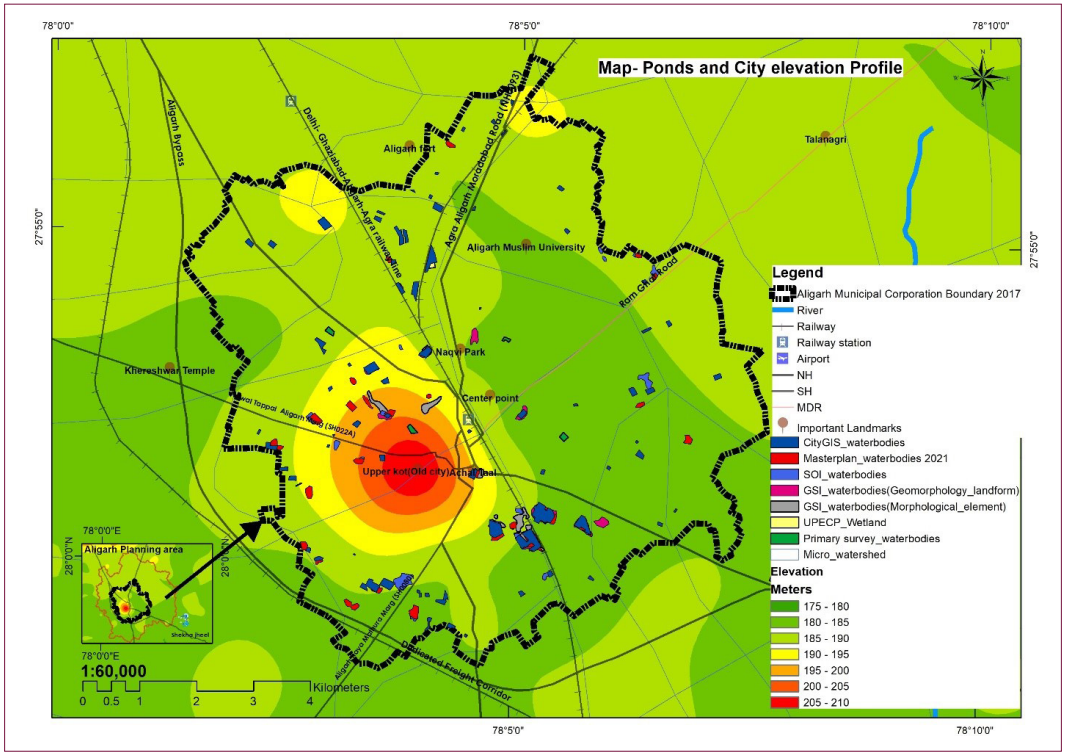
As history suggests, while the city of Aligarh was selected as a seat of learning by Sir Syed Ahmed for its conducive *'aab-o-hawa'*; the population growth in the past decades, unplanned development, and inadequate infrastructure has led to the degradation of the city's water resources.

Ponds

Multiple agencies have been involved in the preparation of an inventory of waterbodies or ponds in Aligarh city. The city GIS information displays 74 ponds while 28 ponds are listed in the proposed land use plan 2021. There are 22 ponds, marked in the Survey of India Toposheet (2005), most of which are dry in nature. The Uttar Pradesh Environmental Compliance Portal of UPPCB lists 6 wetlands, and the District Environmental Plan 2021 lists 27 ponds. The Municipal Corporation officials stated that there are around 30 ponds within the city (Personal interview, 2022).

[5]*The Ministry of Housing and Urban Affairs (MOHUA) has launched the Protocol for Star Rating of Garbage Free cities. The star rating conditions have been designed in a way to enable cities to gradually evolve into a model (7-star) city, with progressive improvements in their overall cleanliness.*

Map 3: Location of Waterbodies from Various Sources in Aligarh



Source: Prepared by author from SLUSI website (slusi.dacnet.nic.in/dmwai/UTTAR_PRADESH/District/ALIGARH.html accessed on 12, *February 2022*), *Municipal Corporation GIS page, SOI Toposheets*

Consultation with officials of Municipal Corporation (personal interview, 2022b) revealed that the distinction between ponds/waterbodies and water-logged areas is not clearly defined. In India, some of the definitions have been given by the Haryana Pond and Wastewater Management Authority (HPWWMA, 2018), Urban River Management Plan (NMCG and NIUA 2020) and Uttar Pradesh Pond Development, Protection and Conservation Authority Bill 2017 (Third Draft).

On the basis of primary survey 2022, four ponds/waterlogged areas were identified in addition to the waterbodies that were already enumerated for the city. A union approach (set operations) was used to combine the information obtained from multiple sources. Accordingly, a total of 106 ponds were marked within the municipal area.

Table 1: Number of Ponds/Waterbodies/Waterlogged Areas (According to Various Sources) in Aligarh

Sources	Year of Publication/ Reference	Scale	Map Availability in Public Domain	Total Number of Waterbodies/Ponds Observed	Total Number after Union
City GIS Portal (gis.nnaligarh.in/GIS/Home/GISPortal)	2019	-	Yes	74	106
Survey of India (14 Toposheets)	2005	1:50,000	Yes	22	
Master Plan 2021	2003	-	Yes	28	
GSI (Geomorphology)	2020/21	1:50,000	Yes	10	
GSI (Geology)	2016/17	1:50,000	Yes	8	
Uttar Pradesh Environmental Compliance Portal (UPECP) (https://upecp.in/)	2020	-	Only Geo coordinates	6	
Municipal Corporation	2022	-	No	30 (Approx.)	
District Environmental Plan	2021	-	No	27	
Primary Survey	2022	-	-	4 (Total number of waterbodies observed by author)	

Source: Author, 2022

Out of 74 ponds that are listed in the city GIS, 57 are exclusively in the city GIS while the remaining 17 ponds are also mapped in other sources. Similarly, out of 28 ponds mapped in the Master Plan, 14 are exclusively in the Master Plan while 14 ponds are also marked in other sources. Similarly, out of the 22 ponds mapped in the SoI toposheet, 7 are exclusively in the mentioned source. Interestingly, there are only six ponds that are mapped in more than 4 sources and two ponds are mapped in more than 6 sources.

Out of the identified 106 ponds, the author could visit only 80 ponds during the study. Out of the 80 ponds, 16 ponds have been encroached and converted into built-up, open plots, Sewage Treatment Plants, SWM Facilities, agriculture, and plantation. As a result, it was possible to prepare a detailed inventory of only 64 ponds.

Table 2: Classification of Ponds by Size in Aligarh

Size (Ha)	Total No. of Ponds	Total No. of Ponds Inventoried
Less than 0.5	31 (29)	18 (28)
0.5 to 1	28 (26)	16 (25)
1 to 2	25 (24)	18 (28)
2 to 5	18 (17)	9 (14)
Above 5 ha	4 (4)	3 (5)
Total	106 (100)	64 (100)

Note: Percentage in parentheses

Source: Author, 2022 prepared from above listed sources in Table 2

Of these, 64 waterbodies were inventoried and the characteristics of each of them were noted. 17 (26.5%) waterbodies had only residential land use in the demarcated 100m buffer while 12 (18.7%) waterbodies had some space at the edge and 52 (81.2%) waterbodies were found to be partially encroached upon. Connectivity of 53 (82.8%) waterbodies was through pucca roads, the rest were connected by *kuchha* roads. All the waterbodies were observed to have water hyacinth, but 95.3 percent did not have any fish while birds were spotted in 90.6 percent of the waterbodies. Probable sources of pollution in 46.8 percent of the waterbodies were domestic wastewater, solid waste, and cattle wading.

Figure 3: Ponds in Aligarh City

Pond near Gandhi Eye Hospital
Solid waste around the water body

Kali Deh Pond
Solid waste around the water body

Pond near Surendra Nagar
Roaming of animals

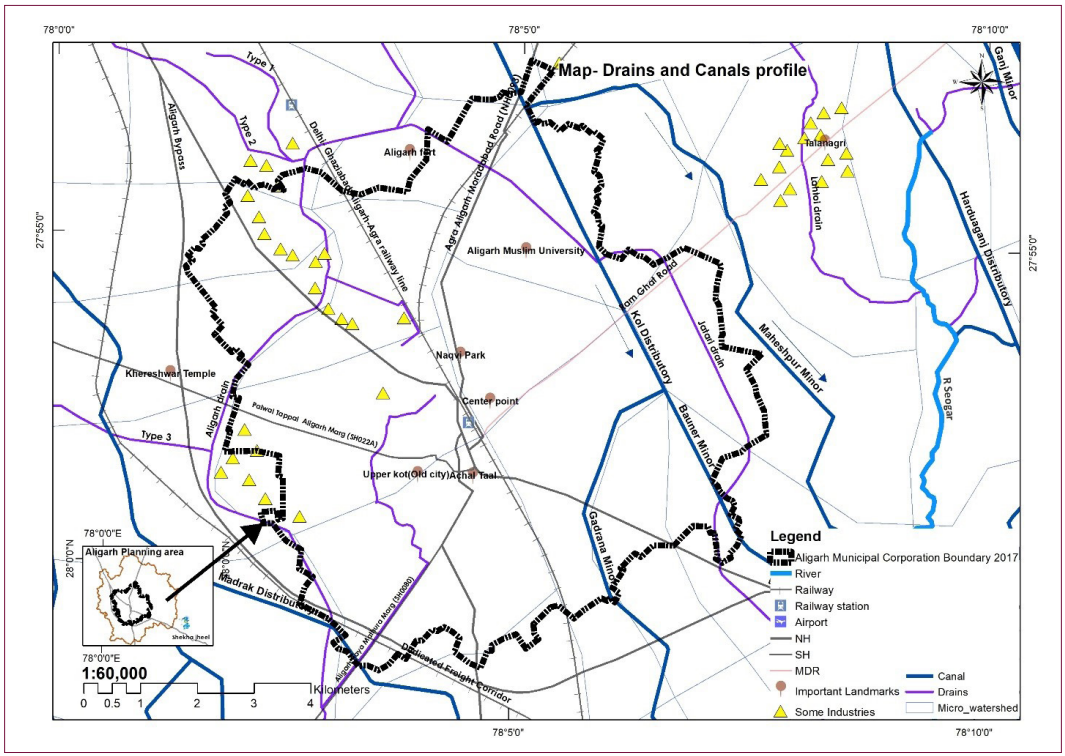
Pond near Pratibha Colony, Exhibition Ground
Solid waste around the water body

Source: Author, 2022

Natural Drains

The quality of water flowing in the minors and distributaries has deteriorated over the years and now, these serve as wastewater drains in the urban area. At present, the Gadrana minor, Boner minor, and Koil distributary are in a degraded condition in the city (*Aligarh khand ganga nahar roaster*, 2020-21). Aligarh drain and Jafri drain were studied in detail under this research.

Map 4: Drains in Aligarh



Source: Prepared by author based on SLUSI website https://slusi.dacnet.nic.in/dmwai/UTTAR_PRADESH/District/ALIGARH.html accessed on 12 February 2022), and SOI's 14 Toposheets

Only unlined drains were inventoried because there is very little interaction between concrete stormwater drains and groundwater. There are 26 industries in Aligarh which are discharging their treated effluent in the Aligarh drain (UPPCB, n.d.). The polluted waters of the Aligarh drain and Jafri drain are being treated under a pilot scheme using Phyto-remediation technology (Treatment of Polluted water, 2021). There is no sewerage network in the vicinity of both the drains. After passing through a nallah, the ITI industrial area's wastewater is discharged into the Aligarh drain. Majority of the slum areas are prone to flooding during rains. The sanitation situation is worse particularly in the outskirts of the city (City Sanitation Plan, 2014), and these outskirts became a part of the city after the 2017 expansion of city boundaries. Eight slaughter houses and 11 other industries were located near the drain which were discharging 6.37 MLD

treated effluent and the drain also carried 96.50 MLD untreated sewage, thereby emerging as a cause of concern for groundwater contamination through infiltration (UPPCB, n.d.).

Table 3: Detail of Aligarh and Jafri Drains, 2019

Drain	Flow (MLD)	Width (m)	Pollution load (mg/l)	Permissible Limit (mg/l) (If water is used for organised outdoor bathing)
Aligarh	118	18*	220	Below 3 mg/l
Jafri	55	9*	Below 250	Below 3 mg/l

Source: Author, 2022; UPPCB, n.d.*

The Aligarh drain and Jafri drain, and three canals namely Koil distributary, Boner minor, and Gadrana minor were studied in detail for this study. The latter were originally irrigation canals but on being engulfed by the city, they have been converted into wastewater drains.

Table 4: Predominant Land Use in the Surrounding Areas of the Drains in Aligarh

Drain names	No of Identified Stretches	Land-use			
		Residential	Mixed	Industrial with other uses	Agricultural
Aligarh	7	-	2	3	2
Jafri	2	-	1	-	1
Koil	1	-	1	-	-
Gadrana	1	-	-	-	-
Boner	1	1	-	-	-

Source: Author, 2022

Figure 4: Drains/Nallahs of Aligarh

A lined drain in the middle of the city | **Aligarh drain near Sarsol area** | **Koil distributary near Sarsol**

Source: Author, 2022

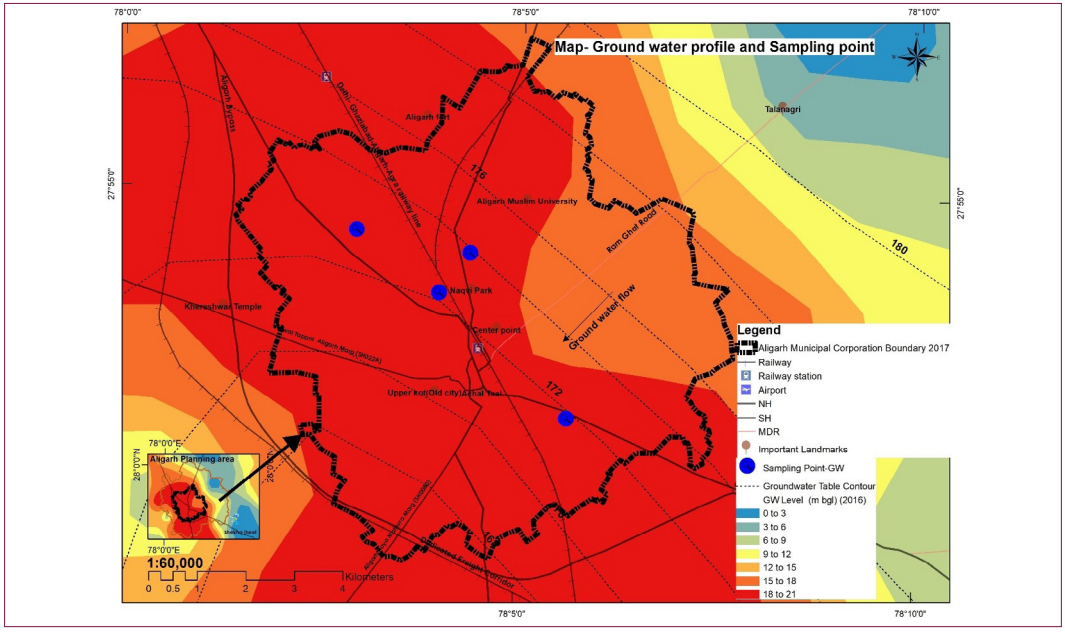
The Aligarh drain was found to be highly polluted. The BOD, which was already very poor (55 mg/l) before entering the city trebled (140 mg/l) after exiting the city. It was a similar case for COD, which increased from 147 mg/l to 316 mg/l (Primary survey, 2022).

Groundwater

Groundwater assumes a special significance for Aligarh as the city is completely dependent on it for all its uses. Due to excessive removal from shallow tubewells, the upper aquifer (9-66m mbgl) is under stress (Khurshid & Kulshrestha, 2008). The flow of groundwater is from the north-west to the south-east. The gradient of the water-table varies from 0.16 to 4.0 m/km. The post monsoon groundwater level has dropped from 8.84 (2011) to 14.42 mbgl (2021) (Jal Jeewan Mission, 2022). The deepest water level i.e., 26.63 mbgl has been observed at Jawahar Park in the Aligarh City area (Khan S. , 2017).

The region's upper aquifer is extremely susceptible to microbiological and chemical pollution (Umar et al, 2001). Groundwater samples from New Basti Colony and Naqvi Park had higher than acceptable limits (BIS standards) of TDS and total hardness. Among these, New Basti Colony had the highest nitrate (28 mg/l), though within the permissible limits (Author, 2022). Past studies also suggest poor quality of water in many places of the city (Anwar and Aggarwal, 2014, Ayub et.al 2011), along with the presence of trace elements (Khan T. A., 2011). More than 80 percent of the city, particularly to the west of the railway line have been found vulnerable to groundwater contamination (Rahman, 2008).

Map 5: Groundwater Flow and Depth in Aligarh



Source: Author 2022, prepared from SOI, SLUSI, CityGIS, CGWB 2014

Disruptions in Interconnectedness

The city has deviated from Sir Syed Ahmad's *'Aab-o-hawa'*. Ponds and drains are polluted while groundwater is also contaminated at many places in the city. The disruption in the interconnectedness has manifested in the form of health issues, loss of biodiversity, and loss of ecosystem services.

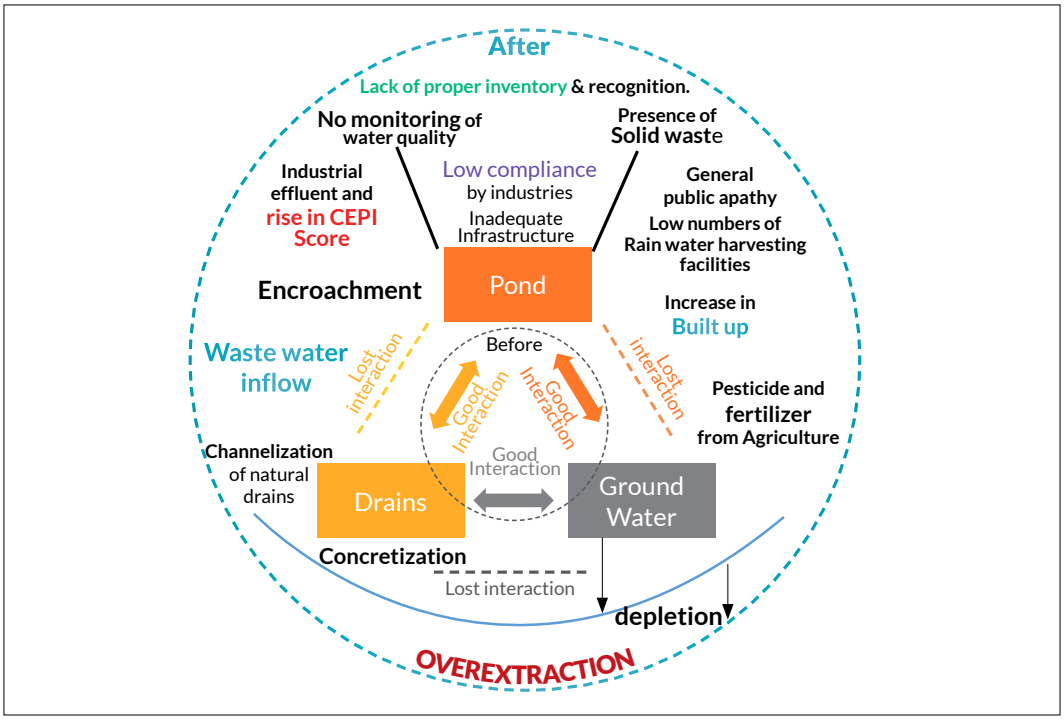
Vector borne diseases like malaria are prevalent in the city and it has been attributed to lack of natural drainage which results in the collection of waste water in depressions (Singh & Rahman , 2001). In 2022, the Health Department declared 39 areas within the city as prone to malaria and dengue (Amar Ujala, 2022c). Aligarh also has a campaign to check vector borne diseases in the post-monsoon phase (Hindustan Times, 2023), but has also been identified as a poor performer for controlling the spread of dengue (Saigal, 2023). Many ponds and drains do not have fish which is an important bio-indicator of the health of the waterbodies.

Pollution in waterbodies is one of the key stressors for the ecosystem services (Wang et.al, 2021, Grizetti et.al, 2016). While many of the provisioning ecosystem services such as fish, drinking water were absent, some of the ponds were being used for cattle wading (livelihood). Among the regulating services, groundwater recharge and discharge has been heavily compromised in terms of the quality of water. Cultural services are prominent for a few waterbodies such as Achal taal, but non-existent for others. Among the supporting services, it was highlighted by environmentalists that the variety of birds spotted near the waterbodies in the city has declined over the years.

Public apathy has also played a role in the current state of affairs. Being prone to waterlogging, the city and the adjoining areas have several waterbodies or depressions that are filled with water, particularly during the monsoons. These are also viewed as a nuisance by many residents as they become breeding grounds for mosquitos and a hub for anti-social activities. In a google survey conducted across the city by the authors, it was found that half the respondents had never visited a waterbody in the city. The presence of odour, absence of seating places and walking tracks, and presence of stray animals near the waterbodies were some of the issues highlighted during the people's perception survey. Few waterbodies, such as Achal taal, that are of religious and cultural significance have been taken over for restoration but with focus on beautification and not rejuvenation.

The trilogy of ponds, drains, and groundwater is undergoing a systemic destruction wherein though the link between the three exist, the exchange of clean water has been taken over by polluted water. The poor state of infrastructure, low compliance by industries, non-existent monitoring of water quality by authorities, and public apathy has destroyed the natural balance between the three components of the trilogy thus leading to the present dismal state.

Figure 5: Destruction in the Trilogy

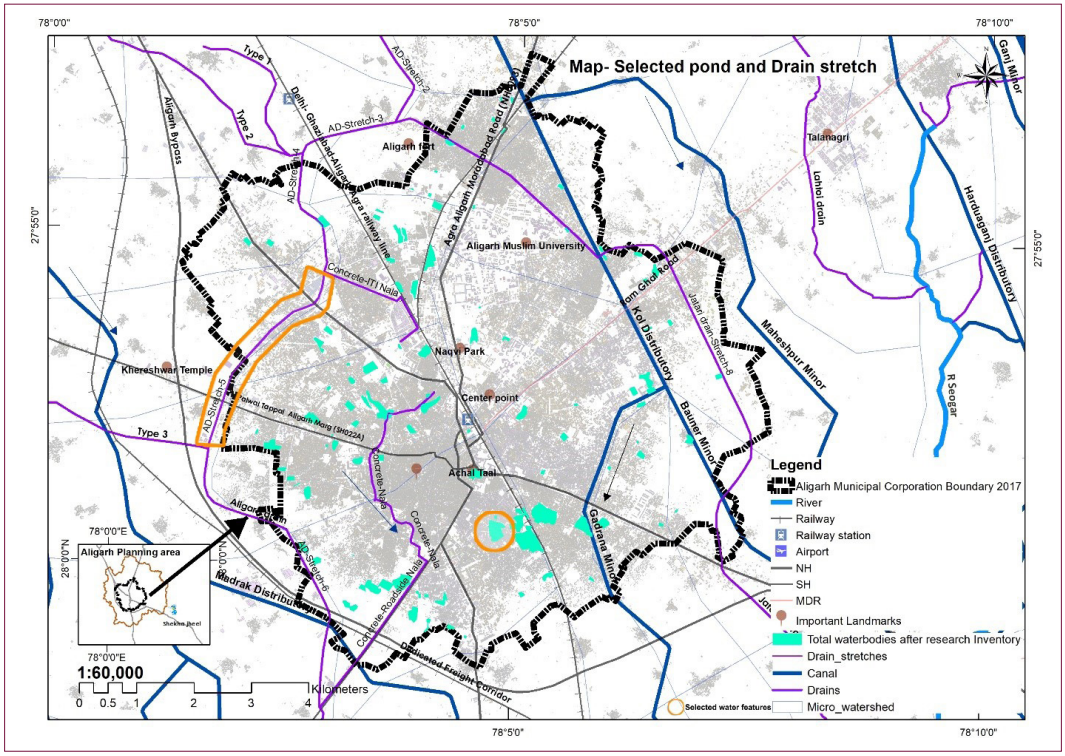


Source: Author, 2022

Prioritization Process

As part of the study, prioritization of waterbodies for rejuvenation was also undertaken. The thought behind the need for prioritization was that rejuvenation of the selected waterbodies should have the highest benefits and co-benefits and to make it financially feasible, the project should be able to access funds under the relevant government of India schemes. This will also assist the administration in holistically selecting the city's waterbodies for rejuvenation. A *"Manual on urban water body diagnostic tool"* prepared by the National Institute of Urban Affairs (NIUA) and UNESCO in April 2022 was also referred for this process.

Map 6: Selected Stretch and Pond for Intervention in Aligarh



Source: Mapped by the author from Survey of India toposheets, 2005

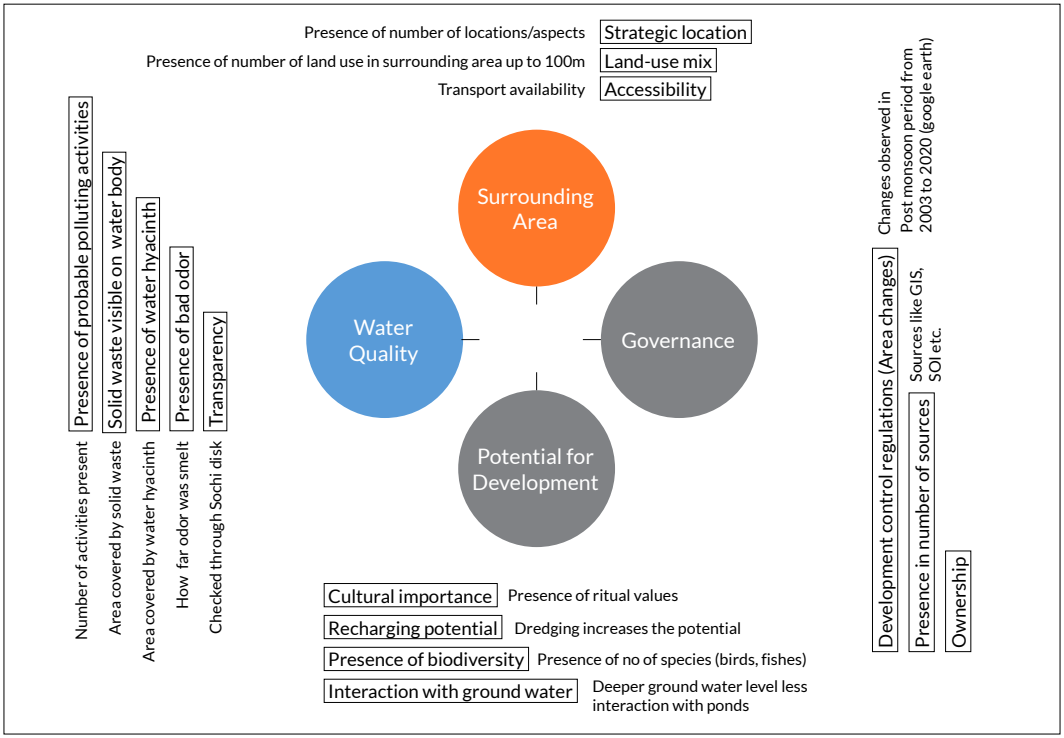
Ponds

Two levels of prioritization process were involved in the selection of ponds. The first level included 'ponds with area above 2ha', wherein 22 out of 106 ponds were selected. The rationale behind the selection of ponds with area of more than 2ha is that they are eligible for inclusion under the Repair, Renovation, and Restoration of waterbodies under PMKSY (Pradhan Mantri Krishi Sinchayee Yojana) scheme, 2017 and thus will be eligible for funds for rejuvenation.

The second level of prioritization was based on 15 sub criteria which were grouped together to form four major criteria. All the sub criteria were given equal weightage. Each sub criteria was given values from 1 to 5 where 1 was the lowest. Based on equal weightage among the sub criteria, after the addition of values, the pond with the highest value was chosen for rejuvenation.

The four criteria were water quality, buffer area/effective micro/watershed characteristics, governance, and potential for development.

Figure 6: Criteria for Ponds



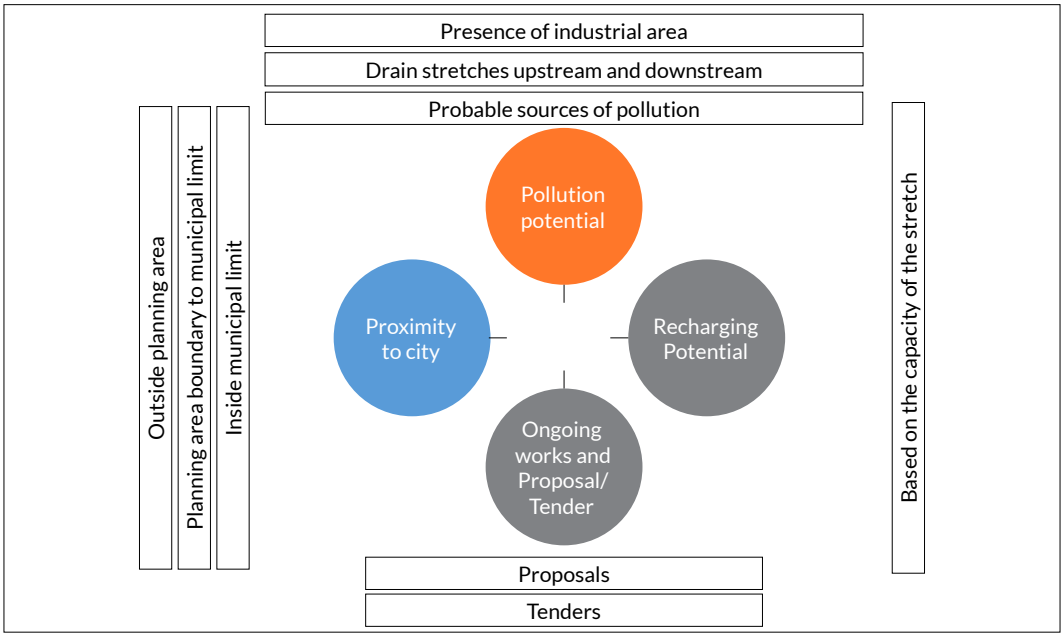
Source: Author, 2022

Out of 22, five ponds were not visited, and the remaining 17 ponds were given a score based on the prioritization process. Out of a maximum score of 75, Kali Deh Pond and New Basti pond scored the highest of 63 and 50, respectively; nine ponds scored in the range of 25 to 50 and six ponds scored less than 25.

Drains

Total 12 drain stretches were identified, which were based on the meeting points of major drains/ nallahs, and the length within the city's planning and municipal boundaries. The four criteria were assessed on a scale of 1 to 3, where 1 stood for the lowest value. The stretch with the highest calculated value will be chosen for rejuvenation, after addition of the values for each sub criteria.

Figure 7: Criteria for Drains



Source: Author, 2022

Out of the seven stretches that were identified for Aligarh drain, three stretches viz. type 1-2 drain meeting point to ITI nallah point, ITI nallah point to type-3 drain meeting point, and type-3 drain meeting point to Chhahari drain meeting point scored the highest (ten). The other four stretches viz. Origin to planning area entry point, from planning area entry point to diversion point, from diversion to type 1-2 drain meeting point, and Chhahari drain meeting point to River Yamuna (Outside Jurisdiction of Aligarh District) scored marginally lower in the range of 7-9. Two stretches of Jafri drain, from diversion till last municipal limit and municipal limit to end point (River Sengur) scored seven and four, respectively. Koil distributary, Gadrana minor, and Boner minor scored below 8.

Three stretches were found to have the same score. To select one, further criteria of length of the stretch and presence within Aligarh city was applied. Thus, stretch 6 was selected as it was the longest and it also flowed through Aligarh city for the longest distance.

Shekha Jheel: The Wetland Perspective

Shekha Jheel is a bird sanctuary and an Important Bird Area (IN-UP-21) near the village of Shekha and Bhavan Kheda, 17 km East of Aligarh city. It is a wetland that is identified under the former National Wetlands Conservation Programme (NWCP). The notified area is 40ha and its depth ranges from 0.91m to 1.22m. However, the area of the wetland is 25ha. It is a natural

perennial (inland) wetland. The area is bounded by the Upper Ganga Canal (UGC), Harduaganj and Sikandrarao distributaries, Bhavan Kheda minor, escapes and Bijaigarh drain (which probably carries wastewater from the Bhavan Khera village into the jheel). The main source of water is the UGC and rainwater. The UGC divides this area into two parts. With time, it became a popular destination for migratory and resident birds for nesting and breeding. However, before 1970, it was a shooting ground for the nearby population. Conservation efforts led by local people and beautification works by the administration started in 2012.

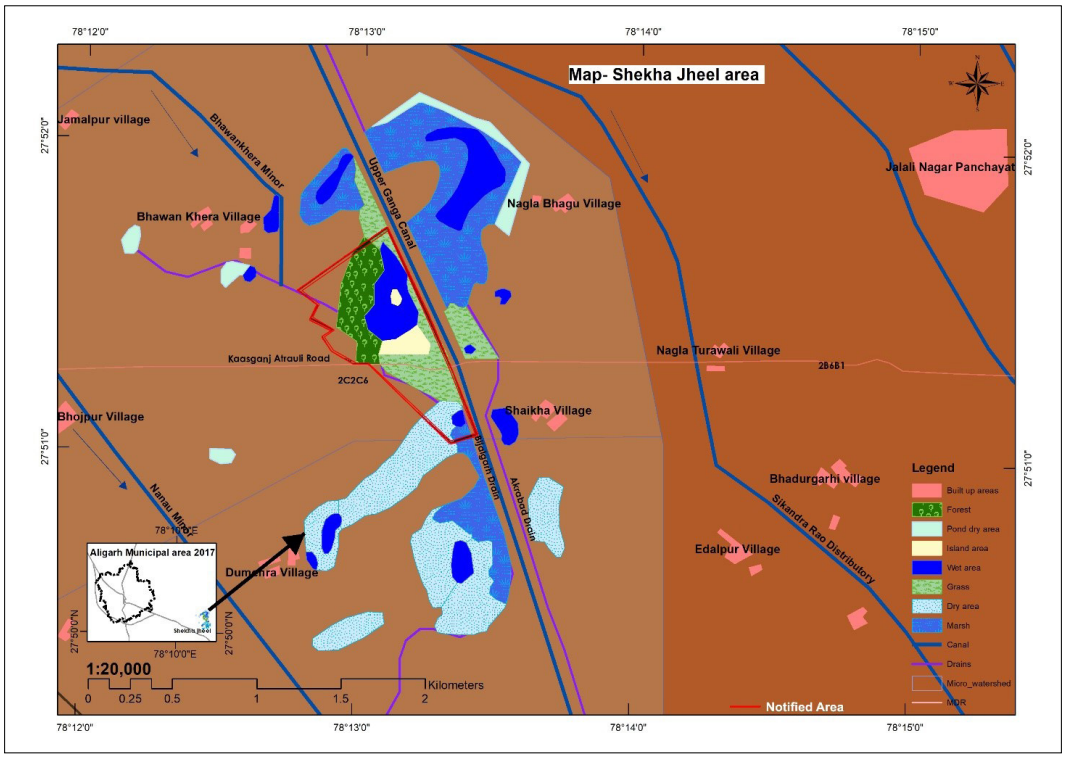
Figure 8: Shekha Jheel in Aligarh

Wetland Area | **Pathway to the Jheel** | **North-western part of the Wetland**

Source: Author, 2022

Grey Lag Goose, Black Buck, Sarus Crane, Greater Spotted Eagle, along with 166 other species which include residents and migratory birds were observed in the area (Bird life International, 2022). Black-necked stork and Wooly-necked stork are the major attractions of Shekha Jheel. The migratory birds follow the Central Asian Flyway route and arrive at this jheel every year. The density of Nilgais (Blue buck/Boselaphus tragocamelus) was maximum in and around the Shekha Jheel i.e., 132 individuals per sq km (Khan and Khan, 2016). The jheel is also recognized in the Wildlife and Eco Tourism Circuit (Western ornithology/Wetland circuit), as per the UP-Tourism policy of 2018. Rejuvenating Aligarh waterbodies of 2C2C6 watershed, will facilitate the rejuvenation of the jheel.

Map 7: Shekha Jheel and its Surroundings in Aligarh



Source: Author, 2022, Prepared from SOI, Primary survey 2022

The notified area of the jheel is almost one-third of the total area under the wetland (Primary survey, 2022). This is demarcated with a red boundary in Map 7. An integrated management plan has been prepared, which was not available in the public domain at the time of the study.

Threats to the wetland arise from grazing and firewood collection from the nearby villages of Shekha and Bhavan Kheda, from invasive alien species like Eichhornia Crassipes (aquatic plant) (Wetlands of India Portal, 2022), Lantana camara, Sida, Parthenium hysterophorus, and Cassia tora (Kalpavriksha, 2009) and agriculture practices during the dry season.

Besides provisioning, regulating, and supporting services for the residents of Shekha and Bhavan Kheda, the cultural ecosystem services rendered by the jheel for the residents of Aligarh is invaluable. It provides a space for residents to escape from the squalor of Aligarh. The findings of the tourist (42 No.) surveys indicated that 89 percent of the tourists were from the city of Aligarh. The reasons for their visit included bird watching for 19 (44%) tourists, picnic for 12 (27%) tourists, and leisure with friends for 17 (39%). Of these, 32 (72%) had a good experience. As per tourists, 24 (54%) felt that they can visit and enjoy the environment of Shekha Bird Sanctuary without much disturbance, as it is not crowded. Total 21 (51%) tourists found it to be a safe place. Only 3 percent visit the jheel regularly and 54 percent intend to visit again.

Strategies and Way Forward

Reclamation of the trilogy is a key element in achieving a resilient Aligarh and getting back the once famed *'aab-o-hawa'*. Authors suggest an integrated and multi-pronged approach that comprises regional level strategies, interventions at the Master Plan level, possible methods for rejuvenation of ponds and drains, finance options, and involvement of residents.

Regional Level Strategies and Benefit Sharing Solutions

Aligarh's water issues cannot be viewed in silo, rather they are embedded in the water region. It is critical to introduce policy and planning interventions for protection of water resources in the regional watershed of the Aligarh drain and other nallahs that pass through the city. While the central government laws, and Wetland (Conservation and Management) Rules, 2017, are applicable for the protection of Shekha Jheel, there is an absence of a potent law for protection of the urban waterbody in Uttar Pradesh. "Uttar Pradesh Pond Development, Protection and Conservation Authority Bill 2017 (Third Draft)" is yet to be enacted.

Authors suggest that the sizes of the ponds to be protected under this bill should be reduced from 0.5 hectare to 1000sqm. This will be more relevant in the urban context where smaller ponds are common and will allow more ponds to be taken up for rejuvenation. A portal (like the Wetland Portal of India) should be launched for the entire state to identify waterbodies/ponds. On such identification, they should be assigned a Unique Identification (UID) Number and steps should be taken for their restoration. Efforts should be made to bring land ownership of ponds under one agency. All the departments need to access the portal and they will need to provide a list along with details of the waterbodies apart from the listed ones on the portal.

Indian Easement Act, 1882 gives all rights to landowners to extract groundwater. Since water is a public trust, it is important to amend the said Act and enact the Indian Easements (amendment) Act, 2019, in which the use of water shall be regulated by the concerned Gram Sabha or the urban local body. The implementation of UP Ground Water (Management and Regulation) Act, 2019 should be strict and it should not allow any exemption for new developments in the state.

Spatial Interventions at Master Plan, Zonal, and Local Area Levels

If water features are included in a Master Plan (a statutory document), the area and the resources will be valued as an asset. It is important that the Master plan, zonal, and local area plans should have a water resource centric vision. Land use planning must consider the natural groundwater recharge areas. Since urban waterbodies receive not only the surface runoff from the immediate surroundings but many a times also through stormwater drains from far off areas. Thus, the completely modified catchment of the waterbody should be delineated and considered for the purpose of rejuvenation rather than just focusing on beautification of the waterbody.

Integration of blue-green infrastructure in the master planning process can enhance their utility and benefits, the way it has been done for Rotterdam, Amsterdam, Kochi, Madurai, etc. Strategies for rejuvenation of waterbodies should also be specific to the land use and the activities that they are located in.

Nature-based Practices for Urban Ponds, Drains, and Groundwater Recharge Enhancement

Nature-based Solutions (NbS) have several benefits and co-benefits and are fast gaining traction in the urban context, thus contributing substantially to circularity. A synergy is needed between the existing grey infrastructure and NbS for optimum results (Tsatsou, 2023). In the context of Aligarh, NbS can be introduced at all scales. For forests and wetlands at the regional scale, while for constructed wetlands, bioswales, rain gardens, floating wetlands etc at the urban scale. These would be instrumental in tackling the critical local issues of floods, polluted water etc.

All ponds should be properly managed, which includes regular removal of water hyacinths and breeding of non-invasive fish species that consume the mosquito larvae. Control of soil erosion through planting native vegetation may also be tried. Urban forests can be generated in suitable areas with natural depressions. Experiences can be drawn from case studies of Hauz Khas and Neela Hauz, Delhi, and the water plaza project at Rotterdam among others. Already, there is partial acceptance of these methods as one of the drains is currently undergoing phyto-remediation, but efforts need to be amplified.

Institutional and Regulatory

The definition of a pond needs to be decided and all agencies should follow that to avoid confusion. There is a need for a GIS-based waterbody mapping and inventory of ponds and drains. The UPPCB has to make sure that all ponds, waterbodies, and groundwater in various areas of the city are regularly monitored for water quality. For better management, capacity building exercises in the district administration, Municipal Corporation, the Forest department, and Irrigation department should be conducted on a regular basis. Land ownership for ponds and waterbodies ought to be centralised under one organization. Strict implementation of the UP GW (Management and Regulation) Act 2019 should be encouraged. Economic instruments such as volumetric pricing of domestic water and incentives for RWH could also be explored. UP Building Byelaws should be modified to facilitate dual piping systems for reuse of grey water and, also to work on the safe reuse of treated wastewater.

Financing Solutions

Water being a state subject, the restoration and rejuvenation of waterbodies is primarily the responsibility of the state government. Finance is available under various programmes and schemes such as the Mantri Krishi Sinchayee Yojana (PMKSY), Har Khet Ko Pani (HKKP), Jal Shakti Abhiyan: Catch The Rain, AMRUT 2.0, and Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGA).

Corporate Social Responsibility (CSR) is also a viable option for bringing funds. Besides, the CSR funds being utilised in a stand-alone manner, convergence with Mission Amrit Sarovar is also permitted.

Cultural/People Connect

People in Aligarh city need to be encouraged to think about drains as a component of a bigger river system rather than merely a place to dispose of garbage. Designing inclusive and secure green areas around waterbodies is important to change people's perceptions. Organizing *mohalla* meetings

and *Pani Sanrakhshan Samvaad* (Water conservation interactions) may be effective engagement strategies. Educational and various related institutions should be involved via adoption of a waterbody, while Corporate Social Responsibility (CSR) activities should be encouraged among the industries of Aligarh. Citizen science and '*Jan bhagidari*' (People participation) can also play a key role.

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Conflict of Interest

The authors declare no conflict of interest.

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Prioritizing 'Urban Drivers' Responsible for Pollution in Ganga River Basin and its Revival through Policy Framework and Effective Community Engagement

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Abstract

Rivers have always been the cradle of civilization as earlier settlements flourished along its flood plains that supported agriculture and farming activities. River Ganga has high socio-cultural value and is regarded as goddess by the people of India. Inspite of its sacredness, people have never hesitated to pollute it with anthropogenic activities. Even after undertaking many programs and missions to clean the river, it is still in a derelict state in many parts of the country. Various factors ('Drivers') lead to river pollution like effluent discharged from industries, urbanization, human anthropogenic activities, infrastructure development, inorganic farming, poor working of sewage treatment plants (STPs) etc.

In this research work these factors are termed 'Urban Drivers'. The research study has been divided into qualitative and quantitative analysis. Data from reports on river pollution by the Central Pollution Control Board (CPCB) has been analysed. In the absence of stakeholders' involvement to identify the critical drivers, the authorities face dilemma in budget allocations as to which must be addressed first. So, here an endeavour has been made to prioritize and rank these drivers by applying the Fuzzy Analytical Hierarchical Process technique by computing weights of the various drivers depending upon their criticalness. The results are compared with the Urban River Management Plan (URMP) of Kanpur and the underachieved objectives have been addressed.

For revival and achieving back the self-cleansing property of rivers, a dedicated policy framework for protecting the 'Riparian Zone' has been proposed. If the prototype of the proposed model is implemented on a larger scale the tangible and intangible issues would be resolved to a great extent as the proposals are within the domain of environment, social, and economic cohesion which are the three pillars of URMP.

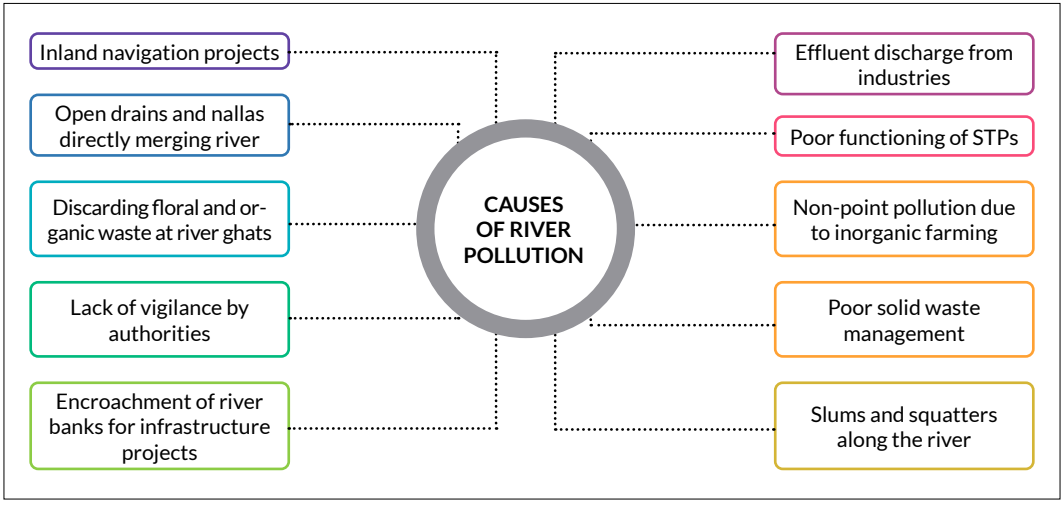
Keywords: Anthropogenic Activities, Riparian Zone, Urban Drivers, Urban River Management Plan

Introduction

India is drained by around 12 major river basins with a catchment area of about 2.5 million square kilometres. River ecosystems include flowing streams that drain the landscape, and feature biotic (living) interactions between plants, animals, and microorganisms, as well as abiotic (non-living) physical and chemical interactions between its many sections. River Ganga is in danger due to the increase of human intrusions. Ganga's quality is deteriorating at an alarming rate, despite various efforts to clean and revitalise the river. Due to an increase in anthropogenic activities the riverine ecosystem is at stake. This has led to the river turning into drains and its derelict state also needs to be tackled immediately (Khatri & Tyagi, 2015).

Causes responsible for its pollution include rapid urbanization, industrialization, infrastructure development, anthropogenic activities, lack of coordination among government entities to incorporate the launched policies, absence of stakeholders' involvement, inadequate policy vigilance, and aversion to the Public Private Partnership (PPP) model etc as depicted in Figure 1. As River Ganga passes through five states, the issues and levels of pollution vary from place to place. The Kanpur belt is one of the major industrial hubs in Uttar Pradesh. The leather tanning factories in Kanpur are the foremost sources of pollution of the river, and the Ministry of Environment, Forest and Climate Change has designated them as "Red Industries in India".

Figure 1: Causes of Pollution



By 2025, India's population is expected to exceed 1.4 billion, with 42.5 percent living in cities. The Ganga basin is the world's most densely populated river basin. The housing demand due to urbanization has resulted in the river fringe being encroached to accomplish it. Urbanization leads to deforestation and the soil becomes loose that ultimately leads to floods. As the states and cities compete for development, building barrages and dams results in the obstruction of continuous flow, which creates risk of the river being converted into a series of enormous ponds that destroys its natural and biological balance. The non-point sources of pollution i.e., fertilizers and pesticides run-off from the agriculture fields containing chemical residuals adds to the river pollution. The superstitious beliefs of people leads to disposal of floral offerings at the river ghats. Landfill sites gradually release their toxic components into the ground, thereby contaminating both the ground and the groundwater.

In recent years, many programmes and drives have been launched by the government to revitalise the Ganga basin, but not all have been completely successful. Each had some limitations and could not be accomplished entirely despite budget allocations. The need of the hour is to examine the existing policies, identify gaps, and bridge the gaps through effective stakeholder and community participation. This would aid in the development of new policies, revitalization of the Ganga River basin, and in the long run, the beneficial environmental impact will aid in the restoration of the degraded ecosystems that are caused by anthropogenic activities.

Due to an increase in anthropogenic activities the riverine ecosystem is at stake. This has led to the river turning into drains and the derelict state also needs to be tackled immediately. Due to pollution, the river has lost its self-cleansing capacity to assimilate and blend the biological waste (Dutta et al., 2020a). The environmental implications of this can result in the extinction of biodiversity and at a later stage impact human life in deleterious ways.

It is clear from the introduction that assessing the success and limitations of the earlier programmes initiated by the government for rejuvenating the river basin is vital as it will help in identifying the bottlenecks. Thus, developing strength–weakness–opportunities–threats (SWOT) matrix to derive policies and procuring the opinions of multiple stakeholders at all levels to suggest the best strategies for reaching the goals of reducing pollution, would be beneficial (Srinivas, Singh and Shankar, 2020).

Since the River Ganga Basin is divided into three segments, the issues and types of pollution threats differ from region to region as per the geographical terrains. Thus, identifying the factors which are responsible for the river degradation and applying techniques that give hierarchy to all the factors as per their criticalness would be advantageous in reaching the best possible solutions. The cities that have prepared their own Urban River Management Plan (URMP) will be assessed to check whether they adhere to the principles or not and will also give an insight to improve the underachieved objectives.

Research Methodology

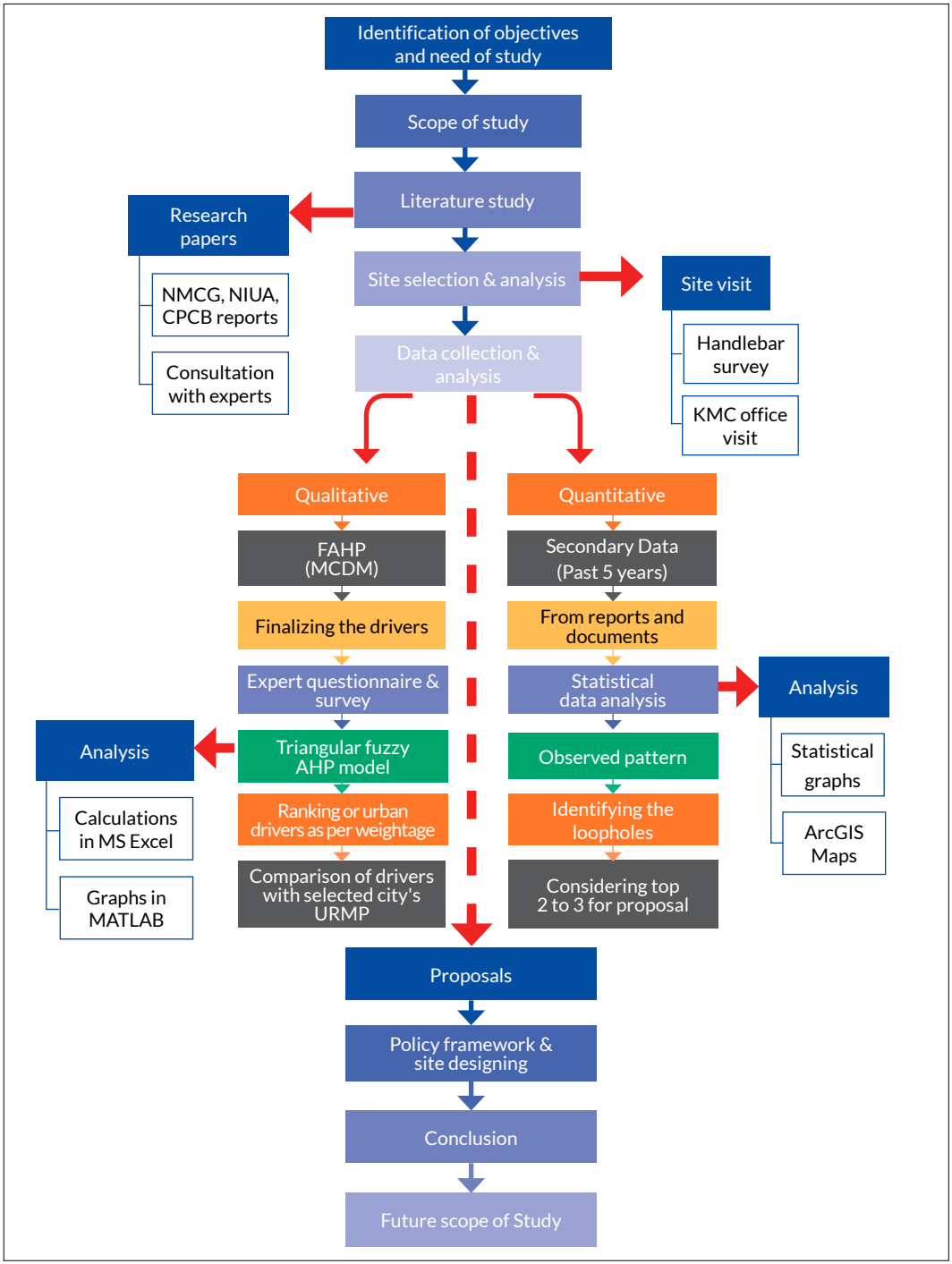
The entire research has been framed in two broad categories: Qualitative analysis and Quantitative analysis. The qualitative analysis comprises Fuzzy Analytic Hierarchy Process (FAHP) which is a multi-criteria decision-making technique (Srinivas et al., 2017). This can assist a decision-maker in making more efficient, adaptable, and realistic decisions that are based on the available criteria and alternatives by employing the FAHP approach. It provides a coherent framework for a needed decision by quantifying its criteria and alternative options and tying those parts to the broader purpose. For this, the polluting drivers were finalized from the literature study and then a comparative matrix questionnaire was prepared that was filled by experts from five different domains.

The domains pertained to experts who were closely associated with the agenda of river water pollution. An ensemble of academicians, environmentalists, research scholars, consultants, and policy makers were identified and were asked to fill the prepared questionnaire. Five experts from each domain with an experience of more than eight to ten years were chosen. Finally, FAHP was applied and the global weight of factors was calculated. The drivers were ranked as per their weightage. These were compared with the URMP of the selected site i.e., Kanpur that helped in the proposal formation of the underachieved objectives.

The quantitative part comprises data collection and analysis from primary and secondary sources. To study the existing condition of the ghats of River Ganga, a site visit to the Kanpur Municipal Corporation office and a handlebar survey was undertaken. The secondary data consists of the statistical data analysis of the annual reports (from 2017 to 2021) that were related to river pollution for the past five years which were taken from the National Mission for Clean Ganga (NMCG) and Central Pollution Control Board (CPCB). For better understanding of the ground scenario, Normalised Difference Vegetation Index (NDVI), and Normalised Difference Water Index (NDWI) maps were prepared and studied in ArcGIS. The NDVI and NDWI analysis was done using Landsat 7 imagery that was taken from USGS (United States Geological Survey) Earth Explorer. The bottleneck was identified and proposals were given for the same.

The crux of the methodology adopted is explained in Figure 2 and proposals were framed accordingly.

Figure 2: Methodology

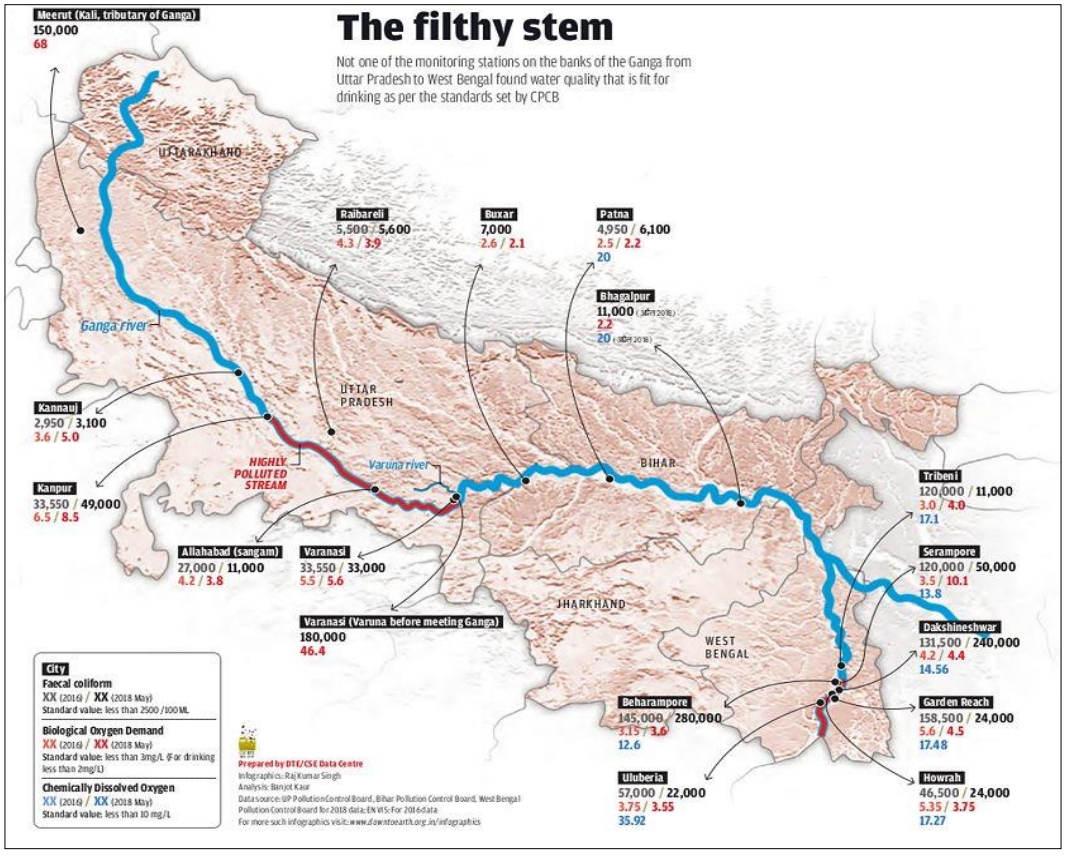


Context of the Site

Kanpur is the twelfth most populous city in India and second most in the state of Uttar Pradesh after Lucknow. It is bounded by the River Ganga on the northern side and River Pandu on the southern side. The city is considered the commercial capital of UP. It is an educational and economic hub which is famous for its leather and textile industries. Although these industries boost the economy of the city, they are also the main culprits behind the pollution of the river.

The water quality of any river is measured by six major factors that are its pH level, the Dissolved Oxygen level {D.O.(mg/l)}, the Biological Oxygen Demand {B.O.D.(mg/l)}, the Chemical Oxygen Demand{C.O.D.(mg/l)}, the total Coliform (M.P.N./100ml), and the Faecal Coliform (M.P.N./100ml). According to a report published by the Central Pollution Control Board in 2013 titled 'Pollution Assessment: River Ganga', the stretch from Kanpur to Varanasi has been declared as the most polluted due to the presence of leather industries and tanneries. (Pollution Assessment: River Ganga, 2013). As seen in Figure 3, the Faecal Coliform, and the Biological Oxygen Demand is the highest in Kanpur city and hence it has been chosen as the study area.

Figure 3: Pollution Content of Different Cities



Source: WordPress, Retrieved from https://flushitblog.wordpress.com.

Kanpur is situated on the banks of the Ganges, and as a result, it is home to various ghats, each with its own unique characteristics. In fact, the Bithoor region of Kanpur was originally known as "Bavan Ghaton ki Nagari" (City of 52 ghats). Many of these are religious ghats where people visit to take holy dip in the river on special occasions as well as to perform rituals. Some are crematoria ghats where both traditional (wooden logs) and electric cremation are adopted. Boating also exists at some of the ghats. But in spite of so many efforts the ghats are still not clean. Although many trash bins have been installed to discard the floral and organic waste but due to the unfathomable attitude and deep-rooted religious beliefs of the people, they continue to discard and immerse floral waste into the river.

Figure 4: Sarsaiya Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 1:04 pm

Sarsaiya is the most visited ghat of the city for religious purposes and during special occasions. It witnesses huge devotee footfalls for a holy dip in the river. As per the boatmen of the area, the depth of water is only around 4-5' in summer and reaches 25-30' in the rainy season.

Figure 5: Parmat Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 1:45 pm

The regretful state of the ghats in the city can be seen in Figures 4 and 5. Despite installing huge trash bins and providing vigilance by the 'Ganga Praharis' people still discard floral and other organic waste in the river. Not only organic but plastic waste is also found near the river beds and

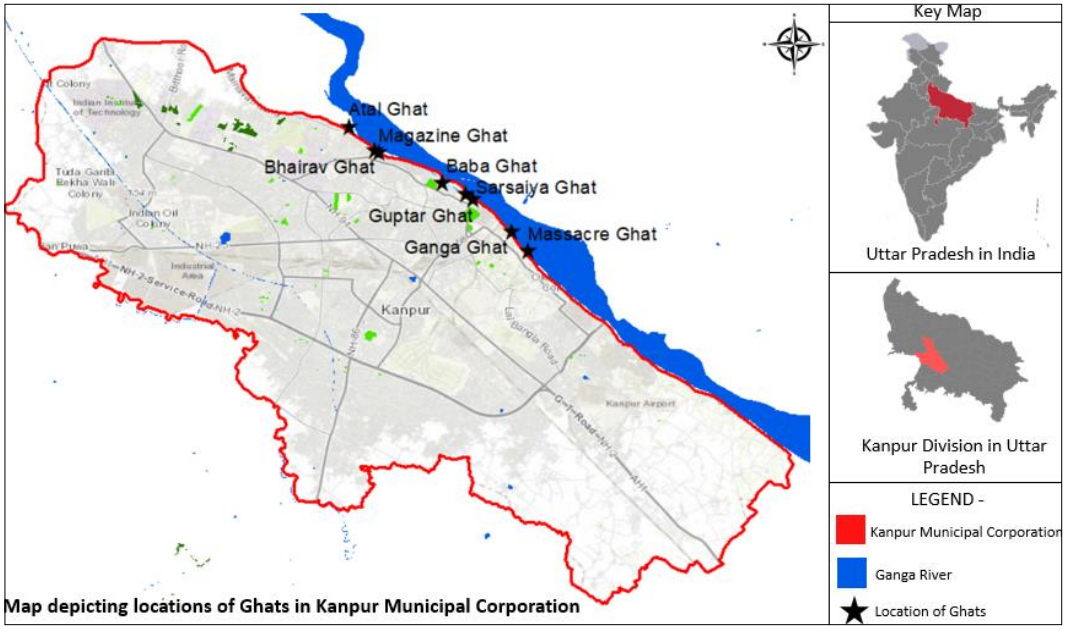
as you all are aware, plastic litter is a serious menace to the water bodies. The most visible impact of plastic debris is the ingestion, suffocation, and entanglement of hundreds of marine species.

Figure 6: Tapping Station at Guptar Ghat, Kanpur

Source: Author, Date 22-05-2022, Time 2:12 pm

To tap and divert the river's flow to the nearest STPs, 'Nallah' tapping stations have been constructed near the river ghats. Guptar Ghat Nallah Tapping Station can be seen in Figure 6. The right-side image shows the dry drain after this station. It flows only during the rainy season, thus carrying storm water with it.

Figure 7: Ghats of Kanpur



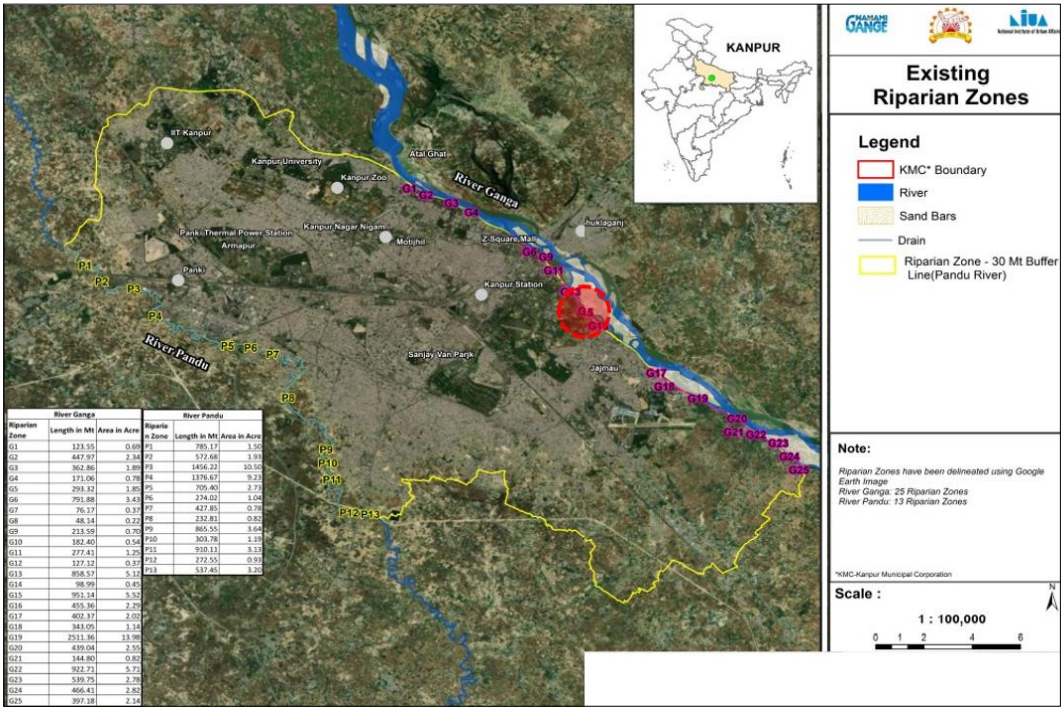
Map depicting locations of Ghats in Kanpur Municipal Corporation

Source: Primary Survey, 2022, Kanpur Boundary: https://extract.bbbike.org/

Figure 8: Selected Site

Source: Google Earth (https://earth.google.com)

Figure 9: Riparian Zones Declared by Kanpur Municipal Corporation



Source: Kanpur Urban River Management Plan (Uttar Pradesh, n.d.)

The Kanpur Municipal Corporation has earmarked 25 Riparian zones along the River Ganga and 13 Riparian zones along the River Pandu. Their length in meters and their area in sq km has been defined and development of the Riparian zones has been proposed for these places. The selected site is 625m in length and 325m in width. Out of the 25 identified sites, this is site number G15. Figure 9 highlights the selected sites:

Data Analysis

Data analysis has been divided into two parts - quantitative and qualitative. Qualitative data analysis is based on the results obtained through the expert questionnaire. Fuzzy Analytic Hierarchy Process (FAHP), a Multi Criteria Decision Making (MCDM) technique has been applied. The quantitative analysis consists of data that is collected from primary and secondary sources; this includes quantifiable data that can be statistically analysed. The quantitative part comprises of data that is collected from the annual reports of Central Pollution Control Board, National Mission for Clean Ganga, Ministry of Jal Shakti etc. This includes point and non-point source pollution data of all the five states (Uttarakhand, Uttar Pradesh, Jharkhand, Bihar, West Bengal). This data has been analysed for the past five years and a pattern has been observed for the various factors that lead to river pollution.

Qualitative Data Analysis

The qualitative data comprises factors that lead to pollution and calculating their weights as per the expert questionnaire. Around thirty research papers were referred to finalize the polluting factors. Based on the literature review, total twenty-six factors were identified that lead to pollution and these were clubbed under seven major heads:

Table 1: Finalized Main Drivers and Sub Drivers

Sr. No.	Main Driver	Main Driver Code	Sub-Driver	Sub-Driver Code
1	Urbanization	M1	Exponential population growth leads to over withdrawal of surface & ground water	U1
2			Lack of awareness among people regarding waste disposal	U2
3			Human greed to over exploit water resources on upstream river	U3
4			Competitive development amongst states along or on the river catchment	U4
5	Industrial Inventorization	M2	Direct or partially treated effluent discharge from industries	I1
6			Rapid increase in the number of GPIs	I2
7			Dumping of hazardous industrial waste near water bodies	I3

Sr. No.	Main Driver	Main Driver Code	Sub-Driver	Sub-Driver Code
8	Anthropogenic Activities	M3	Slums & squatters	A1
9			Superstitious nature of people	A2
10			Partially or untreated municipal sewage discharge in rivers	A3
11			Landfill sites located near the water bodies	A4
12	Governance and Finance	M4	Lack of priority, vision, and mission	G1
13			Dearth of dispute resolving mechanisms	G2
14			Lack of know-how and poor tech-savvy level of the Government	G3
15			Insufficient funds	G4
16	Enforcement	M5	Meagre state of regulations & policies to safeguard rivers	E1
17			Poor surveillance by authorities	E2
18			Leniency in taking actions against GPIs	E3
19			Interoperability of laws amongst various states	E4
20	Artificial Jeopardies	M6	Intensive use of fertilizers & pesticides	AJ1
21			Deforestation leading to soil erosion	AJ2
22			Poor working of STPs	AJ3
23			Polluted stormwater drainage, nallas & tributaries getting merged with the river	AJ4
24	Infrastructure Development	M7	Hydropower & barrage projects	ID1
25			Construction projects leading to either flooding or drying of local water bodies	ID2
26			Riverfront projects degrade riverine ecosystem & changes in LULC (Land Use Land Cover)	ID3

The ensemble of experts was from different domains like environmentalists, researchers, academicians, policy makers, and consultants. Depending upon their professions and the types of work they handled, their views differed on which factors are more responsible for river pollution. Fetching all under one umbrella would be beneficial as issues would then be addressed from a holistic perception. Here the sample size is 11, experts from each domain filled the questionnaire.

The average of all the final weights was taken and the top ten have been listed in Table 2.

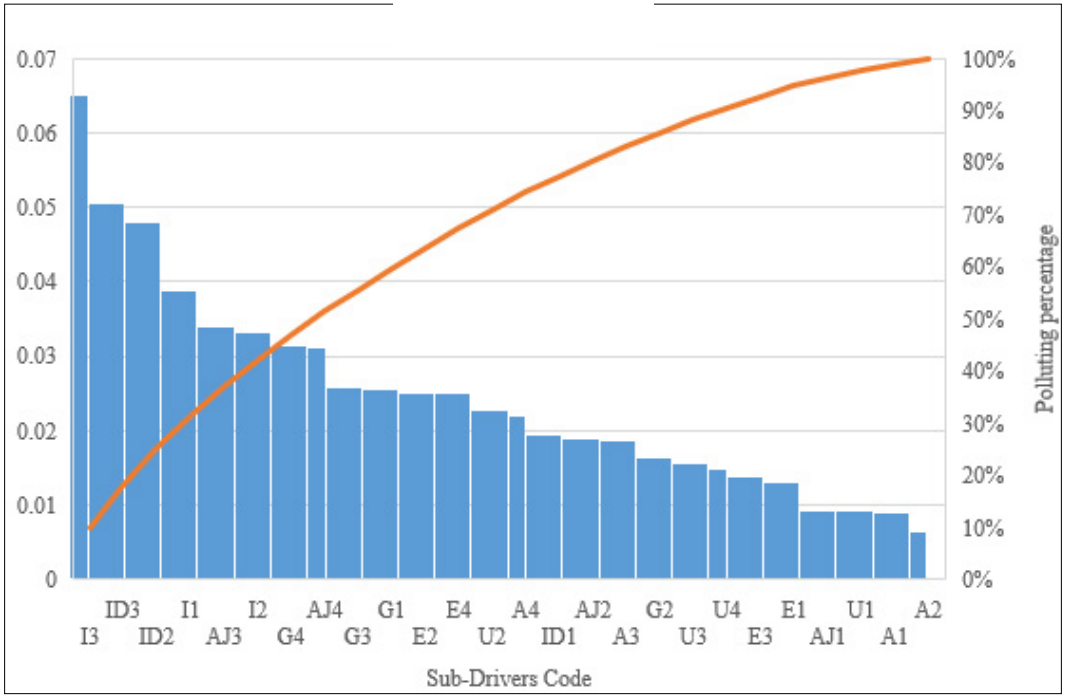
Table 2: Final Ranking of Drivers

Sr. No.	Main Driver	Main Driver Code	Sub Driver	Sub-Driver Code	Final Weight (Geometric Mean)	Ranking
1	Infrastructure Development	M7	Riverfront projects degrade riverine ecosystem & changes in LULC	ID3	0.0880	1
2	Infrastructure Development	M7	Construction projects lead to either flooding or drying of local water bodies	ID4	0.0771	2
3	Industrial Inventorization	M2	Dumping of hazardous industrial waste near water bodies	I3	0.0688	3
4	Enforcement	M5	Interoperability of laws amongst various states	E4	0.0563	4
5	Governance and Finance	M4	Insufficient funds	G4	0.0543	5
6	Industrial Inventorization	M2	Direct or partially treated effluent discharge from industries	I1	0.0537	6
7	Industrial Inventorization	M2	Rapid increase in the number of GPIs	I2	0.0525	7
8	Enforcement	M5	Poor surveillance by authorities	E2	0.0523	8
9	Governance and Finance	M4	Lack of know-how and poor tech-savvy level of the Government	G3	0.0496	9
10	Artificial Jeopardies	M6	Polluted stormwater drainage, nallas & tributaries getting merged with the river	AJ4	0.0458	10

Source: Primary Survey, 2022 (Based on FAHP)

As per the results of the calculated global weights of all the drivers, Urbanization (M) is the only Main Driver that was the least responsible for river pollution. Hence, it is not included in the top ten most polluting drivers.

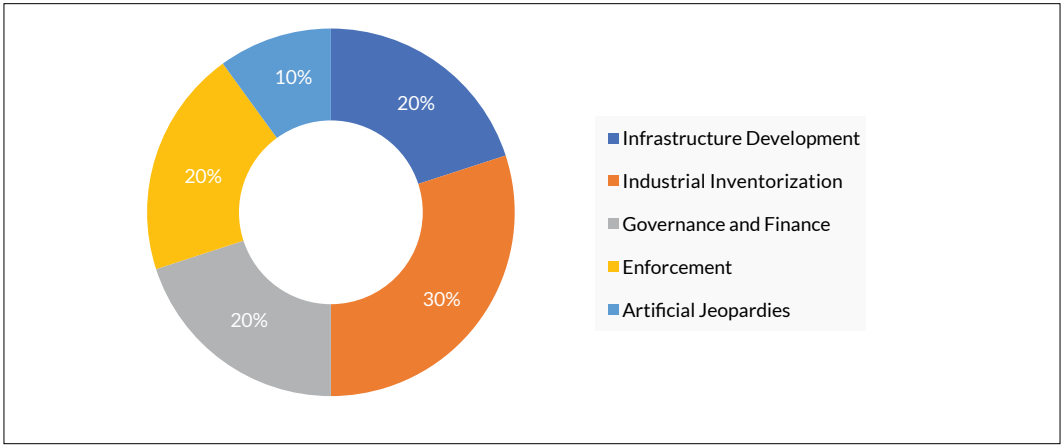
Figure 10: Ranking of Drivers



Source: Primary Survey, 2022

As concluded from the table and graph in Figure 10, the highest weightage is 0.088 for Riverfront projects that degrade the riparian buffer and riverine ecosystem. According to the results, Construction projects that lead to either flooding or drying of local water bodies are the second most polluting factor with 0.0771 weightage. Dumping of hazardous industrial waste near water bodies has 0.0688 weightage with third rank. Interoperability of laws amongst various states has fourth rank with 0.0563 weightage. The drivers with more weightage and towards the left side of 50% of the pareto line are more critical and need to be addressed. The top eight drivers from where the pareto line crosses the histogram are termed as critical and must be tackled. Thus, the top ten polluting drivers are from Infrastructure Development, Industrial Inventorization, and Enforcement and Government-the Finance aspect.

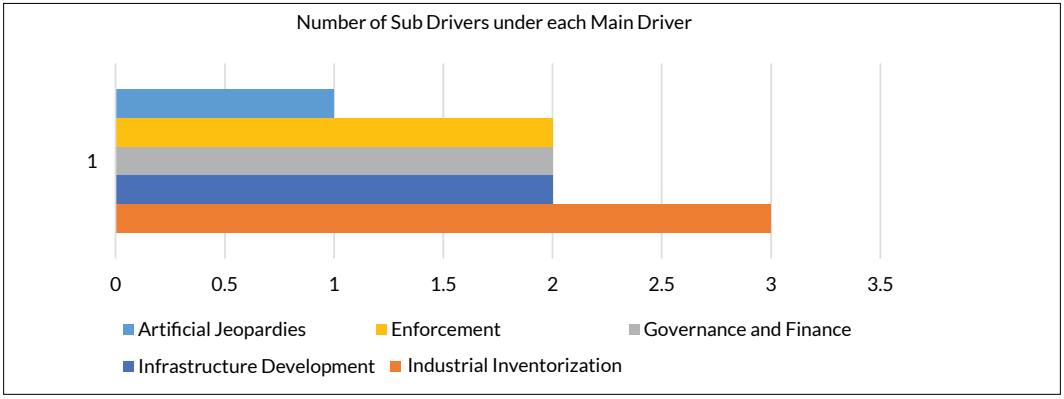
Figure 11: Main Drivers



Source: Primary Survey, 2022

According to the expert's opinions and after removing the fuzziness from their responses, the above-mentioned Main Drivers as shown in Figure 11 were the major contributors that were responsible for river pollution.

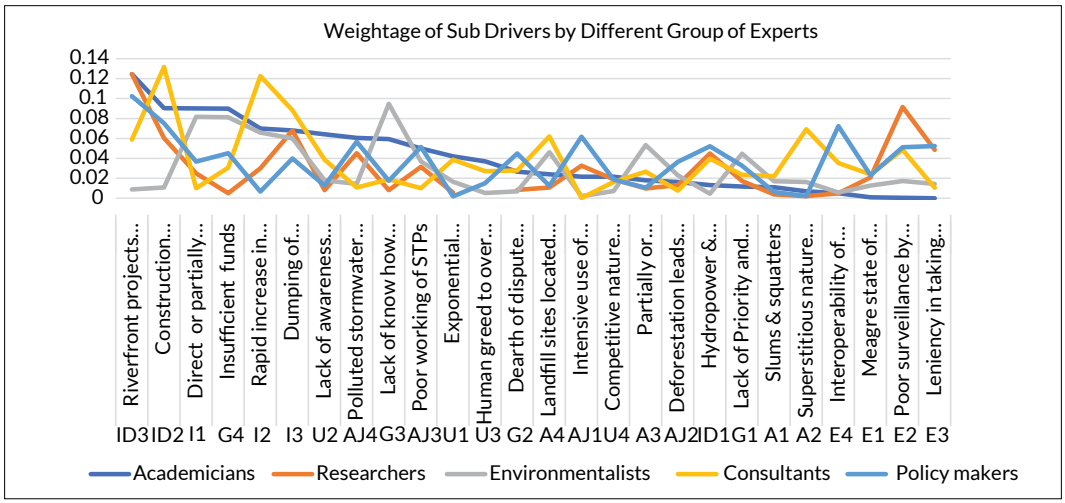
Figure 12: Sub Drivers



Source: Author Primary Survey, 2022

Three drivers are under Industrial Inventorization, followed by Infrastructure Development, and Enforcement and Government-Finance which has two drivers from each head, respectively. Artificial Jeopardies has one driver as depicted in Figure 12.

Figure 13: Opinion of All Stakeholders



Source: Primary Survey, 2022

Figure 13 shows the global weightage of all the drivers as concluded by the responses of all the experts. It is observed that most of the experts gave critical polluting status to following drivers; (Refer Table 1 and 2 for the list or Sub-drivers and the most polluting drivers, respectively).

- Riverfront infrastructure projects degrade riverine ecosystem & changes in LULC
- Construction projects lead to either flooding or drying of local water bodies
- Direct or partially treated effluent discharge from industries
- Rapid increase in the number of GPIs
- Superstitious nature of people

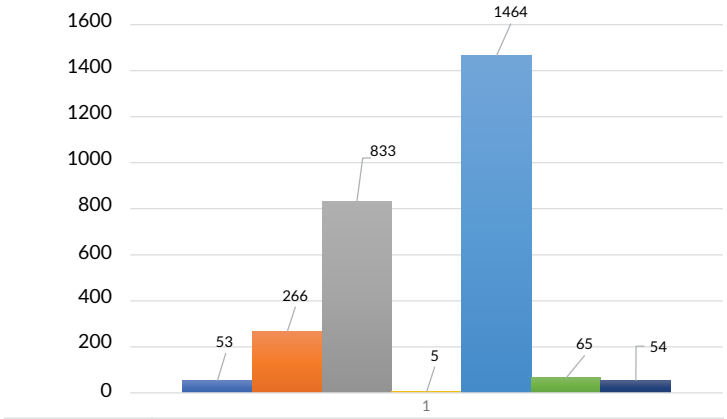
Quantitative Analysis

Industrialization

Industries discharge their chemical wastes in rivers, lakes, and streams that comprise of substances called effluents. Sometimes, factories turn waterbodies into open sewers by dumping oil, toxic chemicals, and other harmful liquids called effluents into them. The industries that discharge more than 100 KLD of wastewater or hazardous chemicals into the water bodies are termed as Grossly Polluting Industries (GPIs). Pulp and paper mills, distilleries, sugar mills, textile units, tanneries, thermal power plants, the food, dairy and beverage industries, chemical units, slaughterhouses, etc. come under the category of GPIs (Srinivas & Singh, 2018).

The GPI data shown in Figure 14 for the year 2020-2021 has been acquired from the CPCB website. In this, along with the mainstream river, industries that lie along the tributaries of the River Ganga have also been considered. In other words, all industries along the GRB (Ganga River Basin) have been considered.

Figure 14: State-wise Number of Grossly Polluting Industries



Bihar	53
Delhi	266
Haryana	833
Jharkhand	5
Uttar Pradesh	1464
Uttarakhand	65
West Bengal	54

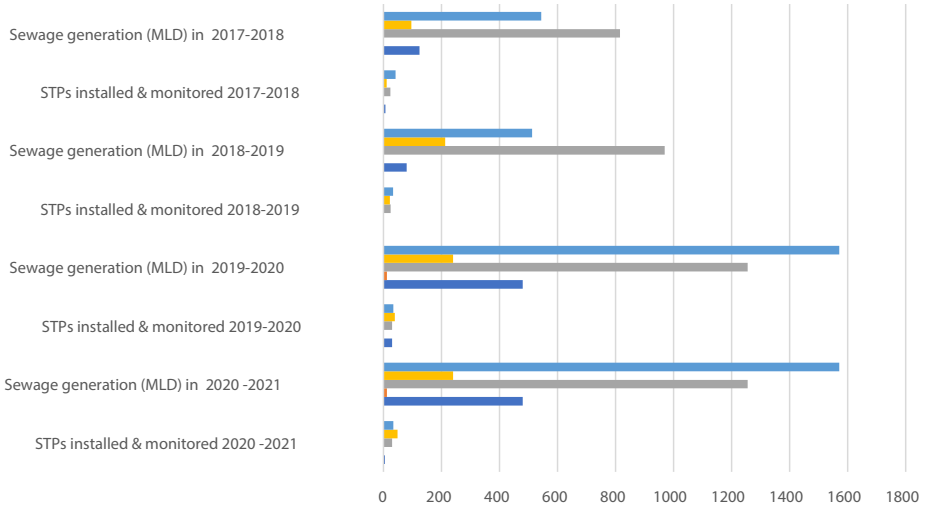
Source: Data compiled by author from NMCG Annual Report, 2016-17

Uttar Pradesh has the highest number of Grossly Polluting Industries (GPIs) which is 53.43% of the total number of industries. Jharkhand contributes the least i.e., 0.18% of the total industries. Kanpur has the highest number of textile industries and tanneries and both these are major contributors to river pollution. According to studies, the stretch from Kannauj to Kanpur has been declared the most polluted stretch and hence this site was chosen. Kanpur – Unnao region is amongst the largest industrial hubs of GRB where various industries exist (Chaudhary & Walker, 2019).

Anthropogenic Activities

These include impact due to agriculture activities, and inorganic farming practices. In urban and rural areas, the water quality gets affected by both point and non-point sources of pollution. Many Sewage Treatment Plants (STPs) are in poor working conditions and in some cases their potential is not fully utilized. Slums & squatters located near water bodies directly discharge their domestic waste into the river but this does not affect much as compared to other factors because by the time such waste enters the river, their level of toxicity decreases. Superstitious nature of people leads to direct discharge of floral, organic waste, mass bathing, and crematorium activities at river ghats.

Figure 15: STPs and Sewage Generation



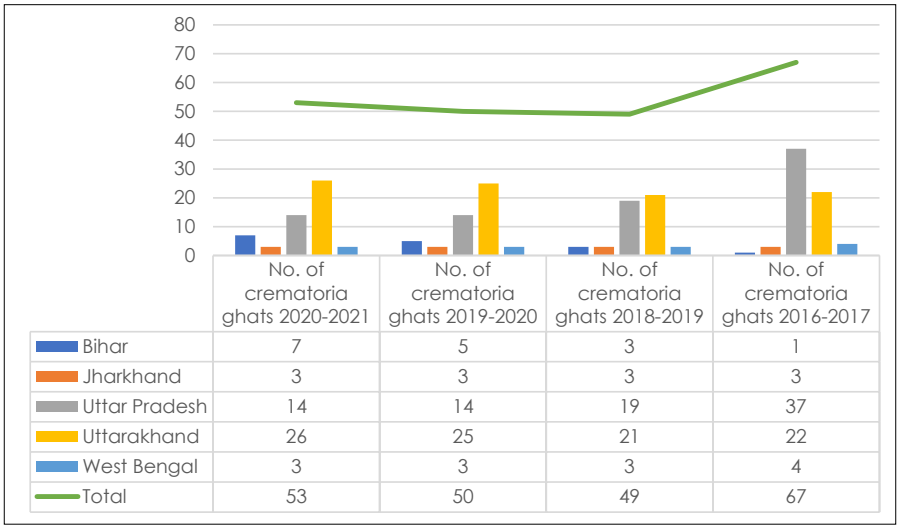
	STPs installed & monitored 2020 -2021	Sewagegen-eration (MLD) in 2020 -2021	STPs installed & monitored 2019-2020	Sewagegen-eration (MLD) in2019-2020	STPs installed & monitored 2018-2019	Sewagegen-eration (MLD) in 2018-2019	STPs installed &monitored 2017-2018	Sewagen (MLD) in2017-2018 STPsinstalled &monitored 2017- 2018
West Bengal	34	1571.5	34	1571.5	33	512.15	42	544
Uttarakhand	49	239.8	39	239.8	22	213.07	11	96
Uttar Pradesh	30	1255.2	30	1255.2	25	969.26	24	815
Jharkhand	2	12	0	12	0	0	0	0
Bihar	5	480	30	480	2	80	7	124

Source: Data compiled by author from NMCG Annual Report, 2016-17; Annual Report, 2020-21; Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

As per the 2021 report, Uttarakhand has the highest number of installed and monitored STPs but the flow in MLD is less as compared to other states. West Bengal has the highest sewage generation, 44.16% of the total discharge from the year 2018 to 2021. Although the number of STPs have decreased in this state but sewage generation has increased. The State-wise data is depicted in Figure 15.

Figure 16 depicts the State-wise number of crematoria ghats and Figure 17 depicts the number of religious ghats along the River Ganga as per the Annual Report, 2020-21, National Mission for Clean Ganga.

Figure 16: Crematoria Ghats



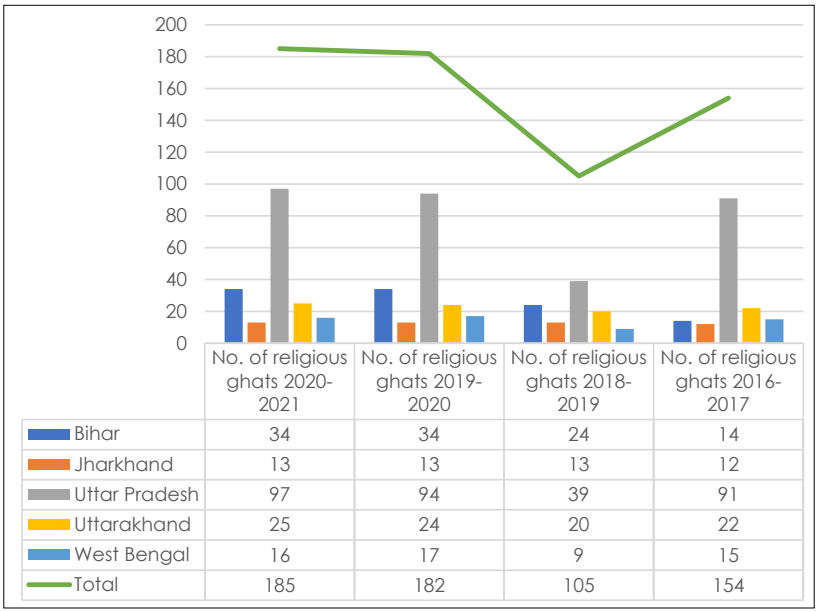
	No. of crematoria ghats 2020-2021	No. of crematoria ghats 2019-2020	No. of crematoria ghats 2018-2019	No. of crematoria ghats 2016-2017
Bihar	7	5	3	1
Jharkhand	3	3	3	3
Uttar Pradesh	14	14	19	37
Uttarakhand	26	25	21	22
West Bengal	3	3	3	4
Total	53	50	49	67

Source: Data compiled by author from the Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

According to the reports, Uttar Pradesh had the highest number of crematoria ghats in the year 2016-2017. In the Year 2020-2021, Uttarakhand had the highest number of crematoria ghats. Year 2018-2019 saw a downfall in the number of crematoria ghats for all states. Many states developed and shifted to electric crematoriums so the number of crematoria ghats decreased from 2016 to 2021. State-wise the number of religious ghats along the River Ganga also decreased as per the CPCB report.

According to a paper, Uttar Pradesh has the highest number of religious ghats which is 53.42% of the total (Journal et al., 2018). The year 2018-2019 saw a downfall in the number of religious ghats for all states. Many new ghats across various states have been developed and some old dilapidated ones have been restored so the year 2021 witnessed the highest number of religious ghats.

Figure 17: Religious Ghats



	No. of religious ghats 2020-2021	No. of religious ghats 2019-2020	No. of religious ghats 2018-2019	No. of religious ghats 2016-2017
Bihar	34	34	24	14
Jharkhand	13	13	13	12
Uttar Pradesh	97	94	39	91
Uttarakhand	25	24	20	22
West Bengal	16	17	9	15
Total	185	182	105	154

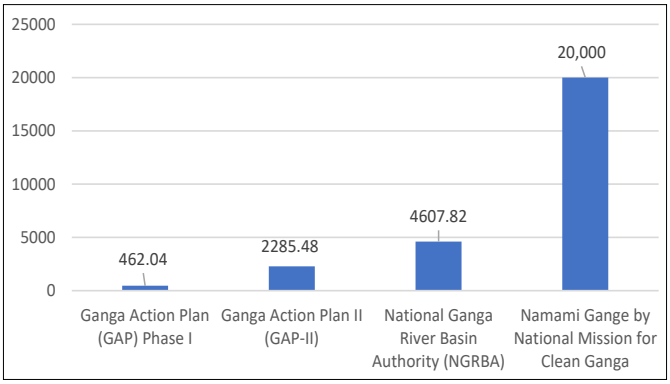
Source: Data compiled by author from the Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

Governance and Finance

Over the past 40 years many projects and programs have been launched by the Government of India, to clean the River Ganga. The first pollution abatement plan, Ganga Action Plan (GAP) was launched in 1985 after a comprehensive survey was conducted by the Central Pollution Control Board (CPCB) (Deekshit, n.d.). The studies conducted by the CPCB indicated that most of the pollution is derived from municipal waste and industrial effluent.

Figure 18 shows the budget/funds allotted for various Ganga cleaning missions under different programs. The budget has increased exponentially over a period of time. The cost shown in the graph is in crores.

Figure 18: Budget Allotted (In Crores INR)



Source: Data compiled by author (Deekshit, n.d.)

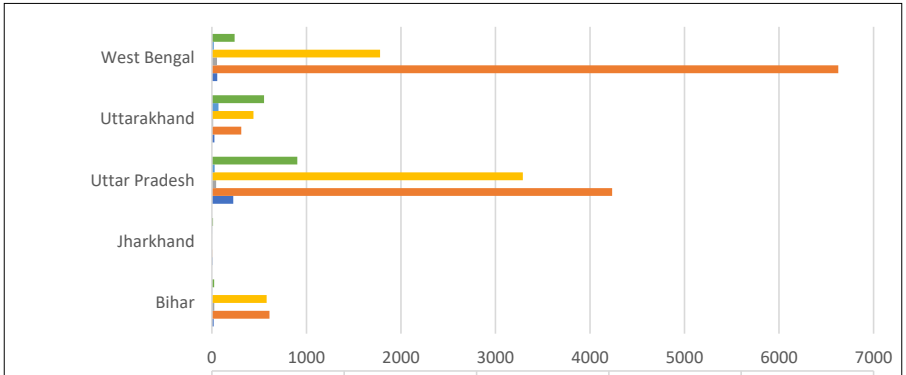
Table 3: Various Schemes to clean River Ganga

Sr. No.	Name of Scheme	Period	Budget Allotted (Rs crores)	Unbridged Gaps
1.	Ganga Action Plan (GAP) Phase I	1985 – 2000	462.04	• The emphasis was limited to the expansion of wastewater treatment facilities. • Technologies used for sewage treatment did not meet the standards for suitability and efficiency. • Absence of water resource management, conservation, and prudent use measures. • Lack of broad knowledge, public participation, and participation by numerous stakeholders (Dutta et al., 2020)
2.	Ganga Action Plan II (GAP-II)	1993 - 1999	2285.48	• Lack of adequate budgetary allocations and resources for operations and maintenance of wastewater treatment facilities resulted in the primary focus on engineering-centric approach, no focus on ecological entities of the river, and a lack of cooperation between federal, state, and local governments.
3.	National Ganga River Basin Authority (NGRBA)	February 2009 – September 2016	4607.82	• It was not possible to integrate the ecological fluxes in Ganga and its tributaries into the basin. • The environment management strategy for the entire Basin neglected to take into account the large and small tributaries. • Lack of long-term involvement of municipal and planning authorities.
4.	Namami Gange by National Mission for Clean Ganga	12 August 2011 – 7 October 2016 (continuing since 2014)	20,000	• Insufficient policy and legal framework • Lack of coordination across diverse riparian states • Decreased emphasis on the river's ecological and geological integrity • Smaller Ganga tributaries have not been added. • Environmental flow allocations are suboptimal industrial pollution control. (Dutta et al., 2020)

Artificial Jeopardies

The ongoing agricultural practices in the Northwest Indo-Ganga Plain (NWIGP) which includes Punjab, Haryana, and western Uttar Pradesh are not sustainable under the current scenario of environmental and agricultural change. Compaction prevents the soil from being able to hold more water and concentrate water flow therefore, it speeds up the flow of water on the soil's surface. This in turn increases the volume and speed of water that is flowing into the waterways and heightens the risk of flooding.

Figure 19: Drains Discharging into River Ganga

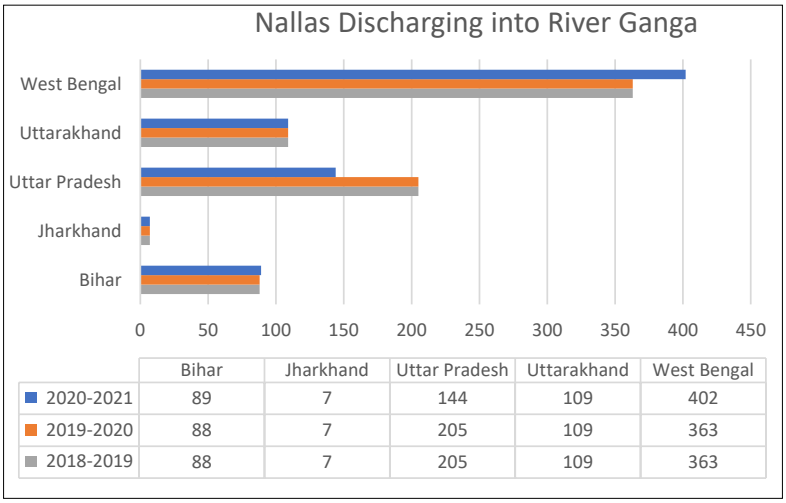


	Bihar	Jharkhand	Uttar Pradesh	Uttarakhand	West Bengal
Total Flow (MLD) 2019	24	12	903	552	240
No. of Drains in 2019	3	1	29	69	20
Total Flow (MLD) 2020	579	0	3289	440	1779
No. of Drains in 2020	25	0	45	14	54
Total Flow (MLD) 2021	609.48	2.89	4234.63	310.3	6627.45
No. of Drains in 2021	19	6	226	27	56

Source: Data compiled by author from Status of Post-Monsoon 2021 Monitored Drains Discharging into River Ganga and its Tributaries (Banganga Ramganga, Kali-East, Pandu, Etc.), Retrieved from https://cpcb.nic.in/ngrba/Drains-Post-Monsoon-2021.pdf

The number of drains discharging into the River Ganga have increased from 2019 to 2021 followed by an increase in flow (in MLD). For the year 2021, Uttar Pradesh had the highest number of drains, 226 which is 67.66% of the total. It is alarming to note that the number of drains in this state have increased five times as compared to the year 2020 that had just 45 drains. West Bengal is discharging 6627.45 MLD of sewage in spite of having 56 drains. This is 56.23% of the total discharge. From the year 2019 to 2021 the sewage discharge has increased 6.80 times which is quite disturbing. In spite of launching so many programs and budget allocations the situation is not in control and open drains continue to pollute the river. The state-wise number of drains with flow in MLD is depicted in Figure 19. The number of nallas directly getting discharged into the river is shown in Figure 20.

Figure 20: Nallas Discharging into River Ganga



	Bihar	Jharkhand	Uttar Pradesh	Uttarakhand	West Bengal
2020-2021	89	7	144	109	402
2019-2020	88	7	205	109	363
2018-2019	88	7	205	109	363

Source: Data compiled by author Annual Report 2020-21, National Mission for Clean Ganga, Department of Water Resources, River Development and Ganga Rejuvenation, Ministry of Jal Shakti, Government of India

West Bengal is the major contributor of river pollution as it has the highest number of nallas i.e., 53.52% of the total for the year 2021. From the year 2018 to 2021, the number of nallas has decreased in Uttar Pradesh whereas it remained constant or had increased in other states. The overall number of nallas has decreased from 772 to 751 for the year 2018 to 2021. So, 21 nallas were either shut down or trapped which is a significant change.

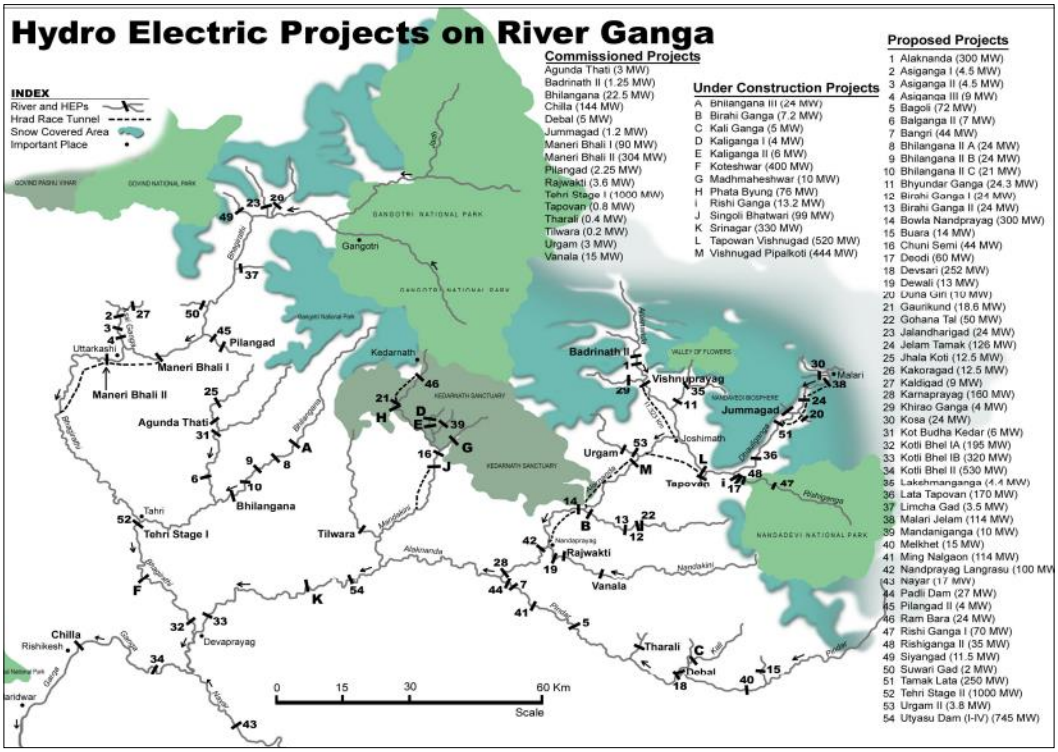
Infrastructure Development

Modifications in the river system of the Upper Ganga segment have occurred due to the construction of Run of the River and Run of the River with Ponding (ROR + RORP) Hydro-Electric Projects. Implementation of these projects have resulted in significant alterations in hourly, daily, and seasonal flows over a substantial river length. Figure 21 depicts the number of Hydro Electric Projects on River Ganga.

Consequences of these projects include:

- Area near such plants suspected to undergo decline of forest cover.
- Frequent landslides.
- Release of greenhouse gases.
- Drying up of natural water resources.
- Moderation in local climate.
- River ecosystem under stress.

Figure 21: Distribution of Hydro Electric Projects on River Ganga



Source: National Ganga River Basin Project (Prasad et al., 2021)

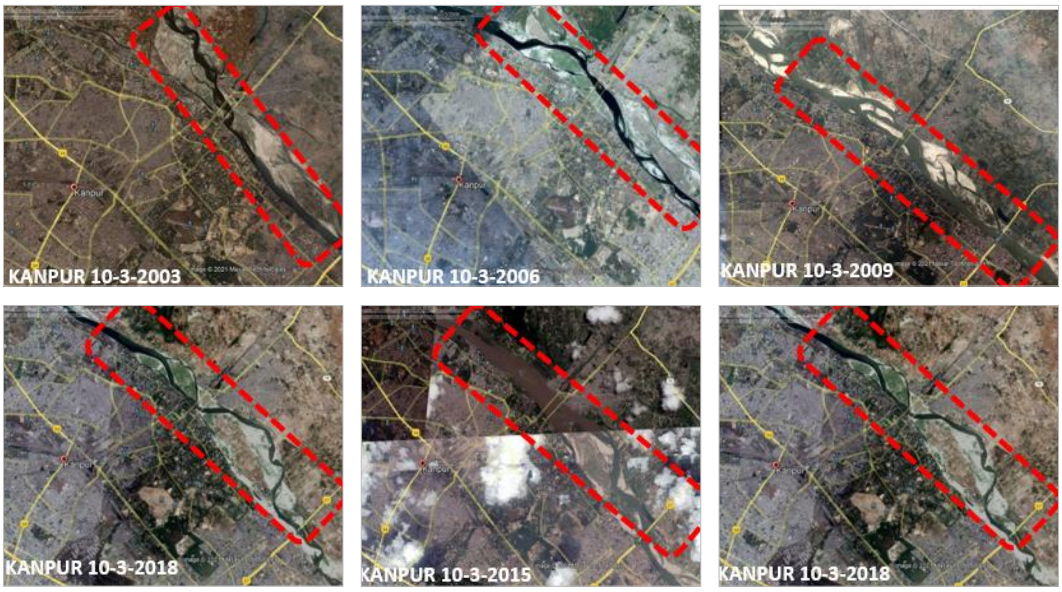
Flow Alteration

A change in flow regime is a major threat to the sustainability of a river's health and its ecosystem services. Increasing water extraction for agriculture, urban, and industrial use severely alters the hydrology in major river basins of the world. The GRB is one of the most vulnerable river basins in the world due to the combined effects of climate changes and development pressures in terms of construction of dams. Alteration of flow regimes in the Ganga basin due to large dams negatively affects the endangered species such as the Ganga River dolphin. Diversion of water for irrigation through canals also reduces the flow of the Ganga. Flow decline in River Ganga during non-monsoon period is a main problem. More than 80% of the annual flow in this river occurs during monsoon which causes widespread flooding.

The satellite imagery of the Ganga River flowing along Kanpur has been studied. The width of the river basin has shrunk and will continue to shrink due to flow alteration. Its direction of flow and colour has changed due to heavy metal discharge from effluent of industries that surround Kanpur city.

There is a change in the ecological flow of the river as visible in the satellite images in Figure 22. The satellite imagery with a three years gap shows the drift in the flow of water. There is a shift in the direction of the river and many sand bars are also visible, which shows that the basin is shrinking and the water is depleting. Due to this, a problem in the ecological flow of the river is observed.

Figure 22: E-flow Alteration in Kanpur

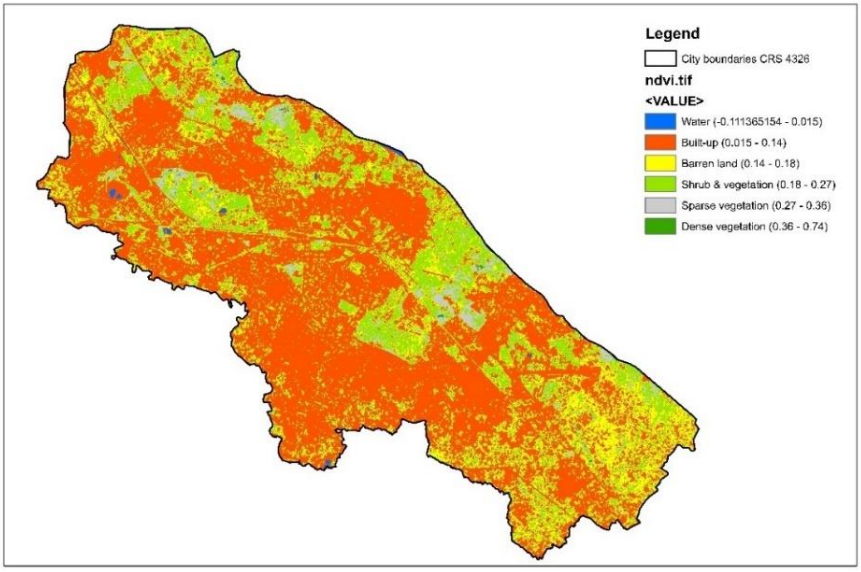


Source: Google Earth (https://earth.google.com/)

Normalized Difference Vegetation Index (NDVI)

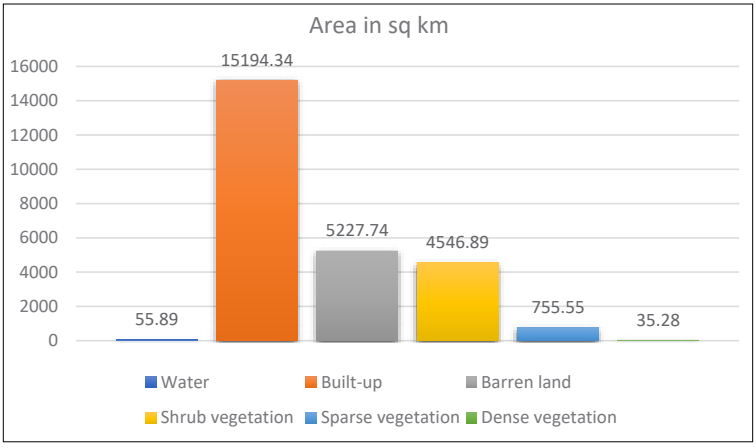
NDVI stands for Normalized Difference Vegetation Index. The near-infrared and visible light reflected from vegetation is used by the NDVI to remotely detect and quantify the presence of live green vegetation health and land use. For the most part, the NDVI measures how healthy and dense the vegetation is in a given pixel of a satellite image. When analysing remote sensing data, NDVI is used to determine whether the target under observation has live, green vegetation that is capable of photosynthesis.

Figure 23: NDVI of Kanpur



Source: Author

Figure 24: NDVI Area of Kanpur Municipal Corporation



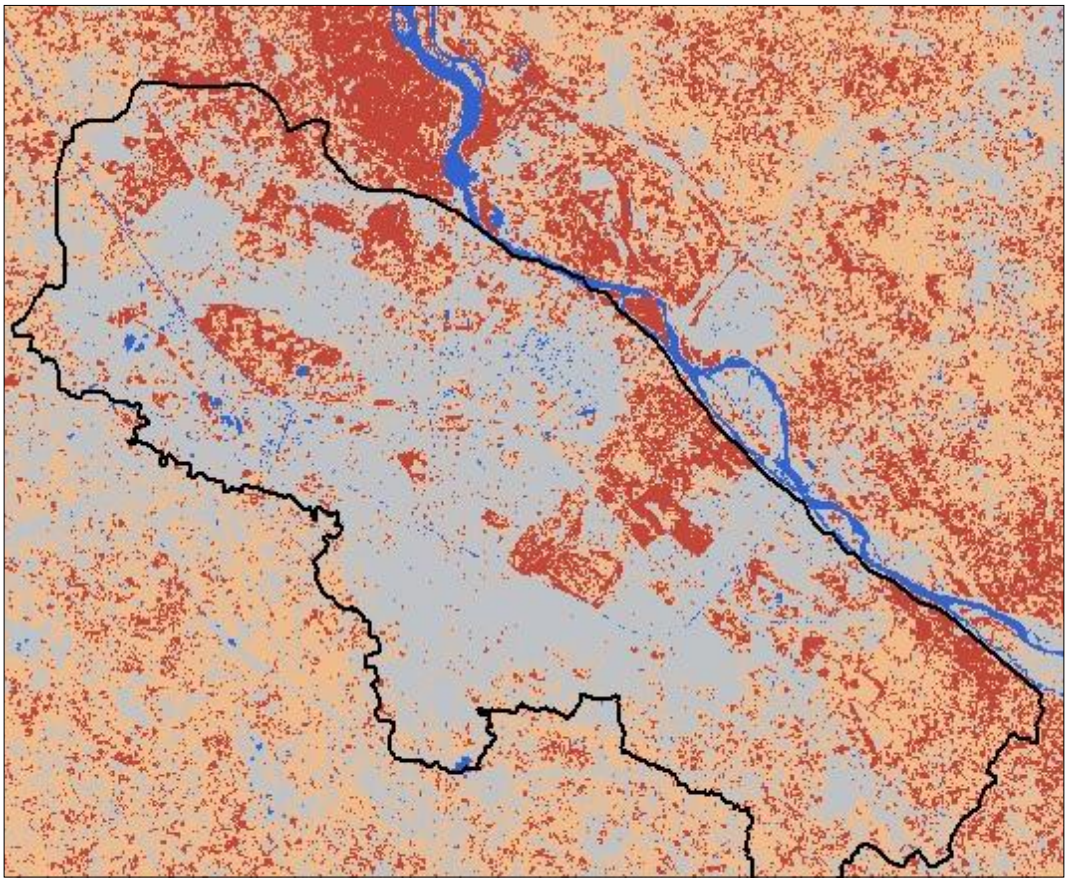
Source: Author

For Landsat-8 the formula for NDVI is B5 – B4 / B5 + B4. Its value is always from -1 to +1. Figure 24 shows that a lot of built-up is present on the northern side from where the river flows. So, the river fringe needs to be protected. Dense vegetation is scanty near the river edge and in the entire city. Shrub vegetation is present in the outer part of the boundary and in the middle of the cantonment area.

Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index (NDWI) is used in satellite imagery to emphasise the open water features, thus allowing a body of water to "stand out" against the land and vegetation. The NDWI determines the moisture content accurately. Figure 25 is the NDWI analysis of Kanpur city:

Figure 25: NDWI of Kanpur



Source: Analysis based on Landsat 7 imagery from USGS Earth Explorer

For Landsat-8 the formula for NDWI is B3 – B5 / B3 + B5. Its value is always from -1 to +1. The values up to 0.2 show extremely dry area, up to 0.4 it shows wet, and > 0.6 shows extremely wet, aqueous surface.

Proposals

Non-point source (NPS) pollution is a major danger to the water ecosystem. NPS pollution control can benefit from riparian zones because of their low energy consumption and minimal operational requirements (He et al., 2020). Numerous studies have documented the removal of nitrate

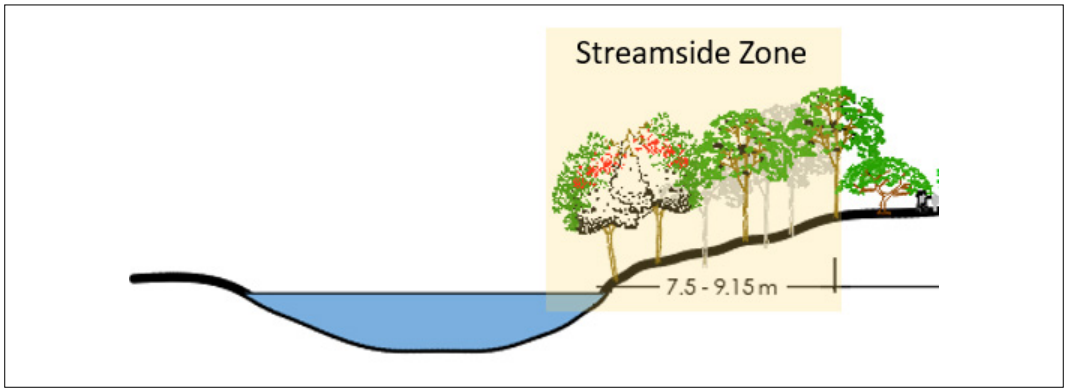
(NO3-N) from the surface and sub-surface agricultural runoff within the moist riparian habitats. Nitrate is a worldwide water pollutant that causes health problems in new-borns and animals and leads to cultural eutrophication of natural water bodies (Fennessy & Cronk, 1997). Non-saturated and saturated soils in riparian buffer strips are favourable to nitrogen transformations, such as denitrification. When denitrification is complete, nitrogen gas is released, which removes nitrogen permanently from the system.

Hence, an appropriate policy framework needs to be prepared to protect the ecotone of the riparian zones. Tables 4, 5, and 6 elaborate the proposed Riparian Zone Policy for the streamside, middle, and outer zones. The succeeding figures show the sections and native species that must be planted in that particular zone. The native species change from region to region, here it is discussed for Kanpur.

Table 4: Riparian Zone Policy (Zone-I) for Ganga Basin in Kanpur

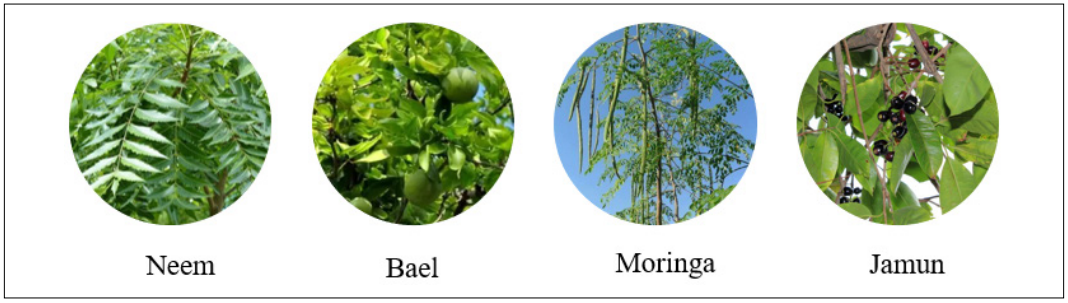
Name of the Zone	Streamside Zone
Zone Width	Minimum 25 - 30 feet or 7.6 – 9.15 m
Type of Vegetation	Native riparian trees with dense canopy, and grasses adapted to a moist environment and beneficial to animals present in this zone. Fast-growing tree species to maintain banks are preferred.
Main Objective of Zone	To protect the physical integrity of the stream's ecosystem.
Zone Functions	• Remove pollutants that are delivered from the stormwater and filter non-point source pollutants. • Reduce the sediments entering the stream and soil erosion. • Maintain base flow of the stream.
Activities Permitted	• Activities that do not hinder and disturb the natural riparian vegetation. • Bioswales can be constructed to filter the stormwater entering the river. • Walkways are permitted.
Activities Restricted	• Discourage grazing by animals and livestock. • Restrict vehicular movement • Discourage cutting of trees
Envisaged Outcomes	• Reduction in erosion of bank soil. • Flood control. • Improved habitat for aquatic life.

Figure 26: Streamside Zone



Source: Author

Figure 27: Native Species of Zone-I



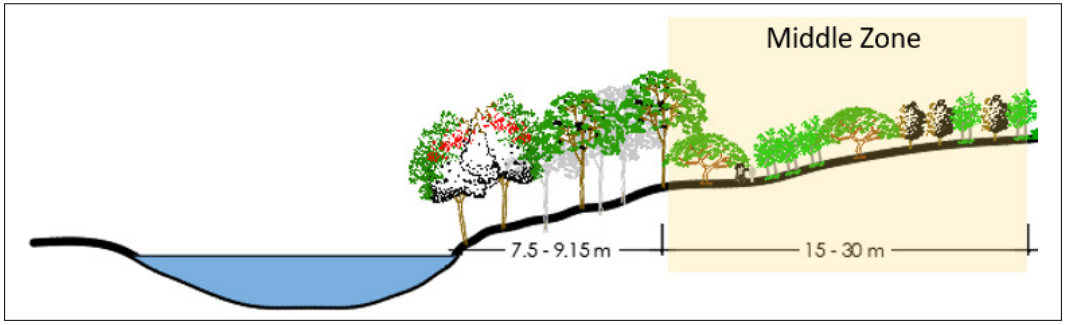
Source: Kanpur URMP

Table 5: Riparian Zone Policy (Zone-II) for Ganga Basin in Kanpur

Name of the Zone	Middle Zone
Zone Width	Minimum 50 - 100 feet or 15.25 – 30.50 m
Type of Vegetation	Predominantly native riparian trees, shrubs, forbs, and grasses must be grown here.
Main Objective of Zone	Provide sufficient distance between streamside and upland development.
Zone Functions	• Stabilize the river bank by beholding the soil. • Denitrification of pollutants by vegetative species. • Protect riparian wildlife habitat.
Activities Permitted	• Walkways, cycle tracks, and temporary wooden structures like decks can be constructed. • Stormwater best management practices (BMPs)
Activities Restricted	By managing vegetation and grading, prevent gullies from forming. Although management for timber or wildlife is encouraged, leaf litter and shade levels should be maintained.

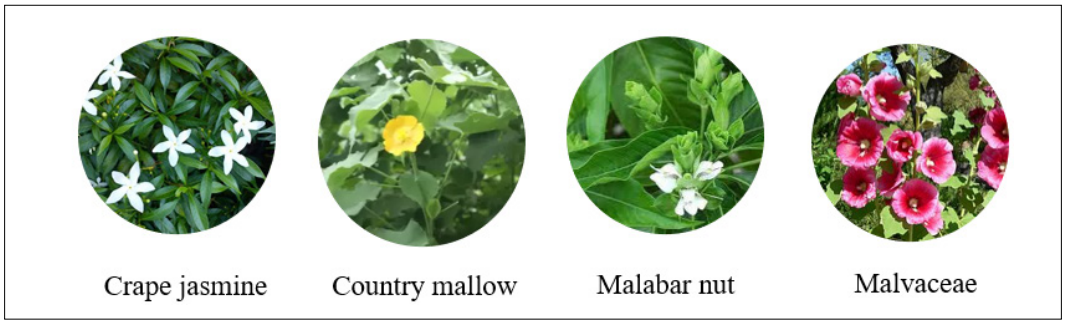
Envisaged Outcomes	• Removal of water pollutants by denitrification • Reduce watershed imperviousness

Figure 28: Middle Zone



Source: Author

Figure 29: Native Species of Zone-II



Source: Kanpur URMP

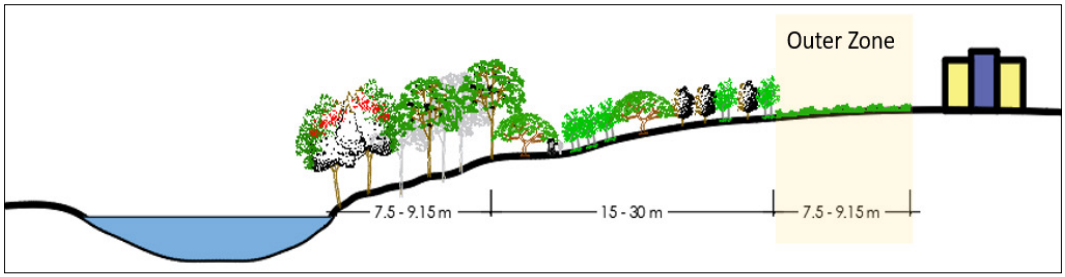
Table 6: Riparian Zone Policy (Zone-III) for Ganga Basin in Kanpur

Name of the Zone	Outer Zone
Zone Width	Minimum 25 - 30 feet or 7.6 – 9.15 m
Type of Vegetation	Dense perennial grasses and some forbs, herbaceous ungrazed grassland must be present.
Main Objective of Zone	Prevent encroachment near river/waterbodies and filter the backyard runoff.
Zone Functions	• Create recreational opportunities • Refurbish the scenic value of the riverfront.
Activities Permitted	• Recreational spaces such as parks, gardens. • Small scale biodegradable compost yards • Low rise diffused settlements for rural areas.
Activities Restricted	Commercial activities, high-rise structures, housing societies

Envisaged Outcomes	• Wetland protection • Dense flora improves microclimate

Source: Author

Figure 30: Outer Zone



Source: Author

Figure 31: Native Species of Zone-III

Source: Kanpur URMP

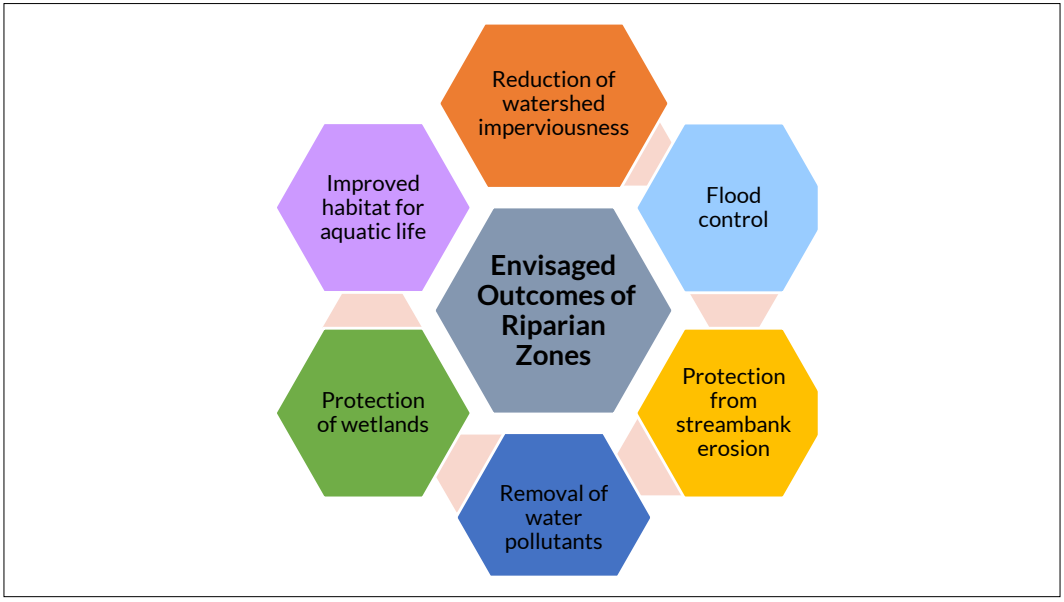
Envisaged Outcomes of Riparian Zones

Reduction of watershed imperviousness – Buffers discourage excessive enclosing of storm drains and hardening of channels. They limit the increase in runoff from impermeable surfaces, as well as erosion and overflow of headwater streams.

Flood control – Properties adjacent to streams often get flooded during monsoon as the stream widens and water overflows. This buffer acts as a shock absorber and barrier thereby protecting the adjoining properties (He et al., 2020b).

Protection from streambank erosion – The consolidation of floodplains and streambank soils by tree roots reduces the likelihood of severe soil erosion. Avoiding development on steep slopes along a stream is the most effective method of preventing erosion (Diversity and Distributions - 2007 - Richardson - Riparian Vegetation Degradation Alien Plant Invasions and Restoration, n.d.).

Figure 32: Outcomes of Riparian Zone



Removal of water pollutants – When placed properly, buffers remove pollutants and regulate flow of water through the developed regions. When planned properly, they provide effective pollutant removal for development within 150 feet of the buffer's perimeter. A forest canopy inhibits the additional warming of streams in developed watersheds.

Protection of wetlands – Stream buffers protect wetlands that are found near streams.

Improved habitat for aquatic wildlife – Many stream ecosystems rely on leaf litter as their primary food supply, and forests offer woody debris that provides cover and habitat structure for water invertebrates and fish. Significant terrestrial habitat, such as forest cover, is preserved via riparian corridors. They are important, species-rich transition zones. Uninterrupted stream buffers serve as "highways" for the passage of plant and animal populations. Amphibians, which

require both aquatic and terrestrial habitats to complete their life cycle, require buffers as well. Buffers preserve the stream's base flow.

A ghat cum recreational space for the identified riparian zone has been proposed. Its salient features are given in the next section.

Ghat Proposal

The existing vegetation of the site has been retained as it is, thereby discouraging deforestation. As one enters the space, towards the right is the 'Garden of Fragrance' and towards the left is community based 'Organic Farming'. There is a circular central plaza that acts as a focal point with water features and informal tiered seating space. Some way ahead is the 'Agroforestry zone' where plants and trees will be planted by the citizens of Kanpur of different age groups. A dedicated space for developing the 'Bio-diversity Park' in the future has been assigned opposite the kids play area. Near the entrance, eateries are also provided in this zone.

After this is the Ghat area with male and female changing rooms, bio-digester toilets, and gazebos for seating. Keeping in mind the religious sentiments of the people, temples have also been proposed. An artificial stream has been created by diverting the actual river, so the people can take holy baths. Trash bins have been provided to discard the floral and organic waste. Assuming that even after providing trash bins people will still discard the waste in the stream so a metal screen has been provided at the other end to trap all the waste. This will be sent to the machine room where it will be converted to organic manure that can be utilized in the farmland thereby promoting organic farming.

An amphitheatre has been constructed to accommodate around 400 people to witness the evening 'Ganga Arti'. This space can also be utilized by the 'Ganga Praharis' to demonstrate skits to raise awareness. A foot over connecting bridge leads to the 'Riparian Zone'. This has dense plantation, walkways, and cycle track for people to spend their leisure time.

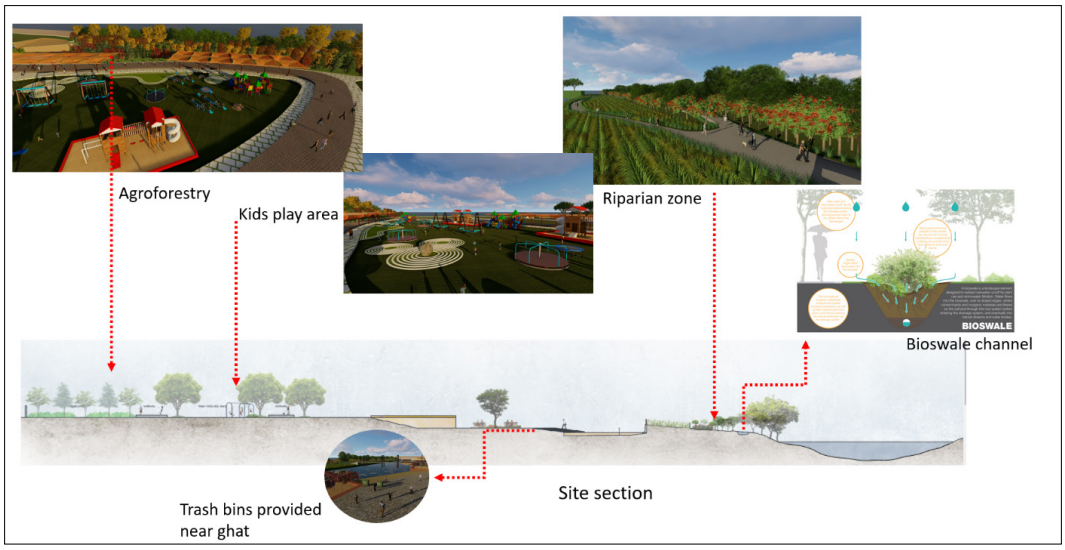
Since the river potential of the city is not up to the mark, a wooden deck for boating is provided at the end which will attract a lot of tourists. An underground 'Bioswale' channel is provided in the riparian zone so that filtered good quality return flow can be achieved for the city, which is one of the priority targets of KURMP (Kanpur Urban River Management Plan). The water from the stream can be treated and utilized for irrigation of the farmland and for some other tertiary purposes.

Engaging citizens in the development of this space will create a sense of belonging and sensitize them to river-centric behaviour. Hence, Nature-based Solutions are proposed to mitigate river pollution and an attempt has been made to achieve the components of KURMP that need improvement. Figure 33 depicts the detailed site plan of this space and Figure 34 shows the site section with views of each part.

Figure 33: Proposed Site of Eco-Friendly Ghat on Ganga River, Kanpur

Source: Author

Figure 34: Site Section



Source: Author

Effective Community Engagement/Public Participation

The proposals are within the domain of three broad principles of the Urban River Management Plan that talks about solutions. The proposals are environment friendly, economic, and encourage social cohesion. Figure 35 depicts the three pillars of community engagement.

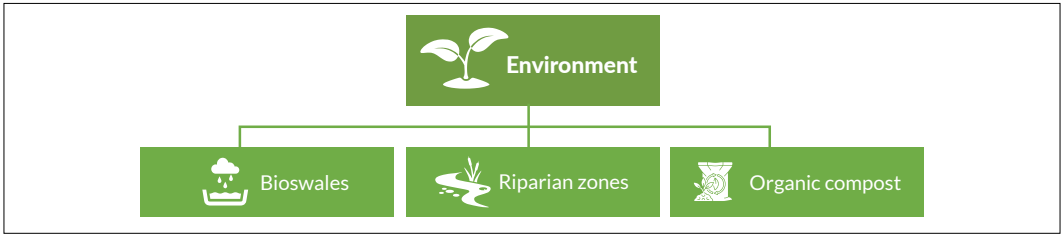
Figure 35: Community Engagement

Source: Author

Environmental

Bioswale will help in filtering the non-point source pollutants and sediments that enter the storm water. In this way good quality filtered return flow to the river will be encouraged. As some catchments are blocked in the city , constructing new catchment areas would invigorate in achieving the target of good quality return flow to the river. The enhanced riparian buffer will help in reducing pollution by denitrification of pollutants and would also act as a shock absorber to mitigate floods. The compost from biodegradable waste will be used as manure for agriculture purposes thereby promoting organic farming. Figure 36 depicts the domains of the Environmental proposals.

Figure 36: Environmental Proposal

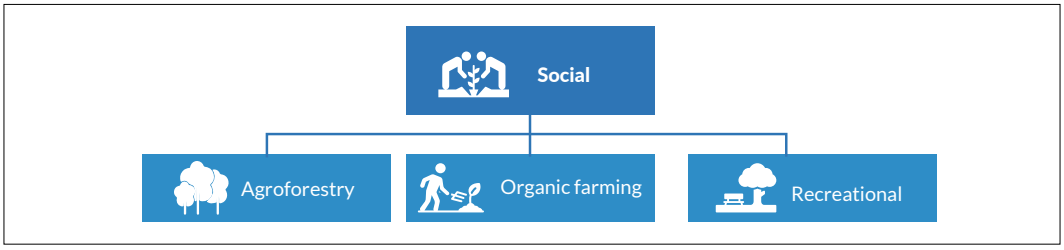


Source: Author

Social

The amalgamation of recreational spaces along with river ghats will boost social gatherings and promote interactions amongst citizens. Agroforestry also has the potential to improve the ecosystem services by sequestering carbon, preventing deforestation, conserving biodiversity, and conserving soil and water. Citizens will be engaged in agroforestry. The flood preventing gabion wall constructed by the citizens will inculcate a sense of belonging to that place. This comes under engaging community in river management activities. The biodiversity/botanical park will induce river and environment sensitive behaviour amongst citizens by educating them about the rich native flora and fauna of their region that needs to be preserved. Figure 37 depicts the domains of Social proposals.

Figure 37: Social Proposal

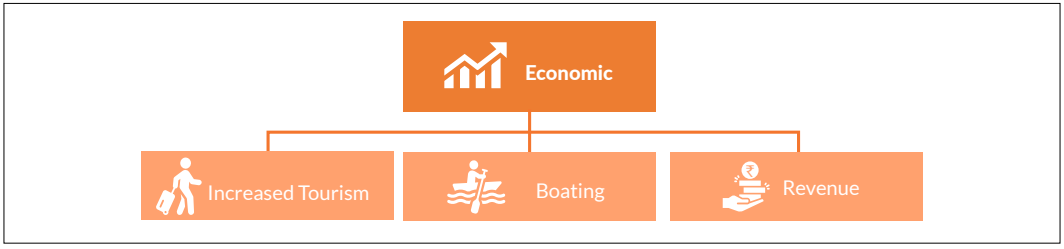


Source: Author

Economic

Most of the riverfront projects in the city are in the form of Ghats (24 in all). So, by clubbing riverfront projects with ghats, and including biodiversity and riverfront parks with them can boost the economy. The only current economic activities that are associated with the river in Kanpur is boating so by introducing a formal boating island with a wooden deck the local commerce (boatmen) near the ghats can be benefitted. The untapped economic potential of the river can be explored further. Visit to the riparian zone would be paid. It has walkways and cycle tracks apart from vegetation. Thus, revenue can be generated from this which can be utilized for the operation and maintenance of such places. Figure 38 depicts the domains of Economic proposals.

Figure 38: Economic Proposal



Source: Author

Outcomes of the Study

The outcomes of an urban river management plan includes various benefits such as improved environmental quality, increased recreational and aesthetic opportunities, capacity building, integration of the river as a vital entity in the development plan, and enhanced economic development.

Conclusion and Way Forward

The results from FAHP prioritized and ranked the pollution drivers, which helped to bring out the pain points in the different segments of the Ganga River Basin. As the stakeholders were from five different domains, so bringing all of them under one umbrella addressed the issues from a holistic approach. These rankings of drivers helped to throw spotlight on some intangible aspects that were included in the sub-drivers but remained neglected.

The 'Handle Bar Survey' conducted in Kanpur along the ghats of the Ganga River gave the on-ground reality check of the current status of the river and the ghats. Interacting with the officials of the Municipal Corporation gave insights on the overall scenario of the city and helped in knowing about the under-achieved targets of Kanpur's URMP.

The proposed policy framework for the riparian zone can be incorporated for other river centric cities as it helps in protecting the river fringe and reducing pollution to a large extent. The Master Plan includes a detailed strategy for improving the riparian buffer along both sides of rivers or the

river-centric cities. The following should be included in the strategy:

- Wherever possible, set aside a 30-meter buffer zone.
- Designate a suitable land use for the riparian buffer.
- Clarify land ownership in the buffer zones.
- The concerned authorities and agencies must create a riparian planting action plan that incorporates the native species.

The learning recreational spaces like botanical gardens and biodiversity parks and paid visit to the riparian zone that has walkways and cycle tracks would generate and boost the economy of the entire city. The development of such projects will help to create awareness amongst citizens, sensitize them to river-centric behaviour, and aid in adapting them to such positive changes. The implementation of this prototype model would change the microclimate of that area and if incorporated for more stretches the entire city would benefit especially during the scorching summers as dense vegetation along the river bank would cool down the climate.

Due to the riparian zone policy some people might have to give up their land to the government and ULBs as no construction will be allowed in this zone, so a precise policy framework is required to give compensation to such land owners. This may vary in class 1 and class 2 cities as well as in urban and rural areas. The compensation to such people can be provided in the form of money, FSI, or Transferable Development Rights (TDR) depending upon the feasibility.

If such a prototype is implemented on a larger scale there would be a surge in the economic benefit of the city as revenue would be generated. More employment opportunities would be created for the people. If required the estimated project cost can be reduced by selling chunks of land to farmers for agricultural purposes only. As technology changes swiftly, after a few years some new technique might be invented to filter stormwater and decompose organic waste, so there should be provision for its inculcation.

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Conflict of Interest

Authors have no conflict of interest to declare.

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Planning for River Sensitive Developments in Cities: A Case Study of Varanasi

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Abstract

Rapid urbanization and population growth have exerted escalating pressure on cities, thereby triggering discord in the intricate relationship between urban environments and rivers. Cities, often accused of contributing to the degradation of rivers and water bodies, are now being urged to adopt a fresh perspective—that of becoming "river-thinking" cities. This paper delves into the case of Varanasi, focusing on the Rivers Varuna and Assi, which were once the vital lifelines of the city. Despite their historical significance, the city missed the opportunity of addressing the deteriorating state of these rivers. The research explores opportunities for Varanasi to shift from having a negative impact on rivers to actively contributing to their health.

Conducted at three levels—city, river fringe area, and the river—the study identifies issues and constraints. The Urban River Management (URM) index is calculated in two scenarios: considering only the Rivers Varuna and Assi and considering all three rivers—Ganga, Varuna, and Assi. Complemented by the on-ground studies, including reconnaissance surveys, observations, site documentations, and activity mapping, the research evaluates the real-world challenges that are faced by the rivers, such as pollution, untapped drains, sewerage overflow, waste disposal, and flood impacts on the local population.

The findings reveal that Varanasi falls short in adequately addressing the river issues, and the URM index suggests that only an elementary level of urban river management is being done by the city. This paper contends that cities worldwide should recognize the urgency of adopting a 'nature first' approach to urban planning. By analyzing planning tools at different levels, this research advocates a paradigm shift in urban planning towards sustainable practices that prioritize the well-being of rivers and the natural ecosystems.

Keywords: Conservation, Nature-first, Planning, River Health, River Thinking, Urbanization

Introduction

The bond between rivers and cities, embodied in a symbiotic relationship, has been the hallmark of civilizations. Unfortunately, over the years, increased development pressures on cities have caused discord in this relationship. Today, rivers in India are in a crisis and face threats on multiple fronts. There are concerns regarding pollution of the rivers, drying up of river stretches, encroachment onto the floodplains, loss of river-related biodiversity, and several others. There is need for new river-centric thinking in planning for "river cities" on their banks, as the city master plan, at present, does not adequately address this. If we continue to pollute rivers the way we are doing currently, then our future might face a serious water crisis. So, there is a need for river-sensitive development, which should be a mix of engineering and planning-related approaches. Initiatives need to be taken to make people empathize with the riverine ecosystems that could restore the health of these water bodies.

Problems faced by rivers within the city boundaries:

- **Poor drainage:** At present, rain falls on hard surfaces which quickly drains into the river system, thus increasing storm flows and runoff and raising the risk of flooding.
- **Encroachment on floodplains:** Development of housing, industry, infrastructure, and agriculture all contribute to increased flood risk, habitat loss, and biodiversity loss.
- **Over-abstraction of water:** Obtaining water from rivers, canals, reservoirs, lakes, or subterranean aquifers for use in agriculture and industry. This could cause watercourses and marshes to dry up, and water levels may sink.
- **Pollution:** Dumping of waste, industrial chemicals, sediments, agricultural pesticides and fertilizers, and oil-contaminated road drainage all contribute to river pollution, which results in the loss of water quality and biodiversity.

Seeing the problem that is being faced by rivers in cities, proper urban river management is the need of the hour for conservation, development, and restoration of river resources within the administrative extent of a city. This aims to achieve a careful balance between the ecological, infrastructural, social, recreational, and economic functions of a river within the city. This should ensure that the river is environmentally sensitive, economically viable, and socially inclusive within the city boundary (NIUA, 2020).

Significance and Need for the Study in Varanasi

Varanasi holds a great religious and historical significance for Hindus in Uttar Pradesh, since it is marked by the convergence of three rivers—Ganga, Varuna, and Assi. Unfortunately, Rivers Assi and Varuna face severe pollution, particularly River Assi which has been reduced to just a drain. Addressing pollution in these tributaries is essential for any meaningful effort to clean River Ganga. Despite their historical importance, these rivers are under threat and demand immediate attention.

River Assi has also fallen prey to unauthorized constructions, thus significantly altering its original character. The encroachments have eliminated the freshwater sources, and the riverbanks are unlawfully occupied. This degradation of the floodplains has not only led to loss of the river's identity but has also hampered the recharging of groundwater. River Varuna, once the lifeline of Varanasi, now faces flooding issues, thus affecting many due to the unauthorized constructions in the flood-prone areas. These rivers, crucial to Varanasi's existence, are now grappling with serious challenges which necessitates a comprehensive city development plan for their restoration and prominence.

The study focused on the impact zone extending 500–1 km from both rivers, and was determined by factors such as city growth, population density, economic activities, social, cultural, and recreational aspects, as well as environmental considerations.

Objectives

The objective of this research paper is:

- To understand the various diameters of a river sensitive planning process and urban river management indexing as part of good practices from cities in India and abroad.
- To analyse and assess the current situation at three levels: city level, river fringe level, and the river level at Varanasi.
- To evaluate the situation and identify the issues in Varanasi with the help of different parameters and from the Urban River Management (URM) Index.
- Formulation of strategies, recommendations, and regulations at all the three levels for river-sensitive development in Varanasi.

Research Methodology

The research methodology for this study has employed a multi-level approach, conducted at the city level, river fringe area level, and river level, with the following key steps:

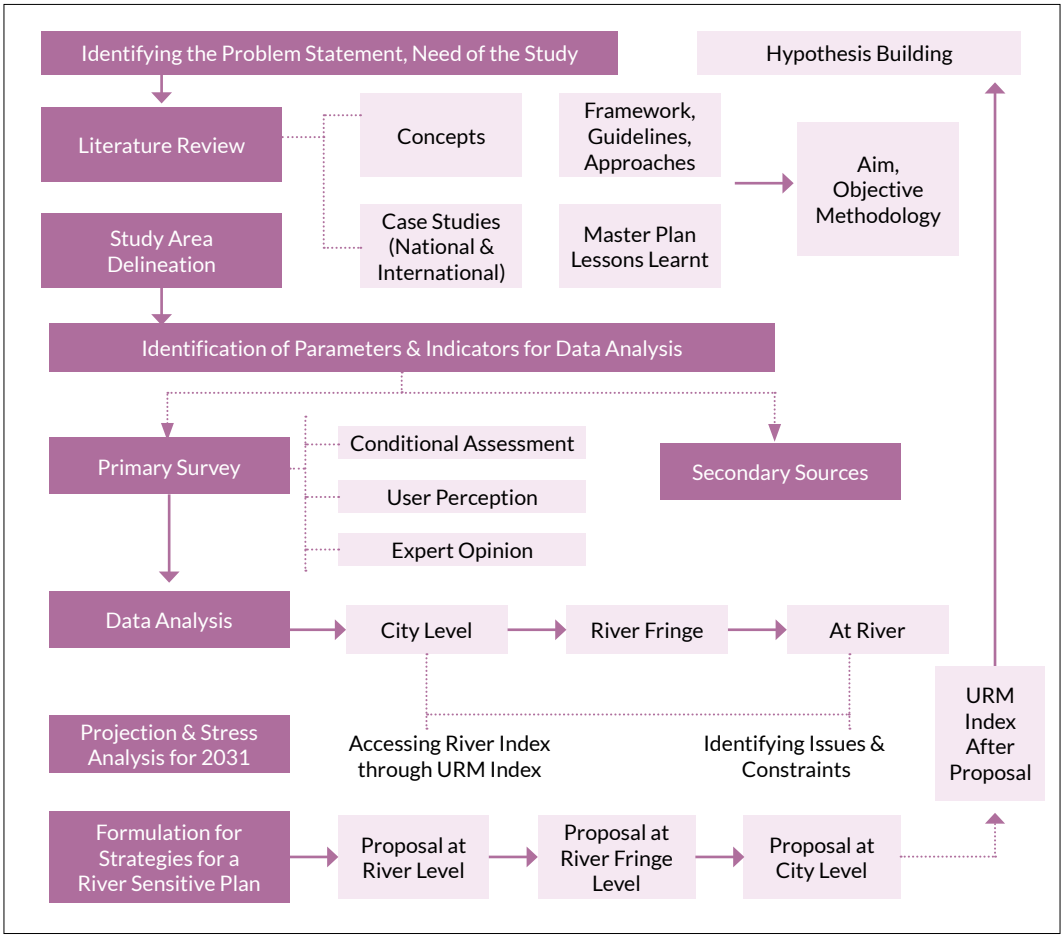
Literature review: The study undertook an extensive review of the existing literature to comprehend the context and necessity of the study. It analyzed various concepts, regulations, and relevant case studies from around the world to identify the best practices. From the literature review it derived the parameters and indicators for data analysis.

Data collection: To gather comprehensive information, data was collected from various authorities. Field studies were conducted by incorporating reconnaissance surveys to assess the overall river and city environment. Current conditions and potential areas for improvement were observed and documented along with site documentation, and activity mapping. A primary survey was also conducted which used a structured questionnaire to capture insights into the public and

expert perceptions of river-related issues, people's engagement with the river, and activities that were being carried on near the river.

Data analysis: Based on various identified indicators from the survey and data collection, analyses were conducted at three levels: at the city level, at the river fringe area, and at the river level. The assessment was done on various parameters such as floodplain management, riparian buffer, eco-friendly riverfront, revival of water bodies, river economy, citizen sensitization, citizen engagement, flood impacts, and quality of living. Based on the analysis, issues and constraints were identified. The calculation of the Urban River Management (URM) Index was done in two scenarios: considering only Rivers Varuna and Assi and considering all three rivers (Ganga, Varuna, and Assi).

Figure 1: Research Methodology



Source: Author, 2022

Projections and strategy formulation: To anticipate future scenarios, projected findings for the year 2031 were declared. Strategies for a river-sensitive approach at the river level, river fringe area level, and city level were developed. Strategies were formulated based on the assessment results. To validate the effectiveness of the proposed strategies, the URM index was planned to be calculated post the formulation of strategy.

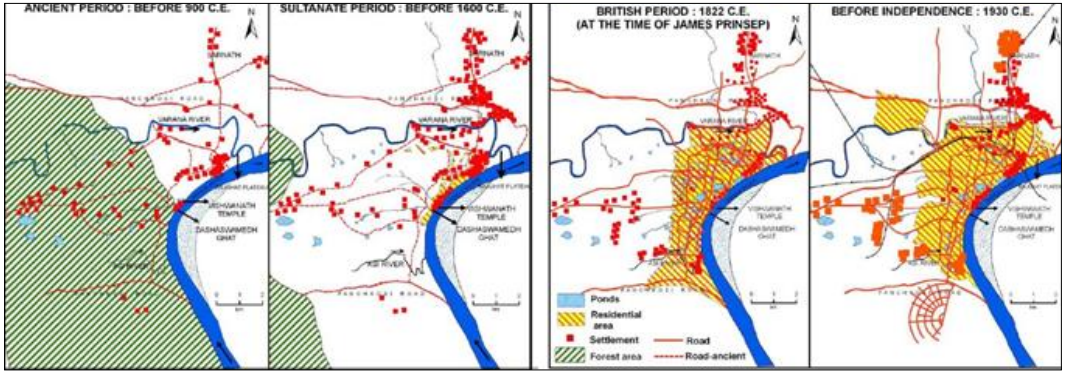
Hypothesis testing: A comparative analysis of the URM Index before and after the strategy formulation was conducted. It was assessed how the developed strategies justified the initial hypothesis.

Study Area

Historical Parlance of Varanasi

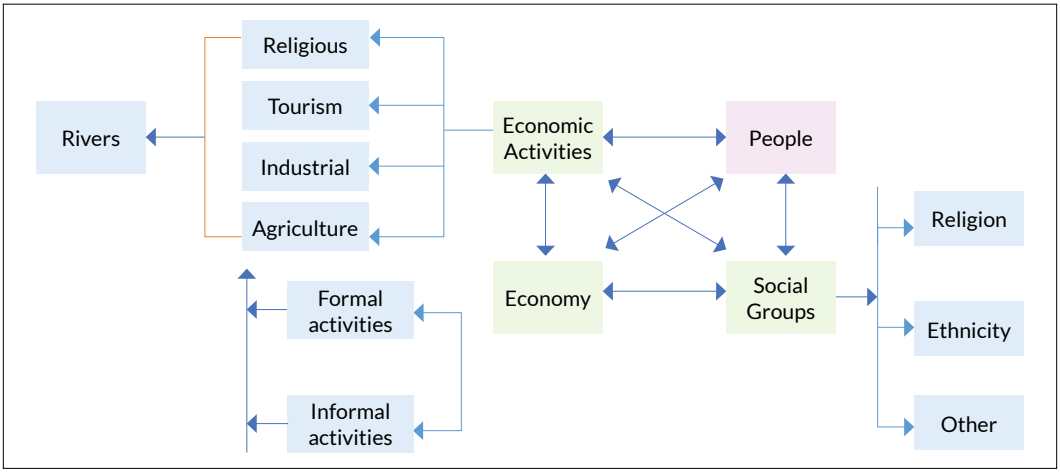
Rivers have always existed for settlements. Varanasi, too, was settled along the river. Varuna and Assi are non-perennial rivers that receive their water from rainfall, whereas the River Ganga is a perennial river. The initial settlement in the city was around River Ganga which was driven by the establishment of textile industries, agriculture, crafts, and mercantile groups along its banks. Over time, the transportation of goods along the river became a significant factor in attracting people to settle in the area. Subsequently, the population gradually shifted towards the northern area near River Varuna and expanded southwards along the River Assi. In the later stages, colonial settlements emerged in close proximity along the River Varuna, and away from the traditional core (Singh and Rana, 2018). The Ganga River area became densely populated and congested.

Figure 2: Growth of Varanasi along Rivers



Source: Singh, 2018

Figure 3: River, People, and the City Connect

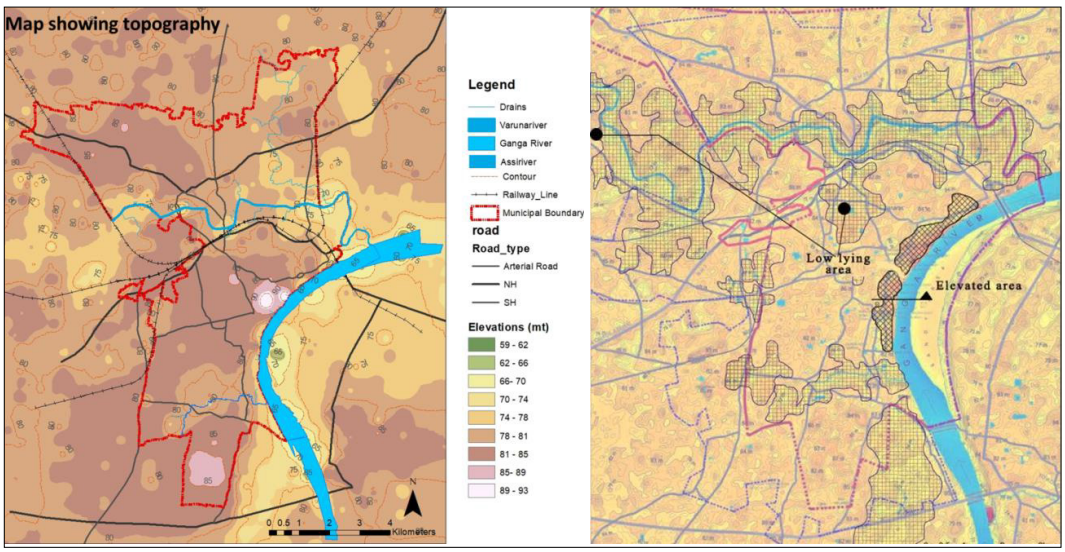


Source: Author

Topography

The city features a soft undulating terrain, with the ground elevation ranging from 71m to 80m above the river level. The highest point reaches 93m, while the lowest fluctuates around 59m. Due to this topography, the regions around the Rivers Varuna and Assi are characterized by lower elevations which result in flooding during the monsoon season.

Map 1: Topography and Low-Lying Areas in Varanasi



Source: Author

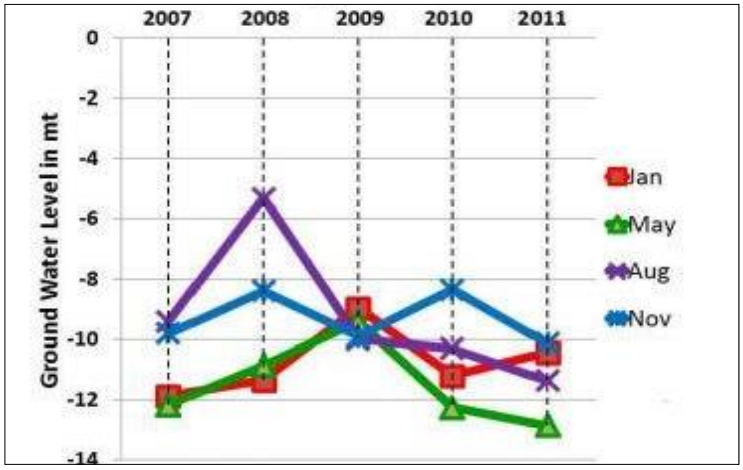
City Level Analysis

To comprehend the underlying reasons for the challenges that are encountered by the river and to suggest a workable remedy, an in-depth examination of the diverse sectors and parameters was conducted at the city level, in this section.

Groundwater

Groundwater serves as a crucial resource and is the foundation for the development of water supply and drainage infrastructure, with its quality directly impacting human health. In the city, groundwater depletion occurs at the rate of 23 cm per year, and the southern part experiences faster depletion, primarily due to extensive extraction by DLW and BHU. In the Trans Varuna area, there is significant reliance on groundwater, with deep tubewells, hand pumps, and private borewells serving as primary sources for water extraction (Gautam, 2013).

Figure 4: Groundwater Table in Varanasi



Source: Central Groundwater Board - Division-III, Varanasi

Water Supply System

The water supply and sewage system in Varanasi were established in 1892 and have now been in operation for over a century. Groundwater extraction constitutes the primary source (62%), followed by the Ganga (38%). The city relies heavily on groundwater, with a yearly depletion rate of 23cm. The Water Treatment Plant (WTP) has a capacity of 330 MLD (millions of litres per day) but treats only 120 MLD, necessitating an upgrade. Municipal water faces contamination from sewers due to their deterioration, and close proximity of the intake well to the Assi Nallah which results in elevated levels of coliform bacteria (School of Planning and Architecture, 2015).

Existing Sewerage Analysis

Regarding the existing sewerage system, it was originally designed for domestic sewage, the traditional layout of open drains in the core city allows stormwater to directly enter the trunk sewer or through manholes and branch sewers. This creates significant pressure on the sewerage network, especially during monsoons. The combined system renders the Sewage Treatment Plants (STPs) ineffective in the rainy season, thus contributing to increased pollution in the Rivers Ganga and Varuna.

Areas that are not covered by the sewer network discharge sewage directly into the Rivers Ganga, Varuna, or in the Assi Nallah, thereby further contaminating the rivers. Varanasi has a total of five STPs with a combined capacity of 399 MLD, and three new STPs (Dinapur new STP, Goithaha STP, and Ramana STP) were established by Namami Gange to cater to the current and projected populations by 2030. Except for Ramana STP, the others are currently operating at full capacity.

Table 1: Total Sewage Generation-Existing Scenario in Varanasi

Total population of Varanasi city 2021	16,36,168
Adding Floating Population 6%	18,27,732
Total water supply @150 lpcd + UFW	343.61MLD
Total sewage/sullage generation @80% of supply	280 MLD

Source: Primary Survey, 2022

Table 2: District-wise Sewage Generated and Gap Analysis in Varanasi, 2021

Sewerage District	POP 2021	Total Water Supply @150+UFW	Total Sewerage generation @ 80%supply	Total STP	GAP
District 1	675845	126.72	101	80+140 MLD= 220 MLD	
District 2	566432	106.25	846		
District 3	229036	42.94	34.35 +198 (Nagwa drain)	50	113.65 MLD
District 4	396108	74.24	59.46	120	

Source: Jal Kal, Bhagwanpur, Varanasi and Primary Survey, 2022

At present, there is a deficiency in sewage treatment for the waste generated in District 3. Many areas lack branch lines which leads to direct discharge of waste into rivers such as the Trans Varuna. Open defecation is observed along the Rivers Varuna and Assi. There also exists significant untapped potential for reuse of the treated wastewater.

River Sensitive Urban Planning for Varanasi: Situational Analysis

To make a city river-sensitive, various planning dimensions need to be addressed in the master plan of that city (NIUA, 2020). Table 3 depicts the planning dimensions addressed in the Varanasi Master Plan 2030. Out of 10 planning parameters, Varanasi Master Plan for river-sensitive has adopted only one, which shows that the city lacks in river-sensitivity in the implementation of the master plan.

Table 3: River Considerations in Master Plan

Planning Dimensions	Varanasi Master Plan 2031		
	Mentioned in Detail	Mentioned without Detail	Not Mentioned
River Sensitive Vision/Objective			
River Background			
River Zone Delineation			
Urban Flooding			
Land Use, Use Premises			
Development Control Regulations			
Groundwater Augmentation			
River Water Extraction for City Use			
River Pollution			
River Navigation			

Source: Master Plan Varanasi 2031-Varanasi Development Authority

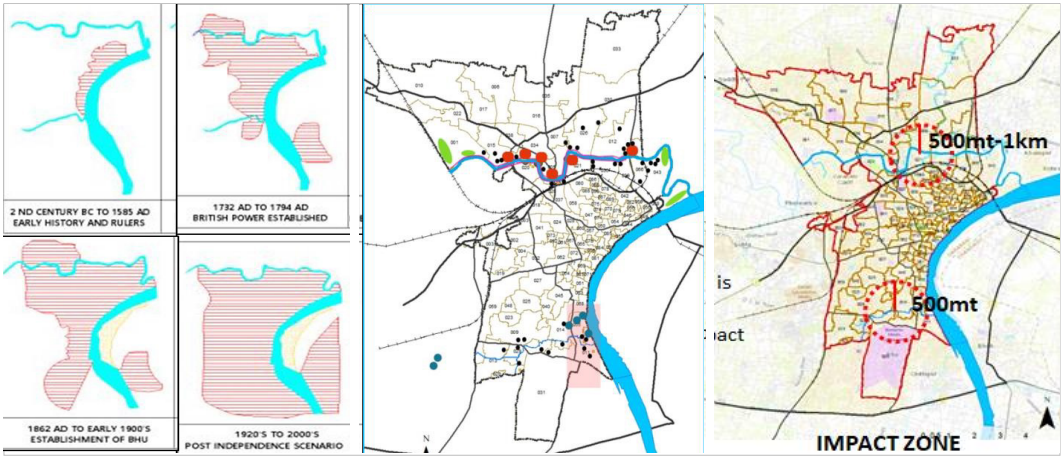
Urban River Zoning Regulations

For river zoning regulations, no active flood plain area has been demarcated. There is provision for a green belt along the Rivers Varuna (50m) and Assi (25m) on both sides, where no development is permitted. Other uses, activity control permits, and prohibited activity zones have been designated for only River Ganga. There is no such provision for Rivers Varuna and Assi.

Delineation of the River Fringe as an Impact Zone

The river fringe, situated in close proximity to the river, holds considerable influence. To identify the most affected zone that surrounds the river, the river fringe was defined based on six parameters. Each parameter underwent analysis, and the cumulative impact zones were demarcated. The six parameters that were considered include the growth of the city, population density, economic activities, social, cultural, and recreational aspects, environmental considerations, and slope contour. After evaluating these parameters, the impact zones for the Rivers Varuna and Assi were established to be within 500–1 km.

Map 2: Delineation of River Impact Zone in Varanasi



Source: Based on Primary Survey, 2022

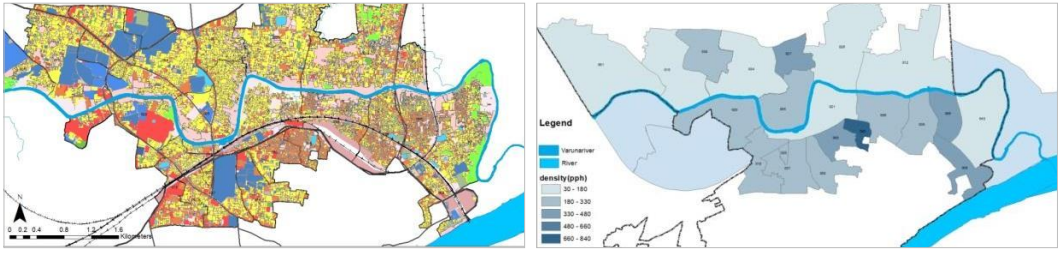
Analysis of the Varuna River Fringe (Impact Zone)

The River Varuna, a minor tributary within the Ganga River system, originates from Mailhan Jheel in Phulpur tehsil of Prayagraj district. After coursing approximately 200 kilometres, it converges with the Ganga River just northeast of Varanasi, the capital of Uttar Pradesh. The river traverses through the districts of Prayagraj, Bhadohi, and Varanasi, covering a total length of 11.58-km within the city limits of Varanasi. Currently, groundwater recharge is limited, and the primary source of water is industrial and domestic wastewater that is discharged into the Varuna River system.

Profile of the Varuna Fringe Area

The Varuna River fringe area encompasses a total of 20 wards which extend within a buffer zone of 500–1 km on both sides of the river. As of 2021, the population in this area was 275,670, with a population density of 231 people per square mile. Map 3 illustrates the distribution of land use and density along the Varuna River fringe area (500–1 km).

Map 3: Land Use and Density along River Varuna



Source: Author, 2022

Slum and Industrial Area in the Outskirts of Varuna River

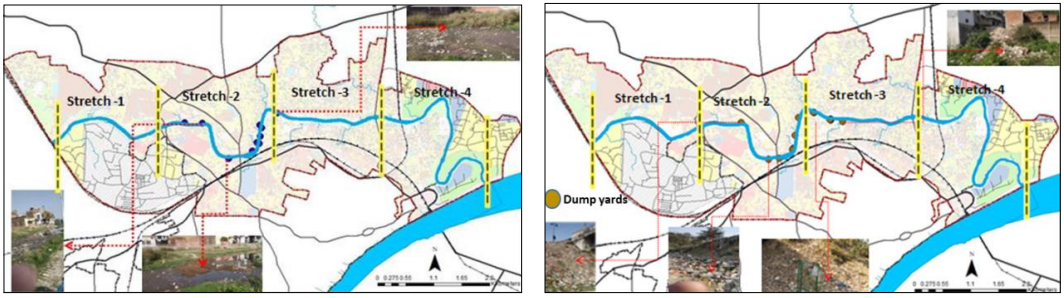
There are eight slums on the outskirts of River Varuna. With a total population of 8970, these slums are well served by community toilets around the area. When we surveyed the slum, the problem faced by a few of them was that those within 50 meters of the river were badly affected during flood time and had to shift to other places. In the Varuna Fringe Area, there are small-scale household dyeing industries of Banarasi Sarees, handlooms in Jalalipura and Kazzakpura, and automobile industries in Raza Bazar, which release effluents into the drains.

Major Issues in the Varuna River Fringe Area

Sewerage and Solid Waste Analysis

As per the primary survey it was found that drains and small scale industries out of which automobile are discharging effluent in Raza Bazar drain which trapped but small household industries are going into sewer which is directly discharge into Varuna. There are few stretches where sewerage overflow is there in the vicinity of River Varuna hence polluting the river. Dump yards near the river is another cause for the pollution of the river. Below, Map 4 depicts the sewerage overflow and dump yard location near the river

Map 4: Sewerage Overflow (Left) and Dump Yard Location (Right) on the Outskirts of River Varuna



Source: Primary Survey, 2022

Total 24 drains within the River Varuna catchment area were identified as discharging directly into the river. The wastewater from these connected drains is directed to the Sewage Treatment Plants (STP) at Dinapur and Goithaha. Conversely, the discharge from untapped drains, amounting to approximately 88 MLD, is directly released into the River Varuna. Survey results indicate that the primary factor that is negatively affecting the water quality of the Varuna River is sewage discharge, followed by urbanization, waste disposal, agricultural runoff, and other factors, as illustrated in Table 4. Some people have also stated that hotels are directly discharging their wastewater into the river.

Table 4: Existing Drain Details on the Outskirts of River Varuna

Name of Drain	Drain Meeting River Varuna	Status	Types of Drains	Observation (Primary Survey)
Phulwaria Nallah	Right Bank	Untapped	Domestic	7.6MLD flow is diverted to STP Dinapur, while 140 MLD & excess flow is discharging into River Varuna
Sadar Bazar Nallah	Right Bank	Untapped	Domestic	Flow is diverted to STP Dinapur
Raja Bazar Nallah	Right Bank	Tapped	Mixed	Flow is diverted to STP Dinapur
Telia Nallah	Right Bank	Tapped		Flow is diverted to STP Dinapur
Nakki Nallah	Right Bank	Tapped		Flow is diverted to STP Dinapur
Central Jail Nallah	Left Bank	Untapped	Domestic	Tapping provision provided but drains directly meeting in River Varuna, slightly blackish green water observed with slight flow
Chamarutha Nallah	Left Bank	Tapped	Mixed	Drain is directly meeting River Varuna
Banaras Nallah	Left Bank	Untapped	Domestic	Discharged into River Varuna
Orderly Bazar Nallah	Left Bank	Untapped	Domestic	Waste water containing slaughtering activity observed
Khajuri Colony Nallah	Left Bank	Untapped	Domestic	Tapping provision was found but damaged during inspection however, drain was directly meeting River Varuna due to choking of bar screen
Hukulganj Nallah	Left Bank	Untapped	Mixed	Drain was directly meeting River Varuna as the tapping provision is in a damaged condition
Nai Basti Nallah	Left Bank	Untapped		Drain directly meeting in River Varuna
Sarang Talab Nallah	Left Bank	Partially Tapped		Flow is diverted to STP Goithaha but currently in a damaged condition.
Narokha Nallah	Left Bank	Partially Tapped		On ground it is discharging into the river
New Drain Identified (Primary Survey)				
Drain 1	Right Bank	Untapped	Mixed	Drain is directly meeting in River Varuna (Hotel wastewater)
Drain 2	Right Bank	Untapped	Mixed	Drain is directly meeting in River Varuna (Hotel wastewater)
Drain 3	Right Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 4	Right Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 5	Right Bank	Untapped	Domestic	Drain is directly meeting in River Varuna

Name of Drain	Drain Meeting River Varuna	Status	Types of Drains	Observation (Primary Survey)
Drain 6	Right Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 7	Right Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 8	Left Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 9	Left Bank	Untapped	Domestic	Drain is directly meeting in River Varuna
Drain 10	Left Bank	Untapped	Domestic	Drain is directly meeting in River Varuna

Source: Primary Survey, 2022; Jal Kal Varanasi

Flood and Associated Vulnerability Assessment

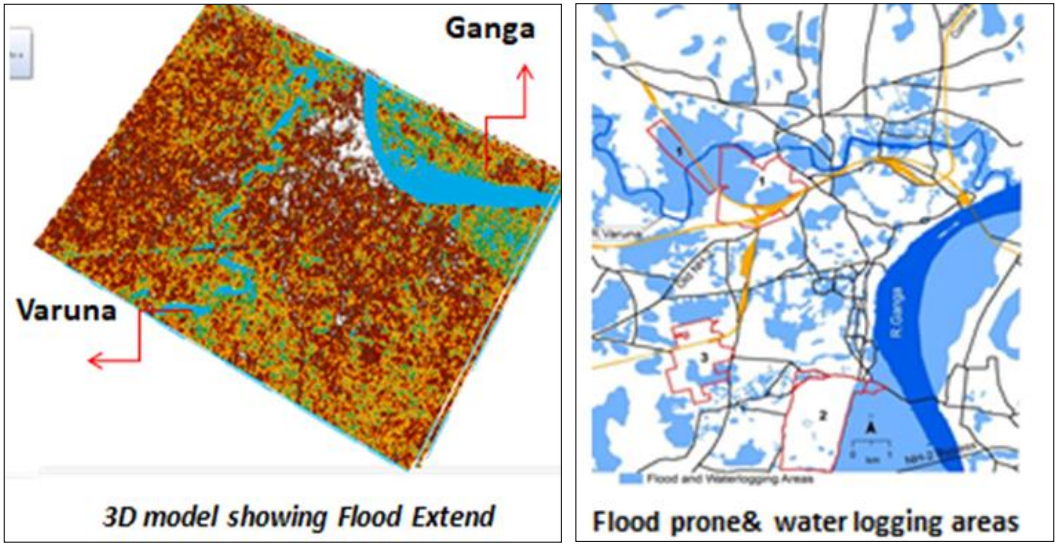
Varanasi experiences annual flooding, with the Highest Flood Level (HFL) reaching 74 meters for the Ganga River. Since the Varuna River flood is influenced by the backflow from the River Ganga, the flood level remains consistent. The danger level is set at 71 meters; however, data from Table 5 reveals that in the past decade, the flood level has surpassed the established danger level.

Table 5: Showing Highest Flood Level in Varanasi

Year	2013	2016	2018	2019	2020	2021
HFL	72.63	72.56	70.18	71.95	71.69	72.32

Source: Irrigation and Water Resource Department, Varanasi

Map 5: Flood Prone Areas around Varuna River



Source: Author, 2022

Moreover, through the modeling assessment that was conducted approximately 200 meters from the River Varuna stretch, identified significant areas as highly susceptible to flooding, while others exhibited moderate vulnerability. Table 6 presents the flood-affected regions on the outskirts of the Varuna River, along with the total population at risk. Additionally, during the survey, when

individuals were asked about the impact of floods on their income, 66% reported an adverse effect, while 33% claimed no impact. Those experiencing income impacts were predominantly farmers whose agricultural lands get submerged during floods.

Table 6: Showing Vulnerable Population in the Fringe Area of River Varuna

Flood Zone Elevation (in m)	Area (Sq km)	Population Affected
70-74 m	0.35	1350
74-75 m	10.99	8420

Source: Primary Survey, 2022

Assessment of the Quality of Living in the Varuna River Fringe Area

Furthermore, the quality of life for residents in the Varuna River Fringe area was evaluated by using parameters that were related to river issues derived from the ease of living index. Each parameter received a score out of 5 points, and the overall score was calculated. A score of 1 indicated poor quality of life, 2 signified fair quality, and 3 suggested excellent quality. The assessment conducted at the Varuna stretch revealed that the quality of living in the Varuna River Fringe area is fair.

Table 7: Quality of Life Assessment of River Varuna Fringe Area

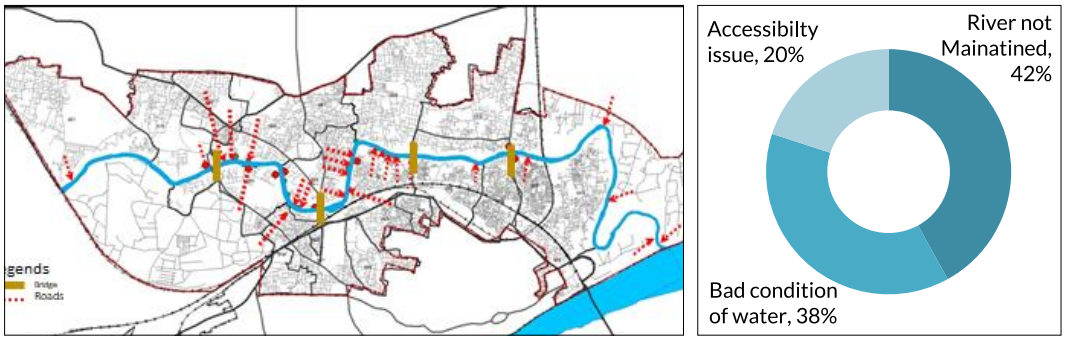
Quality of Living	Scoring
1. WASH & SWM	
Households Connected to Sewerage Network	3
Amount of Wastewater Treated	1
Households with Piped Water Supply	4
2. SUSTAINABILITY	
2.1 Environment	
Water Quality	3
Hazardous Waste Generation	2
2.2 City Resilience	
Has the City Implemented Local Disaster Reduction Strategies	2
Number of Deaths due to Disasters	5
3. HEALTH	
Prevalence of Diseases	
Water-borne Diseases (Jaundice, Typhoid)	3
Vector-borne Diseases (Malaria, Dengue)	3
TOTAL SCORE	1.833

Source: Primary Survey, 2022

Accessibility Analysis in Fringe Area of River Varuna

Map 6 illustrates the roads that are accessible from the river, but a majority of these are katcha roads, with only two ramp roads throughout the stretch. There are four bridges connected on each side. When respondents were asked about accessibility during the visit, 20% reported issues, while 38% attributed poor water and river conditions as reason for disconnecting from the river. Concerning the condition of roads in the area, only 10% considered them to be in good condition, and merely 12% reported the presence of street lights.

Map 6: Accessibility in the Fringe Area of River Varuna



Source: Primary Survey by the Author, 2022

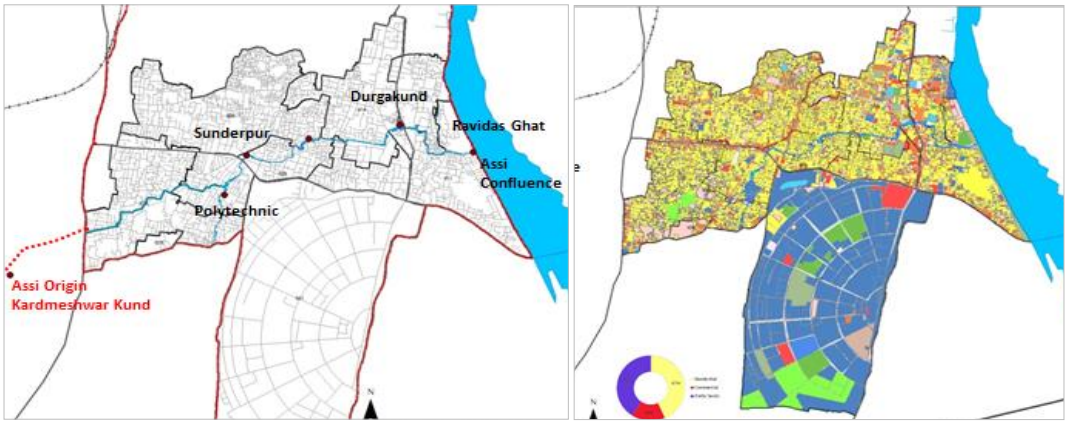
Analysis of the Assi River Fringe (Impact Zone)

The Assi River is believed to originate from Kardmeshwar Kund in the vicinity of Kandwa in Varanasi city, flowing approximately 5.5-km through an unconstructed channel before merging into the River Ganga. The average width of the Assi River is 5.50 meters which is subject to variations due to unauthorized encroachments. Historically, it used to confluence with the River Ganga at Assi Ghat, but presently, it is diverted through Nagwa Mohalla to safeguard Assi Ghat from the impacts of direct pollution. Passing mainly through residential areas towards Ganga, the Assi River traverses the city's historical section, encompassing Assi Ghat and BHU, surrounded by renowned kunds and ponds.

Profile of Assi Fringe Area

Total population of the area in 2021 was 118,871, and the density was 231 pph, as shown in Map 7. Population density is higher near the Assi River. The total number of wards in the area are seven. Total slums in the area are seven with a population of 4597. The eastern part of the stretch has maximum tourist footfalls because of the presence of the Durga Temple, Sankat Mochan, and BHU, as shown in Map 7. The famous Pachkoshi Yatra trail also follows the Assi River.

Map 7: Origin and Land Use of Catchment Area of Assi



Source: Author, 2022

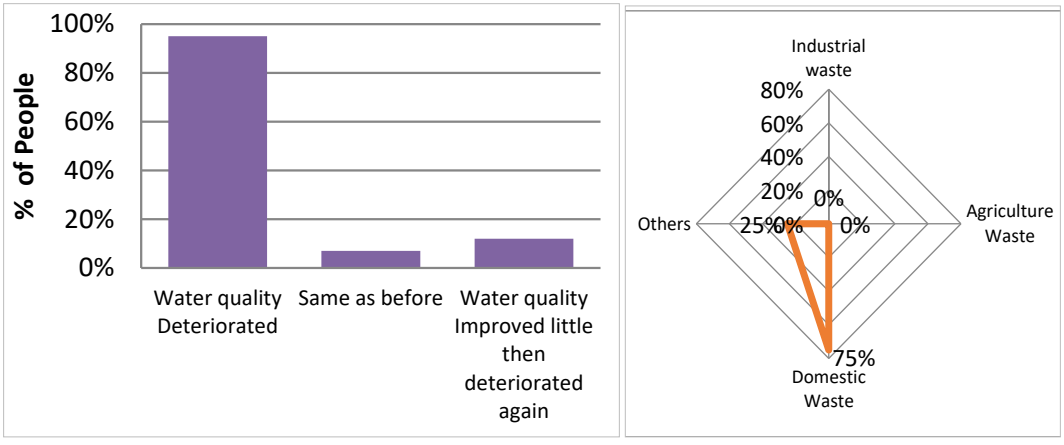
Existing Drainage Condition

The Assi River is served by 13 drains, as illustrated in Map. These drains predominantly carry domestic waste, thus contributing to a total discharge of 198 MLD. The primary characteristic of the Assi River is its course through residential and historical areas of the city, with a width of 5.5-meters.

Situational Analysis: Findings from Primary Survey

In the River Assi area, a comprehensive survey of 124 samples revealed that 91% of respondents believed that the water quality had deteriorated over time. Additionally, 12% acknowledged that the government efforts had initially improved the water quality, but due to a lack of sustained efforts, the water has degraded again.

Figure 5: Condition of the Water Quality of Assi River



Source: Primary Survey, 2022

During the survey, 43% participants described the water quality as very poor, while 58% deemed it poor. When asked about the reasons for this assessment, 75% attributed it to domestic waste, highlighting that houses discharged their wastewater and disposed their garbage into the river. Solid waste is reported to be uncollected within the streets.

Quality of Living in the Assi River Fringe Area: An Assessment

An assessment of the quality of life of the residents in the Assi River Fringe area utilized parameters related to river issues from the ease of living index. Each parameter received a score out of 5 points, and the final score was calculated accordingly. A score of 1 indicates a poor standard of living, 2 signifies fair quality of life, and 3 suggests an excellent quality of life. Table 8 illustrates the assessment that was conducted in the River Assi stretch, revealing that the quality of living in the Assi River Fringe area is fair.

Table 8: Quality of Living in the Fringe Area of River Assi

QUALITY OF LIVING	Scoring	After
1. WASH & SWM		
Households Connected to Sewerage Network	3	5
Amount of Wastewater Treated	2	4
Households with Piped Water Supply	4	5
2. SUSTAINABILITY		
2.1. Environment		
Water Quality	2	4
Hazardous Waste Generation	4	4
2.2. City Resilience		
Has the City Implemented the Local Disaster Reduction Strategies	2	4
Number of Deaths due to Disasters	5	5
3. HEALTH		
Prevalence of diseases		
Water-borne Diseases (Jaundice, Typhoid)	3	5
Vector-borne Diseases (Malaria, Dengue)	3	5
Total Score	2.5	3.2

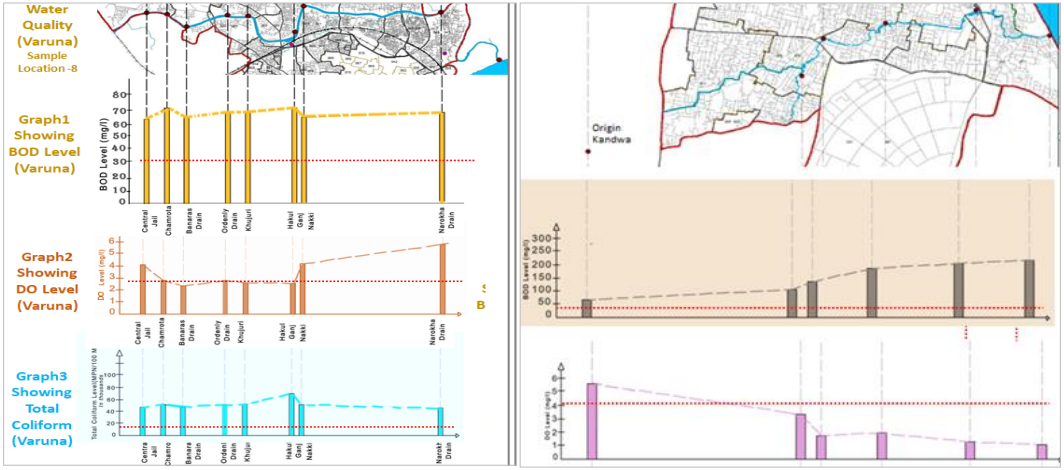
Source: Author, 2022

River Level Analysis

Water Quality Analysis of Rivers Varuna and Assi

Total eight sample locations were surveyed for the water quality analysis shown in Figure 6. Various water quality assessment parameters were considered, like pH value, BOD, DO, and COD. This is the average value of 12 months.

Figure 6: Sample Location and its Parameter Values at Varuna and Assi Rivers



Source: Author, 2022

As per standards, the Biological Oxygen Demand (BOD) for drinking water should be less than 5 mg/L, and in treated wastewater that is disposed in water bodies it should be below 30 mg/L. However, all sample locations in the Varuna stretch exhibit values higher than the standard. Healthy water has Dissolved Oxygen (DO) concentrations above 6.8–8 mg/L and DO levels below 3 mg/L are generally concerning. The survey identified four sample locations in Varuna where the DO levels were less than 3, indicating an unsuitable environment for aquatic plants and animals. Coliform count, between the desirable limit of 500 and the maximum permissible limit of 2,500 Most Probable Number (MPN) per 100 MLD, was observed in both the rivers. Similarly, for Assi River, all parameters surpass the standard values. Consequently, the water quality in the Assi River is more degraded than in the Varuna River, necessitating improvement in the water quality of both the rivers.

Urban River Management (URM) Index for Varanasi

The Urban River Management (URM) Index, measured on a scale of one to five, serves as a snapshot of the situation, which aids in monitoring the URMP implementation and developing overall strategies and policies for improvement (NIUA, 2020b). Various indicators, as depicted in Figure 7, have been considered for Varanasi, assessing how the city manages both the rivers, aside from River Ganga, where numerous interventions have already been implemented.

Figure 7: Indicators for URMP

Source: NIUA, 2020b

In this case, two scores were computed: one with integrated values for all the three rivers and the other considering only Rivers Varuna and Assi. Subsequently, the scoring was conducted for all 10 indicators, as shown in Figure 8.

Figure 8: Urban River Management Index for Varanasi

Indicator 1: floodplain management score

SNO.	Desirable Features	Flood Plain Points	Scenario 1 (All 3 River) A	Scenario 2 (Varuna & Assi B
1	Floodplain boundaries clearly demarcated	15	5	3
2	Floodplain boundaries protected through embankments, roads, or other means	5	4	3
3	Demarcation of no development zone adjacent to the river in the active floodplain	5	4	4
4	Strict enforcement in no development zone	10	5	2
5	Updated database of existing land use in floodplain available	10	8	1
6	Master Plan has clearly indicated permissible and non-permissible activities in the floodplain/river zone	15	5	2
7	All regulations in the Master Plan are enforced (10 points if at least 50% of the regulations are enforced)	15	10	7
8	Presence of river friendly landscaping (e.g. constructed wetlands, bios wales, etc.)	5	1	2
9	Strict monitoring mechanism in place	5	3	2
10	No solid waste dumping on river banks	10	5.5	1
11	Only organic farming practiced in river zone	5	2	2
		Total	52.5	30
	I1=Floodplain Management score =		*3*	*1*

Indicator 2:Net Dissolved Oxygen (DO) score

$$\text{Net DO} = \frac{\text{DO outlet} - \text{DO inlet}}{\text{DO inlet}} \times 100 \text{ where } DO_{outlet} = \text{DO at outlet; } DO_{inlet} = \text{DO at inlet}$$

Scenario 1= -0.111 , Scenario 2 B= -5.2

I2 = Net Dissolved Oxygen (DO) Score 2 = 3

Indicator 3:: Water Body Revival Score

How to measure the indicator:

$$\text{Water body revival factor} = \frac{\text{Number of water bodies in acceptable condition}}{\text{Total number of water bodies}} \times 100$$

= water body revival factor = 25.68

I3 Water Body Revival Score = *score = 1*

Indicator 4: Riparian buffer score

Note:-Only riparian buffer of width greater than 7.5m shall be considered in the analysis of this indicator

I4: Riparian buffer score =0

Indicator 5: wastewater reuse score

$$\text{Wastewater reuse factor} = \frac{\text{Wastewater reused annually}}{\text{Wastewater generated annually}} \times 100$$

= 20.022

= wastewater reuse factor scenario 1 = 20.22 , scenario 2=0

I5: wastewater reuse score s1 =1 , s2=0

Indicator 6: Return flow score

$$\text{Return flow factor} = \frac{\text{Actual annual return flow} - \text{Committed annual return flow}}{\text{Committed annual return flow}} \times 100$$

Indicator 7 :Eco-friendly riverfront score

S.no	Desirable Features	Eco-Friendly Riverfront points	Scenario 1	Scenario2
1	The riverfront project is a source of revenue for the ULB	15	6	1
2	The riverfront project supports commercial activities like shops, stalls,	15	8	8
3	The riverfront project has a footfall of more than 100 people/day	10	9	9
4	The riverfront project is listed as an attraction spot on travel-related websites	15	12	2
5	The riverfront project has good waste management facilities	15	8.5	8
6	The riverfront project is made up of predominantly natural material	10	3	2
7	The riverfront project has soft landscaping elements	10	1	5
8	The riverfront project does not block the natural path of the river	10	6	4
		Total	53.5	39
	Eco-friendly riverfront score =		3	2

Urban River Management Index for Varanasi Analysis

Indicator 8: River economy score

S.no	Desirable Features	Scenerio1	Scenario 2
1	The river is used for navigation (inland or inter-city) or cruises	Only ganga	NA
2	The river is used for water sport activities	(only ganga)	NA
3	The river supports livelihoods of fisher folk	30%	40%
4	The river support livelihoods of farmer	20%	40%
5	The river supports religious and/or cultural tourism	80%	Partial 20%
6	Any other economic use that can be verified	-	-
	I8= River economy score =	5	4

If the river has 3 or more economic uses	river economy score = 5
If the river has 2 economic uses	river economy score = 4
If the river has 1 economic use	river economy score = 2
If the river has no economic use	river economy score = 1

Indicator 10: Citizen Engagement score

S.no	Desirable Features	Scenario 1	Scenario 2
1	Participation of citizens in river health monitoring	2	1
2	Participation of citizens in river clean-up activities	3	2
3	Presence of citizen groups for river conservation	2	1
4	Presence of citizens in committees related to river decisions	1	1
5	CSR funds invested in river-related projects	1	1
6	Any other citizen engagement modality that can be verified	1	1
	I10= Citizen engagement score =	2	1

Urban River Management Index

$$URM_{index} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9 + I_{10}}{10}$$

A= 2.44 (All three rivers)
B= 1.5 (Only Varuna & Assi)

Indicator 9:Citizen sensitization score

S.no	Desirable Features	Citizen Sensitization points	Scenerio1	Scenario 2	
1	Dedicated Information, Education and Communication (IEC) programme for the river-related aspects	20	18	14	s2
2	River related sensitization is part of existing citizen awareness raising programmes	15	12	5	s1
3	Presence of a dedicated website for river-related aspects	5	0	0	
4	Use of traditional sensitization media (e.g. hoardings, murals, competitions, radio)	10	6	3	
5	Use of social media for river-related sensitization	10	4	1	
6	A dedicated river day for the city	10	8	1	
7	Earmarked budget for citizen sensitization	15	6	4	
8	Sensitization of school children through special events	10	7	7	
	Total		61	35	
	I9 Citizen sensitization score =		*4*	*3*	

URM_{index}	Interpretation	What it means
<1.5	Poor level of urban river management	The city is incapable of meeting the basic requirements for effective urban river management. The river is neglected and used indiscriminately without proper planning and management. There are serious concerns for all dimensions of urban river management.
1.6-2.5	Elementary level urban river management	Basic actions required to ensure urban river management are evident. However, there are still major gaps and serious concerns with regards to almost all dimensions of urban river management.
2.6-3.5:	Average level urban river management	The city has a satisfactory urban river management system. However, some dimensions of urban river management are still a cause of concern.
3.6-4.5	High level of urban river management	The city is well-placed with most of the dimensions of urban river management. The dimensions may not be at par with each other, but the overall situation is still nonetheless satisfactory.
4.6-5.0	Ideal level of urban river management	The city is an ideal example of urban river management. There are evidences of exemplary actions against every dimension of urban river management, suggesting that the plans and policies in regards to urban river management are working well.

Source: Author, 2022

The URM Index is calculated by adding all scores of the ten indicators:

$$URM_{index} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9 + I_{10}}{10}$$

A = 2.44 (all three rivers)
B = 1.5 (only Varuna and Assi).

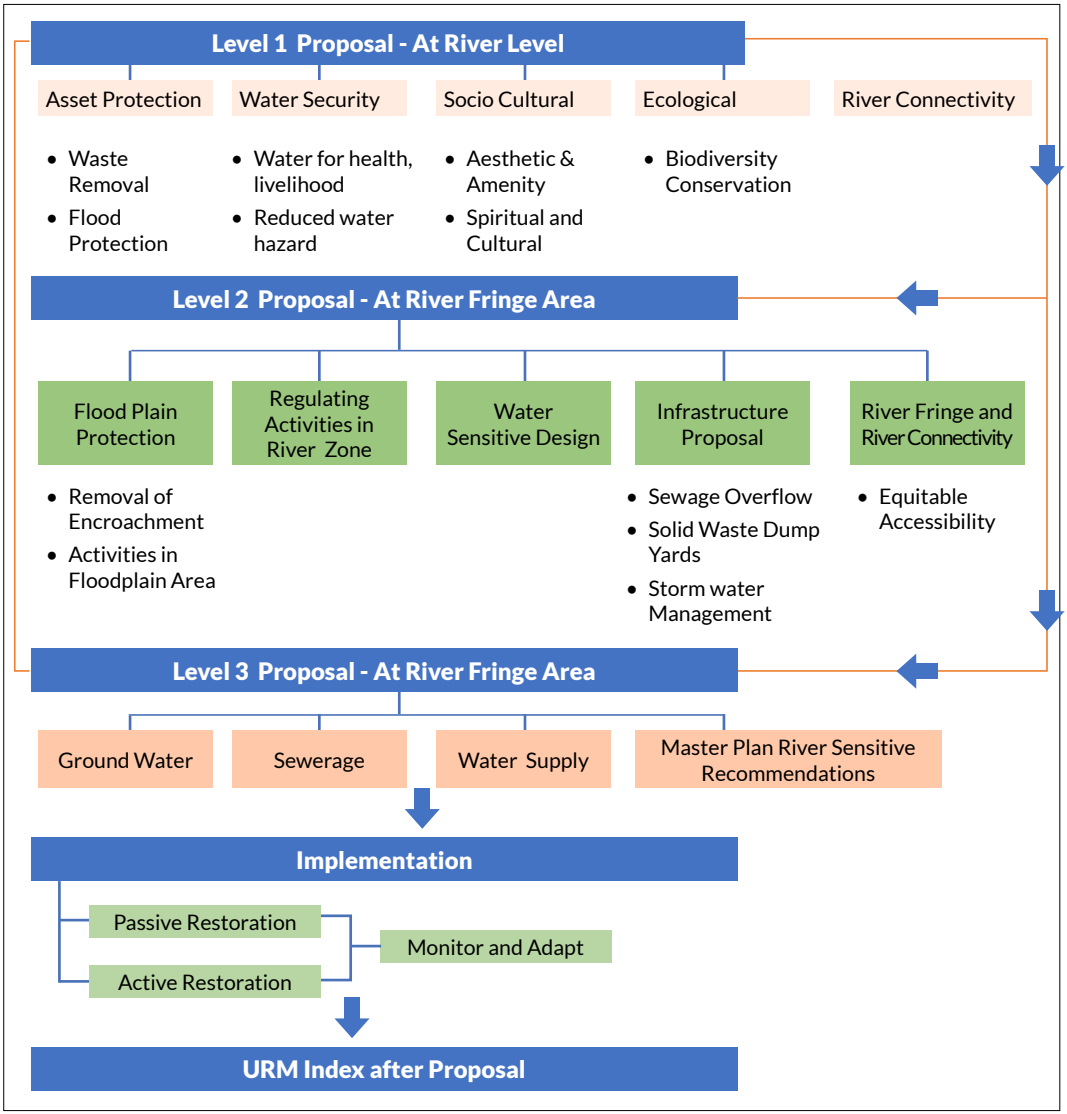
The URM Index for the city considering all three rivers shows that elementary-level urban river management is being done, whereas the URM Index considering only Rivers Assi and Varuna shows poor-level of urban river management.

The Proposal

The proposal is planned with the vision of creating an ecologically sensitive, resilient, recreational space along the Rivers Varuna and Assi that is accessible with clean water flowing through them. The overarching goal is to transform Varanasi into a city that prioritizes environmental sensitivity. The proposal takes into consideration a diverse range of parameters, encompassing physical, social, economic, environmental, and managerial aspects. The strategic solution has been outlined in Figure 9, where the recommendations are presented at three levels: river, river fringe, and the city. Implementation will occur at two levels: active restoration which will require field-level

interventions, and passive restoration which will involve policy-level recommendations. Table 9 shows the proposed interventions for both the rivers.

Figure 9: Approach for the Proposal



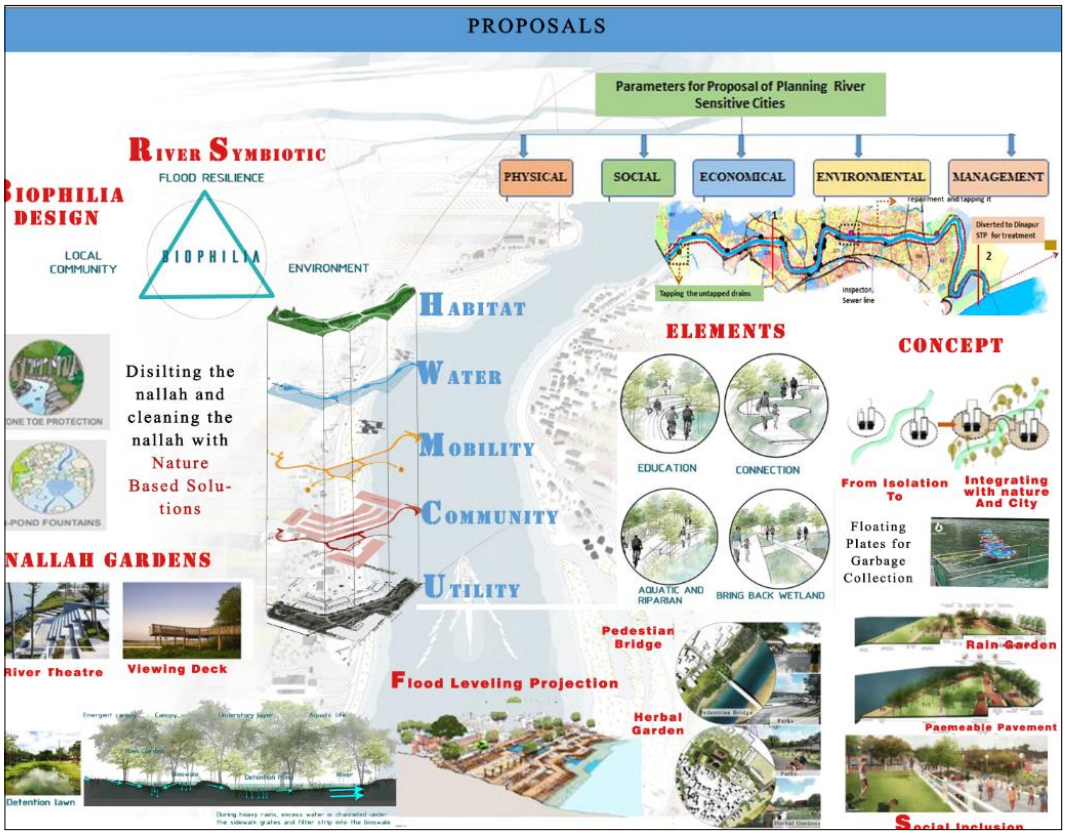
Source: Author, 2022

Table 9: Proposals

Proposals	
At the River Level	
AT VARUNA	**AT ASSI**
Untapped drains would be tapped and diverted to Dinapur STP, which is currently not practised	Nallah Gardens—Cleaning of the Nallah (Technique)
Desilting of rivers and strengthening embankments using desilted material	Construction of Wetlands - Four wetland projects have been proposed along River Assi
Vegetation Development and Microfiltration at the Embankments	Vegetation Development and Microfiltration at the Embankments
Channelizing the river and maintaining its width of 44 m.	
To accommodate extra spillover water, the river to be dredged and its depth to be increased.	
Ghats Amenities (toilets) and ritual spaces at the rest of the 5 ghats.	
5 Pedestrian bridges to connect one end of the river to the other and to connect temples.	
At River Fringe Area Level	
AT VARUNA	**AT ASSI**
Strategies to manage the floodplains	
• Assign a separate use zone category for the river and the floodplains. • According to the highest flood plain level, a prohibited zone of upto 50-75m from the Varuna River, a regulated zone of upto 100m, and a restricted zone of upto 150m are proposed.	Proposal for No Development Zone of 25m along both sides of the river, a green buffer of 25m width, a pedestrian walk zone and a green vegetation buffer with seating is proposed.
At City Level	
Sewerage Proposal	
Immediate Phase (2021–2026) - Renovation phase of the existing sewer pipelines, desilting to be done.	
Phase 2 (2026–2031) - Intercepting the drains, a new sewer line would be laid in district 4 and STP 141 MLD would be constructed in district 3	
Phase 3 (2031–2041) - Installation of smart sensor manholes and SCADA system, Upgradation of Dinapur STP and sewer network of 112km in district 4	

Source: Author, 2022

Figure 10: Various Interventions



Source: Author, 2022

Figure 10 illustrates multiple interventions that have been suggested at different levels. The proposed parameters for these interventions are derived from five indicators: physical, social, economic, environmental, and management.

Proposal for Fringe Area at River Varuna

Removal of Encroachments

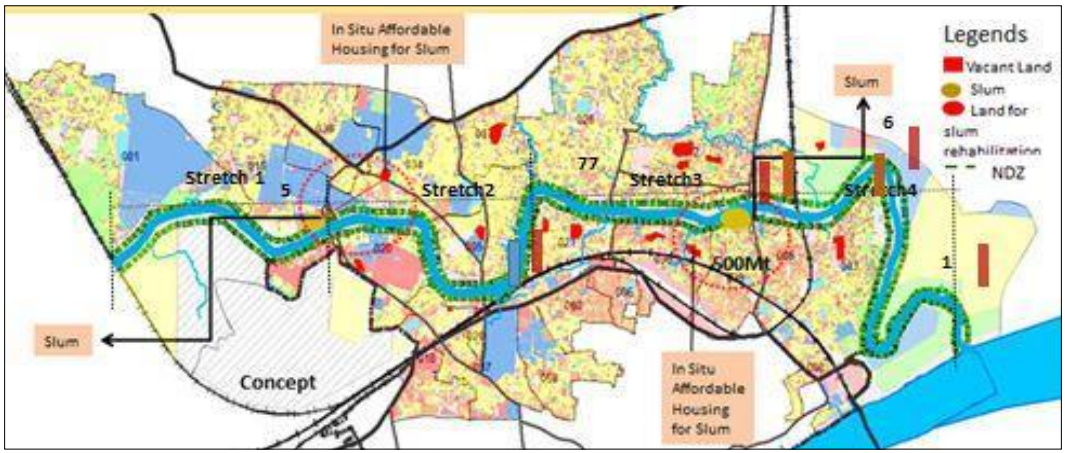
All development in the 50m NDZ will be removed. In situ Rehabilitation (Affordable housing) of three slums in the area (within range of 500m from their work area) has been proposed. The rest of the development will be resettled within 500-1km of their work space. Fourteen hotels cannot be removed so for them regulations will be imposed like no discharge of wastewater and water into the rivers.

Table 10: Encroachment and its Resettled Distance

Stretch	Encroachment on Left Bank	Encroachment on Right Bank	Resettled With Range of:
Stretch 1	22	52	200m
Stretch 2	90	45	1-km
Stretch 3	112	123	500m
Stretch 4	13	22	500m

Source: Author, 2022

Map 8: Proposed Location for Resettlements

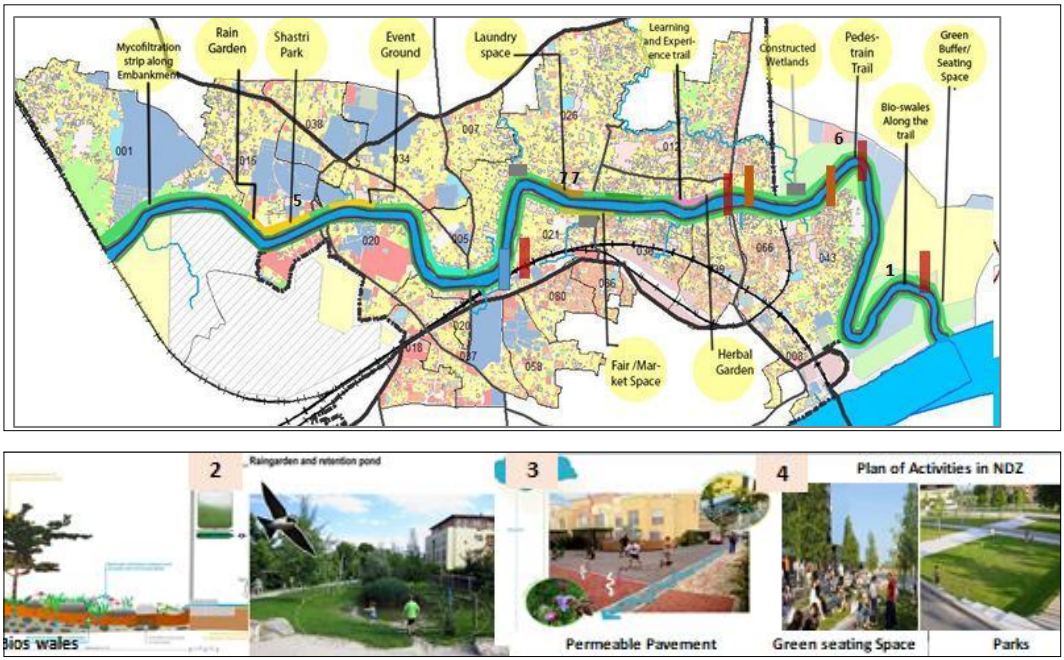


Source: Author, 2022

Proposal for Riverfront Development

Various activities along the riverfront have been proposed as permissible within the river zone. Suggestions include the establishment of parks to serve as leisure spaces for nearby residents, an event ground for temporary activities, and a learning space for educating people about nature, water, and its importance. Herbal gardens are also a part of the proposal. Instead of the previous unorganized fair market, a well-structured field and market space are now available for the residents of Chaukaghat area. Small dhobi ghats have been replaced with a systematic laundry space. Additionally, a rain garden has been incorporated to collect groundwater, and filter strips and bioswales are provided along the pedestrian trail. Permeable pavement is utilized for pathways, facilitating the percolation of water into the ground.

Map 9: Proposed River Front Activities



Source: Author, 2022

River Fringe Area Proposal for River Assi

Removal of Encroachments

All development within the 25-meter No Development Zone (NDZ) will be eliminated. In Situ Rehabilitation which involves the establishment of affordable housing, has been planned for two slums within a distance of 500 meters to 1.5 kilometres from their work area. The remaining developments will be relocated within 500 metres to 1 kilometre of their workplace. Resettlement will follow a model similar to the Kashi Vishwanath Corridor Project which offers both land and incentives to individuals. Table 11 outlines the extent of encroachment on both sides of the river and the corresponding range of resettlement.

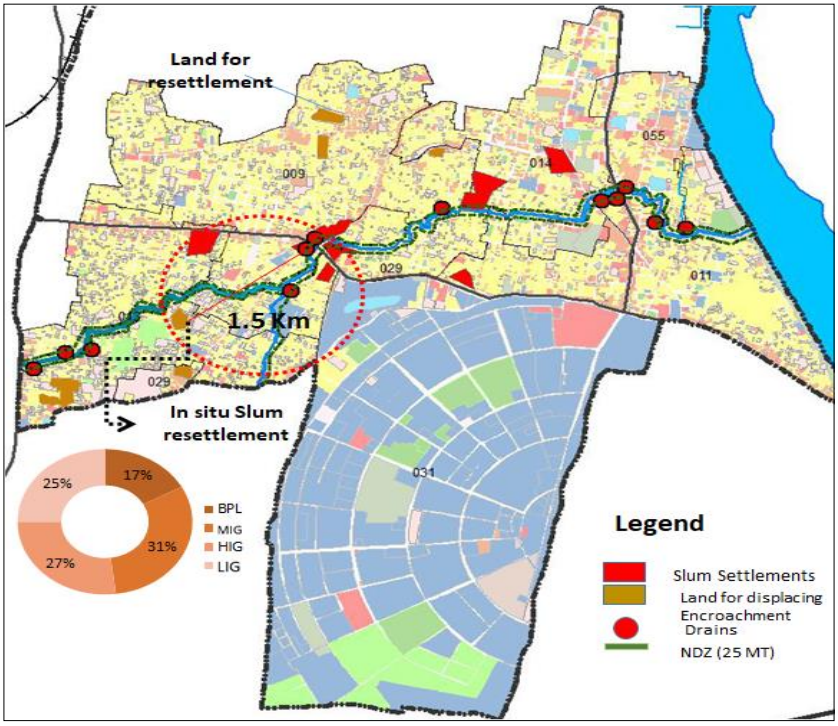
Table 11: Encroachment and its Resettled Distance

Encroachment	Encroachment on Left Bank	Encroachment on Right Bank	Resettled with Range of:
Assi	146	104	2-3 km
Slum	2		1.5 km

Source: Author, 2022

The plan encompasses activities within the 25-meter belt. It proposes a green buffer followed by a pedestrian pathway, and then provides a vegetation buffer with seating spaces.

Map 10: Proposed Location of Resettlements of Slums and Settlements



Source: Author, 2022

City Level Proposal

Proposal for Reuse of Treated Wastewater

As of now, the utilization of treated wastewater is minimal and restricted solely to gardening purposes. Table 11 outlines the sewage generated, with only 70-75 percent, equivalent to 263.25 MLD, undergoing treatment.

Table 11: Quantity of Sewerage Received and Treated Wastewater

Quantity of sewerage received	351	MLD
Quantity of treated wastewater generated for reuse (70-75% of sewerage)	263.25	MLD

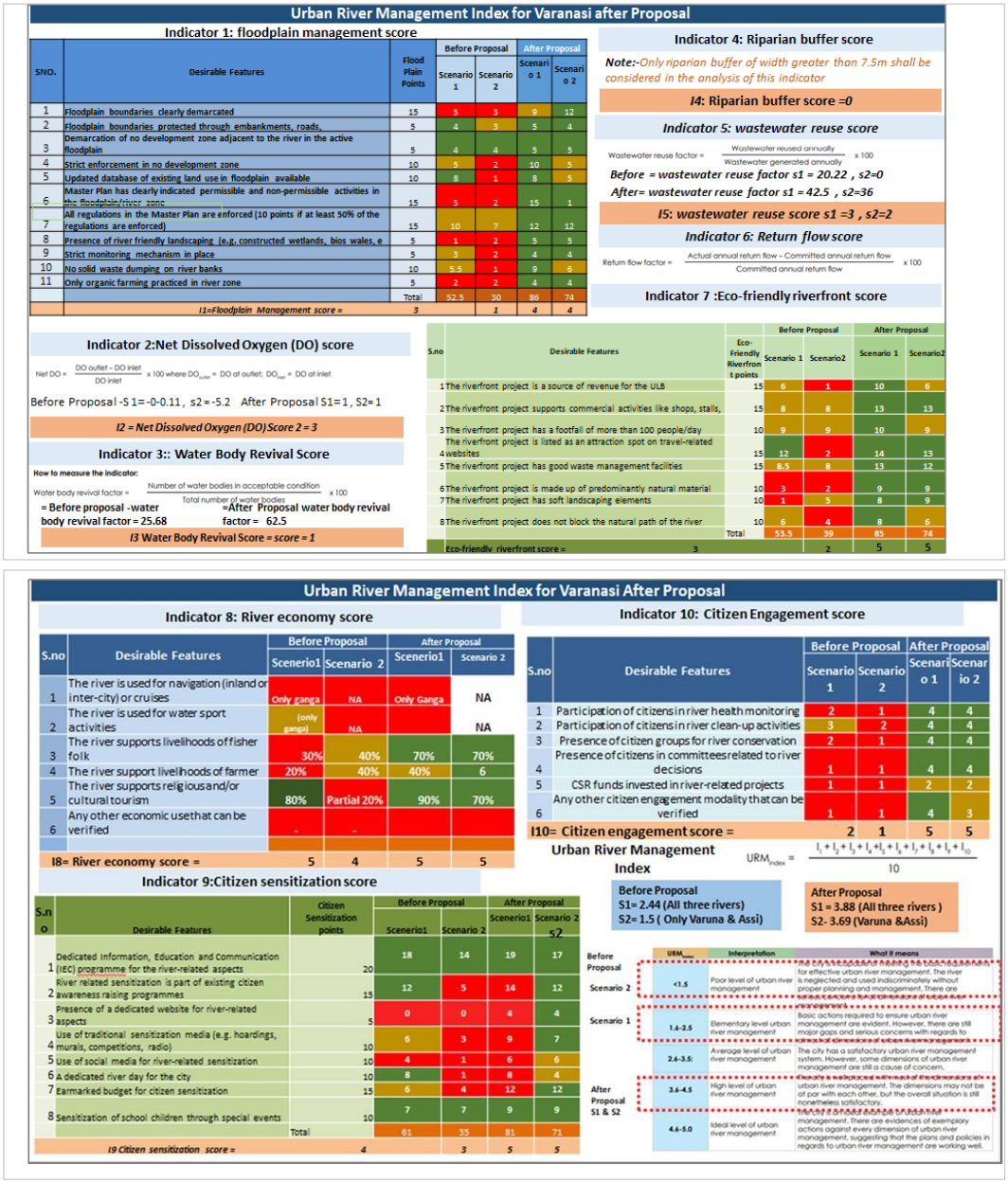
Source: Primary Survey, 2022

Following a priority-based approach, the treated water is then allocated among industrial, agricultural, and gardening purposes. The breakdown for treated water usage is: 89.5 MLD for industrial purposes, 123.7 MLD for agricultural purposes, and 50 MLD for gardening purposes.

Urban River Management Index for Varanasi after the Proposal

The URM Index has been recalculated to assess Varanasi's performance in river management post the proposed interventions. The indexing process was carried out by utilizing the following 10 indicators. Figure 11 shows the calculation of the index by various indicators after the proposal.

Figure 11: URM Index After Proposal



Source: Author, 2022

Urban River Management Index

Each indicator has a value between one and five. An average of all the indicators will yield the URM_{index}.

$$URM_{index} = \frac{I_1 + I_2 + I_3 + I_4 + I_5 + I_6 + I_7 + I_8 + I_9 + I_{10}}{10}$$

After the proposal:

URM Index score A= 2.44 (All three rivers before proposals)
URM Index score B= 3.88 (All three rivers after the proposals)

The URM Index for the city after considering the existing conditions shows that elementary level urban river management is being done, whereas the URM Index after the proposal shows that the city is well placed with most of the dimensions and is managing the river properly. Hence, the hypothesis created is justified: if any city manages its rivers with proper strategies and solutions, then the rivers will not face the issues that they are facing now.

Conclusion

Urban areas contribute significantly to the adverse effects on rivers. Therefore, it is crucial to design cities in a manner that minimizes these impacts by emphasizing a mutually beneficial relationship between urban areas and rivers. This study examined the assessment of Varanasi by highlighting various parameters for river management. It was concluded that the Urban River Management Index for the city, considering the existing condition, shows that elementary-level urban river management is being done, but after proposing interventions with respect to every parameter, the URM Index shows that the city is well placed with most of the dimensions and is managing the river properly.

It is essential for cities to align their development plans with consideration for the rivers by acknowledging the natural disturbance threshold. Worldwide, cities are increasingly recognizing the importance of prioritizing a 'nature first' approach for planning, which significantly influences the overall liveability of the urban spaces. At this juncture, the shift towards Nature-based Solutions is imperative.

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Conflict of Interest

Authors have no conflict of interest to declare.

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Integration of Spatial Technology and Mobile Application for Re-Imagining Urban Rivers Through Citizen Participation: A Case Study of River Hooghly

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Abstract

Extensive use of our water resources has led to a decline in the water quality and volume of water in our rivers. Urbanization has been a major cause of several environmental problems and one of the most neglected aspects of nature are our rivers. To find an environment friendly sustainable approach to clean rivers, this study encourages nature-based solutions to improve the water quality of our rivers and the usage of solar powered boats and biofuels. This study further focuses on River Hooghly in the Howrah region of Kolkata and gives an idea of the river status by using the QGIS (Quantum Geographic Information System) and secondary data, which is subjected to heavy footfalls mainly due to daily religious activities, transportation, and tourism. Unlike the earlier eras where civilization started from rivers, now urban developments are moving further away from them.

There is a need to re-imagine our urban rivers and to develop the citizen and river connect. Remediation of rivers is kept low in the priority list. Hence, to promote citizen involvement in

mitigating pollution-based challenges for rivers, an app user interface (UI) is built by using Flutter Flow which promotes cleaning of rivers through an app-based approach. The app is further editable and extendable and shows how it can be used to make data accessible to citizens and encourages them to clean the river and its banks and contribute to nature.

Keywords: Nature-based, Flutter Flow, River, Citizen Participation

Introduction

Increase in the population of India has led to over exploitation of our water resources and degrading the status of rivers. The increasing demand for water has put a lot of pressure on our rivers as well as on other water resources. Many rivers have dried out due to over extraction of water as well as groundwater from nearby regions. The mitigation measures of floodplains and interference with the riverine ecosystem without understanding what the river demands, has had negative impacts on the environment.

Rivers are one of the most neglected natural resources and are low in the priority list for remediation. Several factors have led to the poor condition of our rivers. The perception of a river varies according to different people from different fields. A river system includes river sources, its tributaries, the riverbed, channels, floodplains, riverbanks, deltas, wetlands, and hydraulics of the river. If any component is affected, it affects the entire river.

There is an immediate need to cease sewage dumping and polluting our rivers and to act responsibly. The effort to look for a cost-effective, less labour-intensive alternative which affects the environment less is continuing.

There is a shift towards Nature-based Solutions with people increasingly trying to utilize nature to remediate the damage that has been done. Nature-based Solutions include bioremediation and phytoremediation. The use of solar energy for ferry services and biofuel is being tested and is highly encouraged. Citizen participation needs to be more focused as citizens are the main culprits in this sin of damaging the environment. Hence, we should look for more ways to involve citizens in mitigating the issues related to rivers.

This study focuses on promoting citizen engagement through an app that is dedicated specifically to rivers so that people know more about rivers and become sensitive towards polluting them. The status of River Hooghly has been analysed by using secondary data from the West Bengal Pollution Control Board (WBPCB) website to study the water quality and to better understand the river. Also, a framework has been proposed to utilize NbS and renewable energy to improve the water quality of the river along with engaging the people for the same.

Status of Indian Rivers

According to the Composite Water Management Index issued in June 2018, more than six hundred million people in India face severe water shortage. Around three-quarters of the country's households do not have access to safe drinking water.

India ranks 120 out of 122 countries in the water quality ranking, with roughly 70% of its water being contaminated. Every year, thousands of people flock to the Ganga's *ghats* (banks) to bathe and pray. This is why it is one of the world's most polluted rivers. It also has alarming quantities of pollutants and sewage waste dumped into it every day by over 1,100 industrial units and many municipalities that are located along its banks. According to a recent assessment by the Central Pollution Control Board, the water in River Ganga is unsafe for bathing, let alone drinking. The apex environmental monitoring agency, the National Green Tribunal (NGT), has ordered Jharkhand, West Bengal, and Bihar each to deposit Rs 25 lakhs for failing to take appropriate steps to reduce pollution in the River Ganga.

The Brahmaputra, a 2900-kilometre-long river that serves as Assam's lifeline, is currently suffering from water pollution that is caused by sewage waste and oil spills. Currently, it is lifeless due to rapid urbanization and lack of efficient infrastructure for trash disposal. According to a recent estimate, at least twenty-eight kilometres of the river in Assam is extremely contaminated. The Yamuna which was once the lifeblood of Delhi and one of India's most revered rivers, has now become one of the world's most polluted rivers. The Yamuna water is exceedingly dangerous to drink because of heavy metal discharges and excessive amounts of Coliform, a disease-causing bacterium.

River Cauvery, which rises in Karnataka before it flows into Tamil Nadu, is subject to intense coastal conflicts and is in a state of decline. Once stable, the river is now a sea of sand, dotted with rocks and bushes on a dry riverbed. Along the entire course of the river, the ecosystem has been destroyed by human activity. The riverbed is severely affected in several sections on both sides. Given the controversy between the two riverbanks, less attention has been paid to the various other creatures of the river. Fish, otters, birds, and butterflies are examples of wildlife that depend on the Kaveri River for food. Populations of fish species such as Masir have declined significantly due to the reduced river water flow. The decrease in flow rate has also led to an increase in pollution. People often bathe in the shallow waters of the Kaveri River but they may not be aware that the levels of faecal coliforms in the water are so high that it is not suitable for bathing.

The River Gomti and its marine life, formerly an important supply of water for the city of Lucknow, are now nearly extinct, due to high pH levels of the water. The state's biggest challenges are indiscriminate groundwater exploitation, sewage disposal, and municipal garbage dumping on the riverbanks. According to ecologists, the installation of diaphragm walls on the river's banks has harmed the river's natural flow and self-cleaning capabilities. The Musi Riverbank is now a dumping ground for many and is slowly disappearing due to severe drought. It has become one of the most polluted rivers in the country. Successive attempts by the government to cleanse the river have been unsuccessful.

River Remediation Practices in India

Plans to restore the spread of polluted rivers can be done by improving the river flow through intervention in basins/catchment areas for preservation and strengthening of stormwater. This concept works by reducing pollutants in the rivers and streams which in turn reduces concentrations to desirable levels. Evaluation of water quality which is provided by water

resources in the long-term gives information on the extent of rivers that do not meet the water quality standards and are identified as contaminated.

Evaluation studies conducted at the source of the river pollution have highlighted the need to build infrastructure facilities (STPs/CETPs/ETPs) for wastewater treatment according to the low flow rate or no flow rate of freshwater in the rivers and streams. The sewage stream makes it a perennial river. To increase the availability of water outside the monsoon for a complete upper-level watershed management requires four phases. These proposed stages of Basin Management are:

- Recognition phase
- Recovery phase
- Protection phase
- Improvement phase

The polluted river stretches throughout the country have been identified for restoration of water quality through identification of the pollution sources and interventions by treatment of municipal and industrial effluents. The river restoration action plans intend to control pollution and restore the river. The infrastructure development for sewage treatment of wastewater generation to improve the quality of water always falls short. The ever-increasing population and the increased use of water in urban areas outpaces the plan for its creation. Even though river action plans have not improved the water quality, in the absence of such plans, the quality of aquatic resources also deteriorates further.

The methodology for river restoration includes:

- Managing catchment areas
- Restoration of the course of river
- Reconnecting floodplains and creating wetlands
- Instream enhancement

Role of FlutterFlow and Application of QGIS for Conceptualizing and Building River Focused Application (App)

As technology has advanced, there is an exponential rise in screen time. Apps have replaced real life interactions. The idea is to turn this virtual curse into a boon by conceptualising an app to help our rivers. This app mainly focuses on democratizing real time data of the river's parameters, incentivising citizens to engage in activities related to improving the condition of rivers, organising events and involving maximum number of people, and lastly, promoting greener alternatives for the river transport network. The app can be designed by using FlutterFlow where it shows how we can build a prototype of the app which can be used for reimagining our rivers.

FlutterFlow is an interface to build an app by using a browser which facilitates a drag and drop feature. It is a faster and easier way to build apps in an effortless way. It is a visual builder that helps to choose the elements from its list and drag and drop them in the desired location on the page. It enables us to easily and smoothly integrate data and API. FlutterFlow has a multi-language app

building facility as well. One can build custom widgets and include customised functions. After all this is done, we can download our code and deploy it in app stores. In this study it has been used to build the app with the purpose of promoting citizen participation.

QGIS is a free open-source graphic information system application for PC that is used for visualizing, editing, printing, and analysing geospatial data. It is also used to export and compose graphical maps. It supports raster, vector, and mesh layers. The point, line, and polygon features are stored as vector layers, and the aerial photographs and satellite images are stored as raster data. In this study QGIS is used for visualizing the study area and understanding its geographical details. Through this platform the app can be used to introduce a new mode of interaction between the citizens and the river which will benefit the environment thus giving a scope to improve the lost connect between the people and the river.

Statement of the Problem

River Hooghly is a major source of potable water in Kolkata. There are several ghats along the banks of river Hooghly which are being used for various purposes such as transportation, religious practices, and tourism. Some are very well managed and well developed but do not address the issue of river pollution. The river is used for procuring potable water while people use it for transportation. It is subjected to contaminants from burning fuel as the river is used extensively for ferry services. The water quality of the river is getting degraded not only due to the contaminants from fuel but also from the tourists who pollute the river and its banks. There is a need for an environment friendly solution to this problem.

The lack of citizen and river connect has also led to an increase in pollution of the river. All this is putting a lot of pressure on the treatment plants and affecting the lives of aquatic species. The BOD of some stretches is so high that it almost makes it impossible for fishes to survive. Most parts of the river are also unsuitable for bathing. It is also noticed that the Dakhineshwar stretch of the river experiences a footfall of over fifty thousand people daily. Hence, it has become imperative to reconnect the people to the river and encourage their contribution towards cleaning it.

Objectives of the Study

The first objective of the project is to quantify the pollution in River Hooghly and propose a framework for improving the water quality and cleaning its banks. The intention is to explore the possibility of employing selected Nature-based methods to minimize the environmental impacts of the remediation process. Bioremediation and phytoremediation are two Nature-based Solutions to the problems that are associated with the polluted river.

The second objective is to carry out feasibility studies of biofuel powered boats and ferry services, and the use of solar powered boats. This will help in energy conservation and decrease the pollutants of fuel in the river. Shifting towards Nature-based sources of energy will help to reduce the environmental deterioration and promote the usage of green energy.

The third objective is to develop spatial technology supported by app-based solutions to monitor, report, and clean plastics and develop the polluted area. The app will help in mobilizing volunteers

in location-based groups who can come together to clean the area. This will help in encouraging public involvement and controlling pollution of the river banks and the surrounding areas.

Scope of the Study

This study will cover all the steps that are involved in designing a UI for the app. The study will be extended to understand the status of the river. In that context, a comparison between the years of 2020 and 2021 has been done to understand the extent of the pollution. QGIS is used to visualize the study area. Further, it gives a framework for utilizing Nature-based Solutions for the remediation of River Hooghly. The scope of solar powered and biofuel powered boats have also been studied to promote a green initiative.

Study Area

The Farakka Feeder Canal, rather than the river's natural source at Giria, provides most of the water that flows into the River Hooghly. The Farakka Barrage is a dam that redirects water from the River Ganges into the Farakka Feeder Canal near Tildanga in Murshidabad district, forty kilometres upstream from Giria. It forms the border between Bardhhaman and Nadia districts South of Baharampur and North of Palashi, but while the border has remained the same, the river is now frequently East or West of its former bed.

The river continues South, passing through Katwa, Nabadwip, Kalna, and Jirat. It originally formed the border between Nadia and Hooghly districts in Kalna, and then between Hooghly district and the North 24 Parganas district further South. It runs through the towns of Halisahar, Chinsurah, Naihati, Bhatpara, Serampore, and Kamarhati.

The study area covers the Dakhineshwar stretch of River Hooghly where religious events take place, till Babughat which is used for ferry services. The case study area taken is a 15 km stretch of the river. The bank is digitized using QGIS.

Figure 1: Digitised Map, Dakhineshwar Stretch of River Hooghly

Source: Google Earth Image

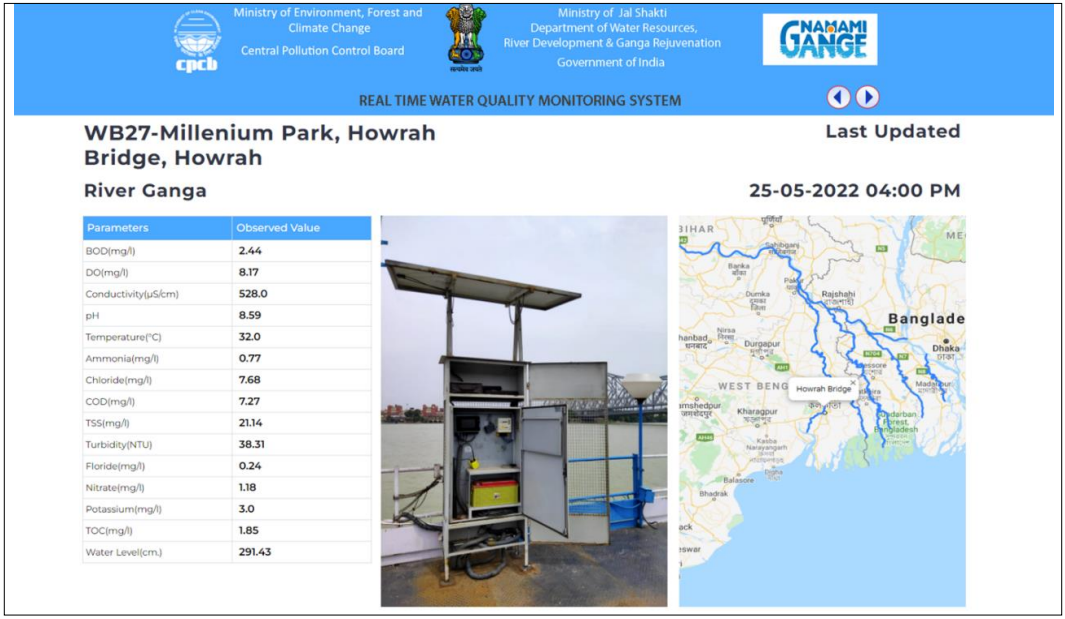
River Hooghly – The Lifeline of Bengal

The Bhagirathi-Hooghly River is a life saver for individuals of West Bengal. It was through this waterway that the East India Company cruised into Bengal and laid out their exchange settlement, Calcutta, the capital of British India. Individuals from different nations like the French, Dutch, Portuguese, and so forth undeniably had their exchange settlements by the banks of this waterway.

The water is a perpetual inventory of the plains of West Bengal for its water system and human and industry utilization. The waterway is traversable and a significant vehicle framework in the district with an enormous traffic stream. From here onward, indefinitely for quite a while, the Calcutta Port was the greatest port of India. Albeit in the past its importance had gone down, of late it is at third position in the rundown of Indian Ports. The innovative compartment port of Haldia, on the crossing point of lower Hooghly and Haldi rivers, presently conveys a significant part of the district's oceanic exchange.

Though contaminated, the fish from the waterway are a means for the neighbourhood economy. The Hooghly waterway valley was the main modern territory of Bengal. Due to the declining jute industry, which was once a well-established business of this district however, is yet one of the greatest modern areas of India. It has a number of little urban communities which frame the Greater Kolkata agglomeration, the second greatest Indian city and the previous capital of the country. In September 2015, the Government of West Bengal declared that redesigning of the Hooghly riverfront in Kolkata will be completed with the assistance of the World Bank subsidizing under the National Ganga River Basin Project Scheme.

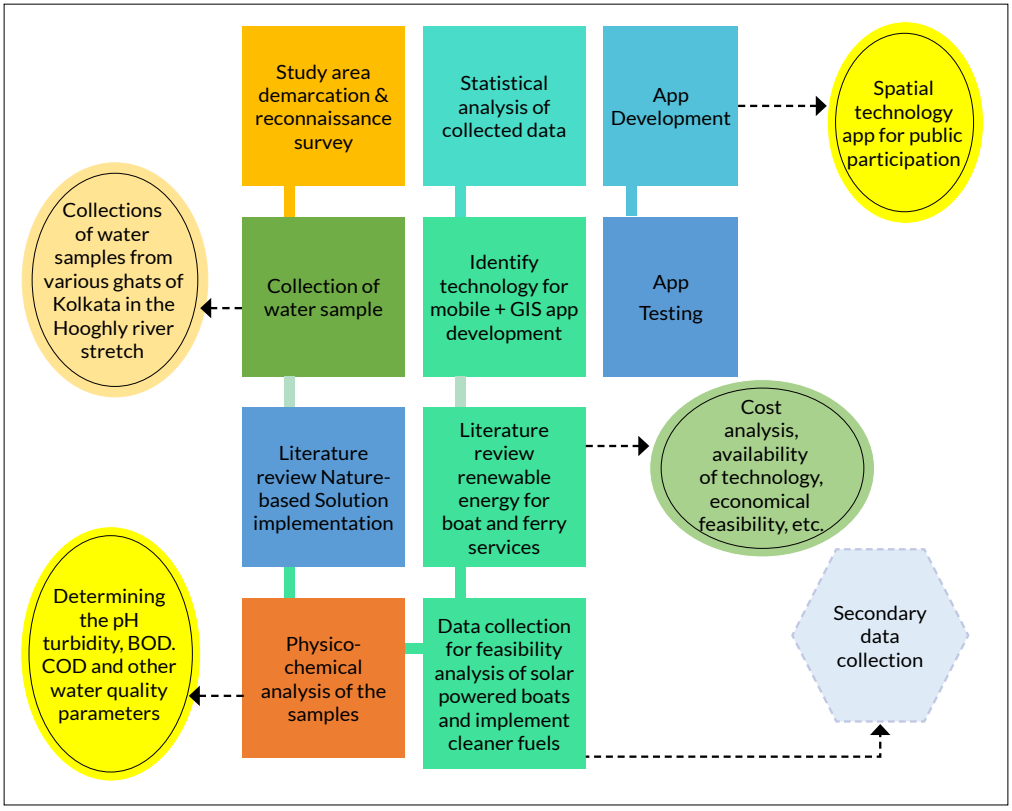
Figure 2: Hooghly River Water Quality Measurement at Millenium Park, Howrah



Parameters	Observed Value
BOD(mg/l)	2.44
DO(mg/l)	8.17
Conductivity(µS/cm)	528.0
pH	8.59
Temperature(°C)	32.0
Ammonia(mg/l)	0.77
Chloride(mg/l)	7.68
COD(mg/l)	7.27
TSS(mg/l)	21.14
Turbidity(NTU)	38.31
Floride(mg/l)	0.24
Nitrate(mg/l)	1.18
Potassium(mg/l)	3.0
TOC(mg/l)	1.85
Water Level(cm.)	291.43

Source: Department of Water Resources, Ministry of Jal Shakti, Government of India

Figure 3: Methodology of the Study



A survey of the Dakhineshwar stretch of the river was explored and observed to understand the study area, for an assumption regarding the pollution status of the river as well as the banks.

A thorough literature review was done to understand the current status of the rivers in India. Through the literature review it was evident that pollution has been degrading our nature and environment. Indian rivers are in a tragic state due to several anthropogenic activities and climate changes. Intervention is required to cease such activities that are ruining the water quality and affecting the survival of aquatic species in our rivers. The literature gives us an idea of the effectiveness of NbS and the possibility and feasibility of NbS in our country. It gives us a glimpse of how we can contribute towards our environment by using greener fuels and renewable sources of energy for ferry services.

Water quality assessment was done using secondary data that was obtained from WBPCB site

and the status of the river was assessed. Water quality parameters included TSS (Total Suspended Solids), TDS (Total Dissolved Solids), turbidity, pH level, E. coli, Faecal coliform, etc.

The platform to build a UI for the mobile app was decided and FlutterFlow was used for designing the User Interface of the app. The UI was developed and the framework was built. The platform enables us to edit, and it is further extendable to be developed into a fully functional app using FlutterFlow.

Data related to the water quality parameters was collected from WBPCB (West Bengal Pollution Control Board). The data was collected from their monitoring stations that are located in the Dakhineshwar region.

Figure 4: Demarcation of the Case Study Area Using QGIS Software

Source: Google Earth Maps

To get the ESRI (Environmental Systems Research Institute) map, the ESRI Satellite option needs to be selected after clicking on search from the quick map services under the Web menu. The plugin for QSM (Quality Systems Management) needs to be installed to access it. After the map is added, the desired location can be searched in the map. To digitize the study area, the edit mode has to be turned on and using the add line feature one can digitize the bank line and mark the stretch of the river. To add locations for ghats, Google My Maps was used, and the layer was exported in QGIS.

Building User Interface (UI) for the Application (App)

The app UI was built using FlutterFlow. You see the Project Dashboard when you sign into FlutterFlow. The Dashboard page assists you in dealing with your undertakings in FlutterFlow. You can make, copy, or erase your undertakings from this page. The page has connections to

different assets that assist you in building applications through FlutterFlow. Your record data and plan subtleties are additionally available from this page.

The point when you are inside any undertaking, this page can be reached by utilizing the home symbol on the navigation menu.

The Widget Panel gives admittance to all the UI components on FlutterFlow. Fundamentally, these are Flutter gadgets that can be relocated on the material. The pursuit bar is convenient to rapidly look for a particular gadget that you need to add to your application.

Widgets (elements) are accessible from the Widgets tab. They are sorted into five categories:

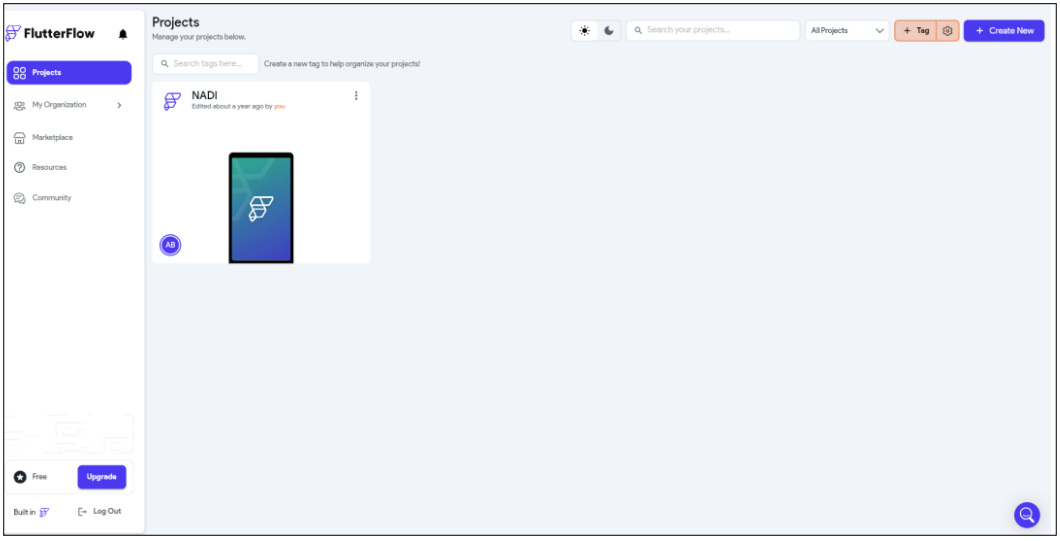
- Most Frequently Used Elements
- Layout Elements
- Base Elements
- Page Elements
- Form Elements

One can use custom UI components in their FlutterFlow project. These custom components are accessible from the Components tab. A new project on FlutterFlow comes with more than 50 pre-built components including sign-in buttons and some other styled layouts. For a new custom component, you can create a custom components section.

The components are also sorted into five categories:

- UI Elements
- Bottom Sheets
- Headers
- Card Views
- Content Views

Figure 5: Project Interface on FlutterFlow



Firebase is a versatile application stage which has coordinated and brought together client libraries in different portable programming dialects. Firebase's different Backend-as-a-Service (BaaS) assists in growing great applications, developing a client base, and bringing in more cash. Each element works freely, but they work far better together. To utilize the Fire store's portable/ web client libraries and other Firebase highlights, we need to add Firebase to our current Google project. Hence, Firebase is added to the project.

Figure 6: Application Interface on FlutterFlow

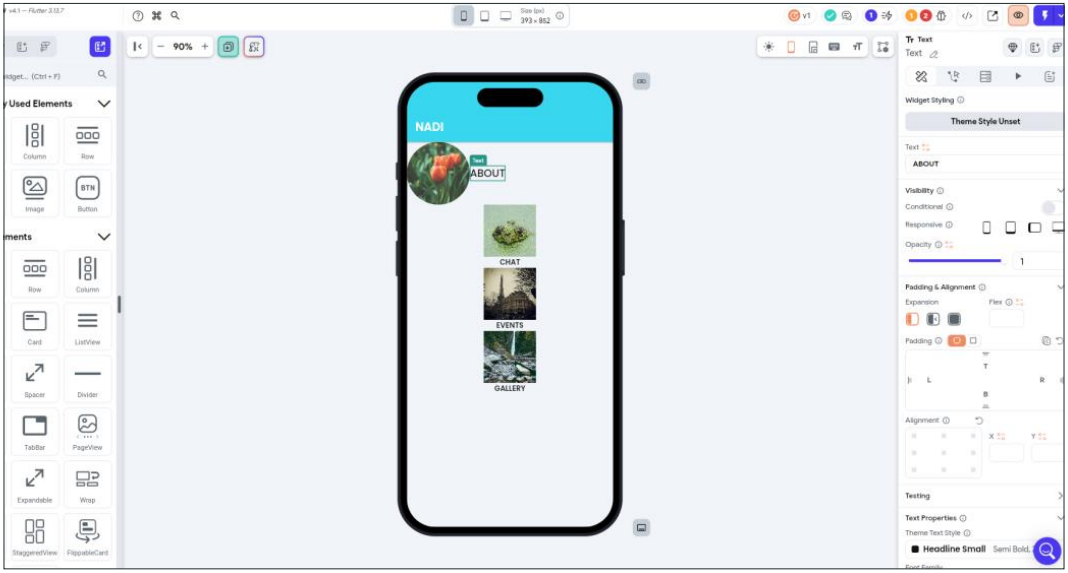
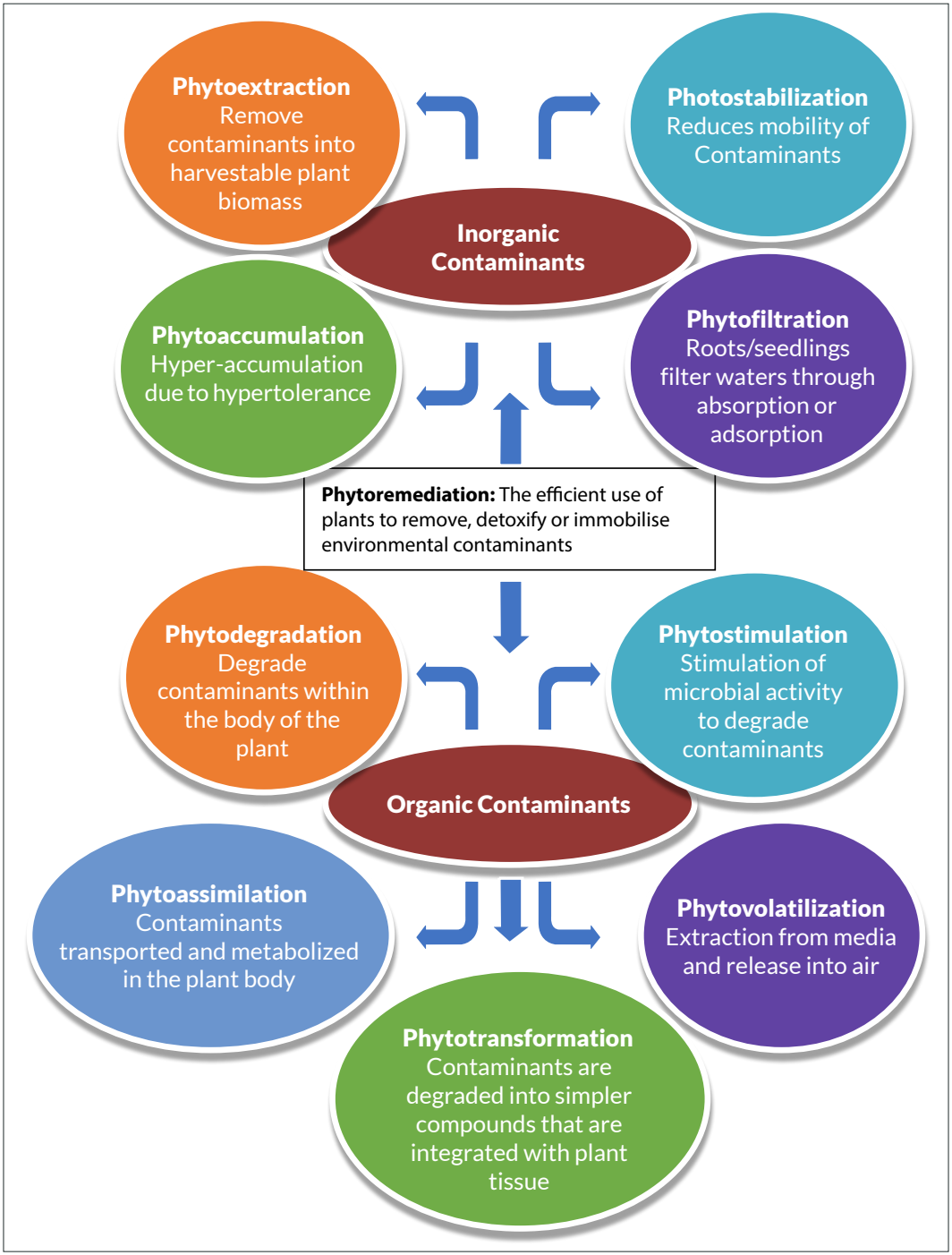


Figure 7: Nature-based Solution



Nature-based Solutions

Phytoremediation: A Plant Based Eco-Accommodating Innovation

United Nations Environment Program (UNEP) characterized phytoremediation as "the productive utilization of plants to eliminate, detoxify, or immobilize natural foreign substances" (UNEP, 2019). Phytoremediation is an eco-accommodating and worthwhile strategy for cleaning defiled media. The components include retention of poisons through roots, gathering body tissues, and decaying and changing contaminations to less hurtful structures. This procedure is utilized effectively in tidying up water pollution, and has acquired genuine consideration by researchers, government and non-government bodies.

Nonetheless, use of plants in the treatment of wastewater began quite a while back (Carolin et al., 2017). Diverse types of sea-growing plants have been confirmed and perceived for their effectiveness to aggregate inorganic and natural pollutants from the waters through aquaculture or field applications. Likewise, the progress of a phytoremediation framework relies upon factors that are related to the seriousness of the contamination.

Besides, different phytotechnologies like phytodegradation, Phytostabilization, rhizofiltration, rhizodegradation, and phytovolatilization have been used for polluted biological systems. Further, the underlying foundations of specific plant species gather, adsorb, and encourage toxins in the dirt and water through the immobilization process. Plants have extraordinary capacity to consume and volatilize foreign substances straight into the environment through the phytovolatilization process. The plants utilize the impurities by certain mixtures that are delivered inside the plant tissues through phytotransformation/phytodegradation process.

Table 1: Oceanic Macrophytes in the Phytoremediation of Natural Poisons

S. No	Plant Name	Response to contaminants	Reference
1	Lemna minor L	Reduced enzymatic activity, photosynthetic efficiency, chlorophyll, roots and shoots growth	Radic et al. (2010) Razinger (2008)
2	Eichhornia crassipes	Reduced growth, chlorosis, wilting, decreased plant height and root length, death of the plant	Theeta et al. (2018)
3	Pistia stratiotes L	Reduction in the root volume,chlorosis, cell membrane damage, reduction in growth rate, photosynthesis, increase in enzyme activity specially such as superoxide dismutase (SOD), catalase (CAT), peroxidase (POX) and ascorbate peroxidase (APX)	Vidal et al.(2019), Theeta et al.(2018)
4	Ipomonea aquatica	Increase in root size and decrease in root length	Jung-Chun et al.(2010)
5	Isoetestaiwanensis	Inhibition of root and shoot growth	Li et al.(2005)
6	Echinodorus amazonicus	Reduced growth, plant height and root length decreased, chlorosis	Theeta et al.(2018)

Source: Ansari, Abid Ali, M. Naeem, Sarvajeet Singh Gill, Fahad M. AlZuaibr (2020). Phytoremediation of contaminated waters: An eco-friendly technology based on aquatic macrophytes application, Egyptian Journal of Aquatic Research, Volume 46, Issue 4, Pages 371-376.

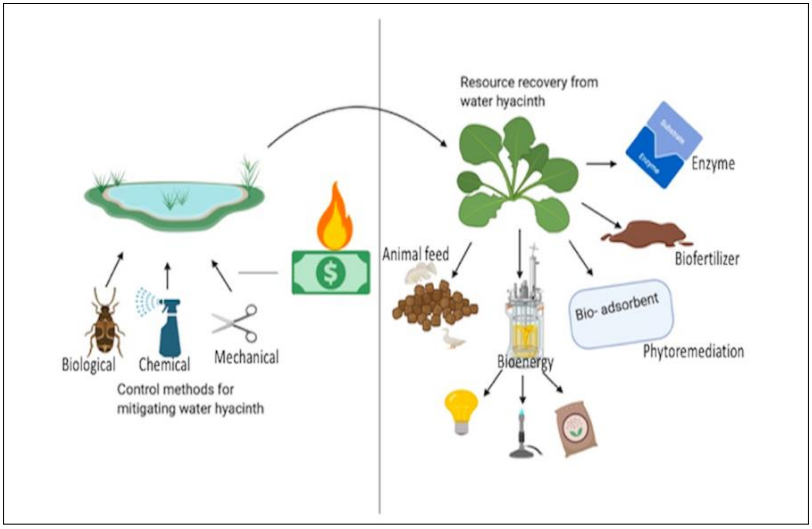
Free drifting macrophytes viz. Salvinia, Lemna, Eichhornia, and Pistia showed their phytoremediation. The HMs like Cd, Zn, Pb, Mn, Ni, and Co up to a scope of 100-1000 times are gathered by the hyper aggregators when contrasted with non-gathering plants. The bioavailable part of metal particles is expanded by the activation components. For example, microorganism growths and microscopic organisms exist in close relationship with the roots of for example rhizosphere and assume a critical part in disposing of the natural pollutants (Erdei et al., 2005).

Oceanic macrophytes in water bodies adjust the physio-synthetic climate of the body. The presence of other oceanic photosynthetic autotrophs cut down the degree of disintegrated CO_2 in water during high photosynthetic movement. These increments disintegrate oxygen in wastewater which causes expanded water pH levels.

E Crassipes or Water Hyacinth as Phytoremediator

The system of Planted Floating Beds can be made by two thick bamboo tubes (TBT). One TBT should have poked holes and the plant is relocated in the upper openings. The other TBT is utilized to fix TBT with openings and make a drifting. Two TBTs are fixed together, and the net is pulled up. It is critical to note that the temperature of the nursery should be within 10 to 20°C as done for River Guxin.

Figure 8: Water Hyacinth as Phytoremediator



Planned Planted Floating Beds give a good climate to the plant. Eichhornia crassipes grow well in summer. The outcomes (Wang et al. 2011) showed that NH3-N, COD, TP of the study stream decreased 48.6%, 20.0%, 63.3% individually. The commercial development of Eichhornia crassipes decreases the turbidity by adsorbing a mass of residue from the stream and work on the look and feel of the water body. Therefore, Phytoremediation is a successful method for eliminating natural matter from the contaminated waterway.

Solar Powered Boats and Promoting Green Initiatives

A solar boat configuration process is unique as compared to an ordinary boat. It begins with characterizing useful and execution needs. Typically, such useful and execution determinations are made to match the customary boats. Solar powered boats are successful as traveller boats where the impetus power required is less (not normal for high velocity boats, pulls, fishing vessels, freight vessels).

A productive solar boat requires two unique yet basic features:

- Decrease in propulsion power
- Improvement in the energy of executives

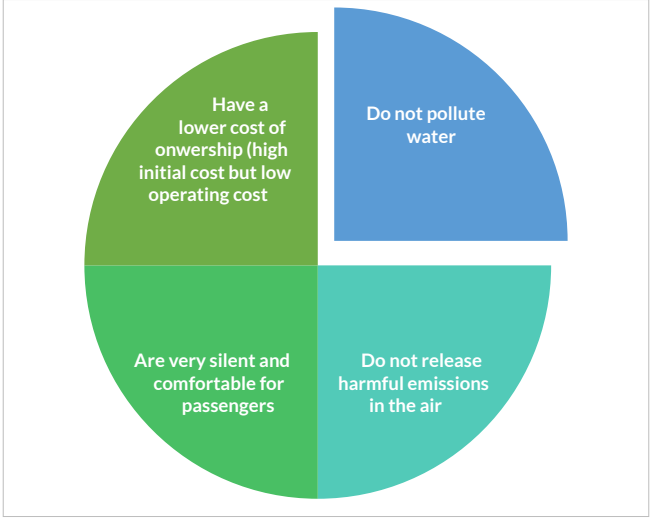
Economic Analysis: Huge solar ships are multiple times costlier than a customary single structure steel ship. If one raises the ergonomics and security guidelines of the regular boats to that of solar ships the proportion is nearly three to one.

The consumable expense (fuel) is approximately Rs 3 million for a huge customary ship as compared to zero for solar ships. Diesel motors and steel frame structures have higher support in comparison to electric engines and FRP bodies. The all-out working expenses of an ordinary ship are approximately Rs 3.5 million each year.

A contextual analysis of 75 Pax Solar Boat from a case study shows that to move 75 travellers across a 2km backwater stretch of Kerala at 5.5 knots speed in a solar ship worked under class. The energy stockpiling size has to be intended for the radiant condition to decrease the expense (diminish the size of the battery bank). For opening the seating of 75 travellers and 3 groups, a sailboat with a deck area of 15m length and 5.5 knots expansiveness is adequate. After numerous emphases, it was found that around 20 kW solar charger power is expected to give energy to the executives. For this reason, the boat size was characterized to 20m length and 7m breadth.

After different emphases, the heaviness of the boat in completely still air was 23 T. A sailboat structure which was chosen gave the best presentation with minimal opposition. This determination of structure depended on improvement of the utilizing computational liquid elements (CFD). This frame needed around 16 kW to drive at 5.5 knots and around 22 kW for a brief period prompting normal 18 kW utilization. Two engines of 20 kW power were chosen that guaranteed 100 percent overt repetitiveness. At full power, the boat will journey at 7.5 knots.

Figure 9: Criteria for Useful Solar Ships



The typical solar energy creation from 1 kW of the sun-powered charger is 4 kWh of energy each day considering the framework effectiveness and standard sun of the area of 5.72 (found the middle value of consistently). Thus, the energy from the sunlight-based chargers is 80 kWh. The absolute energy needed to work the ship for 5.5 hours is 110 kWh. A 50-kWh battery bank of lithium iron magnesium phosphate is chosen for simplicity of game plan and to give energy support. The hole in the energy is given by the lithium battery that can give up to 40 kWh (80% release) from the complete limit of 50 kWh.

An ordinary 75 traveller ship that must be worked with comparable ergonomics and well-being guidelines under order of society endorsement would cost approximately Rs 18,00,000, with a twin 50 HP fundamental motor and utilization of 12 litres diesel each hour overall, and a sum of

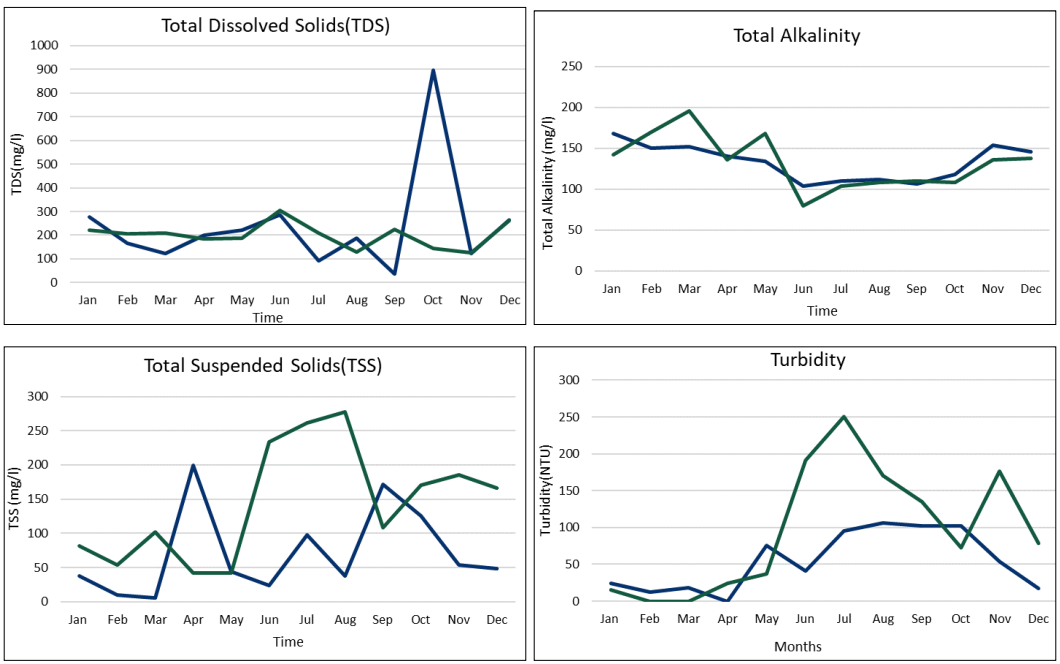
120 litres each day (motors running constantly). The current cost of diesel (Rs 90 per litre) adds up to Rs 900 each day and Rs 3,30,000 each year (350 days running). The diesel cost is expected to consistently increase by 5%. The greasing-up oil can be taken as 10% of fuel cost, which is Rs 33,000 consistently. Support cost for motors is another 5% which is approximately Rs 17,000 each year. Complete working expense each year will be about Rs 4,00,000 (barring work and different costs that are same in both). These are supposed to develop 5% every year. For sun-powered ships, a working expense that comes at regular intervals is the substitution of battery banks of 50 kWh. This can be taken as Rs 35 lakh. An everyday network charging of 40 units (kWh) at the expense of Rs 480 (@11/unit of business power) and a sum of Rs 1,60,000 annually which is expected to develop at 5% each year.

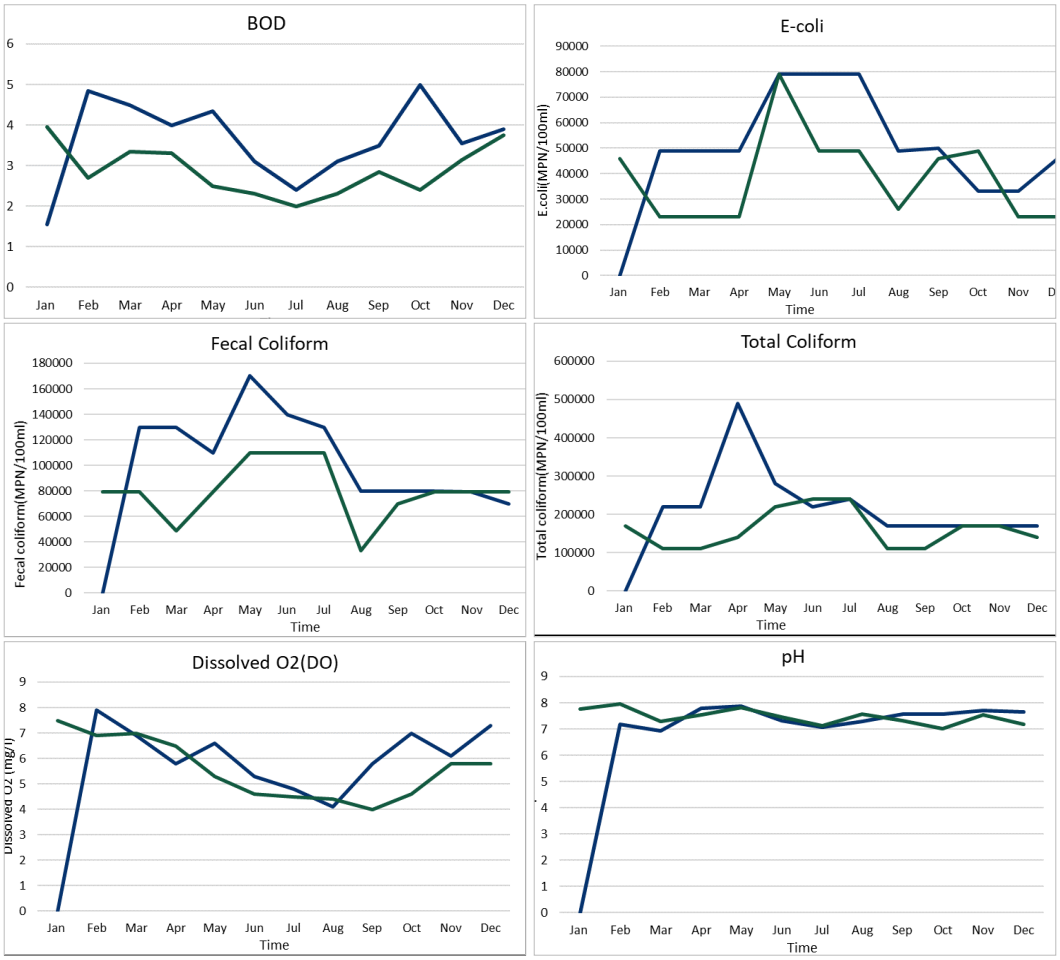
Solar powered boats have higher forthright expenses, but the all-out cost of possession is lower. This boat has an earn back of the original investment time of only three years. Additionally, the boats are intended for a long time, consequently the investment funds will gather. The complete reserve funds in a boat in its 20 years lifetime is Rs 93,50,000. Hence, a similar kind of green solution can be considered for Kolkata's ferry services that could save a major portion of contaminants from ending in the rivers and save money for fuel and promote the usage of green energy.

Current Situation of River Hooghly

Comparison has been shown based on the secondary data that was obtained from WBPCB.

Figure 10: Water Quality Parameter Data Comparison - 2020 (in blue) and 2021 (in green)





Source: WBPCB

The water quality parameters compared in this study are Total Fixed Solids (TFS), Total Alkalinity, Total Suspended Solids (TSS), Turbidity, BOD (Biochemical Oxygen Demand), E-coli, Faecal Coliform, Total Dissolved Solids (TDS), pH, Total Coliform, Dissolved Oxygen (DO).

Absolute solids are disintegrated solids in addition to the suspended and settleable solids in water. In stream water, disintegrated solids comprise of calcium, chlorides, nitrates, phosphorus, iron, sulphur, and other particles that go through a channel with pores of around 2 microns (0.002 cm) in size. Suspended solids incorporate the residual and earth particles, tiny fish, green growth, fine natural garbage, and other particulate matter.

A high centralization of all solids makes drinking water unpalatable and unfavourably affects individuals who are not used to drinking such water. Additionally, complete solids influence the water clearness. Water warms up more quickly and holds more intensity which unfavourably influences the oceanic life that has adjusted to a lower temperature system.

Turbidity alludes to how clear the water is. The significant presence of turbidity in the vast water zone of most lakes is normally phytoplankton, however nearer to the shore, particulates may likewise be muds and residues from coastline disintegration, resuspended base silt, and natural garbage from streams or potentially wastewater releases. Digging tasks, channelization, expanded stream rates, floods, or even too many bases taking care of fish (like carp) may work up base dregs and increase the darkness of water.

Fine particulate material can stop or harm the delicate gill structures, decline their protection from illness, forestall appropriate eggs and larvae, and possibly slow down the molecules that take care of movements. Similarly, decreased photosynthesis brings about lower daytime oxygen into the water. To sum up, the impacts on phytoplankton development are perplexing as they rely upon an excessive number of elements. In general, extremely elevated degrees of turbidity diminishes water clearness. Running water, because of its beating, breaks down more oxygen than still water, like in a repository behind a dam.

Wastewater from sewage treatment plants contains natural materials that are decayed by microorganisms which use oxygen simultaneously. Oxygen consumed by these life forms in separating the waste is known as biochemical oxygen demand or BOD. Other wellsprings of oxygen-polishing squander incorporate stormwater overflow from farmlands or metropolitan roads, feedlots, and bombing septic frameworks. Oxygen is estimated in its disintegrated structure as broken up oxygen or dissolved oxygen (DO). Assuming that more oxygen is consumed than is created, broken up oxygen levels decline, and a few delicate creatures move away, debilitate, or die.

DO levels change occasionally in a 24-hour time span. They differ with water temperature and elevation. Chilly water holds more oxygen than warm water and water holds less oxygen at higher heights. Generally, amphibian creatures are helpless against decreased DO levels in the early morning on warm midyear days when streams are low, water temperatures are high, and oceanic plants have not delivered oxygen since dusk.

Coliform microbes are available in the climate and dung of all warm-blooded creatures and people. Coliform microbes do not cause ailments. Most microbes that can taint water supplies come from defecation of people or creatures. Testing drinking water for all potential microorganisms is intricate, tedious, and costly. It is simple and reasonable to test for coliform microscopic organisms. Waste coliform microbes are a subgroup of aggregate coliform microbes. If infection causing microbes are present, the most well-known side effects are gastrointestinal diseases and general influenza like side effects such as fevers, stomach issues, and looseness of bowels.

The presence of algal growth prompts expansion in pH levels and oxygen fixation. Expansion in both boundaries demonstrate impediments to waste coliforms (Davies-Colley et al., 1999, Awuah et al., 2001). It is assumed that within sight of light, poisonous types of oxygen atoms are created (peroxides and singlet oxygen). The centralization of these atoms increases with expanded broken up or dissolved oxygen (DO) focus. They harm the cytoplasmic layer of the microbes (Awuah, 2006). Waste coliform increments are harmful with changes in pH levels. Research studies have shown that algal poisons assume a part in the inactivation of waste coliforms.

Conceptualization of 'NADI – The River Dedicated Application'

NADI is an app which has been conceptualised for involving the people of the city in mitigating issues related to our rivers. It will not only promote the issues but also help in including people in resolving those issues and make them a part of improving the condition of our rivers. The app facilitates engagement of users and enables them to participate in mitigation measures and help the government to address the river issues.

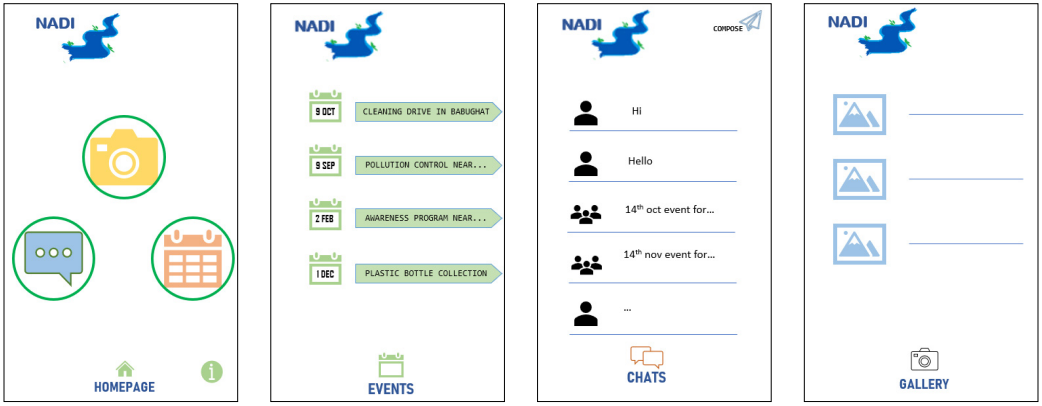
Wireframe

A wireframe is like a field blueprint within the style process. It is a point of reference for practical specifications and offers the merchandise team a basis to start making screens. The wireframing step should not be skipped as the design prioritizes the user's visual experience. An honest computer program is functional, dependable, and comfortable to use. Designers use user-centric designs (user interviews, direct observations, etc.) concerning their target audience and make sure that the visual language they introduce within the UI is well-tailored to suit them.

It is necessary to create an aesthetically pleasing UI because interfaces that have nice aesthetics are perceived usable by end-users as they are in step with the aesthetic–usability effect. Since users are fastidious where apps are concerned, they use them and then abandon those that they do not enjoy. Thus, it is essential to spend time and energy in making excellent user experiences. The higher the design, the better the prospects that users will interact with it and therefore keep using it.

- ***Visualize the structure clearly***: A wireframe is the first real method of a project. It turns abstract ideas into something tangible while not distracting.
- ***Clarify the options of interface*****:** A wireframe provides a transparent communication to the user on how these options will function, where they will be on the particular page, and how they will function.
- ***Facilitate to refine navigation*****:** A website wireframe allows individuals to check run a new site: to visualize how straightforward or tough it is to find the target pages; to see whether the dropdown menus clarify or confuse the users; to search whether the breadcrumbs are useful or distracting; to know whether the direction theme is intuitive, incomprehensible, or somewhere in between.
- ***Build the iterative planning method*****:** Rather than attempting to mix the functionality/layout and creative/branding aspects of the website in one step, wireframes ensure that these components are taken one at a time.
- ***Save time and effort*****:** Wireframing saves time in several ways. The styles are calculated; the development team understands what they have to construct with the blueprint in mind. Content creation becomes much clearer.
- ***Build effective content development*****:** Wireframes offer a summary of the contents. It helps in organizing fonts, numbered lists, bullets, and heads that show neatness and are aesthetically inclined.

Figure 11: User Interface (UI) of the 'NADI– The River Dedicated Application'



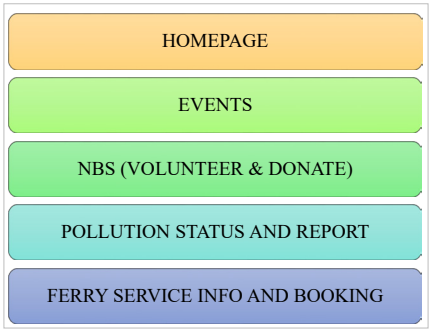
Building Application's User Interface (UI) using FlutterFlow

The app UI is designed in a way where citizens will be able to access information on current assessment of pollution, and they can even plan for events from the events page. Through this app, the pollution status of the river can be checked with the public contributing to the gallery of the app. A person can upload photos along with the location of the place that requires a clean-up and people can volunteer and plan to clean the area. The app can also be used to tie up with any non-governmental organisation (NGO) and make it even more effective in preventing river pollution. The UI features a homepage from where other pages can be accessed, which is followed by the About page, Events page, Gallery page, and Chat page.

The homepage is built in such a way that the purpose is understandable, easy, and simple to use. If the Pollution Status page is clicked, the About page opens to up-to-date status of the river which shows the current river water quality data, where it shows that the river quality is fit for bathing or not and similarly for other activities. The About page reveals the motive behind the app and lets the user understand how and why it is necessary to promote river sensitive developmental strategies for a better future. Pictures can be uploaded which help WBPCB to gather data on the polluted river stretches and banks and helps them to remediate as soon as possible and quantify pollution.

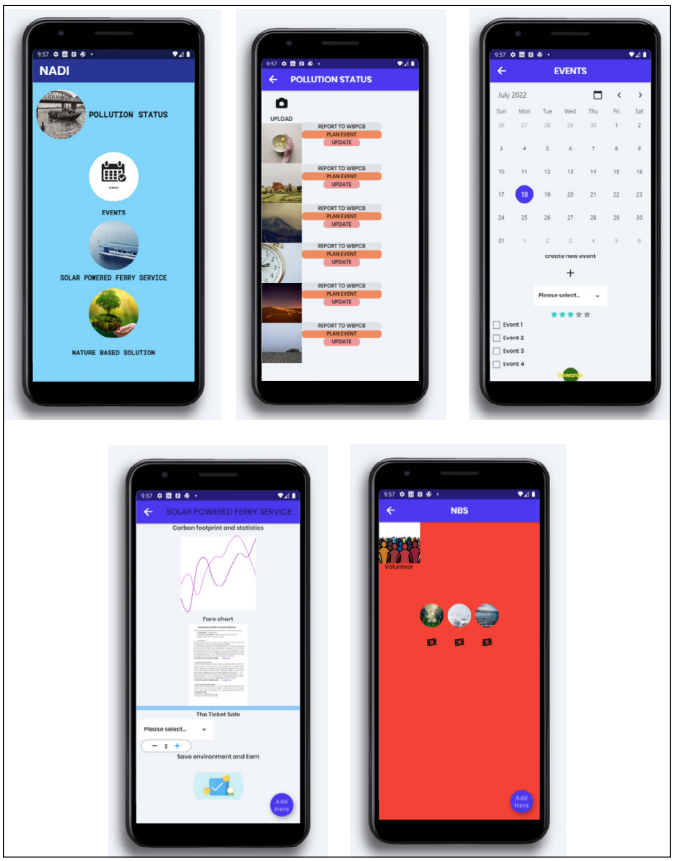
Next is the Events page where different types of events can be planned and accordingly the citizens can arrange for cleaning drives to contribute towards maintaining effective cleanliness in keeping our rivers clean. The solar-powered ferry service page enables users to book tickets and earn rewards. It also shows the details of carbon footprints and the fare chart.

Figure 12: UI Options on the 'NADI– The River Dedicated Application'



The final page is the NbS page, where the users can choose their desired solution to be applied and donate for their desired NbS. The following screens are found in the app:

Figure 13: Different Pages on the UI of 'NADI – The River Dedicated Application'



Discussion

The constant increasing pressure on our natural resources is resulting in increased natural disasters. We must all be more cautious and sensitive towards nature. While thinking of remediation and mitigation of resources, rivers are way down the list. River issues should be prioritized as rivers are the life-line of a city. They provide us with one of the most essential elements on Earth and that is water. The river waters and banks have been severely polluted and according to secondary data there is an unhealthy amount of faecal coliform bacteria which suggests disposal of sewage in the river.

Other than that, the BOD is also above the normal range. Essentially, we need to focus on Nature-based Solutions so that while undergoing remediation there is minimal impact on the environment. To bridge the gap between rivers and people or citizens, the app will help in organizing events for cleaning the river and involving people so that everyone can contribute towards improving the water quality and rebuilding the citizen river connect.

As seen in the graphs (Figure 10), the level of total dissolved solids rises during the month of October at the time of the Durga Puja festival. Idol immersion in the river is a potential cause of increase in dissolved solids. Wastewater discharges and wastes from religious events lead to an increased turbidity in the river which is more pronounced during the festival months. The BOD was almost ideal in January of 2020 but it varied throughout the year. The highest BOD value was observed to be 5 mg/l. Alkalinity should be between 100-250 and for both the years it was within the permissible range.

Faecal coliform was present at exceedingly elevated levels due to sewer disposal into the river. Faecal coliform had the highest value of 1,70,000 MPN/100ml during 2020 which made the water unfit for anything. The pH level should be between 7-8 and it was within the permissible range. E. coli was also present at remarkably prominent levels and during the year 2020 it was seen for a maximum number of months.

Dissolved O_2 was present above the permissible limits for most months during both the years. The values of both the years vary greatly due to covid during 2020. At that time, the river water quality had improved and during 2021 when the situation started improving, the water quality values increased above the permissible limits.

The proposal is to approach the government with the idea of promoting citizen participation. The app can help the government in collecting data or maintaining the environment with the help of people. This app can be of use in places where the government requires assistance with data collection or information and to make the citizens more responsible.

The app can also be utilized for fast action of cleaning and improving the river and its banks. The app facilitates event creation and spreading awareness through social media. It is aimed to be a connect between the citizens and the river and to engage them for data collection and remediation of polluted sites. The app will promote incentives to make citizens participate and engage in such activities.

Engagement of citizens in improving the condition of rivers has become necessary in the current scenario. An App-based approach is a pre-eminent solution. It suggests how a user-friendly app can be easily developed and designed by using FlutterFlow. While this app can become revolutionary in remediation of our water bodies, there are challenges in developing such an app. With rapidly advancing technology it expects an app developer to upgrade with the latest trends. It requires constant learning and investing to adapt in order to build a sustainable app. User experiences and App performance are the most essential factors that will help in making the app successful. It has to go through several optimizations and testing to be able to perform in a comprehensive manner.

A feedback system needs to exist throughout the life-cycle of the app to address any issue. Diverse range of devices, sizes, and OS forms a challenge for developers to make it accessible through any device. The dicey part is the final stage when the app becomes live. It needs marketing, monetizing, and increasing its appeal for maximum users.

The main challenge in developing river-focussed apps is managing the data. There needs to be an incentive-based approach so that people will willingly contribute to the cause and use the app to increase engagement. There must be sufficient awareness about which matters should be handled by the government authorities.

Nature-based Solutions are an emerging technology and a way of curing the environment without impacting it further. The techniques are being executed and tested everywhere to see how efficient they are and how fast the problems can be resolved by using these bioremediation techniques and phytoremediation. It has been noted that where the water is stagnant and of smaller volume, Nature-based Solutions work, but for a river which is an entire system with fluctuating volumes along with dynamic nature of contaminants, it becomes difficult to propose an effective way to utilize NbS for such a cause.

Rivers require an effective system of remediation soon before some of them start disappearing. For future work, the aim will be to develop the app in such a way that it is a collaboration with another government app that citizens are mandated to download. The app development will be followed by approaching the idea with the motive of increasing public involvement in saving the environment. The need for such a framework is extremely important as the environment is gradually degrading and due to increasing population and climate changes it is degrading at an even faster rate.

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Conflict of Interest

Authors have no conflict of interest to declare.

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Strategic Spatial Planning Based on Ecosystem Services (ES): A Case of Cauvery Basin

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Abstract

India's decentralized spatial planning includes administrative borders, which often do not align with ecological boundaries and thus fail to effectively serve the ecological purposes. These borders fragment ownership, governance, and management, thereby posing significant challenges for protection of biodiversity and ecosystems. Despite being intended for administrative convenience, ecosystems or eco-regions cannot be independently managed. This paper proposes a spatial planning strategy for the watershed regions, emphasizing Ecosystem Services (ES) as the central focus. ES are the benefits that humans receive from ecosystems which include provisioning (food, water, energy, raw materials), regulating (air quality, water regulation, climate stability), cultural (aesthetics, recreation, spiritual), and support services. The research employs an exploratory methodology that comprises literature reviews and case studies, which help to identify and map ecosystem service indicators. This involves developing a list of ecological indicators with reference values and mapping selected services using the InVEST model and GIS spatial analysis. The identified indicators will be reviewed and finalized for the watershed region. The study advocates a watershed-based planning approach that will address urbanization and climate change challenges while protecting the natural ecosystems. It concludes with a proposal for integrating ecological and administrative boundaries, thus promoting an ecologically conscious spatial planning approach.

Keywords: Watershed Planning, Ecological Planning, River Basin Plan

Introduction

When it comes to deciding where to live, people are drawn towards water. Throughout human history, rivers have been the lifeblood of any civilization. Humans have chosen to live near rivers for domestic needs, agricultural water supply, and navigation. This trend is continuing till today. However, due to modern socio-economic development, rivers face increasing threats from various sources that include unsustainable withdrawals, pollution, and loss of biodiversity. Anthropogenic activities are to blame for much of the current unfavourable state of our rivers. The ever-increasing pressures placed on river water by these demands in recent times necessitate better river basin management strategies if the basin has to continue to adequately meet these demands.

River restoration and its success rates are dependent on how well it has been integrated into the built and natural environments through urban spatial planning. For successful adaptation, spatial planning is required at ecological boundaries such as watersheds. A watershed is an area where water from multiple sources drains into a single river or ridge. Watersheds are recognized as critical spatial units for planning because they are a link between strategic and site-specific plans. A river basin plan is strategic planning that collaborates for achieving water resource goals, which includes assessment and management of data for a defined geographical watershed.

Over the last two decades, designed watershed strategies have grown dramatically all around the globe. It is becoming increasingly popular in countries such as the United States, China, and Europe. The Integrated Watershed Management Programme (IWMP) in India aims to restore ecological balance by utilizing, conserving, and developing degraded natural resources such as soil, vegetative cover, and water. Even though a lot of research and assessment have been conducted at the watershed or basin level, the adaptation of the same to spatial planning is lacking in India. One of the primary reasons for this is India's conventional planning hierarchy which adheres to administrative boundaries. The fact is that in India, administrative boundaries rarely align along the eco-regions, and often divide eco-regions into pieces that threaten its holistic conservation. Indians must concentrate on basin-level planning to restore the deteriorating rivers and the ecological value of basins. Key steps towards this should be redressing the urban planning framework to include basin-level plans which is an urgent need.

"Urban planning is a goal-oriented process that seeks to balance social, cultural, environmental, technical, and economic considerations within a particular legislative framework" (Angela Heymans, 2019). The current model of urban development profoundly alters the natural environment, thus reducing biodiversity and ultimately threatening the well-being of humans. The socio-ecological approach to urban planning adopts a framework of balancing social and ecological attributes. Many socio-ecological approaches are being adopted for spatial planning, such as the Landscape approach, Green Infrastructure approach, placemaking, and the Ecosystem approach.

According to Rice and Smith, 2017, "the Ecosystem Approach is a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way". This approach fits perfectly for ecological boundaries-based planning. The ecosystem approach is again subdivided into indicator-based, ecosystem assessment-based, and ecosystem valuation-based planning. Ecosystem indicators are simple measures that provide clear understanding of the ecosystem conditions. Hence, this paper studies the ecosystem approach to understand its potential in spatial planning.

The Ecosystem Approach to Spatial Planning is not a new concept, but till today, it has rarely been at the centre of spatial planning. Since the Millennium Ecosystem Assessment (MEA) publication 2005, many researchers and planners have delved into this concept and set examples of better spatial planning. An ecosystem-based spatial development strategy, when used wisely, results in sustainable development and the reconciliation of anthropogenic sources by addressing the drivers that lead to significant Land Use Land Cover (LULC) changes. Ecosystem-based approaches and modelling help in analyzing and forecasting the ecosystem changes over time and space. However, modelling is dependent on geo-referenced data, which is often costly and time-consuming to collect and raises concerns about data accuracy. The development and refinement of analytical tools can significantly contribute to spatial planning.

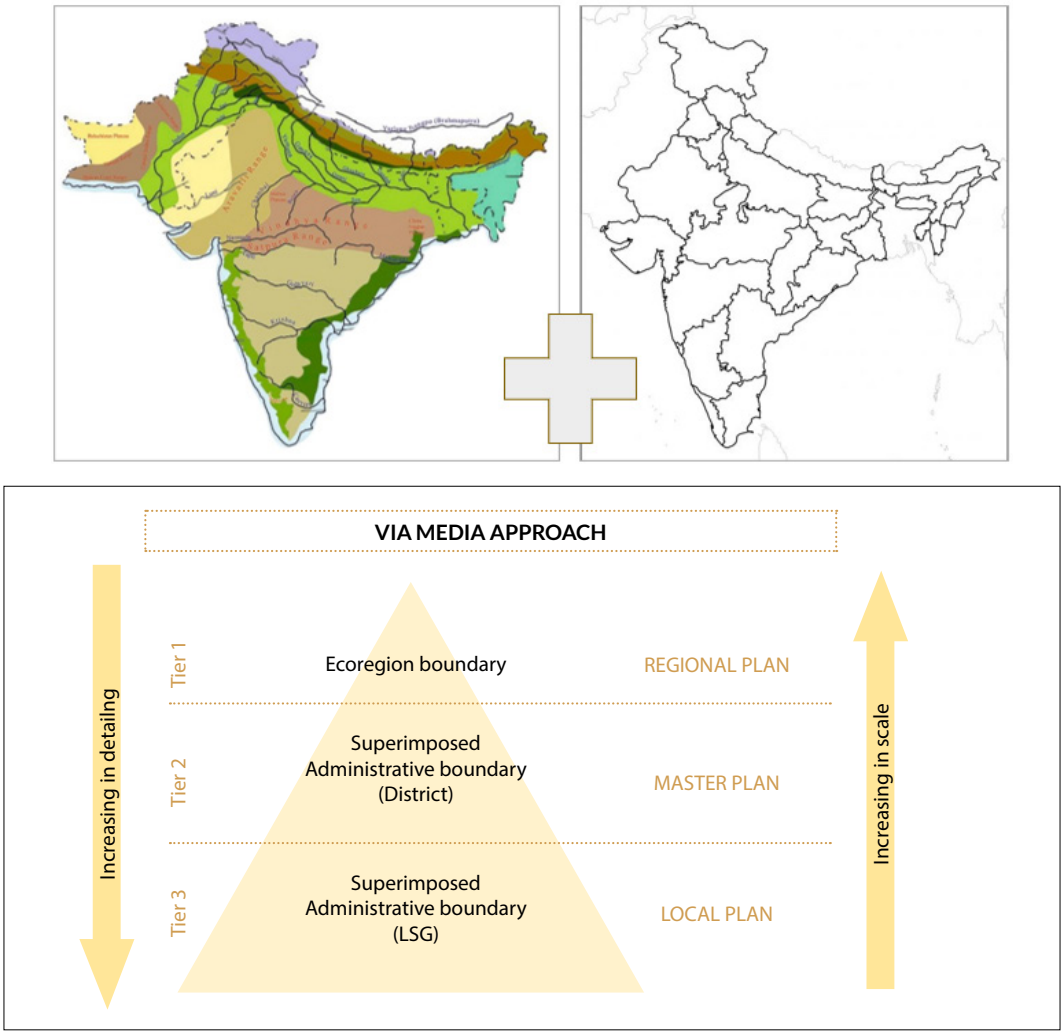
This paper attempts to use an ecosystem approach for strategic river basin planning. Using the Cauvery River Basin as an example, the study looks beyond the administrative boundaries to consider the value of ecosystems, landscapes, and biodiversity. This paper would contribute to the holistic visualization of the river basin and adopt an ecosystem approach for future urban planning.

Conceptualization of the Project

This project is envisioned as a via-media solution[1] that integrates the administrative and ecological borders. Existing decentralised administrative boundary-based planning aids in governance and collecting socio-economic data. However, they fail to solve the environmental challenges that have been caused by development, thus making the region more vulnerable to disaster. On the other hand, ecological boundary-based planning aids in catastrophe resilience, biodiversity protection, and fair resource sharing. The suggested three-tiered research framework will aid in comprehending the eco-region as a whole and then superimposing it on the administrative borders to produce macro and micro recommendations.

[1] *A compromise or middle path between two extreme positions. It seeks a balanced approach that incorporates elements from both sides, aiming to find a practical and acceptable resolution that avoids the disadvantages of the extremes*

Figure 1: Via-Media Solutions for Integrating Administrative and Ecological Boundaries



Source: Prepared by Author

Tier-1 analysis is performed at the eco-region boundary (river basin) to gain a comprehensive understanding of the region and to make recommendations that can be implemented when preparing the master plans at Tier-2 and Tier-3 levels. Tier-2 is defined by superimposing the district boundaries, while Tier-3 is defined by superimposing LSG boundaries. For proposal implementation, detailed assessments are required at the Tier-2 and Tier-3 levels. This Multilevel Framework is a pilot experiment that has been carried out for academic purposes to prioritise the eco-regions in spatial planning.

Objectives and Methodology

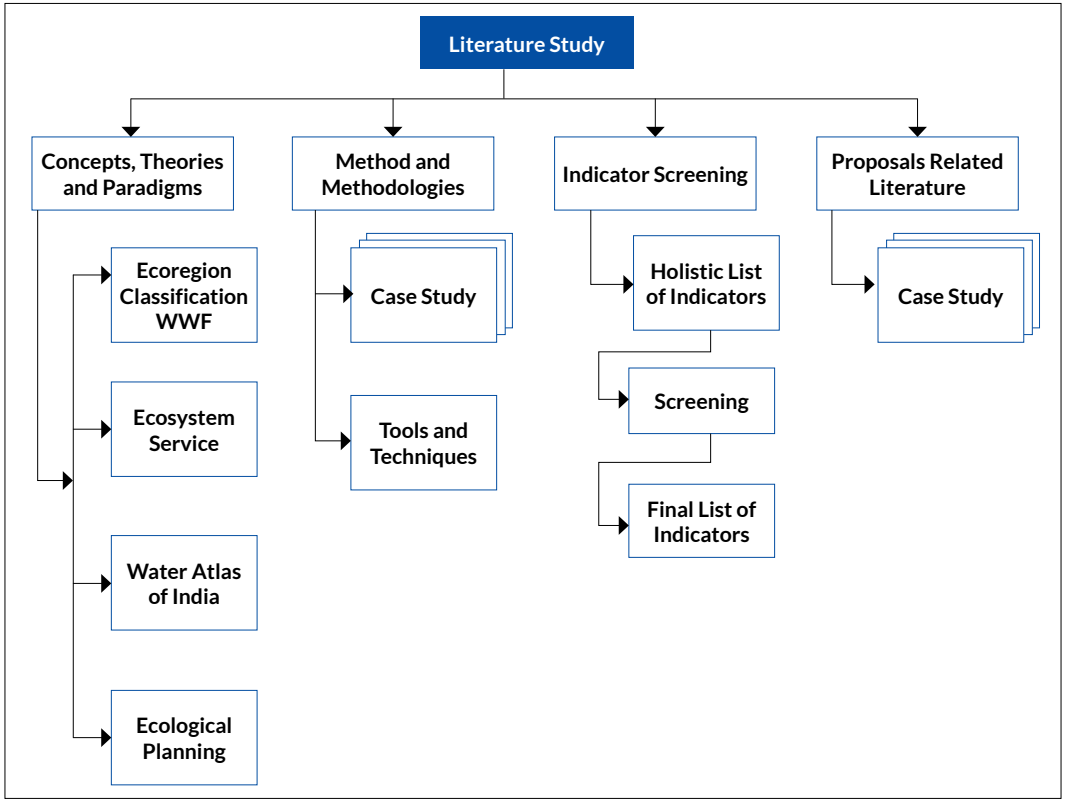
The study aimed to propose a strategic planning process to resuscitate the Cauvery River basin, based on the ecosystem approach as a case study for river management policy framework and planning. The following four objectives were formulated to achieve the aim of the study. Each objective was then sub-divided into tasks and sub-tasks:

- To explore the ecological boundaries and ecosystem approach in spatial planning through literature review.
- To create an indicator system to analyze the ecosystem services of the Cauvery River basin and identify the priority regions and clusters.
- To develop a governance framework that encourages coherent river management research, policy, and planning.

Objective-1: Literature Review

Objective-1 was to explore the concept and the possible ways of incorporating the ecological approach at the basin level. The tasks included remote research and case studies. The research was divided into four sections namely concepts, methodology, indicator screening, and proposals.

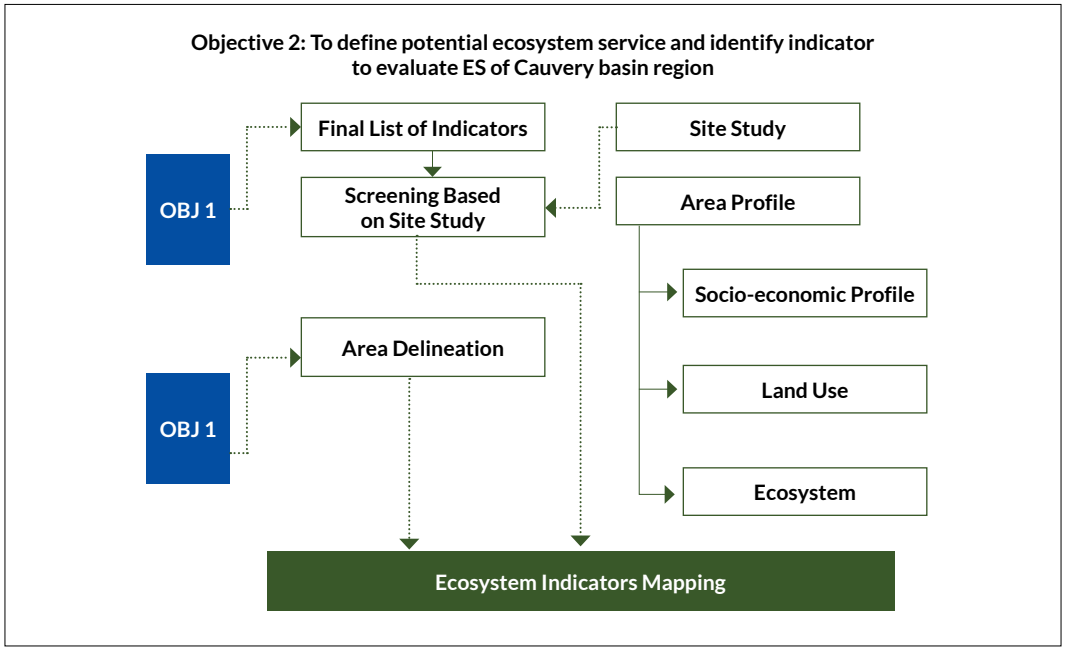
Figure 2: Detailed Methodology of Objective-1



Objective-2: Ecosystem Service Assessment

Objective-2 focused on the study area and delineation along with indicator mapping for assessment of the ecosystem services. The selected Indicators were analysed based on computer-based tools like INVEST, WaterWorld, and ArcGIS. Further, Fuzzy membership and Fuzzy overlay tools were used to create clusters and identify the priority regions. All indicators were converted to raster files and reclassified on a scale of 1-5, where 1 represented the most important area, and 5 represented the least important area. The whole Cauvery basin was divided into five zones, numbered one to five, in order of priority.

Figure 3: Objective-2 - Methodology



Objective-3: Governance Mechanism and Implementation Framework

Objective-3 was focused on redressing the conventional spatial planning in India and proposing a governance framework for better management of the Cauvery basin. The tasks included understanding the lacunas of the existing planning hierarchy and remote research on successful governance frameworks and institutional structures.

Cauvery River Basin

The River Cauvery begins in the Coorg district of Karnataka from a place called Talakaveri and flows into the Bay of Bengal at Kaveripoompattinam. It has a length of 800 kilometres and is known as the Ganges of the South. The basin encompasses three states and one union territory.

Figure 4: View of Cauvery River from Rock Fort of Trichy

Source: Flanet, P. (n.d.). La rivière Cauvery à sec. Flickr. Retrieved from https://www.flickr.com/photos/bridelice/9193038978/ on June 1, 2023.

Table 1: State-Wise Distribution of Drainage Area of Cauvery basin

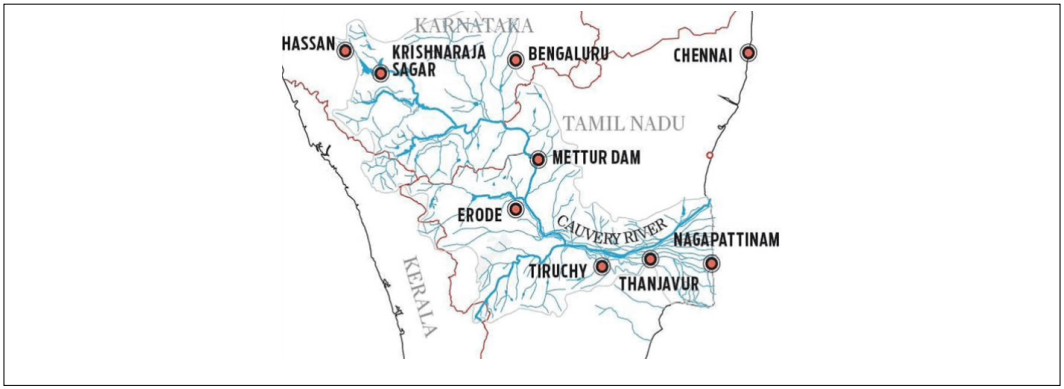
State	Drainage area (sq. km.)
Tamil Nadu	48,730
Karnataka	36,240
Kerala	2,930
Total	87,900

Source: Central Water Commission, 2012

The river basin has approximately 19% forest cover, and the major crops grown include paddy, sugarcane, ragi, jwar, and others. Ecotourism is increasingly becoming a significant economic source in the basin. The river's tributaries are divided into the left bank and the right bank tributaries. Hemavathi, Shimsha, and Arkavathi are the major left bank tributaries. The largest tributary, Hemavathi, flows through Hassan city. Bengaluru is located on the banks of the Arkavathi River. Kabini, Bhavani, Noyyal, and Amaravati are the major right bank tributaries. The Kabani tributaries are well-known for their dam while the Bhavani tributary is popular as it flows through the Silent Valley National Park. Srirangapatnam, Mysuru, Mandya, Mettur, Erode, Karur, Trichy, Tanjore, Kumbakonam, and Puhar are among the major cities on the banks of River Cauvery.

The basin in Karnataka receives rainfall mainly from the South-West monsoon and partially from the North-East monsoon. The basin in Tamil Nadu receives good flows from the North-East monsoon. Its upper catchment areas receive rainfall during summer by the South-West monsoon and the lower catchment areas during the winter season from the retreating North-East monsoon. Therefore, it is almost a perennial river with comparatively fewer fluctuations in flow and is very useful for irrigation and generation of hydroelectric power. River Cauvery is one of the best-regulated rivers and 90 to 95 percent of its irrigation and power production potential has already been harnessed. A major part of the basin is covered with agricultural land which accounts to 66.21 percent of the total area.

Figure 5: Cauvery River Basin and Prominent Cities



Source: InsightsIAS, 2022, Retrieved form https://www.insightsonindia.com/wp-content/uploads/2022/03/river.png as on June 1, 2023.

Cauvery River in South India has been at the centre of a long running water sharing dispute between the states of Karnataka and Tamil Nadu. River Cauvery originates in Karnataka and flows through Tamil Nadu before joining the Bay of Bengal. But water levels in the river have been falling due to insufficient rainfall and this has aggravated the farm crisis in both the states. The water in River Cauvery has been depleted by over 40% in the last few decades, and 87 percent of the basin's original tree cover has been lost (Kaibara, 2021). During summer, the river cannot reach the ocean, and 70 percent of the Cauvery basin's soil gets eroded. With the increasing loss of ecosystem services, it is time to consider a comprehensive approach to river basin management.

Result and Discussions

This section explains in depth the study's major conclusions and their implications. As per the three main goals of the study, sub-sections have been separated accordingly. The knowledge obtained from peer-reviewed publications and case studies has been covered in the literature review, which is then followed by the conclusions that have been drawn from the analysis of the ecosystem services, and finally, suggestions have been provided for the improved governance of the Cauvery Basin.

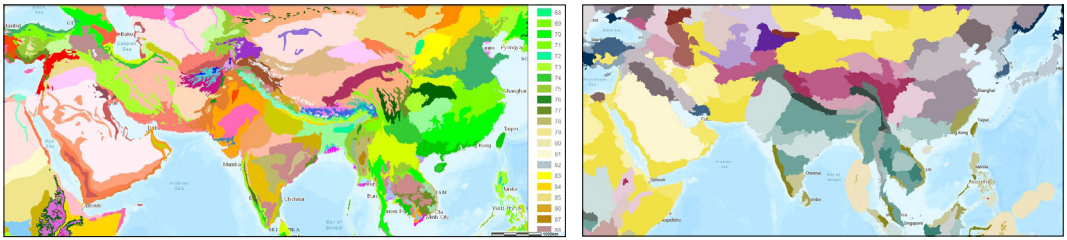
Literature Review

Biodiversity and Eco-region

According to the UN-CBD (United Nations-Convention on Biological Diversity, 2006), "biodiversity is the variation among living organisms from different sources including terrestrial, marine, and desert ecosystems, and the ecological complexes of which they are a part". Biodiversity is not evenly distributed across the Earth but follows complex patterns that are determined by climate, geology, and the planet's evolutionary history. These patterns are referred as "eco-regions." The World Wide Fund (WWF) defines an *eco-region* as a "large unit of land or

water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (David M. Olson, 2001). The WWF divides eco-regions into terrestrial, freshwater, and marine categories. The terrestrial scheme divides the Earth's land surface into eight biogeographic realms and 867 smaller eco-regions. Each eco-region is subdivided into 14 significant habitats.

Figure 6: Terrestrial and Freshwater Eco-regions of the World



Source: WWF, Retrieved from https://www.worldwildlife.org/ on June 1, 2023.

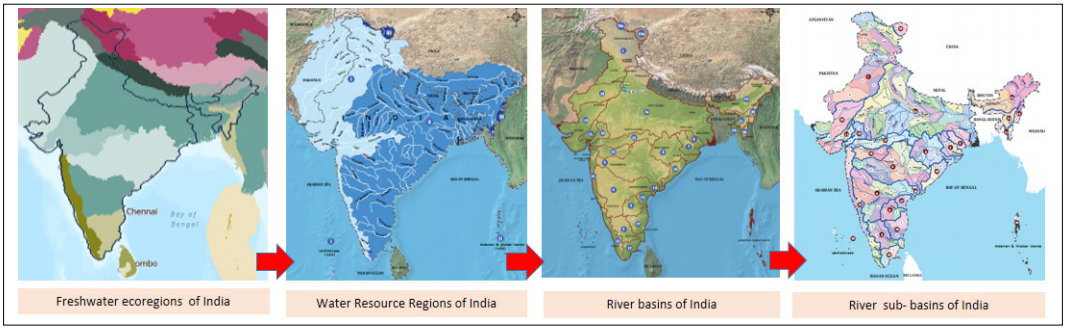
Freshwater systems include rivers, streams, lakes, and wetlands. Freshwater eco-regions differ from terrestrial ecosystems, which define the biotic communities on land, and marine ecosystems, which include biotic communities in the oceans. Freshwater eco-regions are based on the distributions and compositions of freshwater fish species and incorporate major ecological and evolutionary patterns. They harbor a significant fraction of biodiversity and suffer additional classes of threats. Historically, freshwater biodiversity has been overlooked, and very few studies have been done in the freshwater region.

At the basin scale, eco-regions help in introducing information about biodiversity into water-resources or integrated-basin management activities. River-basin studies can also be used as stratification units to ensure adequate representation of the distinct biotas. A counterintuitive planning unit can be introduced to incorporate biogeographic patterns, and in the process of setting continental priorities regional mandates may choose to compare the biodiversity values across eco-regions.

Watershed Regions in India

Water Resources Information System (WRIS), India delineates and codifies the catchment areas into smaller Hydrologic units, i.e. sub-watersheds. User agencies have always felt the need for a national level framework of watersheds, which has been served by the methodology that was developed. The current bulletin on India's Watershed Atlas is an attempt in that direction, with the entire country divided into 6 Major Water Resources Regions, 35 River Basins, 112 Catchment areas, 500 Sub-catchment areas, and 3237 Watershed regions.

Figure 7: Watershed Delineation in India



Sources: India-WRIS (n.d.). Retrieved from https://indiawris.gov.in/wris/ on June 1, 2023.

Journal Reviews and Case Studies

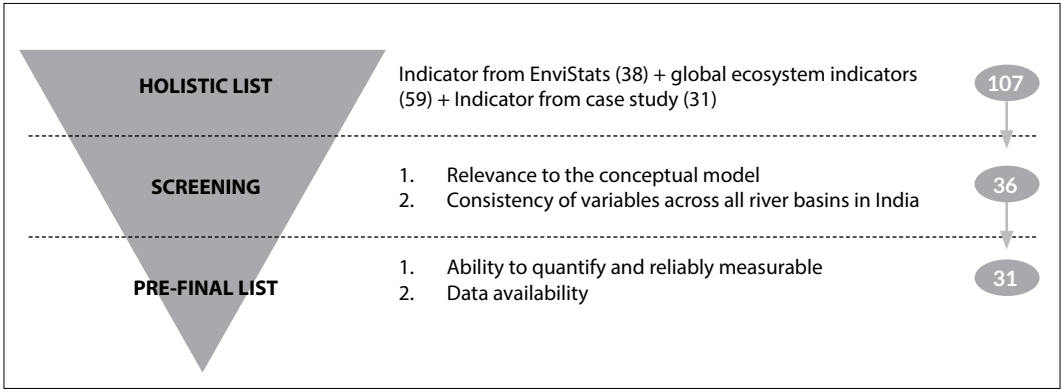
S No.	Title	Inference
1	Integrating ecosystem services into sustainable landscape management: A collaborative approach (Terêncio et al., 2021)	The document focuses on analyzing ecosystem services with the Driver-Pressure-State-Impact-Response (DPSIR) framework. It used Multi-Criteria Decision Analysis (MCDA) and GIS. Spatial problems are characterized by many viable alternatives as well as multiple, conflicting, and wholly incompatible evaluation criteria. A GIS-MCDA can be used to solve complex problems by transforming and combining the geospatial information and value judgments. A GIS-MCDA is a more robust criteria-based technique than a standard binary or 'coincidence' analysis. As a result, it allows additional values of multi-criteria at the same time. This enables more in-depth decision making.
2	Assessment of ecosystem services and sensitivity analysis based on the ANN model and spatial data: A case study in Miaodao Archipelago (Yin et al., 2022)	The study took advantage of the InVEST model and the powerful spatial analysis function of the Geographic Information System (GIS) to map five ecosystem services and Artificial Neural Network (ANN) for ES assessment. Artificial neural networks are widely used computational models in geographic data for classification process, change detection, clustering, linear regression, and predicting the future or forecasting. The study also standardized the data and performed sensitivity analysis. As a whole, the ES contrast and their co-relation were thoroughly investigated. Computer based modelling tools for ecosystem service assessment were also reviewed to identify the most suitable tool for this study. InVEST and WaterWorld were selected among more than 10 tools by considering the input and output data format and GIS expertise.
3	River Basin Planning Principles, Procedures, and Approaches for Strategic Basin Planning at ADB (Pegram, 2020)	The report provides an overview of the characteristics of strategic basin planning and the ten golden rules of basins. The report also helped in understanding the basin planning process and the structure of strategic river basin plans.

S No.	Title	Inference
4	Case study 1: Mekong River Basin Management	The case was studied thoroughly to understand how the Mekong River Commission managed resources and the MRC supports a basin-wide planning process that is based on the principles of Integrated Water Resources Management (IWRM). Rising in the South-eastern Qinghai province, China, River Mekong flows through the eastern part of the Tibet Autonomous Region and Yunnan province, after which it forms a part of the international border between Myanmar (Burma) and Laos, as well as between Laos and Thailand. The trans-boundary planning and management of the basin and governance framework were studied. The MRC Strategic Plan 2021–2025 was also studied in detail to understand the vision, proposals, and how they aligned with the sustainability goals.
5	Case study 2: Yamuna Biodiversity Park	The Yamuna Biodiversity Park is a pilot project for the development of biodiversity parks across the city. The objective of the project was to bring back the original ecological state to sustain the ecological services and goods that it was rendering to the region. Major Learnings from the project were - A Biodiversity Park is only successful if it can attain complete self-sustenance, hence it needs a large area, and it should stick to the native species (Ecological Restoration principle). A typical Biodiversity Park should have two basic components: A Nature Conservation Zone and a Visitor Zone. The criteria for judging if an ecosystem has been restored are to check if it is generating Ecological Services and Goods.

Indicator Selection and Screening

The selection of Indicators was a critical process because the results of the study would be dependent on it. Thus, many national and international reports and studies were consulted before the final selection of Indicators. A thorough set of variables was tallied using case study indicators, global ecosystem indicators, and the EnviStats.

Figure 8: Indicator Screening



These indicators were chosen based on the concept model that emphasised the availability of water and people's well-being, river shed tourism potential and economic opportunities, primary economic sustainability, water regulation and vegetation cover, and disaster mitigation. Indicators were further screened based on variable consistency across all river basins in India.

The pre-financial screening focused on removing those indicators that could not be quantified or reliably measured and were not available. The pre-final list had 31 indicators which could be used for similar studies in different river basins of India (Figure 7). The final list of indicators was again screened based on the context of the Cauvery basin and Tier-1 indicators were formulated. The first screening was done based on the data type where primary data were omitted. Detailed study with primary data could be done at the local self-government level.

The second screening was done to understand which data fit the eco-region scale. Data within the scale of district and eco-region levels were taken forward. Last and the final screening was to omit similar indicators or indicators with high correlation. For example, indicators like forest cover and NDVI had high correlation, hence only forest cover was taken forward in the screening process. The study focuses on 11 indicators out of the shortlisted 13 indicators selected from the pre-final list of 31 indicators.

The indicators were not classified according to the type of ecosystem service, but rather they provided a holistic view of the entire basin. The selection of indicators is based on the author's research interests and thus can be modified for use on other sites. It is a pilot study with very few indicators. Following are the selected indicators (Table 2):

Table 2: Table of Indicators for Cauvery Basin

S. No.	Indicator
1	Economy from paddy
2	Economy from fisheries
3	Economy from tourism
4	Economic dependency on water
5	Water yield per person
6	Exposure to drought
7	Forest cover
8	Carbon storage
9	Biodiversity value
10	Habitat threat
11	Human activity-based contamination

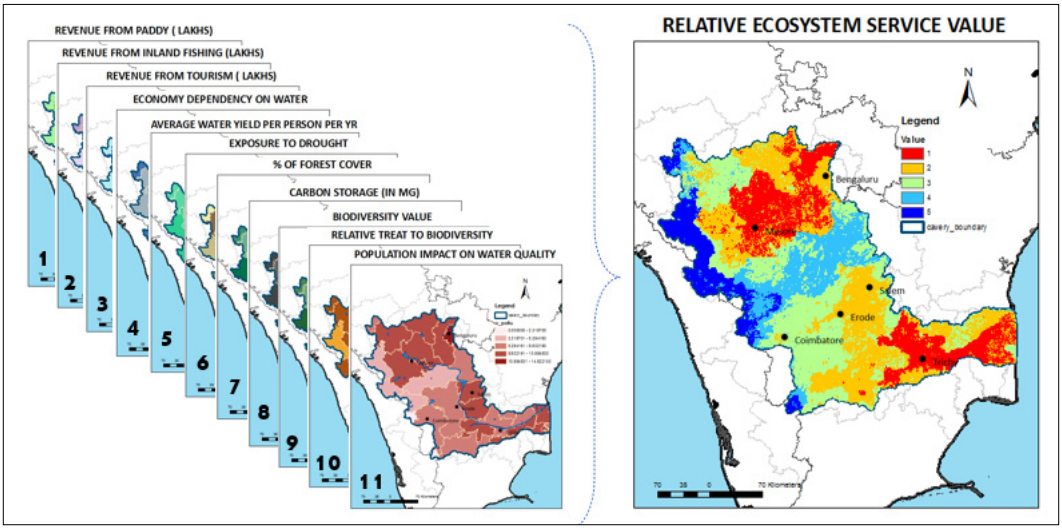
Ecosystem Service Assessment

The use of computer-based evaluation methods for mapping ecosystem services was effective. The analysis was entirely GIS-based and performed in ArcGIS and QGIS (Quantum Geographic Information System). The study used the most trustworthy open source, computer-based assessment method, which evaluated ES using global data that was gathered from the satellite images. Each indicator was mapped out and evaluated both alone and collectively. The study demonstrated that regions having significant economic dependency, poor levels of social welfare, and acute drought sensitivity will be most affected by climate-related hazards. Most of these

districts are in the Cauvery plains (Cauvery delta region).

The risk of food shortages and drought is more likely to occur in areas that have low ecosystem service levels. It is essential to pinpoint governance needs in these districts and increase capacity. Management is crucial to safeguard the socio-economic well-being. A district is more likely to have a high water related economic fraction if a significant portion of its territory is covered by a river. Its water resources will also play a bigger role in supporting the industrial and agricultural operations. Water stress is mostly caused by physical water shortage, which is followed by excessive water demand. Therefore, water stress can be reduced through efficient dam management and the responsible use of water in the region. Urbanization and deforestation lead to more and faster run offs. In contrast to climate change, dam management, and water use, land-use changes are anticipated to have little impact on freshwater supply.

Figure 9: Ecosystem Service Assessment to Identify Priority Clusters



Source: Prepared by Author

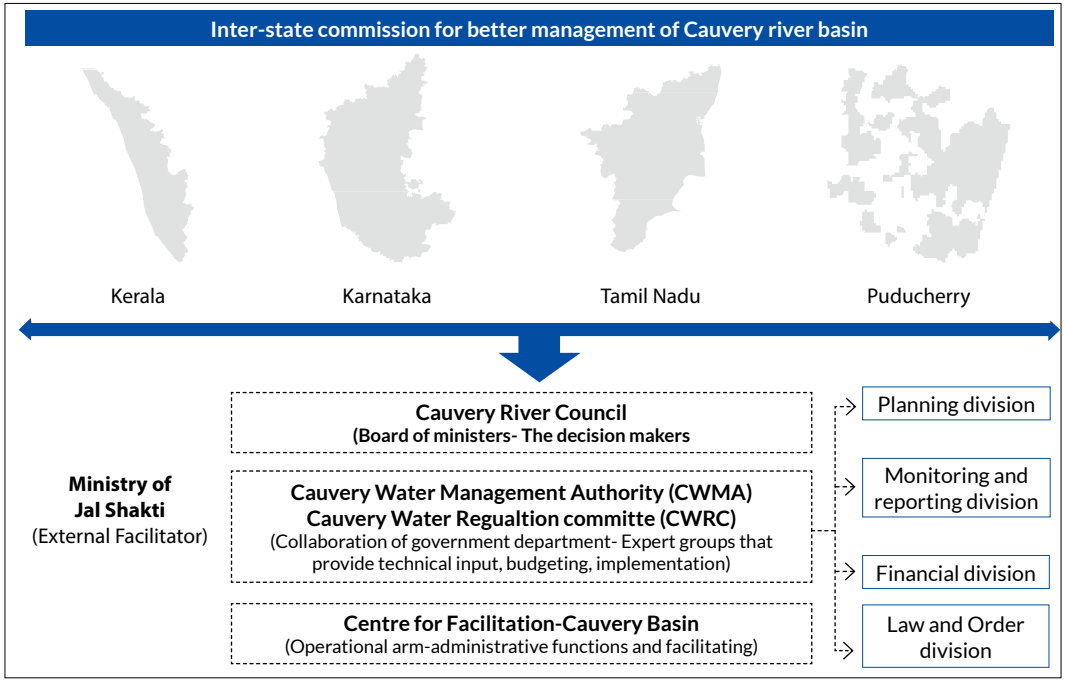
Overlay analysis is a data-mining method for finding discrete cluster groups. The study identified five clusters ranked from low to high relative ecosystem service values. According to the study, rapid ecological restoration is required in areas like Mandya, Bangalore Rural, Thirichirappalli, Thanjavur, and Nagapattinam (High priority cluster) to revive ES. After the green revolution, Cauvery basin's delta region saw a surge in development. The extensive agricultural activities in this region and high demand for water supply led to the deterioration of shallow aquifers in the delta region. River Cauvery being a seasonal river was also drying up due to low rainfall. Thirty percent of the basin region has moderate ES value and is scattered over the districts of Tumkur, Bangalore Urban, Mysore, Dindigul, Pudukkottai, Cuddalore, and Thiruvarur (Yellow coloured region). Almost 8 percent of the territory around the Western Ghats has high ES values, while 50 percent of the region has acceptable ES values. High ES districts include Kodagu, Chikmagalur, Wayanad, Palakkad, and Idukki (Figure 9).

Governance Mechanism and Implementation Framework

The Central Government notified the Cauvery Water Management Scheme on 01 June 2018, inter alia, constituting the 'Cauvery Water Management Authority' (CWMA) and the 'Cauvery Water Regulation Committee' (CWRC) under the Inter-State River Water Disputes Act, 1956. Since then, the Cauvery basin has been managed by these two separate authorities. Their job responsibilities include carrying out the decisions of the Cauvery Water Disputes Tribunal, effective monitoring of the hydro-meteorological situation in the Cauvery basin, and annual and seasonal water account reports. Currently, there is no single, or overall, institution that is directly responsible for management of the Basin.

The study focuses on proposing a suitable governance mechanism for the Cauvery River basin and the same is attached. (Figure 10). An interstate commission for basin management is proposed with three major institutional sub-divisions. Cauvery River Council is made up of ministers from all three states of Kerala, Karnataka, and Tamil Nadu, as well as a representative from the union territory of Puducherry. The river basin's strategic plans are approved by the council. The river basin commission's functional wing comprises the Cauvery Water Management Authority and the Cauvery Water Regulation Committee. Their job portfolio is further expanded with departments such as planning, monitoring, and reporting, financial, and law and order. The Cauvery Basin Facilitation Centre is the commission's administrative arm which connects the commission to all stakeholders in the basin.

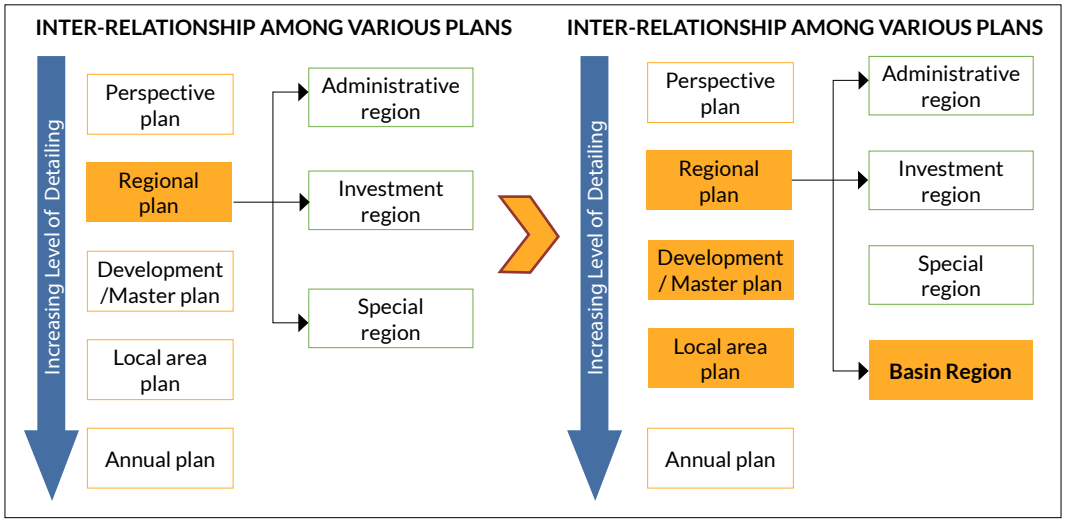
Figure 10: Cauvery Basin Governance Mechanism



Source: Prepared by Author

In India, the existing conventional planning framework excludes river basin/watershed planning. As a result, watershed-level/basin studies are not converted into spatial plans. This thesis proposes a new framework for spatial planning that includes basin plans as a type of regional plan that will be enhanced during the development of the master plans and the local area plans.

Figure 11: Incorporating Basin Plans to Conventional Planning Framework



Conclusion

River basins have been regarded among the most important ecosystems since they play an essential part in providing unique ecosystems for a diverse range of plant and animal lives. Furthermore, these ecosystems provide a variety of goods and services that contribute to public welfare and in poverty reduction. On the other hand, river basins suffer permanent losses because of intense use as well as anthropogenic pressures. As a result, effective and sustainable river basin management has emerged as a critical issue globally. The neglect of natural capital planning is a major flaw in India's spatial planning structure. The study proposed strategic basin planning as a way forward to eliminate this flaw.

Data availability at the eco-regional level makes basin planning easier, hence every ten years, accumulation of the major basin problems and needs must be considered. Basin plans only work when stakeholders coordinate properly; thus, general agreement among downstream and upstream actors should be encouraged. Water resources should be highlighted as critical structuring concepts for spatial planning at all levels. The river basin management approach necessitates not just working to improve the water quality but also integrating the region's environmental, socio-economic, and land use factors.

The main thrust of the present study was to investigate holistic river basin planning over administrative boundaries that bound spatial planning. The principal goal of the research to integrate ecological approach in river basin boundaries was accomplished. As a result, priority regions for ecological restoration were determined. These findings will aid future research on ecological approach in Spatial planning, particularly in terms of strengthening the region's resilience and capacity to adapt to climate changes. Case specific and broad planning recommendations based on the developed model were formulated as an extended arm of the study.

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Conflict of Interest

Authors have no conflict of interest to declare.

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Wastewater Pollution, Declining River Water Quality, and Its Socio-Economic Impact in NCT of Delhi

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Abstract

Historically, rivers have served as crucial life-lines for human settlements, by facilitating the growth of ancient civilizations worldwide. However, the advent of urbanization has brought about a profound shift: rivers that were once pristine sources of freshwater, now bear the burden of domestic and industrial pollutants which is emblematic of the swift economic and technological advancements of our time. This transformation has significantly degraded numerous rivers, including India's esteemed Ganga and its tributary, the Yamuna. Both these rivers endure severe pollution despite their cultural veneration as goddesses in Hindu mythology.

The Delhi NCR contributes significantly to the pollution load in the Yamuna River, causing it to function primarily as a channel for sewage discharge. This study meticulously scrutinizes the sources and repercussions of pollution in the Yamuna River ecosystem, particularly its impact on agricultural communities that are reliant on its waters. Physicochemical parameters—Total Dissolved Solids (TDS), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), and Faecal Coliform—were assessed using data from monitoring stations that were overseen by CPCB/ DPCC. The findings underscore the extensive river contamination and its detrimental socio-economic effects on local farmers.

This research underscores the imperative for inter-disciplinary collaboration across social and environmental sectors to drive innovative solutions for wastewater management. It advocates

emerging approaches such as decentralized wastewater treatment and Nature-based Solutions, to enhance water quality and bolster community well-being, thereby fostering broader social benefits. The effective rejuvenation of rivers like the Yamuna necessitates concerted efforts across sectors to implement sustainable water management practices, thus mitigating the profound impacts of pollution on ecosystems and human livelihoods.

Keywords: Wastewater, River Communities, Urban Agriculture, Nature-based Solutions, Decentralised Wastewater Treatment

Introduction

Rivers have always been at the heart of a society's development. All the world's ancient civilizations thrived along the banks of one or more rivers. Once the most important sources of freshwater, rivers became carriers of wastewater as cities grew. Rivers have paid the price for hasty economic and technological progress through various sources of pollution. Today's rivers are plagued by severe organic, inorganic, and/or pathogenic pollution, as well as low water levels. According to a UNEP report titled 'A Snapshot of the World's Water Quality: Towards a Global Assessment' (2016), one-third of all river stretches in Latin America, Africa, and Asia are affected by severe pathogenic pollution. Furthermore, severe organic pollution affects one-seventh of these river stretches, while salinity pollution affects one-tenth. Increased wastewater discharge into rivers has been identified as the primary source of water pollution (UNEP, 2016).

Water is necessary for the survival of all living things, but it is becoming increasingly scarce as human populations grow and the demand increases for high-quality water for domestic and commercial purposes. Freshwater scarcity is one of the most pressing environmental issues that India is facing in this century. The main obstacles to better water quality management in India are contamination and issues caused by treated, partially treated, and untreated wastewater from urban settlements, industrial operations, and irrigation run-off, as well as poor municipal solid waste management.

In India, wastewater treatment is a serious concern, particularly in rapidly increasing metropolitan regions. According to a 2015 report 'Inventorization of Sewage Treatment Plants' by the Central Pollution Control Board (CPCB), India generates 61,948 million gallons of urban sewage each day. However, every day over 38,000 million gallons of wastewater is discharged into major rivers which even percolates into the earth. Industrial wastewater also needs to be considered. This disconnect between sewage generation and treatment continues to be a major source of river contamination. Moreover, in a recent study done by the Centre for Science and Environment (CSE), 351 contaminated stretches were detected on 323 rivers. This was based on monitoring data in terms of biochemical oxygen demand, an indicator of organic pollution as shown in Table1 (Naraina, 2018).

BOD levels beyond a certain threshold are harmful for aquatic life. DO is digested by bacteria when significant biodegradable organics are present in water, as is the case with most wastewater. When this happens, the DO levels fall below a certain threshold, which has a detrimental influence on life since they are unable to maintain regular life-sustaining functions like growth and reproduction.

Furthermore, in many wastewater streams, eutrophication is caused by the abundance of nitrogen-containing chemicals. This causes algae blooms (the growth of plants in the aquatic ecosystem) and anoxic conditions which results in changes in dominant aquatic biota species, fishkills, and spread of water-borne diseases such as cholera and typhoid (Joshua N. Edokpayi, 2017).

Pollutants also reduce the quantity of usable water, raise the cost of purification, pollute aquatic resources, and impact food supplies. Pollution, in combination with human water demand, impacts biodiversity, ecosystem functioning, and the natural services that are provided by aquatic systems, all of which are important to society. Thus, it is critical to implement effective management approaches for improved water quality and biota conservation.

Table 1: State-wise Polluted Stretches of Rivers in India

States	Urban Sewage Generation (MLD)	Installed Treatment Capacity (MLD)	Polluted Stretches (in Km)
Andhra Pradesh	2871	247.27	6
Assam	703	0.51	28
Bihar	1876	124.55	5
Chhattisgarh	951	0	5
Daman & Diu	55	0	1
Delhi	4155	2693.7	1
Goa	145	74.56	8
Gujarat	4119	3062.92	20
Haryana	1413	852.7	2
Himachal Pradesh	110	114.72	8
Jammu and Kashmir	547	264.74	9
Jharkhand	1270	117.24	8
Karnataka	3777	1304.16	15
Madhya Pradesh	3214	482.23	21
Maharashtra	8143	5160.36	49
Manipur	132	0	12
Meghalaya	95	1	10
Nagaland	92	0	2

Odisha	1121	385.54	12
Punjab	1644	1245.45	2
Rajasthan	2736	865.92	8
Sikkim	24	31.88	5
Telangana	1671	685.8	7
Tripura	154	0.02	2
Uttar Pradesh	7124	2646.84	5
Uttarakhand	465	152.9	13
West Bengal	4667	416.9	17

Source: Naraina, 2018

Objectives of the Research

The research will provide insights and help with wastewater management and its effects on water quality and riverine populations in the study area at the city level. The study focuses on the farming communities in the site area that are dependent and interact with the river on a daily basis. Overall, it attempts to make a case for a more integrated spatial governance of the urban rivers at risk. The following objectives define the path of the study:

- To understand the importance and pollution status of urban rivers in India.
- To assess the existing wastewater management system and identify sources of pollution in the study area.
- To spatially assess the water quality parameters and detect the levels of pollution in the study area.
- To study the impact of river water quality on the livelihood of communities in the site area.
- To propose/recommend strategies for improvement of water quality of River Yamuna.

Study Area

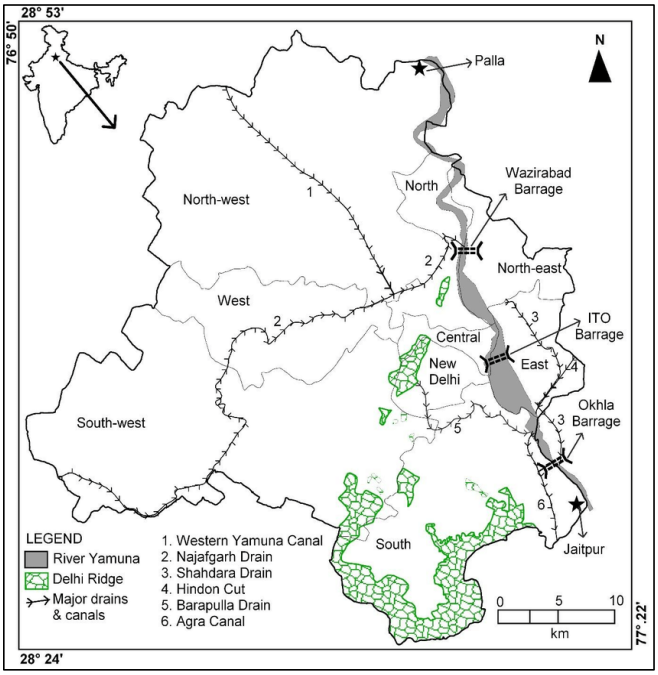
The National Capital Territory of Delhi (NCTD) has a total area of 1,483 square kilometres and is divided into nine census districts and 27 sub-divisions (Tehsils). River Yamuna flows for about 200-km from its source through a series of valleys in the Lower Himalayas before emerging into the Indo-Gangetic Plains. It draws water from several major streams in its upper 200-km stretch. To supply drinking water to Delhi, the river is first tapped via a barrage at Wazirabad. In general, no water is allowed to flow beyond the Wazirabad Barrage during the dry season because the available water is insufficient to meet the water supply-demand of Delhi.

After 22-kilometres downstream of Wazirabad Barrage, there is another barrage, the Okhla Barrage, which diverts Yamuna water into the Agra Canal for irrigation. During the dry season, no water is allowed to flow through this barrage as well. Whatever water that flows in the river beyond the Okhla Barrage comes from domestic and industrial wastewater that is generated in

East Delhi, Noida, and Sahibabad, which enters the river via the Shahdara drain.

The various human and industrial activities generate a large amount of garbage, which is discharged directly into the river without adequate treatment, thus lowering the river's water quality. The Yamuna River flows through the National Capital Territory for only 22-kilometres (or less than 1.6% of its total length). However, the wastes and toxins dumped into that narrow swath account for roughly 80% of all pollution in the 1,376-kilometre-long river (Sharma, 2017).

Figure 1: Flow of River Yamuna in the National Capital Territory of Delhi



Source: Singh et al., 2016

Methodology

The methodology of this study involves a comprehensive approach to understand and address urban river degradation, with the Yamuna River in Delhi as a case study. Initially, a literature review will critically examine the significance of urban rivers for communities, the impact of pollution on these communities, causes of river degradation, parameters that define the pollution status, and evaluation of pollution control proposals in urban master plans. Based on this review, the data collection focuses on assessing wastewater management systems and identifying the sources of pollution. This includes a detailed land use/land cover analysis to capture hydrological

variability and changes over the past decade, and pollution source analysis of sewer and non-sewer areas, drains discharging into the Yamuna, Sewage Treatment Plants (STPs), Common Effluent Treatment Plants (CETPs), and industrial clusters.

Wastewater analysis will evaluate the treatment capacity of STPs, pollution levels in treated effluents, and the end-use of treated wastewater. Spatial assessment of water quality parameters using IDW interpolation will provide a holistic view of pollution levels across the river. Finally, socio-economic surveys will explore the impact of river water quality on the livelihoods and health of riverine communities, integrate perspectives on basic facilities, household economies, awareness of water quality, and health perceptions.

This methodology aims to establish a clear link between rising pollution levels and urbanization pressures, thus informing effective strategies for sustainable river management and community well-being.

Table 2: Aims, Objectives, and Methodology

Formulation Stage	Aims & Objectives		Need of the Study
Literature Review	To critically understand the importance of urban rivers and the causes of their degradation	▪ Significance of urban rivers for cities and riverine communities ▪ Impact of pollution on the communities ▪ Cause of degradation of urban rivers ▪ Parameters to identify the pollution status of a river ▪ Assess proposals regarding river pollution in Master Plans	**Delhi as a Case Study** Identifying current issues, Status of Water Pollution, Impact on Communities
Data Collection & Selection of Study Area (Based on Literature Review)	To assess the existing wastewater management systems & identify pollution sources in the study area	▪ Land Use/Land Cover Analysis: ▪ LULC approach to capture hydrological variability of the Yamuna and changes in the LULC pattern over the previous decade ▪ Pollution Source Analysis: ▪ Sewered & unsewered areas ▪ Eighteen drains falling into Yamuna ▪ STPs and other treatment infrastructure ▪ CETPS & Industrial Clusters that it caters to ▪ Wastewater Analysis: ▪ Assess the treatment capacity of sewage treatment plants (Generation/Treatment Gaps) ▪ Pollution analysis of treated effluents (STPs, CETPs) ▪ End use of treated effluents from STPs	The overall study can help to find a link between rising pollution levels and the pressures of urbanization which may be attributed to increased wastewater generation/ discharge into the Yamuna

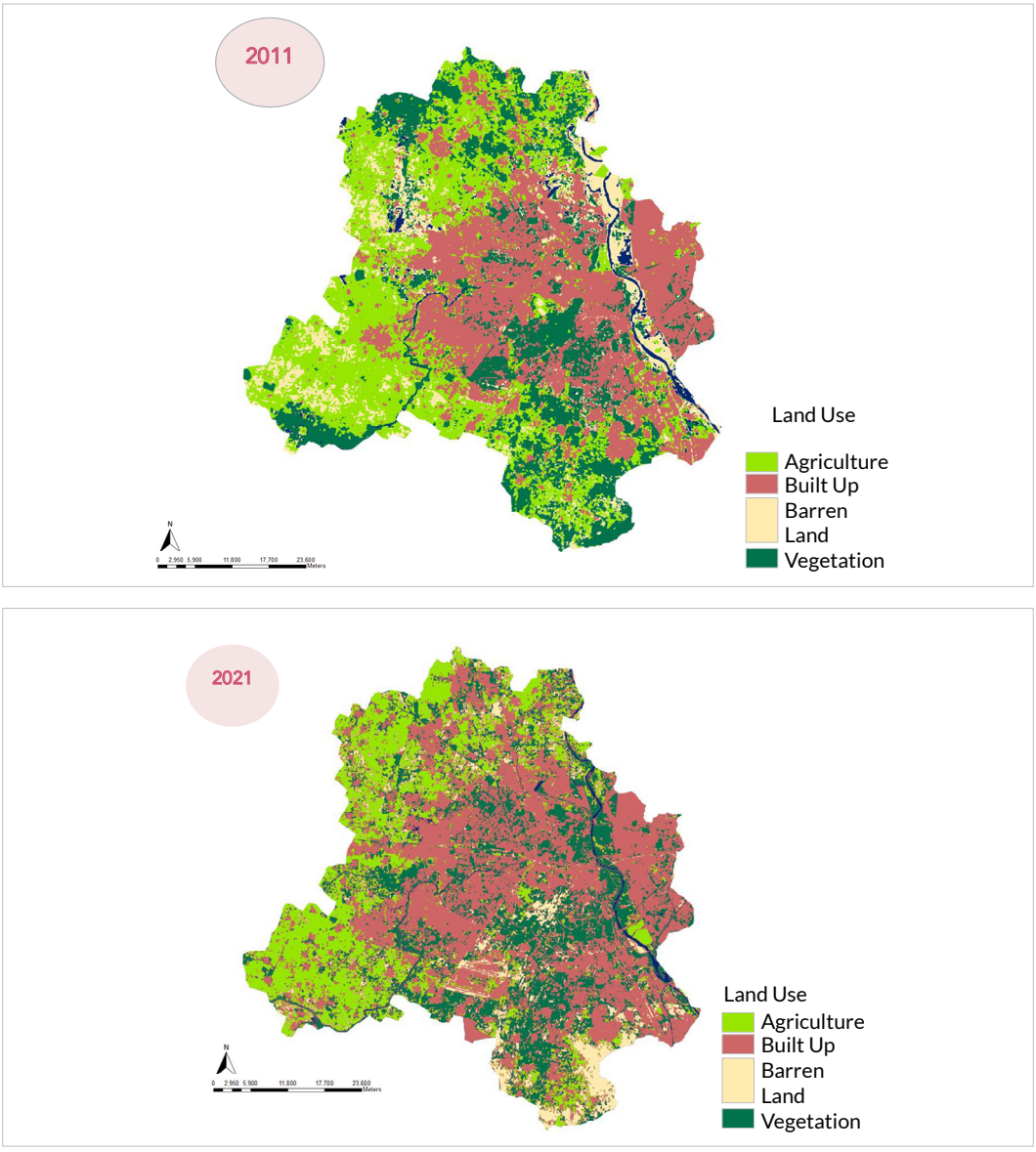
Analysis	To spatially assess the water quality parameters & detect the level of pollution in the study area	To assess the river water quality for pollution parameters, field datasets for the National Water Quality Monitoring Programme (NWMP) from monitoring stations of the Central Pollution Control Board (CPCB)	To assess water quality across the whole river flow area using **IDW interpolation**
Identification of Issues and Problems	To analyse the impact of river water quality on the livelihood & health of riverine communities	▪ Socio-economic Survey questionnaire: ▪ Questions related to basic facilities in households ▪ Livelihoods and Income: Questions related to household economy ▪ Perception of river water /Awareness and opinions about river water quality ▪ Questions related to health	Social research to evaluate the impact of pollution on the livelihoods and health of various riverine communities
Proposals	**To propose strategies for improvement of water quality of urban rivers.** This will incorporate the ecological and biodiversity concerns of poor water quality and support improvements of urban rivers and livelihoods.		

Analysis and Findings

Land Use/Land Cover Analysis

Land Use/Land Cover (LULC) Analysis was performed for year 2011 & 2021 as shown in Figure 2. This was done to highlight the pressures of haphazard development on floodplains and urbanization on River Yamuna's water quality. Almost 44% of major negative change was observed in the Yamuna area. Ignoring the river-flood-plain interactions which play significant roles in the ecology of a river, most of the floodplain has been reclaimed by constructing high levees.

Figure 2: Land Use and Land Cover in the National Capital Territory of Delhi (NCTD), 2011 – 2021



Source: Prepared by Author based on Google Imagery, 2022

Table 3: LULC Change between 2011-2021 in the National Capital Territory of Delhi (NCTD)

2011		2021		% Change (with respect to 2011)	
Area (m2)	Share of Area (% to Total)	Area (m2)	Share of Area (% to Total)		
Agriculture	545	36.62	405	27.24	**-26**
Built-Up	464	31.20	512	34.39	**10**
Barren Land	166	11.16	127	8.54	**-23**
Vegetation	277	18.65	424	28.51	**53**
Water Body	35	2.37	20	1.33	**-44**

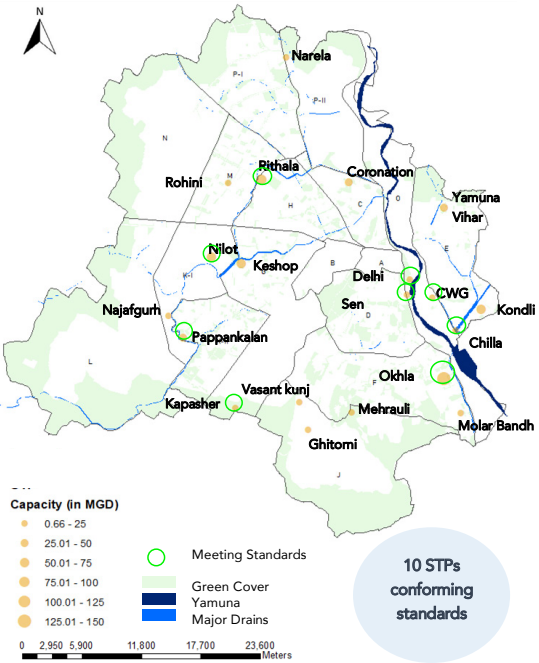
Source: Prepared by Author based on LULC Analysis, 2022

Developments like the Akshardham temple and the Commonwealth Games Village – which consist of multi-storey luxury apartments with a captive power plant – demonstrate how the government has actively encouraged new development by providing huge subsidies to corporate entities. Other concrete developments have followed suit, with the Akshardham temple on the eastern bank and a network of flyovers and wider roads built parallel to the eastern riverfront to accommodate the increased traffic. Within 300 metres from the bank of the river, the Delhi Metro Rail Corporation (DMRC) has built a Yamuna Bank metro station, a large train depot, and a retail mall near the Games Village, and the remaining property along the river has been earmarked for similar projects. Patches of agricultural land are being replaced by skyscrapers at a rapid pace. Instead of the ecological zone established in the Master Plan of Delhi- 2021 (MPD – 2021), these developments provide material expression to riverside development that reflects other western cities and ignores the fundamental socioeconomic and environmental challenges.

Availability and Utilisation of Sewage Treatment Plants

Delhi Jal Board (DJB), constituted under the Delhi Jal Board Act, 1998, has the responsibility of production and distribution of water as well as collection, treatment, and disposal of domestic sewage in the NCT Delhi. DJB is working in a phased manner to provide sewerage facilities to all the unsewered areas and cater to the requirement of unprecedented growth of population up to the year 2031. This is being done firstly, by extending the sewerage facilities to those command areas where outfall infrastructure exists.

Figure 3: Mapping STPs Conforming Standards in the NCTD



Source: Prepared by Author, 2022

Presently, Delhi generates around 744 million gallons per day (MGD) of sewage – considering 80% of the 930 MGD water supply. The 35 sewage treatment plants operational at 20 locations across Delhi treat up to 597.26 MGD of sewage. To tackle pollution, the environment ministry has strengthened rules for Sewage Treatment Plants (STPs) that discharge wastewater into rivers and other sites.

Furthermore, Delhi Pollution Control Committee releases a monthly report on the quality of treated water discharge. However, from the analysis of the December 2021 STP Monitoring Report, it was observed that 23 STPs (70%) do not discharge treated water as per standards (Delhi Pollution Control Committee, 2021). It was found that the main parameters that do not conform to the standards are TSS, BOD, and COD. Higher levels of BOD and COD indicate a higher amount of organic waste or sewage in the water/wastewater.

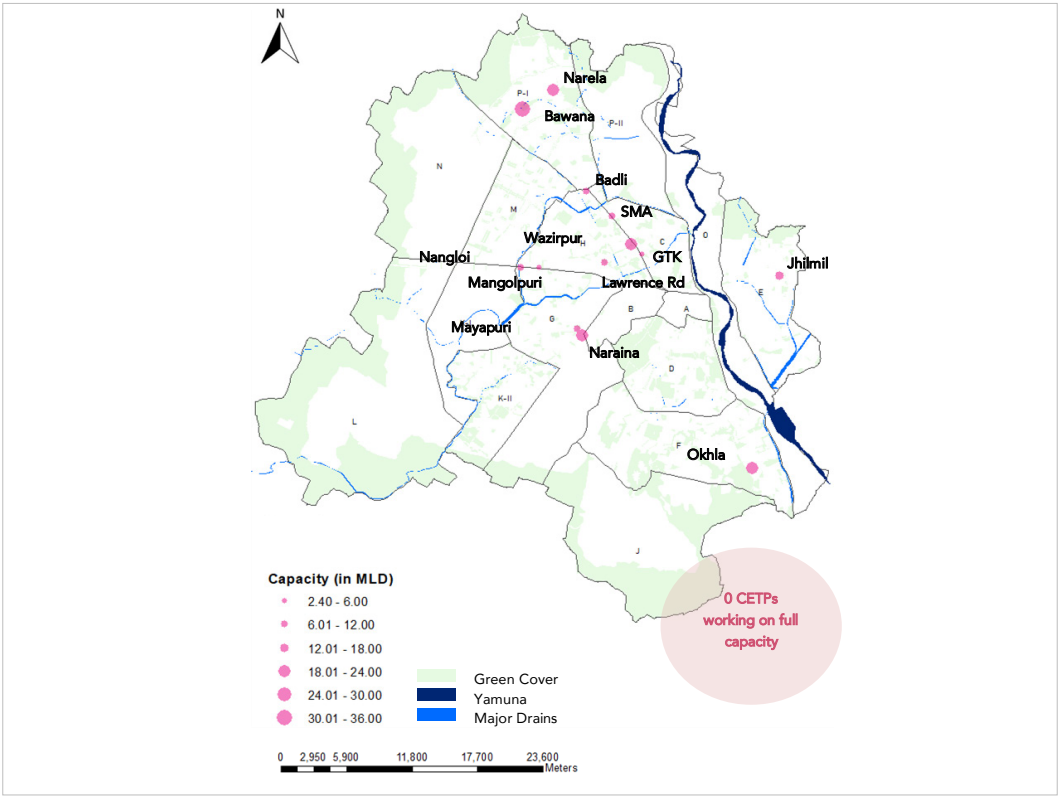
Availability and Utilisation of Common Effluent Treatment Plants

Delhi State Industrial and Infrastructure Development Corporation Ltd. (DSIIDC), a government organisation has been assigned the responsibility to establish, operate, maintain, and manage the Industrial Estates in Delhi. At present, 33 approved planned Industrial areas exist in Delhi. Out

of these, 17 are connected to 13 CETPs which are marked in Figure 4. The total Capacity of the 13 CETPs in Delhi is around 212.3 MLD. However, the total effluent flow generated is only 52.72 MLD. This shows that the utilization of CETPs is only 24.8 per cent.

This indicates that CETPs are not functioning up to the designed capacity probably because all industries have not taken connection to the CETPs. Thus, industrial waste from all the industries is not being treated and is being disposed directly into the drains. The main parameters that are not conforming to the standards are TSS in influent discharge and sulphide and BOD in effluent discharge. Higher levels of BOD indicate a higher amount of organic waste or sewage in water/ wastewater. However, the quality of the CETPs effluent standards (outlet) is monitored by Delhi Pollution Control Committee which shows that in July 2021, nine CETPs did not discharge the treated water as per standards (Delhi Pollution Control Committee, 2021).

Figure 4: Mapping of Common Effluent Treatment Plants in the NCTD

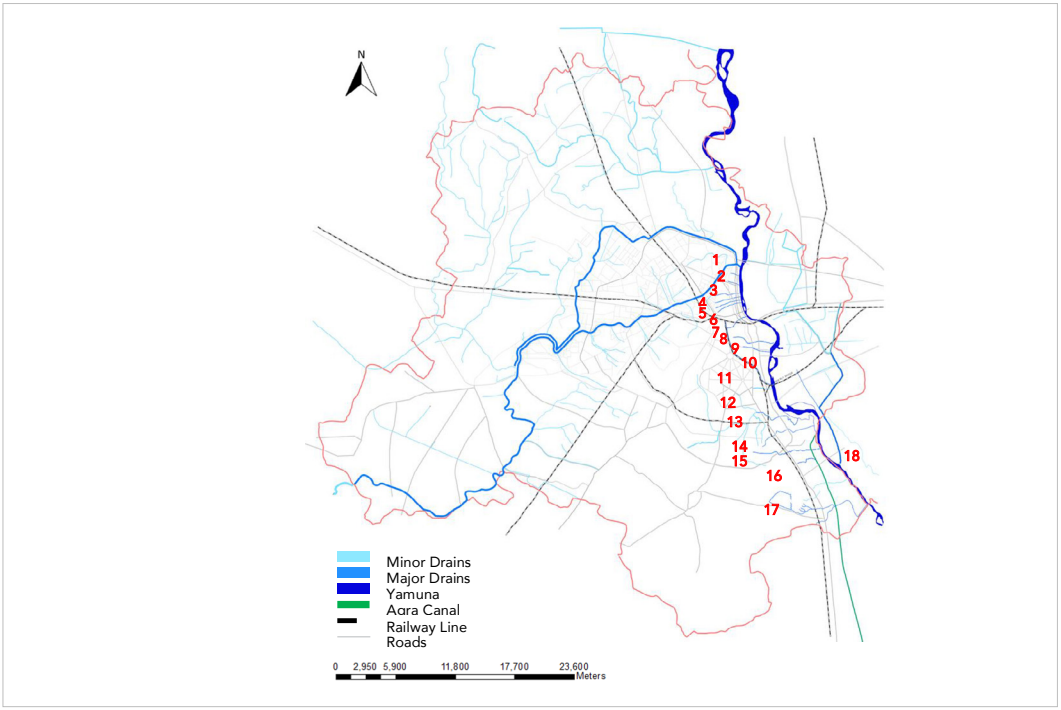


Source: Prepared by Author, 2022

Distribution of Drains and Unauthorised Colonies (UACs)

Total 18 drains of Delhi discharge the water flow into River Yamuna during both dry and rainy periods and contribute to around 80 per cent of pollution in the river. Furthermore, till now in Delhi, out of 1,799 UACs, only 561 (31%) have sewer lines laid. In non-sewered settlements, the household domestic wastewater is either collected in a septic tank or it is discharged directly into open drains (University of Virginia, 2018).

Figure 5: Distribution of Drains in the NCTD



Source: Prepared by Author using Google Imagery, 2022

Mapping Spatial Pollution

The mapping of spatial pollution along the Yamuna River in Delhi was conducted by using Inverse Distance Weighting (IDW) interpolation to analyze the Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and faecal parameters. This involved extrapolating pollution data from established monitoring points to create continuous maps that showed concentrations of pollutants. The BOD measurements indicated significant organic pollution, COD assessments highlighted the overall pollution levels, and faecal parameters provided insights into microbial contamination.

To analyze the river water quality as per the concerning pollution parameters, data for the years 2011 and 2021 was sourced from the National Water Quality Monitoring Programme (NWMP) at the monitoring stations that were managed by the Central Pollution Control Board (CPCB) and Delhi Pollution Control Committee (DPCC). By mapping these interpolated results, pollution hotspots were pinpointed along the river and this methodology enabled a comprehensive spatial analysis of the pollution dynamics which supported evidence-based decision-making for effective river management and environmental protection measures.

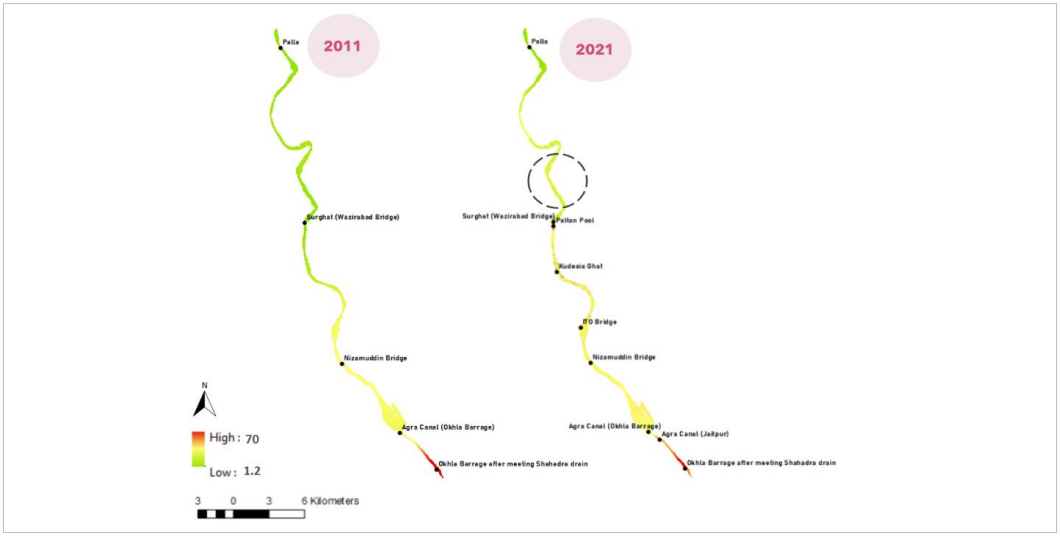
Biological Oxygen Demand

BOD gives an estimate of the organic pollution in water and wastewater. In both 2021 and 2011, the BOD levels remained under permissible limits only till the Wazirabad Barrage. Also, in Figure 6 it can be seen that in both 2021 and 2011, after the Wazirabad Barrage the values increased by almost 30 times as the river reached the Okhla Barrage. This led to decomposition of organic material and excess release of nutrients, such as nitrogen (N) and phosphorous (P) thus producing dense algal bloom which lowered the Dissolved Oxygen (DO).

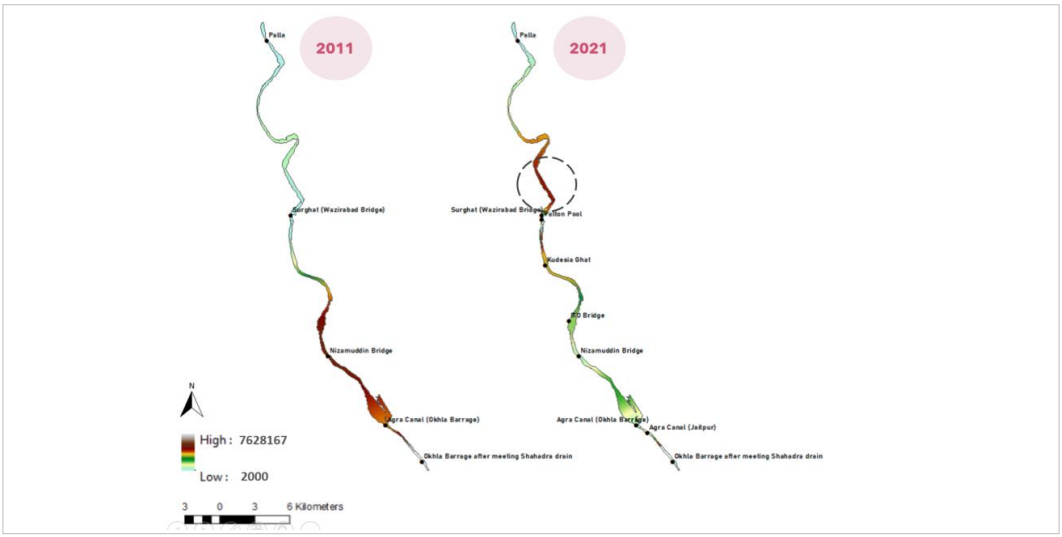
Faecal Coliform

Faecal Coliform gives an estimate of the biological pollution in water and wastewater. In both 2021 and 2011, faecal coliform was not within the permissible limits except at Palla (2020) as shown in Figure 6. Contact with such water results in exposure to pathogenic bacteria and is often associated with contamination by faecal material of humans or animal sources. Leaking sewage pipes or septic systems could be the sources for this.

Figure 6: Spatial Pollution Mapping of Biological Oxygen Demand (top) and Faecal Coliform (bottom) in the NCTD



Source: Prepared by Author using IDW Interpolation on ArcGIS, 2022

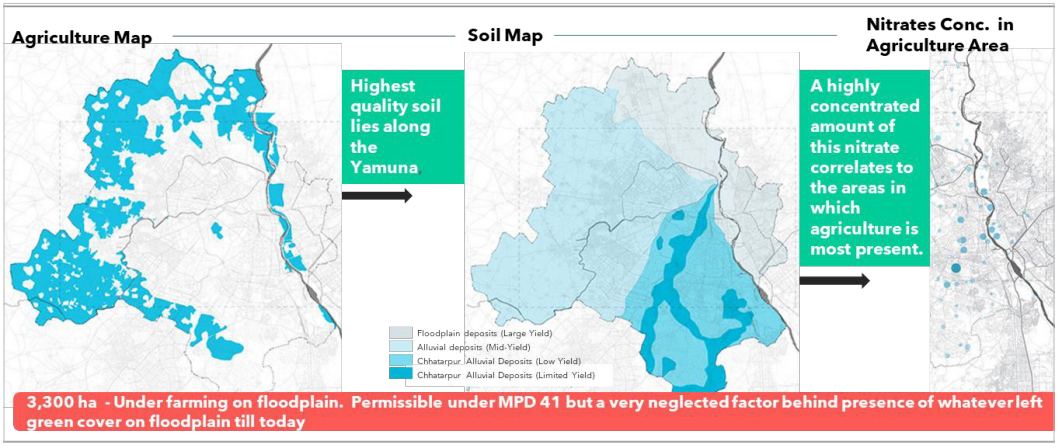


Source: Prepared by Author using IDW Interpolation on ArcGIS, 2022

Agricultural Run-off

While the highest quality soil lies along the Yamuna, most agricultural practices take place along the city's periphery and that too in low-quality soil because of limited access to the river. As a result of industrial effluents and untreated sewage water, Delhi's soil is highly contaminated with heavy metals and pesticides which are matters of concern regarding crop production and food safety. On the other hand, contamination of River Yamuna also occurs because of soil contamination through agricultural pesticides, fertilizer residue, and farmland waste that creates unhealthy run-off (University of Virginia, 2018).

Figure 7: Agriculture Mapping on Delhi's Floodplain



Source: University of Virginia, 2018

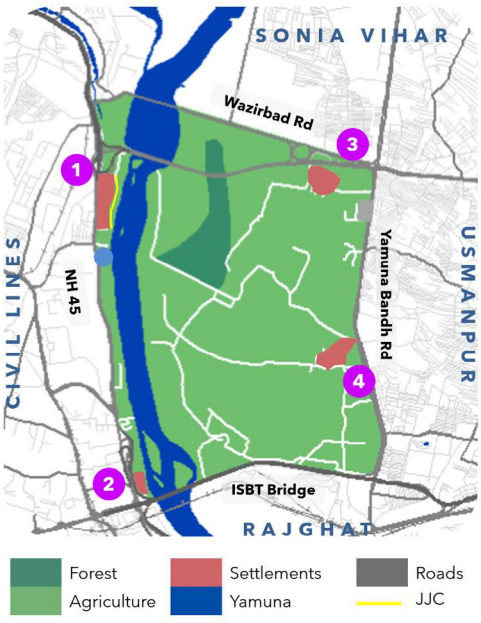
Site Selection and Analysis of Riverine Communities along Yamuna Bank

At site level, the study's main aim was to assess the condition of people living close to the River Yamuna and those who are directly dependent on it for their livelihood. The assessment would be in terms of living environment, availability of physical infrastructure, and impact on health. To conduct site-level research, the area between Wazirabad Barrage and ISBT Bridge was selected (Figure 8) as it is located downstream of the Najafgarh Drain in Sub-Zone II which contributes to about 60 per cent of the total pollution in the river.

The site consists of four residential colonies namely New Aruna Nagar Colony, Ladakh Vihar Colony, Gehri Mandu Village, and New Usmanpur. New Aruna Nagar was selected for a detailed study because of the diverse socio-economic profile of the area. Farmers are involved in agricultural activities in the river's floodplain behind New Aruna Nagar Colony. This community of farmers was also selected for research and all fifteen households were surveyed.

New Aruna Nagar was selected for detailed study because of the diverse socio-economic profile of the area with majority of the households involved in the commercial sector. Further, systematic sampling was conducted in this colony. Every fourth household was surveyed with a sample size of 100. In addition to the river's floodplains behind New Aruna Nagar Colony, farmers are involved in agricultural activities. This community of farmers on the floodplains has also been taken for the research and all 15 households were surveyed.

Figure 8: Site between Wazirabad Barrage and ISBT Bridge, Delhi selected for Survey



Source: Prepared by Author using Google Imagery, 2022

Basic Facilities in Households

There is piped water supply for all households in New Aruna Nagar Colony. However, during the dry season the water that is received by the households is dirty and it smells which forces them to buy bottled water. At present, there are no sewer connections; although one in every third household has a septic tank i.e. 47 per cent, but due to lack of regular pumping and proper drainage (sludge continues to build), it contaminates the nearby water bodies as well as the underground water.

Figure 9: Latrine Facility in New Aruna Nagar

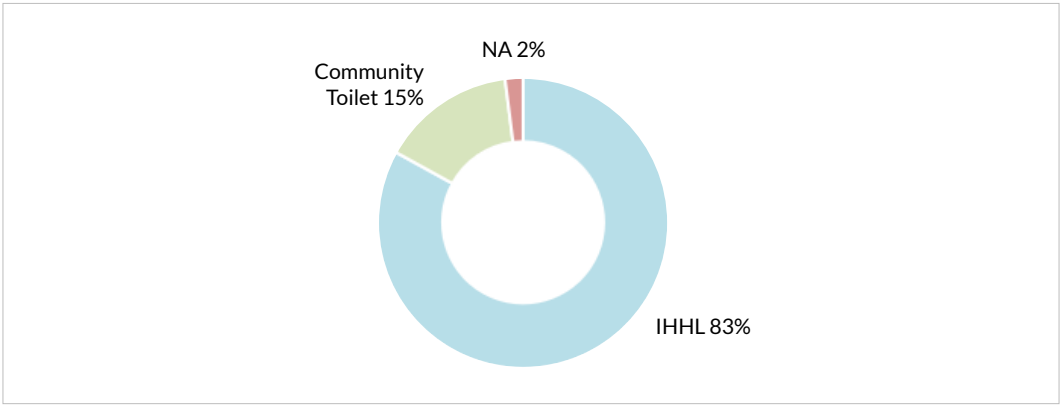
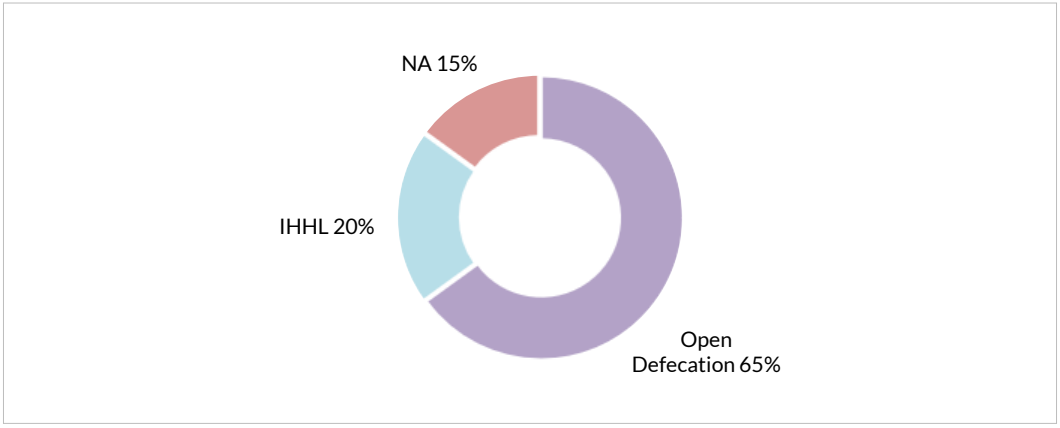


Figure: 10 Latrine Facility in Riverine Communities



Source: Primary Survey, 2022

It was observed that behind New Aruna Nagar Colony, facing the west bank of the river, the farmers were living at a bare-minimum level. These farmers did not even have access to proper sanitation facilities as shown in Figure 9. They practiced open defecation at makeshift arrangements that were installed on narrow drains which carry wastewater from Majnu Ka Tila to the river. However,

a government tap has been installed for drinking water purposes. Though most of the farmers also had a hand pump installed on their farmland, but they did not use its water for drinking because of high concentrations of fluoride that are present in the groundwater. Every morning, they fetch water from the government's public tap.

Health, Occupation, and Impact of Pollution

Occupation and Pollution Impacts

New Aruna Nagar Colony has extensive human activity like shops, eateries, vendors, and vehicles that are spread all over. No Impact on their Business is mentioned because as such the interaction of this community with River Yamuna is zero with respect to their occupation. Also, even though the polluted river does not affect their occupation to a large extent, these extensive human activities in return, affect the pollution levels of the river through discharging wastewater directly into it.

Figure 11: Occupation Type - New Aruna Nagar

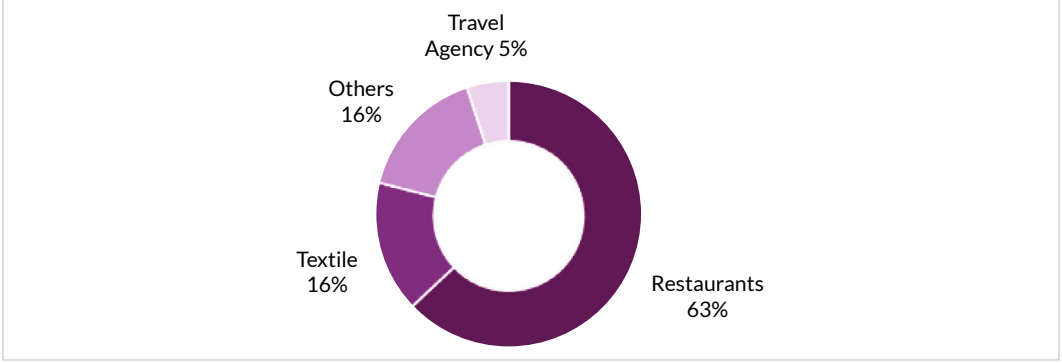
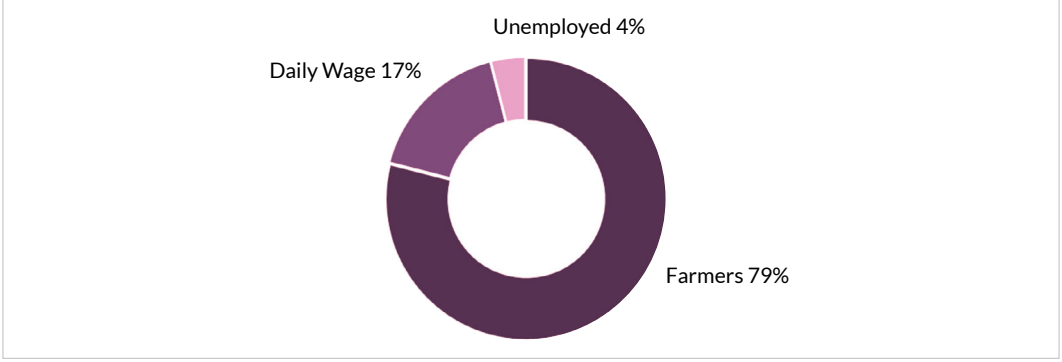


Figure 12: Occupation Type - Riverine Communities



Source: Primary Survey, 2022

In the farmer's communities, the major occupation source is farming which is around 79 per cent. The major vegetables that are produced include cucumber, and bottle gourd in summers and cauliflower, spinach, and lettuce in winters. However, due to lack of fresh and clean water sources for irrigation, wastewater discharge from drains/River Yamuna is used. Because of this, crops irrigated by the Yamuna River spoil sooner and this requires a high use of fertilizers. Such conditions also force them to change the type of crops grown over the year.

Health and Pollution Impacts

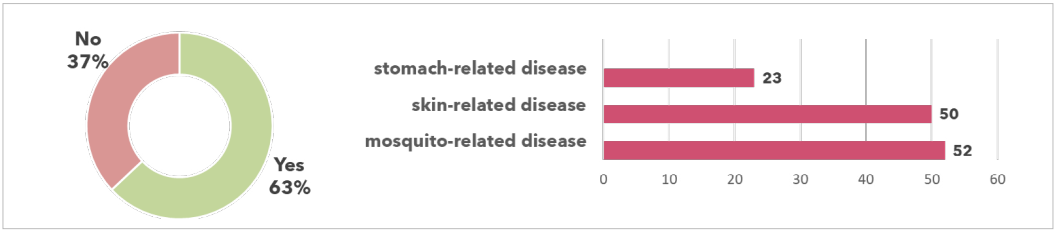
In New Aruna Nagar Colony, 95% of respondents said that River Yamuna's water quality had an impact on their health, especially on children. Of these, maximum cases recorded were of mosquito-related diseases which was followed by stomach and skin-related diseases, respectively, as shown in Figure 13.

Figure 13: Yamuna Water's Impact on Health & the Types of Diseases Reported - New Aruna Colony

Source: Primary Survey, 2022

In the farming communities, when asked about the Yamuna River's impact on their health, half the respondents did not answer. Only 34% respondents answered the question, out of these 63% believed that Yamuna's water quality had an impact on their health as shown in Figure 14. This was mostly because a majority of respondents were hesitant to think that river pollution could be the cause of any disease as they believed in the river's divinity. However, those who accepted, responded that they frequently suffered from mosquito related diseases, which were followed by skin and stomach related diseases. This is because they remain in close contact with the wastewater and the River Yamuna's polluted water for irrigation purposes.

Figure 14: Yamuna Water's Impact on Health & the Types of Diseases Reported – Riverine Communities



Source: Primary Survey, 2022

Issues

Land Use/Land Cover

In the last ten years, rapid urbanization has resulted in significant reduction of vegetation and the Yamuna area. This type of urban sprawl negatively impacts the quality of the river because more drains are built along these urban areas which outflow into the river.

STP & CETP Analysis

The existing sewerage treatment facilities are not sufficient:

- Inadequate coverage of sewerage results in wastewater flowing into the open Nallas causing pollution of the River Yamuna (only 31% UACs have sewers laid)
- Almost 20% wastewater that is generated by domestic users is discharged directly into the river
- It was noted that 23 STPs (70%) do not discharge treated water as per the given standards
- Nine CETPs do not discharge treated water as per the effluent standards (outlet)
- The generation-treatment gap continues to increase because of rapid population growth

Community Assessment

- Due to lack of tenure, space, and economic constraints the urban poor are unable to access safe sanitation
- People who use river water for their livelihood report diseases like joint pains, stomach aches, nausea etc
- Pollution of the river water affects the crop yields and farmers are forced to rethink about the types of crops to be grown for cultivation
- In turn, heavy use of fertilizers is also washed into the River Yamuna because of the use of wastewater for irrigation of crops

Discussion

Cross-Sectoral Collaboration and Wastewater Recycling at Different Levels

A combination of decentralized and in-situ treatment systems can be planned through Nature-based Solutions. This will help to tackle the issue of wastewater generation-treatment gap in a way that urban farming that is being practised on the river banks, can be preserved and promoted through reuse of recycled waste-water; thus, improving the quality of farming and the livelihood of farmers.

Table 4: A Strategic Combination of Decentralized and In-situ Treatment Systems

HARD To overcome the issue of connecting areas to centralised STPs		SOFT to overcome the issue of changing floodplain Land-Use		
APPROACH	HARD	SOFT		
Zone O II	Wastewater Treatment through DWWT in the Colonies	Nature Based Agriculture as Created Habitat	Riparian Restoration	Green Pathways
A combination of hard & soft measures can be planned through nature based solutions to tackle rising concerns on wastewater pollution.	Treat wastewater at a local level Reuse of Treated water in Agriculture Recovery of O & M Costs	Ecological Restoration of Floodplain through Natural Farming (Promote Green Jobs) Farmers trained to become guardians of parks along Yamuna.	Filtering Agricultural Run-off Restoring natural habitat along the river bank	Open space routes that are managed for both conservation and enjoyment. Forms river-people connect

Source: Prepared by Author, 2022 Site Level Proposals

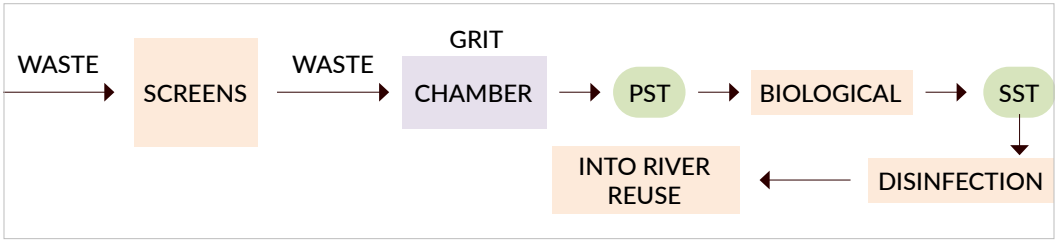
Decentralized Wastewater Management Systems

As per guidelines of the Ministry of Urban Development (MoUD), Decentralized Wastewater Management (DWWM) can be defined as "the collection, treatment, and disposal/reuse of wastewater from individual homes, clusters of homes, isolated communities, industries, or institutional facilities, as well as from portions of existing communities at or near the point of waste generation" (Guidelines for Decentralised Wastewater Management, 2012).

Advantages:

- At any point, the water flows remain small in the system
- Less environmental disturbances as smaller pipes are installed during the construction of the system
- Without routing more flows to the existing centers, new treatment centers can be added; making it easier to expand the system
- Less investment is required for laying down sewer pipelines
- The quality of treatment is more efficient as compared to the traditional system
- Efficient reuse of treated sewage for toilet flushing, irrigation, etc.
- Easier maintenance of sewerage system

Figure 15: Process of Decentralized Wastewater Technology (DWWT)



Source: Guidelines for Decentralised Wastewater Management, 2012

Selection of Technology to demonstrate Decentralized Wastewater Technology at Site Level

India has a number of efficient technologies to treat wastewater at the local level. However, factors to be considered while selecting technologies for DWWM are land required, capital cost, and operation & maintenance cost for unauthorized colonies. Land is the biggest constraint for any kind of wastewater treatment system. On the basis of these factors, CAMuS-SBT was specifically selected for the site as shown in Table 5. Further, this DWWT is the most suitable prototype for the selected area as it cannot be replicated in other areas. On the basis of varied factors, other suitable systems can be proposed for different areas.

Table 5: Factors for Selecting Technology at Site Level

FACTORS	CAMuS-SBT (600 KLD)
Land required	420 sq.m.
Capital Cost	Rs. 62.1 Lakhs
Operation & Maintenance costs	Rs. 6 Lakhs

Source: Calculations done by Author based on (Centre for Science and Environment, n.d.)

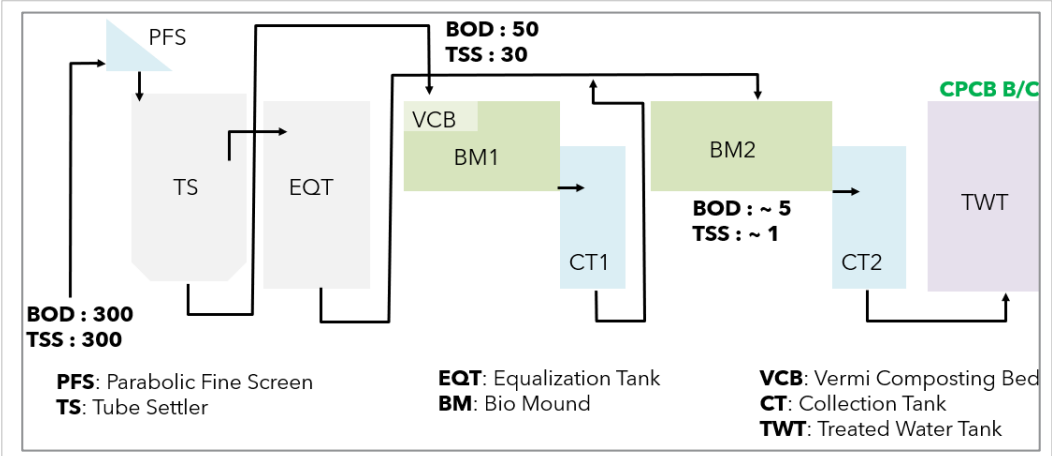
CAMuS-SBT

Continuous Advanced Multistage System – Soil Biotechnology (CAMUS-SBT) is an advanced technology that uses only local supplies and is an oxygen-supplying biological engine which can treat all wastewater - domestic, municipal, and industrial). Media used in the bio-reactors create a natural ecosystem that ensures a minimum lifespan - 25 years for desired hydraulic and organic loading (Shankar, P. H., n.d.).

Features:

- It's a green/clean technology
- No noise and odour
- Optimal usage of space
- No external aeration and no formation of bio-sludge
- One time media installation
- Low power consumption (1/3 of conventional STPs)
- Efficient removal of pollution
- Long life
- Creates green habitats

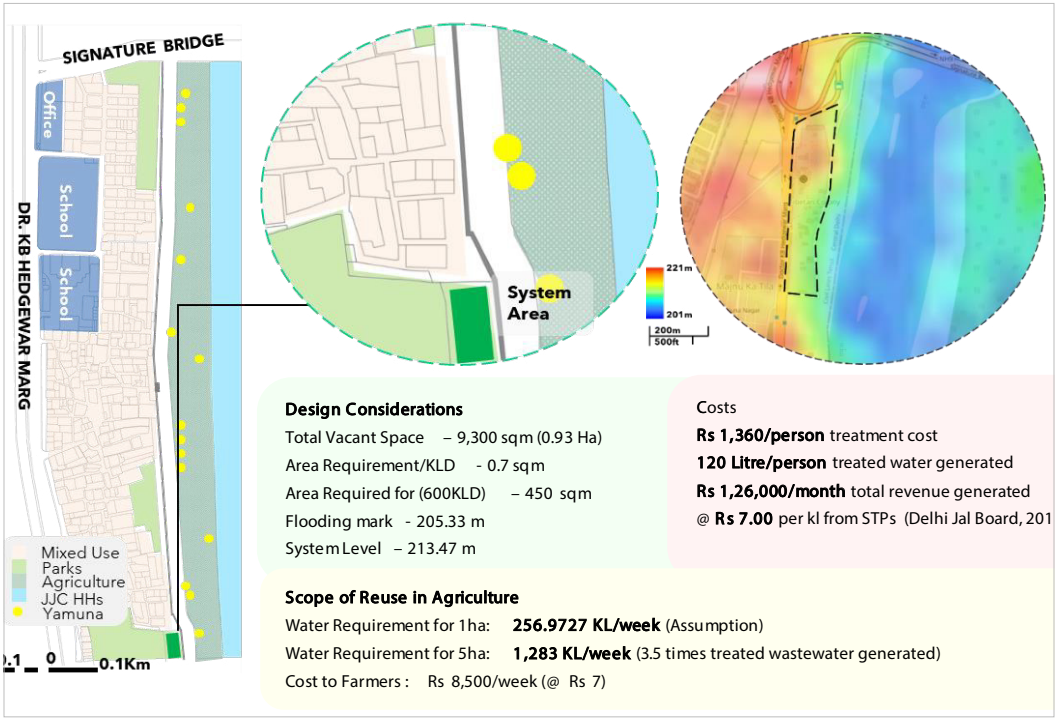
Figure 18: CAMuS-SBT Process



Source: Centre for Science and Environment, n.d.

Site Selection for Technology

Figure 19: System Area of Technology in New Aruna Nagar, Delhi



Source: Prepared by Author, 2022 based on standards recommended by Centre for Science and Environment, n.d.

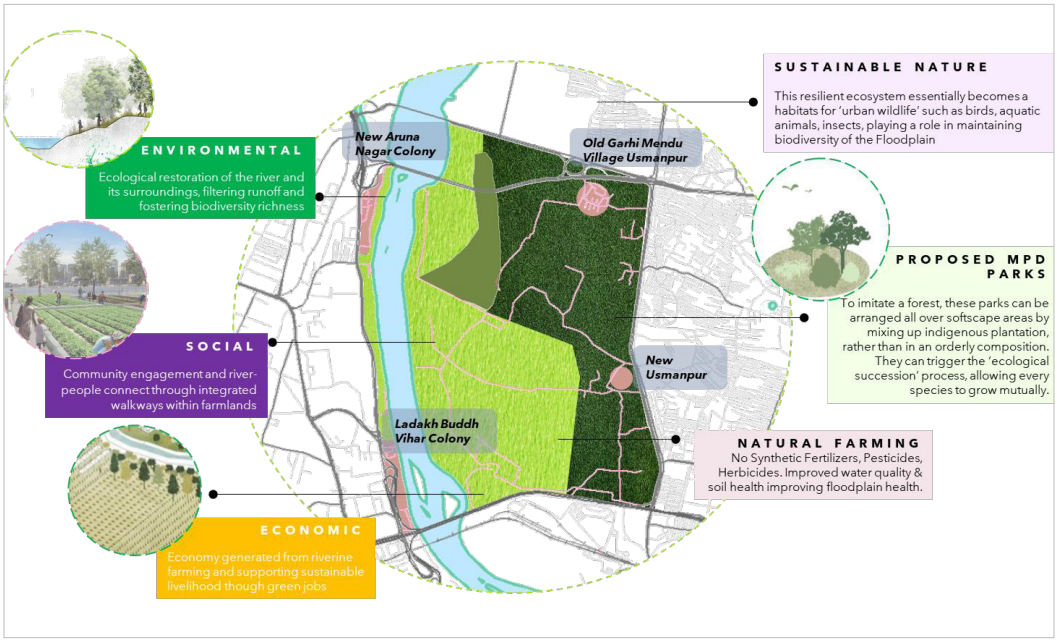
BOD and COD are less than five with the removal efficiency of both greater than 99%. Effluent can be used for construction, flushing, plantation, and irrigation as the discharged water is equivalent to CPCB designated Use Category 'B/C'.

Floodplain Level Proposal

The proposed Master Plan 2041 of Delhi Development Authority (DDA) places strong emphasis on the development of green belt and improving people's engagement with the city's "green and blue resources". The "Green-Blue strategy" which focuses on water bodies and the land around it, offers to give the city a unique shape (Rajput, 2020). Further, as per MPD-2041, agriculture is a permissible land use for Zone O. Integrating Nature-based Farming practices into it will not only help in tackling the agricultural run-off pollution but will also support the theme of re-imagining 'River Yamuna' and Delhi's floodplain image. Thus, the reframed vision for development should be along the lines where there is 'Integration of farming with the existing/proposed parks, and public spaces to improve floodplain health in terms of biodiversity, water quality, and soil health'. This will be done through interventions discussed below and can be replicated across the entire floodplain:

- Environmental: Through Riparian Buffer (30 M) - Ecological restoration of the river and its surroundings, filtering run-off, and fostering biodiversity richness.
- Social: Community engagement and river-people connect through integrated green walkways within the farmlands and proposed parks.
- Economic: Economy to be generated from riverine farming and supporting sustainable livelihood through green jobs.
- Sustainable Nature: This resilient ecosystem to essentially become a habitat for 'urban wildlife' such as birds, aquatic animals, insects, and play a role in maintaining biodiversity of the floodplain
- Proposed MPD Parks: To imitate a forest, these parks can be arranged all over the softscape areas by mixing up indigenous plantations. They can trigger the 'ecological succession' process, thereby allowing all species to grow mutually
- Natural Farming: No synthetic fertilizers, pesticides, or herbicides to be used. This will help in improving the water quality and soil health thus improving the health of the floodplain.

Figure 20: Floodplain Level Proposals based on Urban Agriculture at Site Level



Source: Prepared by Author on ArcGIS, 2022

Stakeholder Identification

Any planning vision for River Yamuna and its floodplains in Delhi must consider and reconcile the concerns and interests of all stakeholders. For successful implementation of community-based projects, stakeholder engagement is a main component. Stakeholders are involved in the planning and implementation stages so as to achieve consensus and take into account their needs and interests. This allows all stakeholders to understand the potential impacts of the proposed activity on the community and their contribution towards better implementation of the project.

Table 6: Stakeholders and their Contribution to the Project

Stakeholder Categories	Their Motives	Potential to Implement
Authorities DJB CPCB DDA NMCG	Respect for laws and regulations Public health Cleanliness of the city Conforming with Master Plans and other plans	Power for enforcement through regulatory framework in terms of connections and safe disposal of treated wastewater, and management of treatment units Link with other authorities can help in land transfer Training methods and materials to be developed with subject matter specialists and trainers to support integrated agro-ecosystem
NGOs (Rights of Farmers, Environmental Groups)	Clean environment Capacity building programs Transparency and Public Participation	Community awareness on effects of current farm practices Conducting workshops and creating awareness about Nature-based agriculture Collaboration between researchers and land users on the promotion of a productive and sustainable farming system
Potential end-users for Reuse Farmers DDA Forest Dept	Affordable and safe products Increase in yield	Increase DWWTs revenue through selling of end-products For irrigation For maintaining green spaces under various agencies
Households (users and owners)	Clean environment	Pressure on municipal authorities and service providers Better management of onsite systems

Conclusion

Although River Yamuna's water quality is at par with that of a healthy river, this study clearly demonstrates that the river is still an important part of many people's lives. The river's management in the city is more likely to create grey infrastructure and recreational areas in and around the river. However, the constant discharge of wastewater drains into the river has yet to be entirely addressed. Delhi also needs to address its unplanned urban growth and try to restore the river's natural ecological flow to allow wastewater to be diluted between Wazirabad and Okhla. Furthermore, Delhi must decentralize its wastewater management through in-situ treatment with focus on soft infrastructure, local reuse, and mainstream septage control, as new, illegal growth will emerge by the time the grey infrastructure covers the existing areas that are unsewered. This game of catch-up will continue until we acknowledge the problem, and move away from sewage and centralized systems and towards sanitation for all.

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Conflict of Interest

The authors declare no conflict of interest.

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Revitalization of Urban Waterfronts through WaTOD: A Case of Jhelum River in Srinagar

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Abstract

Cities with rivers are increasingly looking at expanding their public transportation network by turning towards water transit as an alternative to land-based transportation. This approach aims to supplement the existing transportation network, thereby reducing traffic congestion and mitigating pollution.

Urban areas have been the epicentre of growth and a destination for employment opportunities. Therefore, they are in a constant flux due to migration from peripheral areas in search of jobs and better living conditions which eventually leads to urban sprawl. According to the Census 2011 projections, cities are expected to accommodate 41% of India's population by 2030, which is up from 31% in 2011. There are numerous benefits of urbanization, such as economies of scale and access to education, but there are also negative externalities, such as environmental degradation and reduction in the quality of life.

Srinagar has seen a rapid surge of urbanization, with increasing population and limited geographical features. The city is expanding horizontally at a very fast pace, resulting in the rise of private vehicle ownership, traffic congestions, road accidents, air pollution, haphazard growth, and a decline in the use of public transportation (Government of Jammu and Kashmir, 2020).The Urban Sprawl has shown major impacts on waterbodies and wetlands, the haphazard growth has

resulted in encroachment over water bodies and has fragmented them from the wetlands which has made the city more susceptible to floods (Srinagar Development Authority, 2015).

The Water Transit-Oriented Development (WaTOD) model aims to prepare a development plan by directing the importance of water bodies as an element of transit-based growth. The outcome is a water-centric city which will develop its urban land-use near water transit terminals to boost inland water transportation in conjunction with roadways and railways to make a sustainable urban transportation systems. This also involves redevelopment of the waterfront district for high-density business, residential, and tourism purposes along with Water Transit Terminals and proposed parks and green spaces that will encourage movement along the river. The development model will focus on building a relationship between livelihoods and water bodies to create a sense of attachment by converting water into an asset rather than a barrier.

Keywords: Urban Sprawl, Central Business District (CBD), Urbanization, Srinagar

Introduction

Though rivers, canals, backwaters, and creeks make up India's vast network of inland waterways but as compared to other developed countries India has underused its waterways for transportation services (Lambert, 2010). The failure to recognise the potential impact of inland water transportation system on national economies continues to be a key issue (EBP U.S., 2021). Inland waterways in industrialised nations, such as the United States, the European Union, and China, have been modernised, according to the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP), and a substantial commercial Inland Water Transport (IWT) sector has emerged (Amos et al., 2009).

In India, inland waterways account for less than 1% of overall transportation, compared to 8.7% in China and 7% in the European Union (Government of Assam, 2016). When compared to neighbouring countries, IWT moves around 35% of freight in Bangladesh (UNESCAP, 2021). Rival routes of transportation, such as rail and road, are less established than river ports. In Thailand, inland water transport is second to roads in terms of freight moved, accounting for around 20 million tonnes (Pomlaktong et al., 2011). In and around Bangkok, passenger travel is considerable, with several kinds of services, including express services.

Inland waterways provide a more ecological and cost-effective alternative to road and rail cargo transportation (Tournaye et al., 2010). According to a report by the World Bank, as cited by Mukhopadhyay, 2017, the cost of transporting one tonne of freight across one kilometre is Rs 1.41 for railways with a capacity of 85 tonnes, and Rs 2.28 for roadways with a capacity of 24 tonnes, whereas IWT costs Rs 1.19 per tonne with a capacity of 105 tonnes (Mukhopadhyay, 2017). In the coming decades, inland waterways are expected to become a more ecologically friendly option than roads and railways in terms of energy efficiency, noise pollution, and emissions as traffic congestion and emissions from land-based transit grows.

Inland water transportation was a significant mode of cargo and passenger movement in India in the early twentieth century, but the influence of railways and road modernization led to its neglect (Hayter & Sharp, 1983). IWT now carries less than 0.5 per cent of India's freight traffic, compared to 66 per cent for roads and 27 per cent for railways (Hejib & Pade, 2018).

This research concentrates on identifying the various potentials of inland water transportation in the country as well as analysing the existing water transportation models in India and overseas. The study will look into the laws, policies, and initiatives that have been put in place by government agencies to find what else can be viable. It will also examine the institutional frameworks of important entities in India that are responsible for inland water transportation and point out the fundamental problems that are causing inland water transportation to be underutilised.

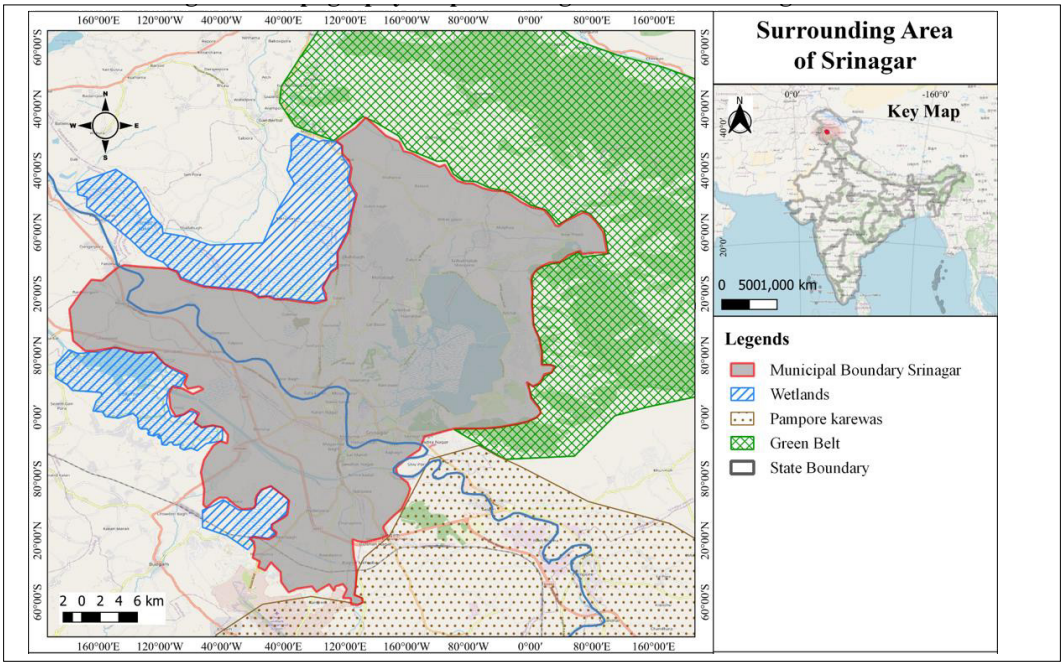
Rationale of the Study

Srinagar is the summer capital of the union territory of Jammu and Kashmir (J&K). It is located at an altitude of around 1586 meters above mean sea level on the banks of the Jhelum River. According to the Census 2011, the state's urban population expanded by 36.42% between 2001 and 2011, outpacing the national average of 31.1%. Kashmir region sums up about 63% (2.2 million) of J&K's urban population out of which Srinagar individually accounts for 55% (Srinagar Development Authority, 2015). The current development appears to be more focused on road corridors. The city is expanding along the major roads, hesitantly approaching clogged flood basins (Mohd & Hassan, 2019; Shah et al. 2023). In Srinagar city, the land-use conversion of natural wetlands to other uses is being done on a vast scale into residential, commercial, and agricultural activities (Dar et al., 2020).

The wetland coverage dropped from 5.21% in 1971 to 2.6% in 2014 (Kuchay et al., 2014). As a result, wetlands have fragmented from the water bodies, thus increasing the city's vulnerability to floods. The city's northern and eastern wards are connected by a green belt making any construction illegal, Pampore karewas on the South, and the wetlands on the West (shown below in Figure 1). Therefore, vertical expansion is the way forward, but it must be done correctly by taking into account the soil's bearing capacity and providing strong planned foundations for the soil (Primary Survey: 10th – 23rd February 2022).

Srinagar city has faced uncontrollable migration from the peripheral areas, and traffic is at an all-time high. According to the Comprehensive Mobility Plan (CMP) for Srinagar, roadways with a Right of Way (ROW) of less than 20 metres dominate the road network, and 91% of the entire road network has travel speeds of up to 20 km/h (Government of Jammu and Kashmir, 2020). This shows congestion in the city, which requires interventions related to road widening, which involves significant financial commitment, effort, and a huge amount of land acquisition, making it a tough proposition. The state Government is also making efforts towards rejuvenating the water transit system of the city to release the pressure on land transport.

Figure 1: Topography Map of Srinagar and Surrounding Areas



Source: Srinagar Master Plan 2035

Water Transit Oriented Development (WaTOD)

Water Transit Oriented Development (WaTOD) is a hybrid version of Transit-oriented Development (TOD), where the usual approach is more concentrated on Mass Rapid Transit System (MRTS) i.e. railways, and Bus Rapid Transit System (BRTS) i.e. buses. The WaTOD model focuses on integrated water transport and land use development. This includes development along water transit terminals and corridors, and building high-density, mixed land use such as business/neighbourhood centres. To promote water transportation and discourage private vehicle ownership, node-based development (i.e., Commercial, residential, etc.) or corridor development can be prospective approaches. WaTOD is based around one-fourth of a mile of the water transit stations to promote water transport and by making the water body the most important element of growth (Thompson et al., 2006).

To make water transportation successful, it needs to compete with or complement the alternative modes of transportation (Pratas et al. 2023). Ferry transportation is a cost-effective means of transit compared to other modes, with ferries alleviating more congestion per cost incurred on other modes. Ferries are similar to buses in that they are low-cost, quick-to-implement means of transportation and do not increase traffic congestion (Tanko et al., 2018).

According to research conducted by the San Francisco Bay Area Water Transit Authority, predicting ferry ridership has been a difficult task because it is not only dependent on the trip time and cost (Water Emergency Transportation Authority (WETA), 2012), but pleasure, aesthetics, comfort, and reliability also play an important role in selecting a ferry as a model (Pantouvakis, 2007). Initially, the ferry's inability to make multiple stops due to the long docking times was a hindrance in the development of water transit. This disadvantage resulted in the ferry's lack of ability to connect multiple TODs, due to which the prospective rider base should grow. With the evolution of marine technology, water taxis are being produced which are much quicker and can carry 100-120 passengers at a time with a top speed of 40-50 kms/h like the one implemented in Brisbane, Australia (Tanko et al., 2018), thus, making the ferry cost and time effective. The long docking times can also be substantially reduced by implementing Automatic Intelligent Docking Systems (AIDC).

The pros of the above-mentioned scenarios highlight water transport with the potential of taking a load of urban transport in conjunction with roadways and integrating multiple TODs/nodes. Water transport is a cost and time-effective alternative and at the same time provides access to other factors as well, such as reliability, access to open spaces, aesthetics, environment-friendly, etc (Rangaraj & Raghuram, 2007). Developing a TOD on a waterfront provides a lot of new challenges that need to be dealt with for the successful implementation of water transport which will play an important role in developing patronage over time. Some challenges that can be faced in developing a WaTOD model are listed below. These challenges have been carefully identified and curated from the literature review.

- The existing land use regulations for development along the waterbody.
- Content with storm hazards such as floods.
- High wind pressure near the shore will affect the high-rise buildings.
- Residential and commercial establishments should be located within half-kilometre of a transit stop.

To make urban water transportation and ferry-oriented development effective, major emphasis should be on terminal architecture and offering added facilities like shelter and business settings, compared to the traditional TOD practices (Thompson et al., 2006). Ferry services, when combined with waterfront restoration projects, have the potential to be a catalyst for economic revival in American cities. According to research, ferry passengers are often leisure users who are less concerned with time and are more prone to remain at ports and utilize supporting land uses (Thompson et al., 2006). These traits imply that effective WaTOD may benefit from the construction of spaces where individuals are more likely to spend time. These should be created in collaboration with the current transportation network and incorporate not just integrated ticketing but also standard signage and navigation to and from other forms of transportation.

A case study of Brisbane's waterway network discovered that the average monthly ferry ridership increased by 40% from 2003 to 2006 (Zuniga et al., 2013). This increase was an outcome of multimodal ticketing and a shift in the nature of development of waterfronts towards residential, commercial, and retail uses from industrial and warehouses (Sipe & Burke, 2011). As a result,

integrating water and land transportation should be the primary focus.

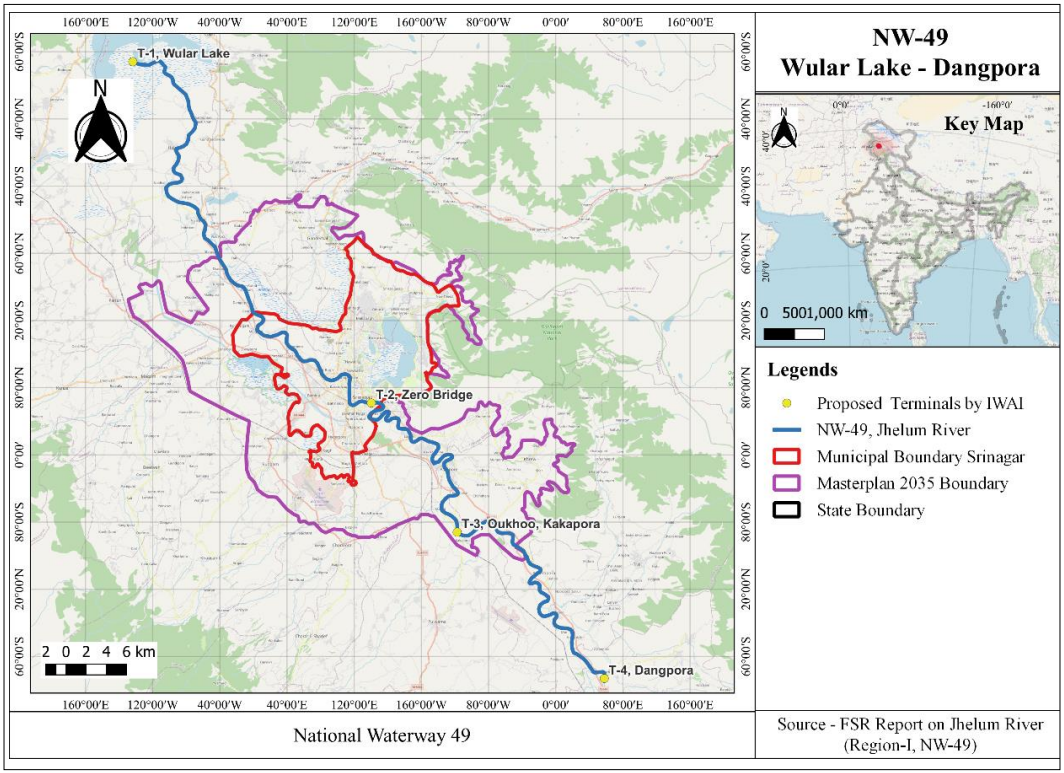
Transportation in Srinagar

Water Transport

National Waterway- 49

The National Waterway-49, located in Kashmir, travels through four districts and spans over 110 kilometres (Figure 2) (IWAI, 2017). According to the IWAI, NW-49 is technically considered feasible for the development of shipping and navigation by the Inland Waterway Authority of India (IWAI) with minimal dredging (IWAI, 2017). The river is navigable throughout the year with agricultural land existing on both its banks along the stretch. IWAI identified four potential terminals on NW-49, which are depicted on the map in Figure 2; one of them, Terminal 2, i.e. the Zero Bridge, is located in Srinagar city. In addition, the river flows from South-east to North-west.

Figure 2: National Waterway – 49



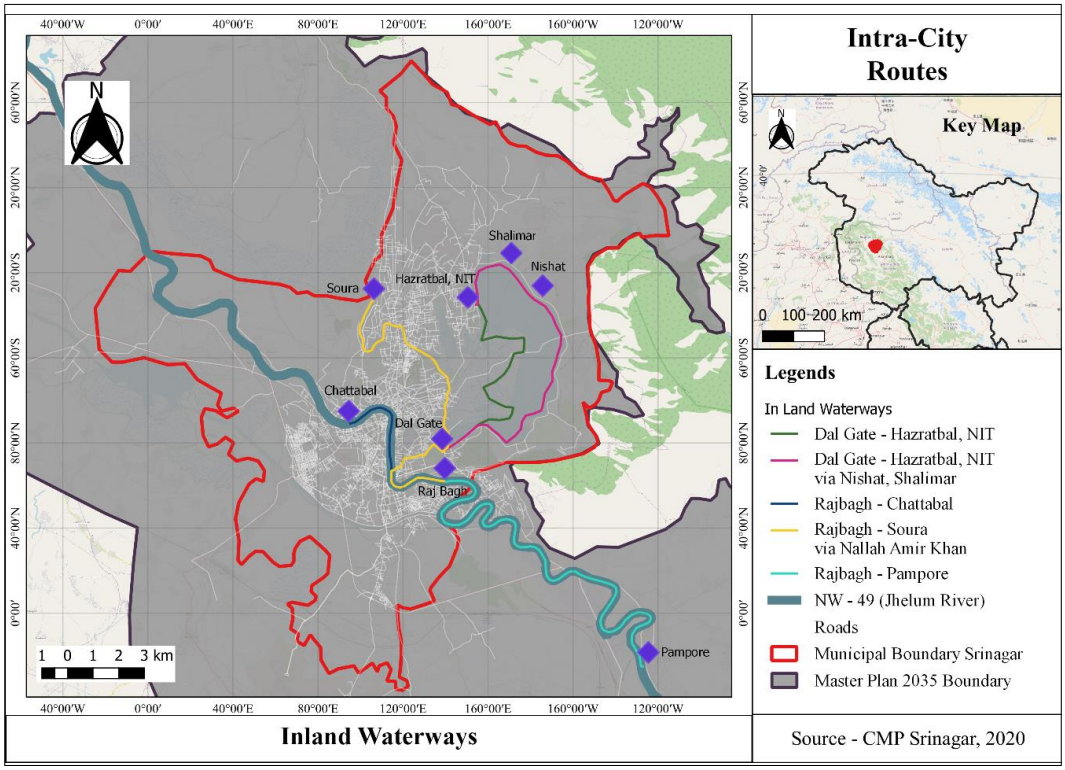
Source: FSR Jhelum River by the Inland Waterway Authority of India (IWAI)

Once known as the "Venice of the East," the river has lost its identity in the pages of history. Srinagar had a deep history of Inland water transportation with boats being the popular means of transport until the canals were closed in 1970 to make room for roadways (IWAI, 2017).

Intra-city Water Transport

River Jhelum has served as the city's historical spine and offers great potential for inland water transportation. The country's road-based transportation infrastructure must be supplemented with water transit. It will also serve as a key tourist attraction for visitors interested in the city's history and beauty. The famous Mughal Gardens, Dal Lake, Hazratbal, National Institute of Technology (NIT), Soura, Chhattabal, and other locations can all be reached via the IWT.

Figure 3: Proposed Intra City Water Routes in Srinagar



Source: Comprehensive Mobility Plan (CMP) for Srinagar, 2020

In the Comprehensive Mobility Plan (CMP) for Srinagar for 2035, five intra-city waterways networks have been proposed which cover a stretch of 60-km with 60 water buses which will be in action by the year 2044(Government of Jammu and Kashmir, 2020). During the period of December and January, the Dal Lake freezes, but the trails are formed to allow smooth passage of the boats, and the Jhelum River is navigable all through the year.

Table 1: Proposed Intra City Water Transportation Routes in Srinagar

Sl. No.	Proposed Inland Water Transport Routes	Length (km)	Phase
1	Dal Gate to Hazratbal/NIT	10	Phase I
2	Dal Gate to Hazratbal via Nishat and Shalimar Baghs	13	Phase I
3	Raj Bagh to Chhatabal (along River Jhelum)	7	Phase II
4	Raj Bagh to Soura via Nallah Amir Khan and Khushalsar	10	Phase II
5	Raj Bagh to Pampore	20	Phase III
Total		60	

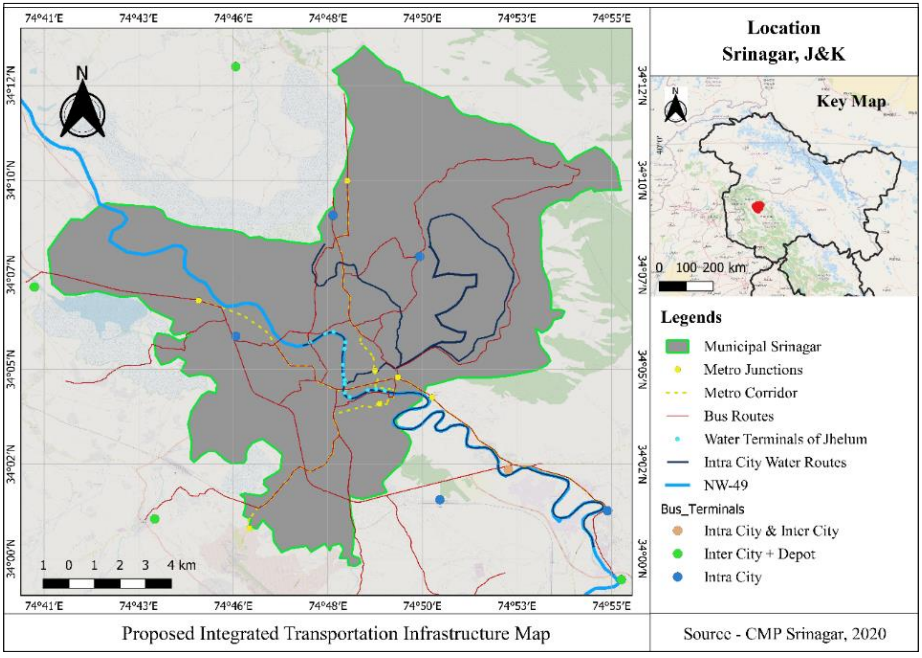
Note: This table shows the proposed intra-city water transportation plan for Srinagar, along with its phasing, as outlined in the Srinagar Comprehensive Mobility Plan 2020.

Source: Comprehensive Mobility Plan (CMP) for Srinagar, 2020

Transport Infrastructure

The proposed Transport Infrastructure for the city was designed in 2020 as part of Srinagar's Comprehensive Mobility Plan 2035 (Figure 4). The water transit stretch of River Jhelum has been chosen for further research since it flows through the city and traverses it in two parts. In addition to water transportation, bus and metro infrastructures are also proposed to serve the city's population (Government of Jammu and Kashmir, 2020).

Figure 4: Proposed Integrated Transportation Infrastructure of Srinagar



Source: Comprehensive Mobility Plan (CMP) for Srinagar, 2020

Methodology

Following is the objective-wise methodology: the initial stage of the research involved a literature review that helped in developing a comprehensive understanding of the concept which included definitions, causes, impacts, and indicators. This review then informed the identification of key parameters for evaluating each terminal to scale down the study area. The second stage involves analysing the built fabric with a focus on existing densities, land uses, and transportation infrastructures utilising the parameters identified in the previous stage. To complement this data analysis, a primary survey is conducted to gather insights directly from stakeholders, such as residents and businesses within the study area. Finally, the research delved into the critical analysis of the three key dimensions (3Ds) of a TOD model i.e. Density, Diversity, and Design.

Therefore, an attempt has been made to implement the WaTOD model in a real-world scenario. The proposals also comprise city-level connectivity-based strategies to implement the multi-modal Integration. The area for residential units for different income mixes was drawn from the Transit Oriented Development Guide for Smart Cities published by National Institute of Urban Affairs (NIUA) to provide affordable housing.

Figure 5: Methodology of this Study

Aim: Regeneration of the Waterfront Districts through Water Transit-Oriented Development.		
Objectives of research	**Scope of Work**	**Tools and Techniques**
To establish a scenario of existing land use patterns and transport along the river.	Demarcating the influence area	Mapping existing land use using google earth imagery & QGIS
	Assessing the population and built form trends in the study area	Demand - Supply gap analysis
To evaluate the TOD framework with existing Land Use Regulations along the water body.	Assessment of land use regulations for development.	Opportunity and Problem Analysis for connectivity
	Identifying the land potential for TOD	Land and Demographic opportunity Analysis
	Identifying the deficit between demand and supply of existing infrastructure.	
To formulate a comprehensive WaTOD plan.	Detailed TOD implementation Strategies	Density, Diversity & Design
	Multimodal Integration	City-level connectivity strategies

Source: Prepared by the Author

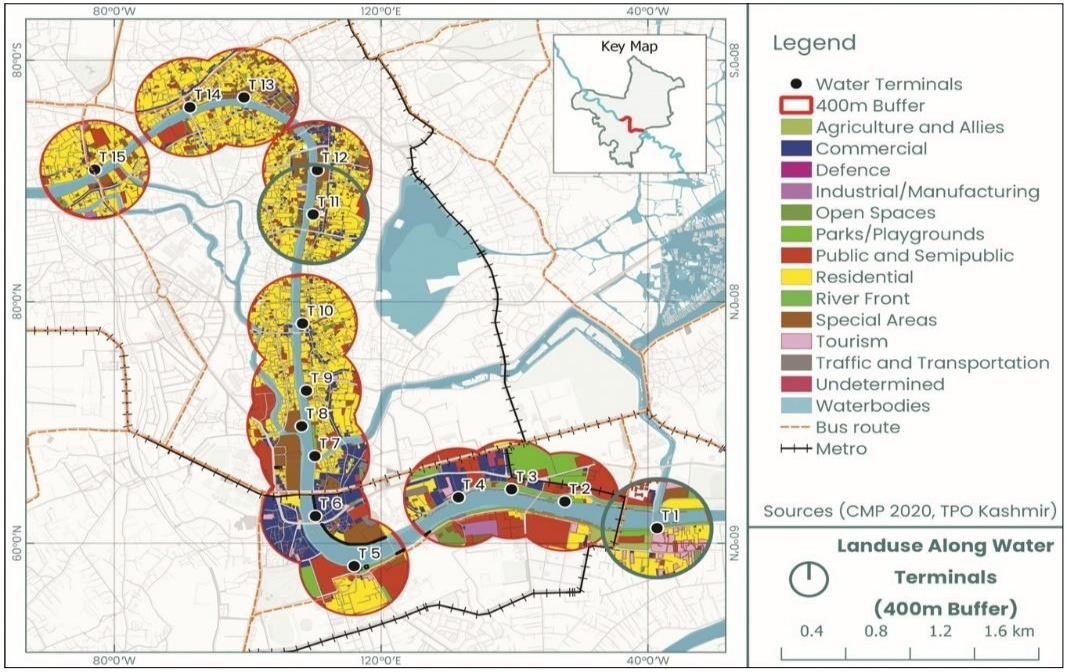
Analysis

Terminal-Wise Land Use Assessment

The water transit route of River Jhelum runs from Southeast to Northwest and comprises a total of 16 terminals. To better understand the characteristics of each terminal, a detailed land-use evaluation was conducted.

The Srinagar city is split into two sections: the old city and the new city. The new city is from Terminal 1 to 5, and the old city is from Terminal 6 to downstream. The characteristics of the two sides of the city vary considerably based on a variety of factors that will be examined further.

Figure 6: Land-Use Map of the Terminals of Jhelum Water Transit stretch in Srinagar



Note: This map highlights the 15 intra-city water terminals along the Jhelum River and their areas of influence within a 400-meter radius.

Source: Town Planning Organisation, Kashmir (2015), Comprehensive Mobility Plan for Srinagar, 2035

Terminal 1: Zero Bridge

The Zero Bridge terminal has the potential to be the major IWT hub of the city, catering to both intra-city and the terminals of National Waterway-49. Residential and commercial (tourism) are the most common land uses in the region. This zone is predominantly inhabited by a transient population as it houses Srinagar's major educational training centres, paying guests (PG), and hostels. Additionally, it is a well-known place among travellers. The majority of the structures here are villas with large gardens.

Terminal 2: Peerzu

Peerzu has gained popularity among locals for its diverse range of cafeterias and dedicated spaces for relaxation, coupled with extensive and well-structured open environments.

Terminal 3: Regal Chowk

Terminal No. 3, commonly referred as Regal Chowk, is characterized by land uses primarily centred around commercial activities, owing to its proximity to the Central Business District (CBD). The area exhibits a mixed-use pattern, with ground floors predominantly dedicated to commercial enterprises while the upper floors accommodate office spaces.

Terminal 4: Lal Ded Hospital
This is primarily characterized by the presence of a commercial zone that surrounds the hospital premises. Additionally, the area accommodates a significant number of office establishments, contributing to the mixed-use nature of the zone.

Terminal 5: Amira Kadal
This terminal is in the Lal Chowk area, which serves as the Central Business District (CBD) of Srinagar city. 'Kadal' is a Kashmiri word, meaning a bridge. This zone is predominantly characterized by an abundance of commercial settlements and exhibits mixed-use configurations. The ground floors are primarily allocated for commercial purposes, while the upper floors are used either as warehouses or office spaces. Noteworthy features of the area include parallel roads to the River Jhelum with a Right of Way (ROW) measuring 10-meters, and the widest ROW spanning 16-metres.

Terminal 6: Basant Bagh
According to the Srinagar City Master Plan 2035, this terminal is designated as an unplanned residential zone (Srinagar Development Authority, 2015). The area is predominantly residential which is characterized by haphazard and organic development, with structures reaching up to G+3.

Terminal 7: Divisional Commissioner's Office
The terminal is primarily characterized by public and semi-public zones. This is home to the Divisional Commissioner's office which is situated in the historic Seher-e-Garhi Palace that was originally constructed by the Dogra rulers. The palace, with its significant historical importance, was the summer residence for the Dogra rulers. Its strategic location near the river acted as a major transportation route.

Terminals 8 & 9: Ganpathyaar and Old Habba Kadal
Extending downstream from Terminal No. 7 is the old city that is primarily characterized by residential land use and organic development.

Terminals 10, 11, & 12: Old Fateh Kadal, Khanqah-e-Maula, and Maharaj Gunj
The area is dominated by residential and commercial buildings and is home to two historical markets of the city: Zaina Kadal Market which is renowned for brass utensils, and Maharaj Gunj Market that is famous for spices. Maharaj Gunj was the old Central Business District (CBD) of Srinagar city, situated on the bank of River Jhelum. The characteristics of the area include narrow streets, a dense circulation network, and high population density. This zone features vernacular architecture which includes historic and religious structures. The widest Right of Way (ROW) observed was 6-meters, while the minimum ROW was 1-meter. The old city of Srinagar was least affected by the 2014 floods, as it sits at a higher elevation.

Terminals 13, 14, 15, & 16: Bul Bul Lankar, Nawa Kadal, Safa Kadal, and Chattabal Weir
According to the master plan, the principal land uses in this region are unplanned residential and mixed-use. This area of the city is a mix of old and recent developments that showcase vernacular as well as modern structures.

Figure 7: Built Form around Water Terminals of Srinagar City

Terminal 1 Zero Bridge **Major Land uses:** Residential, Hostels & Hotels	 G+2	 G+1	 G+2
Terminal 2 Peerzu (Island) **Major Land uses:** Parks, Restaurant/ Cafes.		 G	 G+1 (Mixed use)
Terminal 3 Regal Chowk **Major Land uses:** Commercial, Public-Semi Public	 G+3	 G+5	 G+3
Terminal 4 LD Hospital **Major Land uses:** Commercial, Residential, Public-Semi Public	 G+3	 G+4	 G+1
Terminal 5 Amira Kadal **Major Land uses:** Commercial, Public-Semi Public	 G+3	 G+2	 G+2
Terminal 6 Basant Bagh **Major Land uses:** Residential	 G+3	 G+2	 G+3

Terminal 7 Div. Comm. Office **Major Land uses:** Public-Semi Public, Tourism	 G+1	 G+1	 G+1
Terminal 8 Ganpathyaar **Major Land uses:** Residential	 G+3	 G+3	 G+2
Terminal 9 Old Habba Kadal **Major Land uses:** Residential		 G+2	 G+2
Terminal 10 Old Fateh Kadal **Major Land uses:** Commercial, Residential, Heritage	 G+1	 G+2	 G+2
Terminal 11 Khanqah-e-Maula **Major Land uses:** Religious Tourism, Mixed Use	 Maula	 G+3	 G+2
Terminal 12 Maharaj Gunj **Major Land uses:** Residential, Mixed use, Heritage	 Jamia Masjid	 G+2	 G+2

Terminal 13 Bul Bul Lankar **Major Land uses:** Religious, Tourism, Residential	 Masjid	 G+2	 G+1
Terminal 14 Nawa Kadal **Major Land uses:** Religious Tourism, Mixed Use	 G+3	 G+3	 G+2
Terminal 15 Safa Kadal **Major Land uses:** Residential, Mixed Use	 G+2	 G+2	 G+3
Terminal 16 Chattabal Weir **Major Land uses:** Residential, Mixed Use	 G+3	 G+2	 G+2

Note: This table shows the built environment within the 400-meter influence zones of the water terminals.
Source: Primary Survey, 10th – 23rd February, 2022

Following a terminal-wise built form analysis, the study area was narrowed down to two terminals, corresponding to the factors outlined in Table 2. These terminals showcase opposite characteristics when compared. Terminal 1, known as Zero Bridge, symbolizes the new city, while Terminal 11, Khanqah-e-Maula, represents the old city. These two terminals were selected to illustrate the contrasting sides of a potential WaTOD Model, based on their differing characters, and to answer the question: How can WaTOD function in these two scenarios?

The old city is densely populated, has a small Right of Way (ROW), and is dominated by built forms with historic character. In contrast, the new city terminal, Zero Bridge, exhibits entirely different

characteristics such as a sparse road network, minor congestion issues, large plot sizes, and so on. Given these distinctive features, both terminals will require an entirely different approach for the WaTOD. These varied models aim to conserve the existing fabric of the place while simultaneously providing easy access to the water body.

Table 2: Parameters for Site Selection

Parameters	New City (T-1: Zero Bridge)	Old City (T-11: Khanqah-e-maula)
Plot Size	Max (200 sqm) Min (100 sqm)	Max (70 sqm) Min (40 sqm)
Road Network Density	1.5%	4.2%
Min. ROW	3-m	1-m
Max. ROW	16-m	6-m
Parallel road to Jhelum	Yes	No
Congestion No (Reason: Enough ROW)		Yes (Reason: Encroachment, Roadside Parking)

Note: This table shows the analysis of the existing built environment around the water terminals, along with the parameters used for selecting the study area.

Source: Prepared by the Author

Density Projections

The population projections in the Srinagar Master Plan-2035 encompassed the entire Srinagar Municipal Corporation area, including the outgrowths. However, our research focuses on two 400-meter buffer zones around the selected water terminals, namely Zero Bridge (Terminal-1) and Khanqah-e-Maula (Terminal-11). Consequently, the population projections were recalculated to approximate the demand gap analysis for the horizon years 2022, 2025, and 2030. These population forecasts were derived by applying the compound interest formula, incorporating the growth rate provided by the Master Plan for 2035 (Table 3).

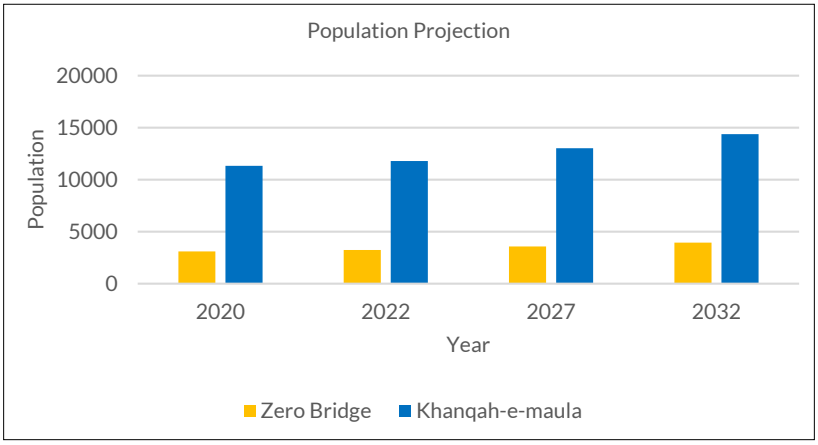
A few assumptions were made in the Srinagar Master Plan-2035, considering rapid transportation, flux in economic activities, and external inputs. Firstly, it was assumed that as of 2020, the population growth in the Srinagar Metropolitan Region had maintained relative stability, persisting at the current rate of 1.8%. Secondly, looking ahead to the period between 2020 and 2030, there is an anticipated increase in population for both urban and suburban areas, with an expected rise of growth rate to 2.0%. However, in the subsequent years from 2030 onward, the growth rate for the local region is projected to decline, settling at 1.8% for the remainder of the plan period up to 2035 (Srinagar Development Authority, 2015).

Table 3: Population Growth Rate of Srinagar City

Year	Growth %
2015-2020	1.8%
2020-2030	2%
2030-2035	1.8%

Source: Srinagar Master Plan-2035

Figure 8: Population Projection for the Two Terminals of Srinagar City



Note: This table shows the projected population for the influence zones of the two water terminals selected for the study area (Zero Bridge terminal and Khanqah-e-maula terminal), based on the growth rate mentioned in the Srinagar Master-plan 2035.

Source: Author

The Srinagar Municipal Corporation provided the population-wise density of each ward. Once the density of wards within the buffer zones was determined, an estimated projection for the density of each buffer zone was made using the vector intersection tool in GIS. This allowed us to obtain individual densities for each buffer zone. Thus, the buffer zone density of the Zero Bridge terminal was 52.75 PPH (Persons Per Hectare), while for the Khanqah-e-Maula terminal, it was 192.10 PPH. A significant variation was observed in the densities of these two terminals which is attributable to Khanqah-e-Maula being the old CBD of Srinagar City. Similarly, significant contrasts were also noted in the city's physical characteristics due to their density distribution.

Floor Area Ratio (FAR)

The digitization of building footprints in the Buffer zones was carried out, along with their existing heights that were obtained from the primary survey. Subsequently, this information was processed to determine the existing and projected Floor Area Ratio (FAR) for the Buffer zones.

Table 4: Developable Land in the Buffer Zones, Srinagar City

S.no.	Category	Developable Land (Ha)	
		Zero Bridge	Khanqah-e-maula
1	Built-up Area	0.42	0.64
2	Area of Buffer	0.50	0.50
3	Area of Waterbody	0.10	0.05
4	Available land for Development	0.41	0.45

Note: These calculations determine the available developable land within the 400-meter influence zones of the water terminals, accounting for water body buffer zones and other exclusions.

Source: Author

Income Mix

Primary surveys were done to determine the population mix of the Buffer zones of the two terminals. The results are shown in Table 5.

Table 5: Projected Residential Demand in the Buffer Zones for Different Income Groups in Srinagar

Buffer Zones	Parameters	EWS	LIG	MIG	HIG
Zero Bridge	Percentage	15%	23%	45%	17%
	Population	1775.21	2721.99	5325.64	2011.91
	Dwelling Units	355.04	544.40	1065.13	402.38
	Unit size (sqm)	27.8	46.4	83.6	165
	Built-up area (sqm)	9870.18	25260.09	89044.66	66392.95
Khanqah	Percentage	15%	50%	25%	10%
	Population	492.35	1641.15	820.58	328.23
	Dwelling Units	98.47	328.23	164.12	65.65
	Unit size (sqm)	27.8	46.4	83.6	165
	Built-up area (sqm)	2737.44	15229.88	13720.02	10831.6

Source: Author

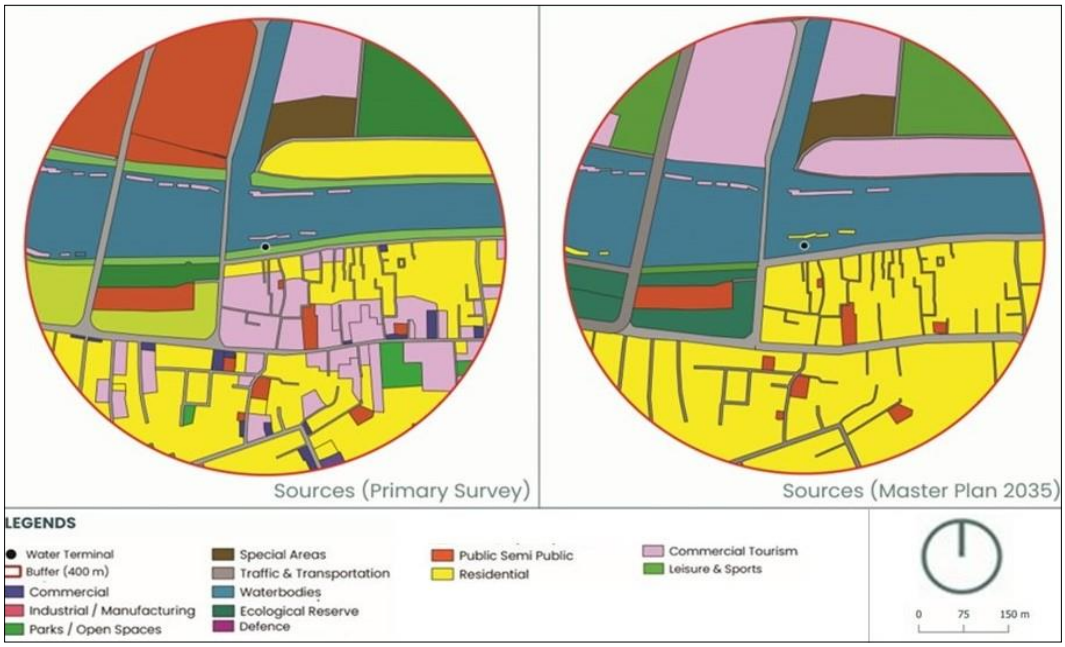
As per recommendations, the above calculations will be used to distribute the total built-up area required for land uses other than residential.

Land Use of Water Terminals in the Buffer Zones

Terminal 2: Zero Bridge Terminal

The residential and commercial areas of the Zero Bridge Terminal underwent significant modifications. The residential zone has been expanded while the commercial area has been decreased in the proposed land use. More commercial space will be needed to sustain the growing residential, therefore mixed land use is required to satisfy local demand.

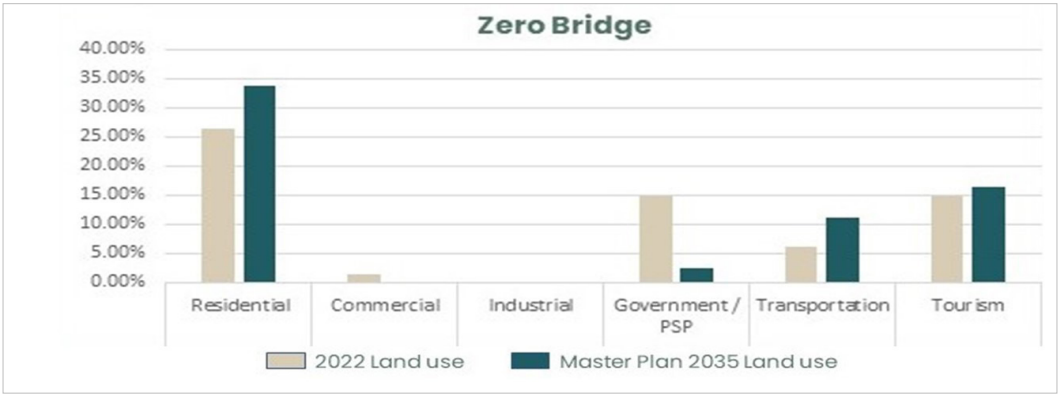
Figure 9: Land Use Map for Zero Bridge Terminal, Srinagar



Note: The 2022 scenario is collected from primary survey, whereas the 2035 scenario is taken from the Srinagar Master-plan 2035.

Source: Primary Survey (10th – 23rd February 2022), Srinagar Masterplan 2035.

Figure 10: Land Use Variation for Zero Bridge Terminal Buffer Zone, Srinagar



Source: Author

Terminal 11: Khanqah-e-Maula

This terminal has not undergone any significant changes, however, 12% of the total land area has been transformed from the special areas to adaptive reuse for the tourism sector. After considering the demand and the current situation to improve accessibility and safeguard the

historic area from transportation-related damage, the terminal has been relocated from its original site to one that is close to the bridge.

Figure 11: Land Use Map for Khanqah-e-Maula Terminal, Srinagar

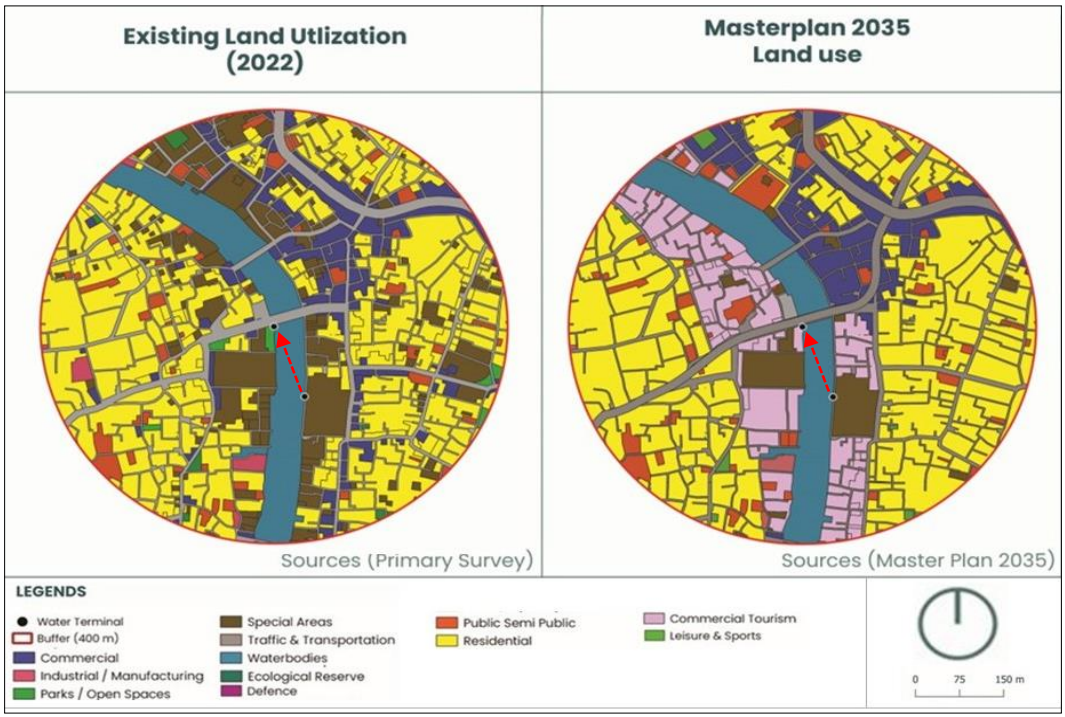
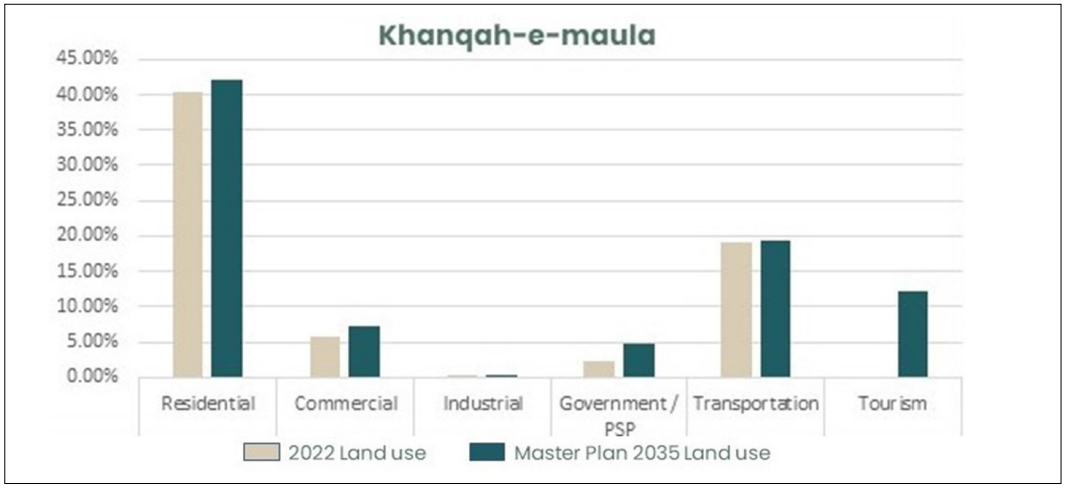


Figure 12: Land Use Variation for Khanqah-e-Maula Terminal Buffer Zone, Srinagar



Recommendations

Density

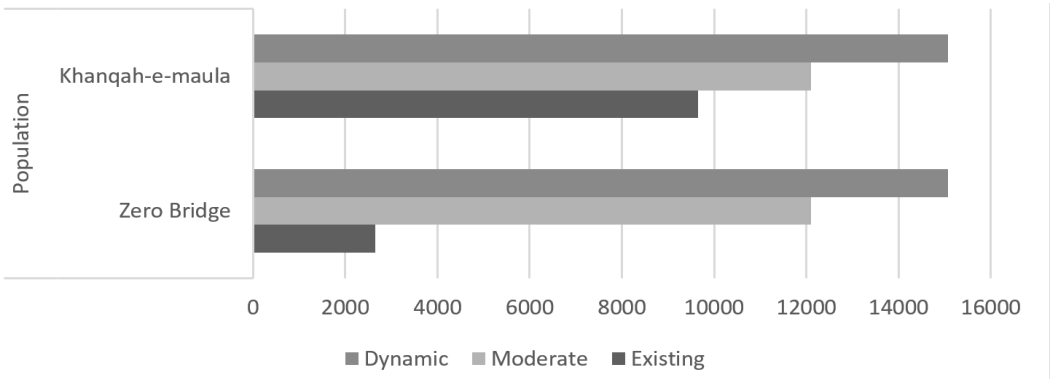
The existing and proposed densities of the buffer zones, as per the Master Plan, led to the development of three scenarios for the WaTOD model: Existing, Moderate, and Dynamic. The Existing Scenario represents the current density of the study area which provides insights into the present distribution of land use that is based on the current population dynamics. The Moderate Scenario incorporates the proposed density from the Master Plan, specifically considering the density that is outlined in the Master Plan-2035, which is 241 PPH. The third is the Dynamic Scenario which represents the WaTOD Model. In this scenario, an increase of 25% is assumed from the Moderate Scenario. The mentioned percentage was determined through a literature review of the existing Transit-Oriented Development (TOD) case studies that suggests an average increase of 25 per cent.

Table 6: Proposed Density Scenarios in Srinagar

Scenario	Density (PPH)	
	Zero Bridge	Khanqah-e-Maula
Existing	52.75	192.1
Moderate	241	241
Dynamic	300	300

Source: Srinagar Master Plan 2035

Figure 13: Population Projection of the Proposed Density Scenarios at the Two Terminals, Srinagar



Following the population density distribution, four scenarios were formulated for Floor Area Ratio (FAR) in the Buffer zones. This approach was adopted to allocate the total built-up area that will be required for land use other than residential. The scenarios for FAR distribution are summarized as:

- Scenario 1: The total area of the Buffer zone is considered as the plot area.
- Scenario 2: The area covered by water bodies has been subtracted from the total area to determine the available land for development, which is referred to as the plot area.
- Scenario 3: All-natural features, including water bodies, defence areas, ecological reserves, and

heritage sites have been excluded to define the remaining developable land as the plot area.

- Scenario 4: Only the area covered by major land uses, such as Residential, Public, Semi-public, Commercial, Industrial, and Tourism, were considered as the plot area.

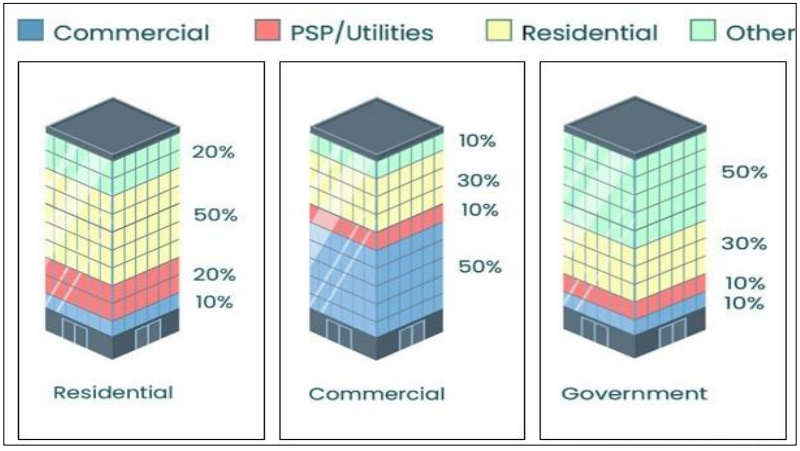
Table 7: FAR for the Buffer Zones as per the Assumed Scenarios in Srinagar

Land Use	Terminal	FAR			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Existing	Zero Bridge	0.8	1.0	1.0	1.4
	Khanqah-e-Maula	1.3	1.4	1.6	2.6
Proposed (Master Plan-2035)	Zero Bridge	0.8	1.1	1.2	1.6
	Khanqah-e-Maula	1.3	1.4	1.5	1.9

Diversity

The proposed FAR has been distributed by aligning with the recommendations that are outlined in the National Transit-Oriented Development (TOD) Policy 2021 (Government of India, 2021) (Figure 14) based on the land use distribution of the two terminals.

Figure 14: Mix of Uses/Distribution of FAR in TOD, Srinagar



Source: National TOD Policy of India, 2021

Figure 15: Built-up Area for the Buffer Zone of Zero Bridge Terminal (Srinagar) as per the Density Scenarios

	FAR	TOTAL PROPOSED LAND USE	Built-up Distribution			
EXISTING	1.5	0.170	0.13	0.03	0.05	0.05
		0.083	0.04	0.06	0.01	0.01
		0.011	0.01	0.002	0.002	0.01
MODERATE	2.5	0.170	0.17	0.03	0.07	0.07
		0.083	0.05	0.08	0.02	0.02
		0.011	0.01	0.00	0.00	0.01
DYNAMIC	3	0.170	0.25	0.05	0.10	0.10
		0.083	0.07	0.12	0.02	0.02
		0.011	0.05	0.02	0.02	0.08

(All areas are in square kilometres)*

Source: Prepared by the Author

Figure 16: Built-up Area for the Buffer Zone of Khanqah-e-Maula Terminal (Srinagar) as per the Density Scenarios

	FAR	TOTAL PROPOSED LAND USE	Built-up Distribution			
EXISTING	1.5	0.21	0.16	0.03	0.06	0.06
		0.10	0.04	0.07	0.01	0.01
		0.02	0.01	0.004	0.004	0.02
MODERATE	2.5	0.21	0.21	0.04	0.08	0.08
		0.10	0.06	0.10	0.02	0.02
		0.02	0.01	0.005	0.005	0.02
DYNAMIC	3	0.21	0.32	0.06	0.13	0.13
		0.10	0.09	0.15	0.03	0.03
		0.02	0.02	0.01	0.01	0.04

(All areas are in square kilometres)*

Source: Prepared by the Author

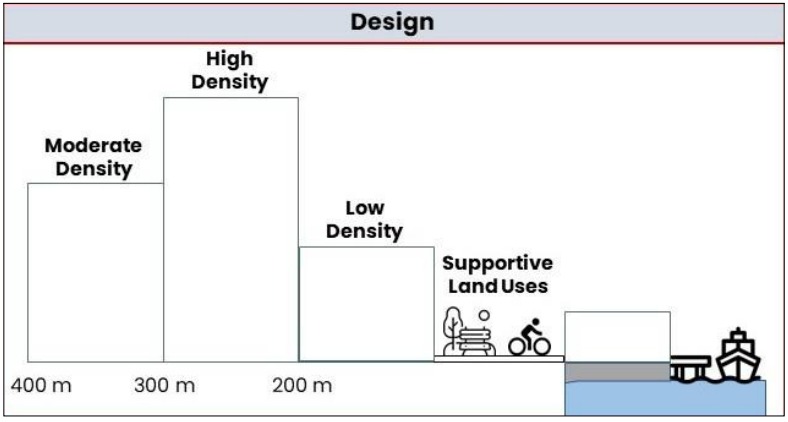
Design: River City Interaction

To ensure that TOD does not merely become high-density development only along transit areas, potentially leading to a higher concentration of private vehicles and congestion, Urban Local Bodies (ULBs) must make sure that the comprehensive implementation of the all-important aspects of TOD takes place as outlined in the earlier sections.

Cities should strive for transparency and clarity in TOD policies and procedures, thus providing economic incentives for all the stakeholders. This approach would facilitate multiple landowners to come together, build consensus, and save time in the implementation of TOD.

For long-term commitment of public agencies and the private sector in the implementation of TOD, cities should establish clear and equitable rules for sharing costs, benefits, and risks among stakeholders.

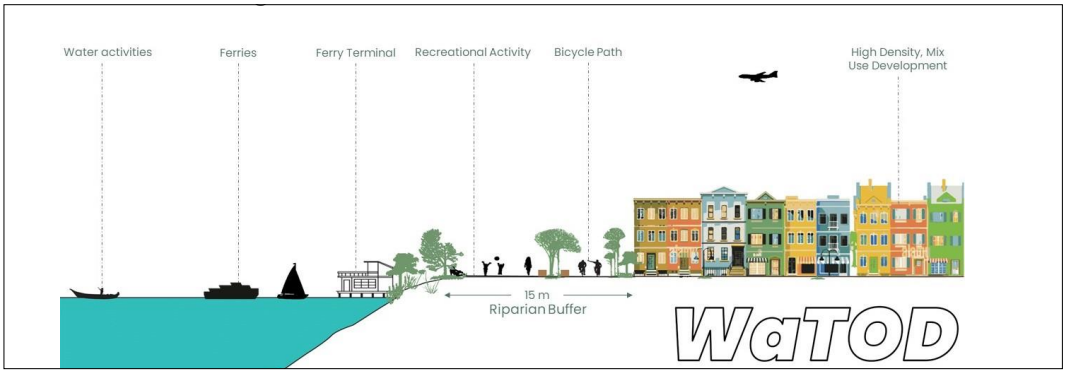
Figure 17: Density Diversification in WaTOD



Source: Prepared by the Author

Based on the literature review, supportive land uses are recommended to be located closest to the river to provide open spaces for social gatherings and communal activities. Following this buffer, densities are categorized into three levels: High, Moderate, and Low, with scaling by 200m to 400m, respectively. The proposal suggests placing Low density closer to the river due to potential water overflow, particularly during the rainy season. Moderate density is positioned farther from the river, aligning with the existing built fabric and zoning considerations. Finally, High density is strategically placed in the centre to optimize land use zoning.

Figure 18: Intersection of WaTOD Model with the River



Source: Prepared by the Author

People's movement along and adjacent to the river will help to promote water transport as a mode of choice. Therefore, it is essential to provide supportive land uses along the water corridor. The ferry terminals can be designed in an interesting way to attract people and serve as recreational spaces that are integrated with the open areas around the water body, including the buffer zone.

To enhance the riparian buffer along the riverbanks, a strategy for buffer zone management should be developed and implemented. These strips of vegetated land hold the potential to provide various environmental benefits. These include stabilizing the stream banks which lead to a reduction in erosion and sedimentation. Moreover, they contribute to the infiltration of stormwater runoff, maintain the base flow of streams, and offer organic matter that acts as a source of food and energy for the aquatic ecosystem. Additionally, these vegetated strips provide tree canopies that shades the streams and regulates temperature, further contributing to the overall ecological well-being of the area.

However, cities may also implement a three-zone riparian buffer, with more riparian flora along the riverside, small and medium shrubs in the middle zone, and a pathway with native trees in the landward portion that is based on the availability of land in the river zone.

Connectivity: Multi-Modal Integration

Since people have become more active than ever before they are regularly using transportation amenities. There is no way to establish an end-to-end transportation system. As a result, issues such as traffic congestion and pollution arise. Multi-modal integration is used to seamlessly connect the numerous transport modes and maximise the potential of mass transportation to clear congestion and establish a sustainable system, as well as ease people's mobility. The main principles are to reduce the number of interchanges and, if that is not possible, then make the transition as smooth as possible. For this reason, transportation services are separated into two types: mass transit and feeder services. The idea is to make it easier for people to use the mass transit system in a timely and comfortable manner.

The logical interpretation of transportation modalities involves several fundamental steps. Firstly, there is a need to increase accessibility and coverage to cater to a wider population. The second step is to focus on shortening the journeys and saving time for commuters. Additionally, efforts should be directed towards decreasing the number of interchanges in the transportation system, thereby simplifying the travel experience. Lastly, a crucial aspect is to design and implement a system that is viable for the long term, thus ensuring the sustainability and efficiency of the transportation infrastructure.

The success of the mode is determined by how well it is received by the general audience. The willingness to change modes will be determined by the length of time and frequency of service, trip distance, walk time and distance, level changes between services, ambience of the surroundings (rain, sun, etc.), convenience of transfer, and the overall trip cost. Walking is preferable for distances under 0.5 km, and NMT is recommended for distances between 0.5 and 1.5 km.

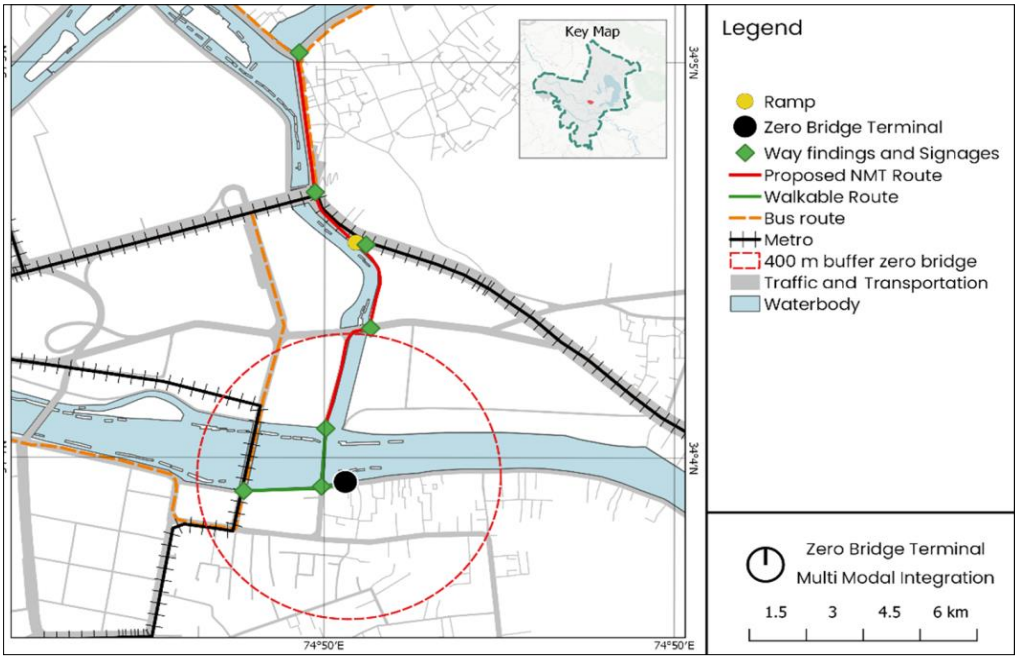
Three types of integration are necessary to generate beneficial responses:

- **Physical Integration:** Physical infrastructure is completely integrated with the pedestrian and NMT environment, as well as their connectivity to feeder services and ultimately, to the mass transport system. Providing parking and other common services at the stations where the interchange will take place has also been planned.
- **Information Integration:** By simply and uniformly providing information about the service, such as a timetable, route maps, and real-time information.
- **Fare Integration:** Commuters benefit from an integrated fare system which includes a common card and integrated tickets.

Terminal-1 (Zero Bridge) Buffer Zone

An intermodal system has been proposed at the Zero Bridge terminal, connecting it to the nearest mass transit station. Two mass transit points are accessible from this terminal. For the first point, commuters would need to walk along a 200-meter pathway through the park.

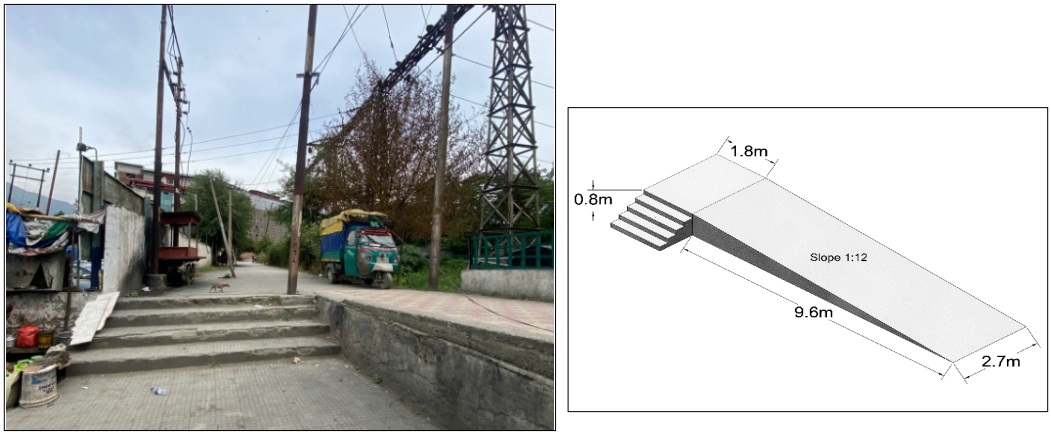
Figure 19: Multi-modal Integration of Zero Bridge Terminal



Source: Prepared by the Author

In the second scenario, commuters will have to walk across a pedestrian-only Zero Bridge for a distance of 200-meters, then board a Non-Motorized Transport (NMT) to reach Dal Lake, covering a stretch of 1-km. Along this route, stairs located near Krishna Dhaba, parallel to the footpath, are proposed to be converted into a ramp for the NMT (Figure 20).

Figure 20: Ramp Provided for Easy Accessibility of Non-Motorized Transport (NMT)

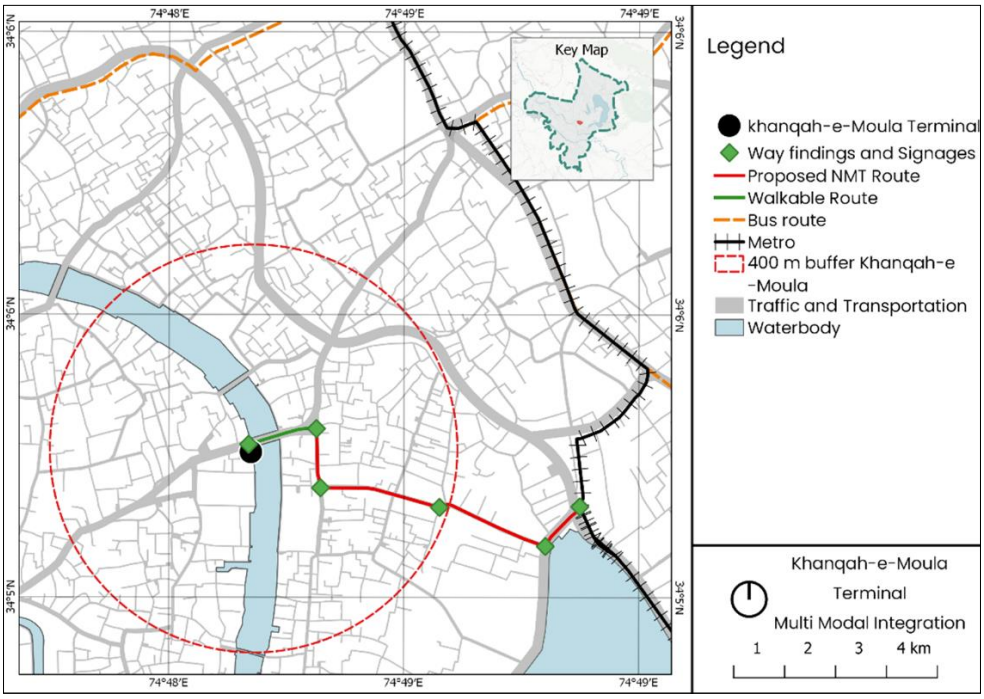


Source: Prepared by the Author

The dimensions of the ramp have been determined by following the guidelines of the Indian National Building Code 12.18.1. A width of 2.7 meters was available which will be fully utilized for the ramp. The height will measure 0.8 meters, and the slope ratio of 1:12, as per IRC 011 (2015), was implemented. Calculations based on this slope ratio yielded a ramp length of 9.6 meters. In addition, a perpendicular staircase has been proposed which will feature five steps with a riser of 0.15 meters and a tread of 0.3 meters.

Terminal-11 (Khanqah-e-Maula) Buffer Zone

Figure 21: Multi-modal Integration of Khanqah-e-Maula Terminal, Srinagar



Source: Prepared by the Author

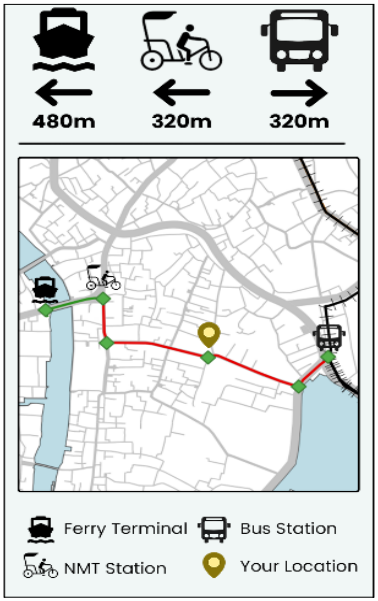
At the Khanqah-e-Maula terminal, an intermodal system has been proposed which will connect the terminal to the nearest mass transit station that is approximately 650-meters away. The chosen route spans a length of 800-meters. Commuters will need to walk approximately 150-meters via the New Zaina Kadal and then board the Non-Motorized Transport (NMT) to reach the station, making it a direct 650-meter stretch.

Wayfinding and Signages

To facilitate navigation and locate the terminals and key nodes easily, proposals for signages have been developed. The primary focus of these signages is to ensure clear and consistent information at the junctions for enhanced visibility. They will convey information about the terminal's location, distance, routes, and more. Six specific locations have been identified to install the signages

which will cover both the Zero Bridge and Khanqah-e-Maula terminals and the associated routes (Figures 19 and 21).

Figure 22: Signages for Ferry Terminals, Srinagar



Source: Prepared by the Author

Integrated Ticketing System

A proposed integrated fare card system for tickets aims to provide commuters with the convenience of using any service without the need to purchase new tickets or different cards. These cards will be obtainable at the ferry terminal, thus streamlining the usage of the entire transportation system and facilitating seamless switching between modes. Given the fixed route for the Non-Motorized Transport (NMT), pricing will be determined based on the distance travelled along that route. Customers will have the option to make direct payments to the NMT operator using the card at the point of use.

Conclusion

In general, there is a substantial demand for water transportation, but its viability in the current landscape that is dominated by land transport, raises significant questions. The observed congestion in Srinagar city presents a novel challenge in urban transport which demands an alternative mode of transportation. The old city of Srinagar is particularly affected by the rising demand and constrained transportation infrastructure since it is unable to expand due to land limitations. The closure of the old canal system, which was once the lifeline of a thriving water economy, further complicates the situation. Although there is potential for revival, its scope is limited, and it is primarily suited for long-distance travel along with cargo movement, tourism, and leisure activities.

However, Waterfront Transit-Oriented Development (WaTOD) emerges as a crucial factor in developing new cities. It not only contributes to the city's aesthetic appeal but also prompts the question of whether aligning development towards a river, rather than turning away from it, could lead to better river management.

Creating new roads may not be financially viable, thus Inland Water Transport (IWT) is a possible option. Yet, further research is necessary to ensure that these high-density developments are ecologically sensitive. Currently, there is a lack of comprehensive research on high-density riverfront development, and the existing models lack proper documentation which results in the availability of limited data to assess their effectiveness.

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Conflict of Interest

The authors declare no conflict of interest.

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