INTEGRATING URBAN SANITATION AND RIVER HEALTH: PLANNING FRAMEWORK FOR RIVER-SIDE CITY

MASTER OF PLANNING

(Urban Planning)

by

GAURAV NIPSAIYA

(24209011120)

MAULANA AZAD
NATIONAL INSTITUTE OF TECHNOLOGY,
BHOPAL- 462003 (INDIA)

JULY, 2026

©MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY,
BHOPAL– 462003 ALLRIGHTSRESERVED

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CANDIDATE'S DECLRATION

I hereby certify that the work which is being presented in the dissertation entitled "Integrating Urban Sanitation and River Health: Planning Framework for River-Side City" in partial fulfillment of the requirements for the award of the Master of Planning (Urban Planning) and submitted in the Department of Architecture and Planning of the Maulana Azad National Institute of Technology, Bhopal is an authentic record of my own work carried out during the period from July 2025 to June 2026 under the supervision of Dr. Krishna Kumar Dhote, Professor, Department of Architecture and Planning, Maulana Azad National Institute of Technology, Bhopal.

The matter presented in this dissertation has not been submitted by me for the award of any other degree of this or any other Institution.

Gaurav Nipsaiya

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Dr. Krishna Kumar Dhote

MAULANA AZAD NATIONAL INSTITUTE OF TECHNOLOGY, BHOPAL

CERTIFICATE OF PLAGIARISM

This is to certify that the Thesis entitled **"Integrating Urban Sanitation and River Health: Planning Framework for River-Side City"** is a piece of research work carried out by Gaurav Nipsaiya, Scholar No. 24209011120 under my guidance and supervision for the degree of Master of Planning (Urban Planning) from the Department of Architecture and Planning of Maulana Azad National Institute of Technology, Bhopal (M.P.) India

To the best of my knowledge and belief he is to certify that:

i. Prima face this thesis can be considered for the award of the degree,
ii. Thesis does not contain any work which has previously submitted for the award of any other degree.
iii. Percentage of plagiarism is less than 8% (max 8-12% as per clause 10.12). Please check report is enclosed for reference.
iv. This thesis work:
a. Has not been carried out in collaboration with any other organization.

Gaurav Nipsaiya

Dr. Krishna Kumar Dhote

Countersigned by
Name : Dr. Krishna Kumar Dhote
HOD, Department of Architecture and Planning

Abstract

Urban river systems in rapidly growing cities are increasingly threatened by untreated wastewater, stormwater pollution, and land-use pressures, resulting in severe ecological degradation and heightened public-health risks. Despite numerous initiatives, most urban sanitation interventions remain fragmented and fail to consider the interconnected nature of wastewater flows, river ecology, and urban development. This thesis presents an integrated framework for improving urban sanitation and river health in river-side cities, informed by a comprehensive bibliometric analysis, methodological review, and multi-domain synthesis of global research from 2000–2024.

The study examines key drivers of river degradation—wastewater discharge, microbial contamination, combined sewer overflows, and inadequate treatment capacity while identifying emerging approaches such as nature-based sanitation solutions, decentralized wastewater treatment. Co-authorship networks and keyword analyses reveal major thematic clusters around water quality, wastewater treatment technologies, microbial pollution, catchment hydrology, and climate resilience. The findings highlight that integrated, system-wide strategies are essential for river restoration, especially in data-scarce and rapidly urbanizing regions.

Building upon international best practices and the contextual analysis of the River Narmada and its adjoining settlements, this thesis proposes an Integrated River-Sensitive Urban Sanitation Planning Framework based on five pillars: urban sanitation infrastructure, pollution source control, river-health monitoring, ecological and spatial planning, and governance with community participation. The framework integrates grey infrastructure, including interceptor sewers, pumping stations, and sewage treatment systems, with nature-based solutions such as riparian restoration, wetlands, bioswales, rain gardens, and seasonal floodplain farming. By aligning sanitation planning with river ecosystem processes, the framework provides a practical roadmap for improving water quality, restoring river health, enhancing public health, and strengthening urban resilience through sustainable river-sensitive development.

This thesis contributes a holistic, scalable, and adaptable framework to support sustainable river-side city development, offering a pathway toward cleaner rivers, healthier communities, and resilient urban environments.

सारांश

तेजी से बढ़ते शहरी क्षेत्रों में स्थित नदी तंत्र अनुपचारित अपशिष्ट जल, वर्षा जल प्रदूषण तथा भूमि उपयोग के बढ़ते दबावों के कारण गंभीर रूप से प्रभावित हो रहे हैं, जिससे पारिस्थितिकीय क्षरण तथा जनस्वास्थ्य संबंधी जोखिमों में वृद्धि हो रही है। यद्यपि इस दिशा में अनेक पहलें की गई हैं, फिर भी अधिकांश शहरी स्वच्छता हस्तक्षेप खंडित रूप में कार्य करते हैं और अपशिष्ट जल प्रवाह, नदी पारिस्थितिकी तथा शहरी विकास के परस्पर संबंधों को समग्र रूप से नहीं देखते। प्रस्तुत शोध नदी तटीय शहरों में शहरी स्वच्छता एवं नदी स्वास्थ्य में सुधार हेतु एक एकीकृत रूपरेखा प्रस्तुत करता है, जो वर्ष 2000-2024 के वैश्विक शोध साहित्य के व्यापक बिब्लियोमेट्रिक विश्लेषण, कार्यप्रणाली समीक्षा तथा बहु-आयामी अध्ययन पर आधारित है।

अध्ययन में नदी क्षरण के प्रमुख कारणों–जैसे अपशिष्ट जल का निर्वहन, सूक्ष्मजीवीय प्रदूषण, संयुक्त सीवर ओवरफ्लो तथा अपर्याप्त उपचार क्षमता–का विश्लेषण किया गया है। साथ ही, प्रकृति-आधारित स्वच्छता समाधान तथा विकेन्द्रीकृत अपशिष्ट जल उपचार जैसी उभरती हुई अवधारणाओं की पहचान की गई है। सह-लेखन नेटवर्क एवं कीवर्ड विश्लेषण से जल गुणवत्ता, अपशिष्ट जल उपचार तकनीकों, सूक्ष्मजीवीय प्रदूषण, जलग्रहण क्षेत्रीय जल विज्ञान तथा जलवायु सहनशीलता से संबंधित प्रमुख विषयगत समूहों का पता चलता है। अध्ययन के निष्कर्ष दर्शाते हैं कि विशेष रूप से तीव्र शहरीकरण वाले तथा सीमित आंकड़ा उपलब्धता वाले क्षेत्रों में नदी पुनर्जीवन के लिए एकीकृत एवं प्रणाली-आधारित रणनीतियाँ अत्यंत आवश्यक हैं।

अंतरराष्ट्रीय सर्वोत्तम प्रथाओं तथा नर्मदा नदी एवं उससे लगे बस्तियों के संदर्भगत विश्लेषण के आधार पर यह शोध “एकीकृत नदी-संवेदनशील शहरी स्वच्छता नियोजन रूपरेखा” (Integrated River-Sensitive Urban Sanitation Planning Framework) प्रस्तुत करता है। यह रूपरेखा पाँच प्रमुख स्तंभों पर आधारित है–(i) शहरी स्वच्छता अवसंरचना एवं अपशिष्ट जल प्रबंधन, (ii) प्रदूषण स्रोत नियंत्रण, (iii) नदी स्वास्थ्य निगरानी, (iv) पारिस्थितिकीय एवं स्थानिक नियोजन, तथा (v) सुशासन एवं सामुदायिक सहभागिता। इस रूपरेखा में इंटरसेप्टर सीवर, पम्पिंग स्टेशन तथा सीवेज उपचार संयंत्र जैसी ग्रे अवसंरचनाओं को रिपेरियन पुनर्स्थापन, आर्द्रभूमि (वेटलैंड), बायोस्वेल, वर्षा उद्यान तथा मौसमी बाढ़क्षेत्रीय कृषि जैसे प्रकृति-आधारित समाधानों के साथ एकीकृत किया गया है। नदी पारिस्थितिकी प्रक्रियाओं के अनुरूप स्वच्छता नियोजन को जोड़ते हुए यह रूपरेखा जल गुणवत्ता सुधार, नदी स्वास्थ्य पुनर्स्थापन, जनस्वास्थ्य संवर्धन तथा शहरी सहनशीलता को सुदृढ़ करने के लिए एक व्यावहारिक मार्गदर्शिका प्रदान करती है।

यह शोध सतत नदी तटीय शहरी विकास के लिए एक समग्र, विस्तार योग्य एवं अनुकूलनीय नियोजन रूपरेखा प्रदान करता है, जो स्वच्छ नदियों, स्वस्थ समुदायों तथा अधिक सहनशील शहरी पर्यावरण की दिशा में एक प्रभावी मार्ग प्रशस्त करता है।

Acknowledgement

I would like to take this opportunity to express my heartfelt gratitude and acknowledge the contributions of all those who made it possible for me to complete and present this research work. First and foremost, I extend my sincere thanks to my guide, Dr. Krishna kumar Dhote for their expert guidance, constructive feedback, and unwavering support throughout the research process. Their patience and invaluable suggestions were instrumental in refining my ideas and methodology.

I am deeply grateful to our coordinator, Dr. Seemi Ahmed, for her insightful direction and consistent support throughout the research process. I also wish to thank all the faculty members of Maulana Azad National Institute of Technology, Bhopal, who offered their valuable advice and assistance at various stages of my research project.

I am also profoundly thankful to our Head of Department, Dr. Nakul Dhagat, for fostering a supportive and conducive environment that greatly contributed to the progress and success of our projects.

This work would not have been possible without the contributions of all these individuals, to whom I am sincerely thankful.

TABLE OF CONTENTS

Contents

CHAPTER 1 1
Introduction 1
1.1 Background 1
1.2 Need of Study 1
1.3 Research Gap 2
1.4 Aim 7
1.5 Research Question 7
1.6 Keywords 7
1.7 Objectives 7
1.7.1 Phase-1 7
1.7.2 Phase-2 8
1.8 Scope & Limitations 8
1.8.1 Scope 8
1.8.2 Limitations 10
1.9 Assumptions & Expected outcomes 11
1.9.1 Assumptions 11
1.9.2 Expected outcomes 12
1.10 Data Collection Framework 16
1.11 Methodology 18
1.12 Research Design 23
1.13 Take aways and Conclusion from Phase 1 to Phase 2 23
Chapter 2 25
Literature Review 25
2.1 Review of Literature on River-Sensitive Urban Sanitation 25
2.2 Bibliometric Analysis 29
2.1.1 Contributions of country 29
2.1.2 Keywords 31
2.3 Case Studies 34
Indian Case Studies 34
Dravyavati River Rejuvenation Project, Jaipur, Rajasthan 34
Sabarmati Riverfront Development Project, Ahmedabad, Gujarat 37
Kham River Restoration Initiative, Chhatrapati Sambhajinagar, Maharashtra 40
Musi River Restoration Proposals, Hyderabad, Telangana 43
International Case Studies 47
Cheonggyecheon Stream Restoration Project, Seoul, South Korea 47
Singapore River Cleanup Programme, Singapore 49
Chapter 3 52

Indicators of Urban sanitation and River health. 52
3.1 Indicators of Urban Sanitation & Solid Waste Management 52
3.2 Indicators of River Health 57
Chapter 4 60
Understanding the linkages between indicators of urban sanitation, Community health and river health. 60
Urban Sanitation and Organic Pollution Linkages 60
Wastewater Treatment and River Ecosystem Health 61
Faecal Sludge Management and Microbial Contamination 61
Solid Waste Management and River Degradation 62
Governance, Institutional Capacity, and Environmental Outcomes.... 63
Chapter 5 66
Identification of Study Area 66
Chapter 6 70
Data Analysis....70
6.1 Study Area Profile....70
6.2 Spatial Analysis Maps....73
6.2.1 Narmadapuram Boundaries Map....73
6.2.2 Narmadapuram Connectivity Map....73
6.2.3 Narmadapuram Contour Map....74
6.2.4 Narmadapuram Drainage Map....75
6.2.5 Narmadapuram Population Density Map 76
6.2.6 Narmadapuram Satellite Image 77
6.2.7 Narmadapuram Slope Map 78
6.2.8 Narmadapuram Ward Map 79
6.3 Assesment of sanitation/SWM infrastructure.... 80
Chapter 7 88
Result and discussion.... 88
Urban Sanitation Assessment.... 88
Solid Waste Management Assessment.... 89
Faecal Sludge Management Assessment.... 90
River Health Assessment 91
Linkages Between Urban Sanitation and River Health 92
Planning Framework Assessment....93
Overall Findings.... 94
Conclusion.... 94
Chapter 8....95
Proposals & Recommendations 95
Proposal Framework for River-Sensitive Urban Sanitation Planning....95
REFERENCES....105
ANNEXURES....109

List of Figures

Figure 1 Data Collection Framework 17
Figure 2 Flow Chart of Thesis Methodology 22
Figure 3 Co-authorship network analysis among countries 30
Figure 4 Density map of country-level co-authorship in rainfall-runoff modeling research (2000–2024). 31
Figure 5 Co-occurrence network visualization of keywords. 32
Figure 6 Co-occurrence overlay visualization of keywords. 33
Figure 7 Loop Diagram 63
Figure 8 Location of Urban Local Bodies along River Narmada in MP 68
Figure 9 Location Map of Narmadapuram 71
Figure 10 Administrative boundaries of Narmadapuram 73
Figure 11 Narmadapuram Connectivity Map 74
Figure 12 Narmadapuram Contour Map 75
Figure 13 Narmadapuram Drainage Map 76
Figure 14 Narmadapuram Population Density Map 77
Figure 15 Narmadapuram Satellite Map 78
Figure 16 Slope Map of Narmadapuram 79
Figure 17 Ward Map of Narmadapuram ULB 80
Figure 18 Approaches for proposals 97
Figure 19 Various Interventions 102

List of Tables

Table 1 Research Design..... 23
Table 2 Indicators for River Health 58
Table 3 Linkages Between Urban Sanitation Indicators and River Health Indicators..... 64
Table 4 List of Urban Local Bodies along River Narmada in Madhya Pradesh..... 67
Table 5 Projected Sewage Generation 81
Table 6 Service Level Benchmark values for Narmadapuram..... 82
Table 7 Service Level Benchmark values for Narmadapuram..... 83
Table 8 Service Level Benchmark values for Narmadapuram..... 85
Table 9 Consideration of River in Master Plan..... 86
Table 10 Consideration of River related planning component in Master Plan 98

ABBREVIATIONS

CPCB	Central Pollution Control Board
CSIR	Central Scientific and Industrial Research
DEE	Department of Environment and Energy
EPA	Environmental Protection Agency
ICT	Information and Communication Technology
NEERI	National Environmental Engineering Research Institute
NGT	National Green Tribunal
NPS	National Park Service
NOC	No Objection Certificate
MPPCB	Madhya Pradesh Pollution Control Board
PHED	Public Health and Engineering Department
SOP	Standard Operating Procedure

CHAPTER 1

Introduction

1.1 Background

River-centric urban sanitation planning focuses on integrating river health into the framework of city development and sanitation management, recognizing rivers as critical but vulnerable ecological assets within urban landscapes. This approach emerges from pressing global and regional challenges, as rapid urbanization has led to increased pollution of rivers from untreated sewage, industrial effluents, and encroachment, especially in developing regions such as India, where more than 70% of urban wastewater is discharged directly into rivers without treatment. (AFFAIRS, 2021)

In broader implications river-centric urban sanitation planning aligns with global policy frameworks like the Sustainable Development Goals (SDG 6: Clean Water and Sanitation, SDG 11: Sustainable Cities and Communities), and is recommended by both national task forces and international organizations such as the United Nations Environment Programme (UNEP). A sustainable, community-driven, and data-informed approach holds potential for reversing the decline of urban rivers, safeguarding ecological and economic functions, and promoting healthier, more liveable cities.

1.2 Need of Study

As urbanization increases and management practices are poor, cities face more urgent problems of water pollution, urban flooding and deteriorating ecological health of rivers. Untreated sewage and industrial effluents are discharged into many urban rivers, which degrade water quality, lead to loss of biodiversity and pose health hazards to those living near the rivers. Historically, urban planning has overlooked the health of the river, focusing on engineering solutions and ignoring crucial ecological concerns like floodplain management and groundwater recharge. This has made the chances of flooding high and caused public health problems due to waterborne infections being disseminated via polluted rivers. (9,10,11,12,13).

Besides, there is a huge gap between policy ambitions and on-the-ground implementation on how to conserve and integrate rivers in urban development frameworks. Research is needed to develop holistic planning methods, simplify the regulatory framework, and encourage collaboration between stakeholders to promote sustainable urban growth while protecting river ecosystems. Such studies can also help cities to meet global commitments to clean water, sanitation and climate resilience, which are increasingly vital for healthy cities and equitable growth. If these gaps are not addressed, environmental deterioration will continue and cities would be less resilient to disasters associated with climate change.

The Narmada Ghat Survey 2024 undertaken by the Atal Bihari Vajpayee Institute of Good Governance and Policy Analysis found major gaps in cleanliness, hygiene, accessibility and infrastructure along the ghats along the River Narmada. The survey brought forward several important findings pertinent to river sensitive urban sanitation and riverfront planning:

- Only around 20% of the examined ghats had working toilet facilities, reflecting the gross inadequacy of the public sanitation infrastructure.
- Less than 12% ghats had proper hygiene related facilities including handwashing spots, drinking water access or maintenance systems.
- More than 75% ghats did not have coordinated solid waste disposal systems and so open dumping and direct disposal of waste near riverbanks were seen.
- Around 80% of the ghats were inadequate in hygiene and public safety features like as lighting, drainage, cleanliness and safe access infrastructure.
- There was lack of effective drainage for waste water in several ghats resulting in direct runoff and grey water discharge into River Narmada.
- The poll also noted insufficient provisions for women, older adults and those with disabilities, raising concerns about inclusive and gender-sensitive riverside development.
- Religious and cultural activities including bathing, ceremonial offerings and meetings were often conducted without supporting sanitation infrastructure, adding pressure to the river ecosystem and public hygiene conditions.

The report recommended:

- integrated planning of riverfront sanitation,
- Decentralised waste management methods,
- sanitation facilities with sex-disaggregation,
- enhanced operation and maintenance mechanisms,
- Coordination between river conservation bodies and urban local bodies.

Research Gap

Fragmented Understanding of Urban Sanitation and River Health

However, existing research is fragmented, sectoral and largely metropolitan focused, with significant conceptual, spatial and governance gaps in understanding sanitation–river interactions in medium and small river cities such as Narmadapuram on the Narmada River.

Most sanitation and water pollution studies focus separately on urban sanitation infrastructure and river pollution instead of linked urban ecological systems. In India, research on sanitation has largely concentrated on infrastructure provisioning, toilet coverage, extension of sewerage and execution of national schemes like Swachh Bharat Mission and Atal Mission for Rejuvenation and Urban Transformation. Whilst, the river health studies are mostly based on the water quality parameters including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), faecal coliform and dissolved oxygen levels. There has been little academic work to study the interaction of changing sanitation practices, wastewater management systems, stormwater drainage and solid waste disposal methods throughout time and their effects on riverine ecosystems especially in secondary urban centres.

Geographical Bias in Existing Research

In the context of the Narmada River basin, most environmental studies are concentrated around larger cities such as Jabalpur and Indore, while comparatively limited research exists for river-dependent medium towns like Narmadapuram. This

geographic bias has led to a lack of awareness of sanitation governance, riverside pressures, and ecological vulnerabilities in smaller Urban Local Bodies (ULBs) even as they are becoming increasingly urbanized, with growing informal settlements and deficient wastewater infrastructure.

Studies by the Central Pollution Control Board have pointed to the flow of untreated sewage into Indian rivers over and again, but there is not enough city-level investigation associating sanitation infrastructure shortcomings with river health outcomes in medium-sized river towns.

Lack of Longitudinal and Spatially Integrated Studies

Another major research gap lies in the absence of longitudinal and spatially integrated studies. Most available studies are static and project-based, offering only short-term assessments of sanitary infrastructure or river water quality. Longitudinal studies assessing the impacts of urban expansion, population growth, sanitation investments, and changing governance arrangements on river ecology over long time periods have been very few.

The cumulative ecological repercussions of untreated sewage, greywater discharge, open drains, solid waste dumping and seasonal religious activities remain inadequately recorded in the places like Narmadapuram where the urban growth immediately interfaces the riverbank.

Inadequate Integration of Socio-Cultural Dimensions

Current sanitation planning frameworks also demonstrate limited integration of socio-cultural dimensions associated with rivers. The Narmada River is a major religious, cultural and spiritual environment, as well as a hydrological resource. The dynamics of waste generation and river contamination is heavily influenced by ritual bathing, idol immersion, cremation traditions, large crowds during festivals and river bank occupations.

However, current studies on sanitation and river management tend to be technocratic in their approach, without giving sufficient attention to local socio-cultural practices

and behavioural aspects and traditional ecological knowledge systems. This divergence reduces the efficiency of sanitation programs and leads to implementation gaps at the local level.

Governance Fragmentation and Institutional Coordination Challenges

Another important governance need is institutional fragmentation. Various agencies are responsible for sanitation, wastewater management, drainage, river conservation and environmental monitoring including the Narmadapuram Municipal Council, the Madhya Pradesh Pollution Control Board, the Narmada Valley Development Authority and state level urban development departments.

The existing literature contains few assessments of the degree of coordination, policy convergence, and institutional accountability among these institutions. Furthermore, there is little empirical evidence as to whether urban sanitation missions and river conservation programmes work in an integrated manner or only through discrete sectoral approaches.

Absence of Equity and Inclusion Perspectives

Another shortcoming is the insufficient integration of equity and inclusion ideas into studies on sanitation and river health. Populations at risk, who live in riverbank communities, informal colonies and poorer areas, frequently lack adequate access to sanitation facilities, drainage infrastructure and solid waste management services.

Women, Scheduled Castes (SC), Scheduled Tribes (ST), elderly and those with disabilities are more vulnerable to poor sanitary conditions and environmental degradation. However, intersectional consideration of social vulnerability, exclusion, and unequal access to sanitation is almost entirely absent in previous river-city studies.

Operational and Environmental Gaps in Sanitation Infrastructure

Although pollution control mechanisms such as Sewage Treatment Plants (STPs) and decentralized wastewater systems are included in urban sanitation planning,

operational inefficiencies, under-capacity infrastructure, and maintenance failures frequently result in untreated wastewater entering urban drains and eventually discharging into rivers.

There is limited research that has evaluated the actual environmental performance of these systems in improving river health indicators inside smaller urban communities. Contemporary policy frameworks tend to emphasize infrastructure development rather than ecological objectives, leading to a gap between sanitation coverage figures and actual gains in river water quality.

Limited Integration of River-Sensitive Urban Planning

The emerging discourse on "river-sensitive urban planning" and "river cities" advocates integrated approaches involving riparian protection, ecological restoration, sustainable drainage, and nature-based solutions. But in the development scenario of medium towns situated on the banks of Narmada River, this view is not thoroughly researched.

Urban encroachments, riverbank building, poor drainage planning, land-use changes continue to have a profound impact on river systems, but these interactions are not well studied through integrated planning approaches.

Research Gap in the Context of Narmadapuram

Therefore, the present study seeks to address these gaps by undertaking a comprehensive investigation of urban sanitation systems, governance mechanisms, and river health linkages in Narmadapuram. The objective of the project is to develop an integrated and longitudinal understanding of the impact of sanitary infrastructure, waste management techniques, socio-cultural activities, institutional coordination and urban expansion patterns on the ecological condition of Narmada River.

The research aims to contribute to the creation of a river-sensitive and inclusive urban sanitation planning framework suitable for medium-sized river cities in India by considering environmental, governance, spatial and social elements.

1.3 Aim

To prepare an urban sanitation planning framework that integrates urban sanitation and river health.

1.4 Research Question

- How does urban sanitation impact the health of the River Narmada over time and vice versa?
- How effective are the governance mechanisms and urban sanitation interventions undertaken by the local urban body in improving sanitation infrastructure and service delivery in Narmadapuram?
- To what extent have sanitation and solid waste management governance practices in Narmadapuram influenced the ecological health of the Narmada River?
- Do river cities require different approaches to urban sanitation planning and river health management compared to non-river cities?

1.5 Keywords

Urban Sanitation, River Cities, Water Supply,Sewage Management, Solid Waste Management (SWM), River Health, Public Health and Sanitation

1.6 Objectives

1.6.1 Phase-1

- Identifying the indicators of urban sanitation, Community health and river health.
- Understanding the linkages between indicators of urban sanitation, Community health and river health.
- To Identify the study area from ULBs across the stretch of Narmada River.
- To assess existing urban sanitation data of selected study area and river water quality parameters from primary/secondary data.

1.6.2 Phase-2

- To evaluate the present status of sanitation infrastructure and services (eg. toilets, sewers, faecal sludge management, solid waste management, STPs) in the identified settlement.
- To assess the additional burden on sanitation infrastructure and solid waste management systems arising from socio-cultural and religious practices in Narmadapuram and their impact on the ecological health of the Narmada River.
- To perform an integrated spatial analysis using GIS by generating DEM-based terrain parameters (contour, slope, and drainage order), mapping drainage networks, and assessing sanitation infrastructure and pollution sources and hotspot to evaluate their combined impact on river health.
- To formulate a planning framework that aligns urban sanitation strategies with river conservation goals, ensuring resilience against urbanization.

1.7 Scope & Limitations

1.7.1 Scope

The study is limited to the municipal boundary of the selected city and the portion of the Narmada River within the city, and the direct river consequences of urban sanitation are analyzed, but not the upstream rural and industrial influences. The goal of this study is to build an integrated framework of urban sanitation, community health and river health in the cities on the rivers. It looks at sanitary infrastructure, wastewater flows, pollutant channels, governance mechanisms and how these factors interact to impact river ecosystems and public health. The study aims to examine the influence of sanitary infrastructure, waste management methods, socio-cultural activities and municipal governance systems on river health and environmental sustainability in a medium-sized river city.

The geographical coverage of the study is limited to Narmadapuram comprising riverbank regions, bordering urban settlements, some chosen wards, ghats, informal settlements and areas having direct influence on the river ecology. The focus is especially on the river-adjacent villages and metropolitan areas which are exerting direct strain on the Narmada River due to sanitation and solid waste.

The thematic scope of the research covers the following interlinked components:

- Urban sanitary infrastructure includes sewerage, septic tanks, drainage, public toilets and waste water disposal methods.
- Solid waste management strategies such as collection, segregation, transportation, disposal systems and riverside garbage accumulation.
- Evaluate sanitation and solid waste challenges due to socio-cultural and religious practices such as ritual bathing, idol immersion, festivals, cremation activities, mass gatherings and pilgrimage-related activities along the riverbank.
- Urban governance and institutional arrangements for sanitation management, environment monitoring and river protection with organizations like Narmadapuram Municipal Council, Madhya Pradesh Pollution Control Board and other competent departments.
- Community attitude, behavioural practices and awareness on cleanliness, trash disposal and conservation of river.
- Ecological indices of river health, including water contamination, wastewater discharge, solid waste build-up and environmental degradation along the river corridor.

It also studies the efficacy of sanitation related schemes and programs including Swachh Bharat Mission, river conservation initiatives and local sanitation policies to tackle river sensitive urban sanitation concerns.

Methodologically, the study adopts a mixed-method approach integrating:

- Quantitative evaluation of sanitation coverage, waste generation, drainage and available environmental data.
- Qualitative methodologies including field observations, stakeholder interviews, focused discussions and community level assessment.
- Mapping and spatial analysis of sanitation infrastructure and waste disposal locations, drains and environmentally sensitive riverbank zones.
- Review planning papers, sanitation reports, environmental regulations and policy frameworks pertinent to urban sanitation and river conservation.

The purpose of this study is to contribute to the creation of a river-sensitive urban sanitation framework for medium-sized river towns by integrating the environmental, social, cultural and governance components within the planning process.

1.7.2 Limitations

1. Geographical Limitation

The study is limited to the specified locations of Narmadapuram and not extended to the whole basin of Narmada river. As such, the findings may not fully represent circumstances in other river cities or rural communities along the river corridor.

2. Data Availability and Quality Constraints

The study is based on secondary data collected from government offices, local records, environmental reports and available water quality assessments. Such data might:

- Include discrepancies or gaps in time,
- Vary in accuracy and approach among agencies.
- May not be available for particular regions or parameters,

Availability of real-time environmental monitoring data is limited which may impair detailed assessment of pollution trends and ecological conditions.

3. Technical Limitations

The study is mostly based on existing field observations, municipal records and publicly available spatial data. Detailed hydrological modelling, constant water quality monitoring and assessment of the subterranean drainage are not within the scope of the present research. Satellite imaging and secondary spatial data may also fail to detect micro-level pollution sources and informal discharge locations.

4. Institutional and Administrative Constraints

Information on sanitary infrastructure, wastewater discharges, and treatment works performance can be difficult to get due to administrative procedures, limited public access to documents, or fragmented responsibilities among many agencies.

5. Socio-Cultural and Ethical Constraints

Social sensitivities could be involved in the assessment of sanitation practices connected with religious and cultural activities along the Narmada River. Local communities, pilgrims or religious stakeholders may sometimes be unwilling to talk about open disposal practices, pollution and sanitation behaviour.

6. Limitation in Environmental Assessment

The ecological health evaluation of the river is based on selected environmental indicators and existing data sets. The scope of this study did not include detailed biodiversity assessment and aquatic ecosystem analysis and seasonal hydrological fluctuations.

7. Time and Resource Constraints

The limits of time, people and financial resources did not allow intensive household level surveys and comprehensive seasonal environmental monitoring throughout the urban region.

Notwithstanding these limitations, the study gives vital insights into the interaction between urban sanitation, solid waste management, socio-cultural practices, governance systems and river health in Narmadapuram. The results are anticipated to facilitate further research and contribute to the sustainable and river-sensitive urban sanitation design in similar riverine towns.

1.8 Assumptions & Expected outcomes

1.8.1 Assumptions

- Sanitation infrastructure directly affects river health. Waste water created in river-side cities that is not properly handled ultimately reaches the rivers in their vicinity.
- River water quality is associated with health outcomes of the community, especially through pathways such as bathing, irrigation, fishing and contaminated ground water.

- Secondary data and published literature give sufficiently accurate information to map sanitation–health–river links.
- It is expected that government regulations, urban cleanliness programs and river rejuvenation projects are executed as described, even if enforcement differs.
- Conceptual linkages between sanitation, river health and community health are consistent throughout most riverside urban contexts, notwithstanding local variances.
- Existing environmental indicators (BOD, COD, nutrients, pathogens, access to toilets, etc.) are presumed to be legitimate assessments of river ecosystem health and sanitation performance.
- Climate impacts (e.g., excessive rainfall) can affect sanitation systems and river water quality, but are considered here as extrinsic to the basic sanitation-river relationship.
- The systems-thinking paradigm assumes that causal links identified in the literature are sufficiently generalizable to construct an integrated framework.

1.8.2 Expected outcomes

The Study attempts to investigate the relationship between urban sanitation systems, solid waste management practices, socio-cultural activities and ecological health of Narmada River in the setting of Narmadapuram. This study intends to provide interrelated empirical, planning, governance and environmental outputs contributing toward river sensitive urban sanitation planning.

The expected results of the investigation are:

1. **Understanding the link between urban sanitation and river health**

The study will assess the direct and indirect impacts of the urban sanitation systems, wastewater disposal practices, drainage networks and solid waste management systems on the ecological condition of the Narmada River in Narmadapuram.

The research is intended to identify:

- Main sources of river pollution associated with sanitation,

- Areas with untreated sewage discharge and inappropriate solid waste disposal,
- Effects of poor drainage and sanitary infrastructure on health of rivers,
- Environmental impacts of urban activity on the riverfront.

The project will also look at how riverfront conditions influence sanitation practices, trash disposal behaviour and urban environmental management in the city.

2. Socio-cultural pressures on sanitation and solid waste management

The study will evaluate the additional load on the sanitary infrastructure and solid waste management systems owing to socio-cultural and religious activities along the riverbank of Narmadapuram.

This involves an evaluation of:

- Activities of ritual bathing,
- Religious festivals and gatherings,
- Idol's immersion practices,
- Cremation activities
- Pilgrimage associated garbage creation and congregation on the river front.

Such operations are likely to increase the generation of waste, put pressure on public sanitation systems, cause congestion in drainage and pollute the Narmada River.

3. Identification of Critical issues of Sanitation and Riverfront Environment

Field observations, geographical analysis and sanitation infrastructure assessment will be used to identify the sanitation-deficient and ecologically vulnerable areas in Narmadapuram.

The study is expected to identify:

- Open drains and wastewater discharge points discharging into the river,
- Susceptible sites for solid waste dumping,
- Riverfront areas without proper sanitary facilities,

- Settlements with a strong environmental demand on the river ecology.

This assessment will guide the prioritizing of sanitation and environmental measures in river near areas.

4. Assessment of urban governance and institutional mechanisms

The study will assess the efficacy of governance systems, institutional coordination and sanitation management mechanisms for river protection and environmental management in Narmadapuram.

The research will look at:

- Institutional roles and duties for sanitation and river management
- Coordination of municipal and environmental authorities,
- Effectiveness of implementation of schemes on sanitation & waste management,
- Existing loopholes in monitoring, maintenance and enforcement systems.

Findings are expected to point to institutional constraints affecting river sensitive urban sanitation design.

5. Knowledge of Community Perception and Practices about Behaviour

The study will throw light on public awareness, sanitation behaviour and trash disposal practices of riverfront communities and users of the river ecosystem.

The research is expected to investigate:

- Community perceptions on cleanliness and sanitation of the river,
- Behavioural practices resulting in environmental degradation,
- Public awareness of implications of garbage dumping on river health,
- Involvement of local populations in sanitation and environmental management operations.

6. Developing a River Sensitive Urban Sanitation Framework

One of the key intended objectives is to build a river-sensitive urban sanitation and solid waste management framework for medium-sized river cities like Narmadapuram.

The suggested framework is anticipated to:

- Coordinate sanitation planning with river conservation aims,
- Address the socio-cultural components of riverfront activities,
- Encourage ecologically conscious waste management strategies,
- Enhance synergies between sanitation and environmental governance systems,
- Promote sustainable riverfront planning and management.

7. Contribution to Sustainable Urban Planning and River Conservation

The study is likely to contribute towards the larger discourse on sustainable urban growth, sanitation planning and river conservation in India.

The findings may provide support for:

- Development of river sensitive sanitation systems,
- Improved urban environmental planning methods,
- Enhancing riverfront management practices,
- Recommendations on sanitation-related river pollution reduction policy,
- Future work on urban sanitation and river ecology in mid-sized river cities.

Overall, the study is designed to provide a complete understanding of how sanitary infrastructure, solid waste management systems, socio-cultural activities, governance mechanisms and community behaviour all affect the ecological health of Narmada River in Narmadapuram.

Provides a comprehensive roadmap for building integrated urban sanitation-river health policies for river-side towns in India and abroad.

1.9 Data Collection Framework

A flowchart similar to the one shown in Figure 1 depicts the organized method that was utilized to gather, organize, and integrate data for the research project titled "Integrating Urban Sanitation and River Health in River-side Cities." To begin, the objectives of the study are defined, and important indicators for sanitation, community health, and river health are chosen according to their significance. In addition to the methodical collection of secondary information, policy papers, GIS layers, and scientific literature, the framework also includes the possibility of conducting stakeholder consultations with key government departments. Prior to the process of synthesis into a unified analytical database, each dataset is subjected to validation and thematic organization. An integrated strategy like this one guarantee that the final framework will be constructed on trustworthy evidence, viewpoints from multiple sectors, and multi-dimensional information, which will support a comprehensive understanding of the relationships between sanitation, health, and rivers.



Figure 1 Data Collection Framework Source: By Author

1.10 Methodology

The research uses a mixed-methods approach, employing quantitative analysis, qualitative inquiry, geographical assessment, and policy evaluation to explore the relationship between urban sanitation systems and river health comprehensively. This methodology aims to identify present problems, evaluate the performance of infrastructure and governance and to provide an integrated framework for sustainable urban sanitation and river-sensitive development.

1. Secondary data analysis-driven river health assessment

The existing health status of the river is assessed by the analysis of secondary water quality data collected from government agencies, pollution control boards, municipal records and public reports. The assessment is based on the key physical, chemical and microbiological markers of river pollution levels and ecological status. Parameters:

- Biochemical Oxygen Demand (or BOD)
- Chemical Oxygen Demands (COD)
- Dissolved Oxygen (DO);
- Ammonia (NH3)
- Total Coliforms & Faecal Coliforms

The temporal and spatial fluctuation in water quality is studied to determine pollution trend, key contamination zones and likely sources of degradation. This analysis gives a basic understanding of the connection between sanitation infrastructure and river health.

2. Stakeholder Consultation and Qualitative Evaluation

- Semi-structured interviews and targeted talks with important stakeholders to understand on-ground reality and institutional perspectives, including;
- Municipal sanitation engineers and officials
- Urban planners and planning authorities

- Representatives of pollution control board
- Local communities and riverfront users
- Commercial Establishments and Informal Sector Workers

Qualitative examination addresses issues of sanitation service delivery, wastewater management methods, public perceptions of river pollution, governance constraints, operational inefficiencies and potential for improvement in urban-river management. The results contribute to capturing socio-institutional elements that are typically not represented in quantitative databases.

3. GIS Based Spatial Analysis and Pollution Hotspot Mapping

In this study, the Geographic Information System (GIS) tools are used to create a comprehensive spatial database of the subject area.

The mapping exercise consists of:

- Existing sewer infrastructure
- Public sanitation assets, Septage management facilities
- Outfalls and stormwater drainage systems
- Solid waste management infrastructure
- River corridors and water bodies
- Land usage and settlement patterns

We integrate water quality datasets, drainage discharge locations, sanitation infrastructure gaps and field observations to identify pollution hotspots. Spatial analysis allows to visualize the relation between urban expansion, sanitation 5zones.

4. Policy, Planning & Institutional Review

This is done through a rigorous desk-based analysis to examine the policy and institutional framework controlling urban sanitation and river management.

The review includes:

- National policies on water and sanitation
- Guidelines for urban river management
- Municipal Sanitation Plans
- Development plans and city master plans
- Rejuvenation of rivers
- Legal and regulatory framework relevant to the activity

Further, successful case studies of river restoration and sanitation management in Indian cities are analysed to find best practices, implementation methods, governance models and transferable lessons pertinent to the research area.

5. Gap Analysis of Infrastructure and Governance

Brings together findings from the water quality study, stakeholder engagements, geographical analysis and policy review to identify the existing gaps in:

- Provision of sanitation facilities
- Wastewater collection and treatment and septage management systems
- Solid waste management techniques
- Mechanisms for institutional coordination
- Monitoring and data management systems
- Sense of community and community involvement

The gap analysis aids in pinpointing major deficiencies influencing sanitation performance and river ecosystem health.

6. Creation of an Integrated Urban-River Health Framework

The last step of the research is the integration of all findings into an Integrated Urban-River Health Framework that encourages the confluence of sanitary planning, river conservation, governance and community participation. The framework is based on modern methodologies espoused by agencies like National Institute of Urban Affairs (NIUA) and National Mission for Clean Ganga (NMCG) particularly the tenets of River-Sensitive Urban Planning and Urban River Management.

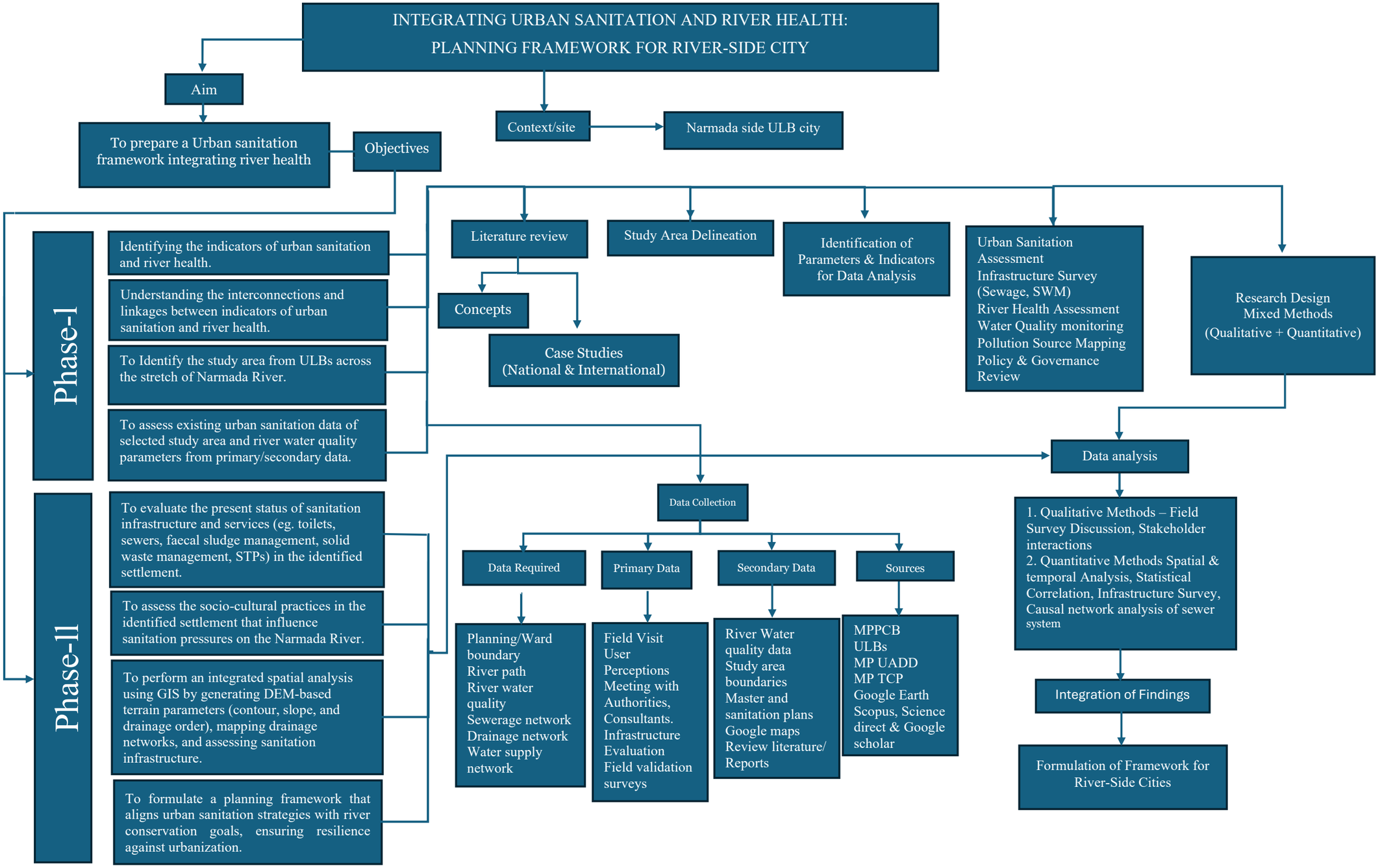

Figure 2 Flow Chart of Thesis Methodology *Source-Author*

1.11 Research Design

Assessment of River-Sensitive Urban Sanitation in Settlements Along the River Narmada Using a Mixed-Methods Approach

Table 1 Research Design

Aspect	Quantitative Methods	Qualitative Methods
Data Sources	- Water quality parameters (e.g., DO, BOD, COD, coliforms) - Urban sanitation metrics (sewage coverage, waste management status, public/community toilet)	- Research papers, reports, databases - Interviews with stakeholders (municipal officials, NGOs, residents)
Instruments	- Service level benchmark - Satellite data (for mapping) - Surveys/questionnaires	- Stake holder interview guides - Field Validation - Observation protocols
Data Analysis	- Descriptive and inferential statistics - Change in water quality parameters (river health, sanitation indicators)	- Thematic content analysis - service level benchmark analysis

Source - Author

1.12 Take aways and Conclusion from Phase 1 to Phase 2

Phase 1 of the study developed the conceptual, theoretical and analytical framework of the study by identifying and analysing inter-relationships between indicators of urban sanitation, community health and river health. This phase provided a systematic knowledge of the sanitation-river health nexus by a comprehensive evaluation of current literature, assessment of sanitation and river health datasets and selection of eligible Urban Local Bodies (ULBs) along the Narmada River. The report also provided insights into key indicators, current environmental and sanitation concerns, and major gaps in governance, monitoring and integration between urban sanitation planning and river conservation activities. The findings offered an evidence-based framework for understanding the effects of sanitation systems on river ecosystems and community well-being.

On this basis, phase 2 moves from theoretical understanding to field-based inquiry and geographical assessment in the specified study region of Narmadapuram. The validated indicators and links identified in Phase 1 inform the detailed assessments of sanitation

infrastructure and services, including toilets, sewerage systems, faecal sludge management, solid waste management and wastewater treatment facilities. The phase further analyzes the additional demands of socio-cultural and religious activities on sanitary systems and the ecosystem of the rivers. In Phase 2, we use GIS-based spatial analysis of topographical features, drainage networks, pollution hot spots and sanitation infrastructure to develop empirical data on the pathways by which urban sanitation conditions affect river health. Interactions with stakeholders and field observations reinforce greater awareness of local challenges and opportunities.

The knowledge created from the two phases is then synthesized to provide an integrated River-Sensitive Urban Sanitation Planning Framework to connect urban sanitation policies with river conservation objectives. The framework aims at promoting environmentally sustainable, socially responsive and climate-resilient planning of riverbank villages along the Narmada River.

In essence, Phase 1 determined ‘what needs to be measured and understood’ in terms of the sanitation–community health–river health nexus, while Phase 2 investigates ‘how these relationships work in the real-world context of Narmadapuram and what interventions are required’ to realize sustainable urban sanitation and river health outcomes.

Chapter 2

Literature Review

2.1 Review of Literature on River-Sensitive Urban Sanitation

Urban Sanitation in India: Policy and Progress

Chronic underinvestment and systematic geographical inequities have long characterized India's urban sanitation system, a reality that national missions have only just started to address. Foundational literature on Indian urbanism notes that historically, the state's approach to sanitation has privileged elite, formal enclaves over peri-urban and informal populations (Chaplin, 2011). The launch of Swachh Bharat Mission (SBM) and SBM-U 2.0 was a paradigm shift in the policy rhetoric from a strictly supply focused infrastructure to a framework focusing on behavioural change. As O'Reilly and Louis (2014) describe in their key analysis of Indian sanitation policy, effective interventions require a 'toilet tripod' of multi-scalar political will, altering societal norms and trustworthy infrastructure.

However, critical scholarship shows a stark gap between the policy goals of SBM and the socio-environmental effects in the long term. Institutional reports celebrate increased access, while scholarly critiques contend the state's measures are fundamentally wrong, measuring building rather than sustained consumption or ecological safety. As McFarlane (2012) points out, "mainstream infrastructural interventions are often characterized by a 'techno-managerial' bias, wherein sanitation is cast as a straightforward engineering challenge rather than an inherently political issue of urban citizenship." Moreover, the new-age interventions like as the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) are heavily dependent on capital-intensive, centralized sewerage networks. This infrastructure-oriented strategy, scholars contend, overlooks the spatial reality of medium-sized cities that are urbanizing rapidly and leaves underprivileged people on the margins of these city's development, particularly those living in environmentally fragile, proximity to rivers (Narain, 2016).

Rivers and Sanitation: Ecological Consequences

The environmental science literature is replete with examples of the ecological degradation of India's urban rivers, a catastrophic gap between urban metabolism and watershed health. In her sweeping study of the water and waste economy in India, Narain (2012) characterizes the contemporary Indian metropolis as one that adopts a "flush-and-forget" model, one in which municipal planning intentionally decouples water sourcing and wastewater disposal. Because urban planning has traditionally focused on household toilet building rather than on the full treatment of waste water, domestic sewage has become the primary source of contamination of rivers. Kaur et al. (2012) observed that there is a huge gap between the generation of sewage and its treatment capacity in Class I and Class II cities. Due to this, the untreated effluents are directly discharged into drainage channels.

Such infrastructural deficits significantly change the river's hydrology and biology. Existing environmental evaluations demonstrate that this untreated flow increases Biochemical Oxygen Demand (BOD), causes rapid eutrophication and kills dissolved oxygen levels, thus critically impairing aquatic biodiversity (Bhaduri et al., 2011). However, beyond just diagnostic research, the modern environmental planner recommends a fundamental change in the approach to rehabilitation. According to Singh et al. (2020), "River restoration in the Global South is not about isolated engineering interventions, it is about spatially reorganizing urban waste flows." Their findings show a consensus in the literature that a single planning paradigm that clearly incorporates decentralized wastewater treatment, spatial planning and river basin management is required for sustainable ecological outcomes.

Gender and Equity in Sanitation in Riverine Cities

While the necessity of inclusive urban design is acknowledged, gendered sanitation issues remain woefully understudied within the frameworks of river governance and urban infrastructure. Feminist geographers and development experts have observed that sanitation is not a gender-neutral issue of infrastructure but a highly spatialized representation of patriarchal power dynamics. The research by Desai, McFarlane and Graham (2015) in Indian urban settlements shows how the absence of safe, private

sanitation infrastructure grips women in deep everyday anxiety, restricting their movement and physical autonomy. They remark that the daily struggle for access to sanitation is "deeply intertwined with the threat of gender-based violence and harassment" (Desai et al., 2015).

This risk is notably exacerbated in townships beside rivers. Because women in these settlements are in close and everyday contact with the riverfronts for domestic work, bathing and religious ceremonies, their exposures to unclean conditions have serious implications for public health. As Mehta (2011) has pointed out, women are typically treated as mere 'users' by mainstream water and sanitation policies without any recognition of their localized knowledge and specialized hygienic needs such as those for menstrual hygiene management. These scholarly concerns are corroborated by empirical surveys, such as those done along the Narmada River ghats, which demonstrate a preponderance of the absence of gender-segregated functional facilities. Taken together, this body of work emphasizes the critical need for moving beyond sanitation planning as usual, toward frameworks that require universal accessibility and explicitly address the gendered responsibilities of water and waste management.

The Narmada Ghat Survey conducted by the Atal Bihari Vajpayee Institute of Good Governance and Policy Analysis (AIGGPA, 2024) revealed severe infrastructural deficiencies across ghats along the Narmada River. The survey found that only approximately 20 percent of ghats possessed functional toilet facilities, while less than 12 percent provided adequate hygiene infrastructure.

These findings demonstrate the urgent necessity for inclusive sanitation planning frameworks that integrate gender-sensitive infrastructure, universal accessibility, menstrual hygiene management, and public safety considerations within riverfront planning and sanitation systems.

Socio-Cultural Practices and Sanitation Behaviors

Urban riverfronts in India are not only natural spaces but also very complex socio-cultural and religious spaces regulated by ingrained behavioural patterns. The scholarly literature repeatedly points out that ritual bathing, cremation and religious offerings are performed outside of official municipal waste-management systems, resulting in specific localized pollution loads. Basic anthropological studies note that sanitation behavior in India cannot

be understood without an analysis of ideas of ceremonial purity and physical contamination.

Coffey et al. (2014) find that resistance to some sanitation technologies is rooted in the Hindu caste system, for example, in the physical emptying of latrine pits, which has historically been associated with Dalit oppression. Therefore, when community behavioural patterns are ignored, top-down infrastructural improvements consistently fail to reach environmental sustainability. The paradox of the Indian urban river, worshipped for its spiritual purity and used as a physical sink for pollution, creates barriers for regulatory enforcement (Alley, 2002). As Alley (2002) has remarked in her research of the Ganges, "In the cultural imagination, devotion and pollution are not mutually exclusive; a river can be highly toxic, and still be a source of ultimate spiritual purification." This synthesis of the literature reveals that the effective planning for river-sensitive planning requires a culturally appropriate strategy that replaces prescriptive engineering with extensive localized socio-behavioral interaction.

Governance, Policy Fragmentation, and Institutional Challenges

Deeply embedded institutional fragmentation is the most common obstacle to sustainable urban river and sanitation management as reported in the literature. India's urban governance is marked by a very siloed, multi-agency system where water supply, wastewater management and environmental protection are managed by whole different bureaucracies. Ahluwalia (2011) contends that ULBs have been left severely disempowered as the 74th Constitutional Amendment Act has not been implemented in letter and spirit, depriving them of financial autonomy and technical capacity to deal with complex ecological systems.

This sector-by-sector fragmentation promotes overlapping jurisdictions and absolute lack of accountability. Pollution control boards often demand municipal organizations to undertake certain actions, which they simply do not have the cash to undertake (Bhide 2015). Moreover, literature refers to a chronic lack of integrated urban databases and long-term environmental monitoring that cripples evidence-based policymaking (Prasad, 2013). Polycentric, multi-stakeholder governance systems have been found to be more effective than the state-centric model of India and international models in integrating sanitation with ecosystem management (Brown et al., 2009). There is strong academic

consensus that capital investments in urban sanitation will remain ecologically ineffective unless these institutional siloes are broken down through integrated watershed governance.

According to NMCG (2024) SOP many gatherings exceed the natural carrying capacity of riverfront locations and that crowd estimates and environmental capacities are often not scientifically assessed. It recommends a river-sensitive, stretch-based planning approach that considers upstream–downstream linkages and environmental thresholds.

These governance challenges highlight the necessity for integrated institutional frameworks capable of linking urban sanitation services, river conservation strategies, environmental monitoring, and participatory urban planning within river-side cities.

2.2 Bibliometric Analysis

2.1.1 Contributions of country

The network visualization shows the co-authorship ties among the countries contributing to the study on urban sanitation and river health. In this picture, the countries with larger nodes are those with more research output, while the thicker connecting lines between the countries have stronger collaborative connections.

The image reflects that the United States, India and China become the central nodes, which indicates their great influence and high productivity in the research of wastewater treatment, sanitation systems and river ecosystem restoration. These countries have robust bilateral and multilateral collaborations, often co-authoring papers on pollution control, decentralized wastewater treatment, and river health assessment.

Fig 3 further underscores a European contribution, notably from France, Belgium, Italy, Spain and the United Kingdom, which are in an integrated cluster. Their joint output usually relates to sophisticated monitoring technologies, hydrological modelling, governance frameworks and integrated river-basin management and makes important contributions to methodological advances in the discipline.

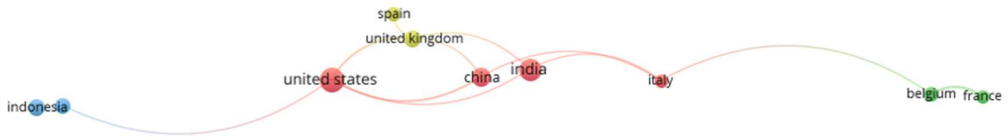

Figure 3 Co-authorship network analysis among countries *Source-Vosviewer*

Indonesia, for its part, constitutes a smaller but unique node, representing an emerging research hub in the Global South. While there are fewer collaborations, its presence indicates a growing academic interest in addressing sanitation difficulties and river degradation in tropical, fast urbanizing areas.

Overall, the network reveals that while global collaboration is strong among leading nations, there are potential to strengthen partnerships with emerging regions. Strengthening such networks could lead to increased knowledge exchange, capacity development and more inclusive, internationally relevant frameworks for the integration of urban sanitation with river health in river-side cities.

Figure 4 depicts the geographical concentration of research effort on urban sanitation and river health. The darker the hue, the bigger the volume of research or strength of collaboration networks in that area.

The picture shows that South Asia, East Asia, Europe, and North America are the most active research hubs. Countries like India, China, the United States, the United Kingdom, Spain, France, and Belgium have dense clusters, indicating high academic engagement with topics like wastewater management, sanitation technologies, water pollution monitoring, and river ecosystem restoration.

The high density around India and China reflects their major issues with urban expansion, wastewater discharge and river degradation – leading to intensive study on sanitation reforms, pollution reduction measures and integrated river health frameworks. Similarly, the United States and European countries contribute much work on advanced treatment technology, decentralized wastewater solutions, hydrological modelling, and governance frameworks for sustainable river management.

By contrast, places such as Indonesia show smaller but distinct clusters of research, indicating rising contributions from fast developing countries experiencing significant sanitation-river health challenges. Their rising map representation reflects growing academic interest and creates chances for deeper collaboration with worldwide research networks.

In sum, the density map indicates that although urban sanitation and river-health research is dominated by a few countries, a broader array of places is slowly getting engaged. Enhancing cooperation between established research hubs and emerging environments might facilitate the transfer of information and capacity building, thereby enabling more comprehensive and context-sensitive frameworks for enhancing river health in fast urbanizing river-side cities.

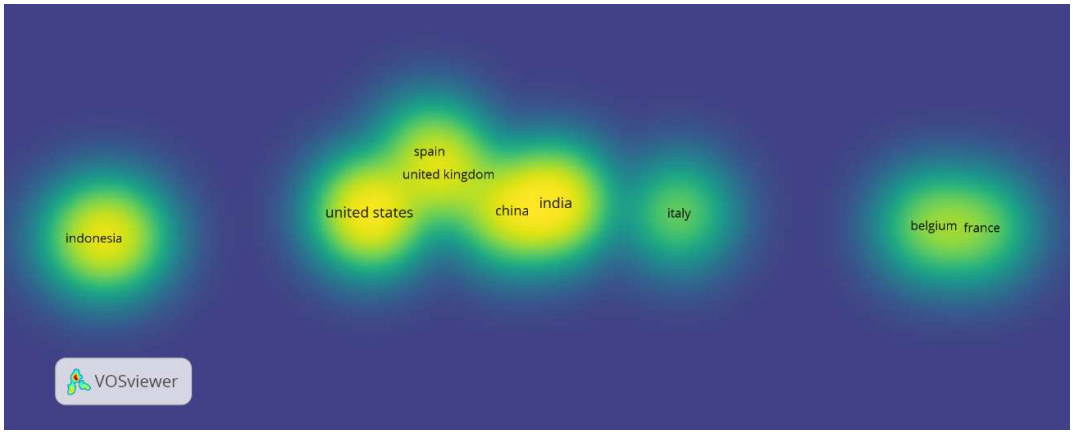

Figure 4 Density map of country-level co-authorship in rainfall-runoff modeling research (2000–2024). Source-Vosviewer

2.1.2 Keywords

The co-occurrence network (Fig. 5) shows tightly linked keywords that constitute multiple major topic clusters associated with urban sanitation and river health. Node size indicates frequency of term, connection thickness indicates intensity of correlation.

The core cluster is centered on river pollution and water quality, with phrases like river pollution, water quality, wastewater, pollution, chemical oxygen demand, and nutrients discharge. It highlights that the degradation of rivers is largely induced by untreated

wastewater, urban effluents and diffuse pollutants, and so represents the crucial interface between sanitation systems and the health of rivers.

A second main cluster focuses on wastewater treatment and sanitation systems, indicated by keywords such as wastewater treatment, sewage treatment, water treatment facilities, wastewater disposal, and reclamation. This shows the relevance of treatment efficiency and infrastructure effectiveness in lowering pollution loads entering waterways.

The public health and microbial contamination cluster includes terms such as Escherichia coli, fecal coliform, health risks, contamination, and environmental monitoring, showing the direct link between poor sanitation, pathogen presence, and community health risks, especially in densely populated river corridors.

Another important cluster includes urbanization, land use change, and groundwater pollution, which is represented by keywords such as urban area, land use, urbanization, groundwater pollution, and aquifers. The cluster illustrates how urban growth and land-use changes intensify surface and groundwater contamination, requiring coordinated urban-environment planning.

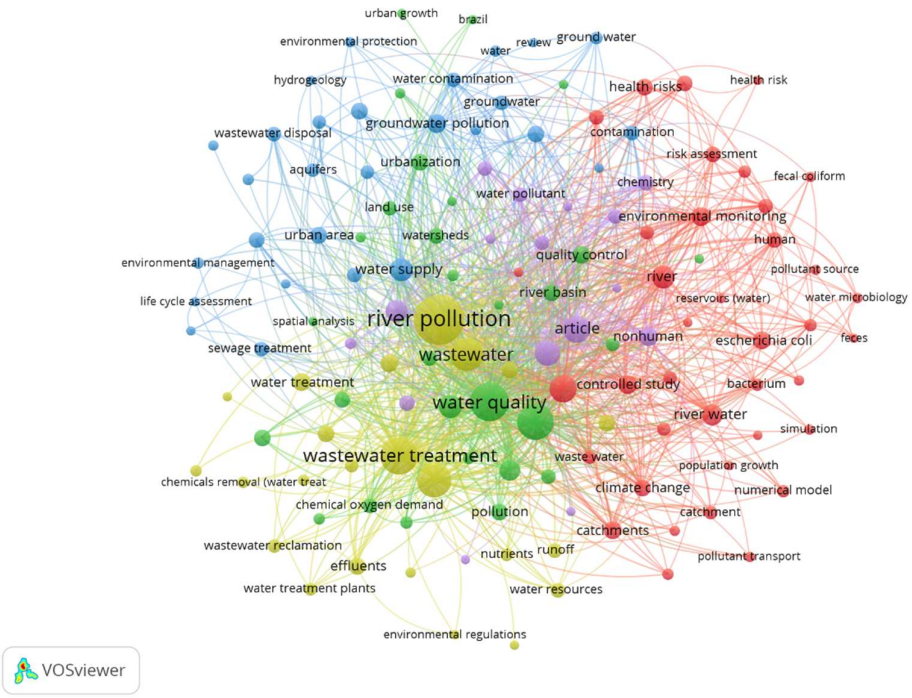

Figure 5 Co-occurrence network visualization of keywords. *Source-Vosviewer*

Finally, the hydrology and pollutant transport cluster (e.g., watersheds, river basin, catchments, water resources, pollutant transport) situates sanitation impacts within larger catchment-scale and hydrological dynamics, highlighting efforts to understand how pollutants move, accumulate, and influence river systems.

The temporal overlay visualization (Fig. 6) illustrates a clear progression in research focus on urban sanitation and river health from 2000 to 2024. Early research (2000–2010), shown in cooler tones, centered on foundational issues such as river pollution, wastewater treatment, water quality, and sewage disposal, establishing the basic scientific understanding of contamination pathways and treatment practices.

During the middle period (2010–2018), research expanded toward urbanization, land-use change, groundwater contamination, and environmental monitoring. This shift reflects growing recognition of how rapid urban growth and spatial transformation intensify sanitation pressures and degrade river ecosystems.

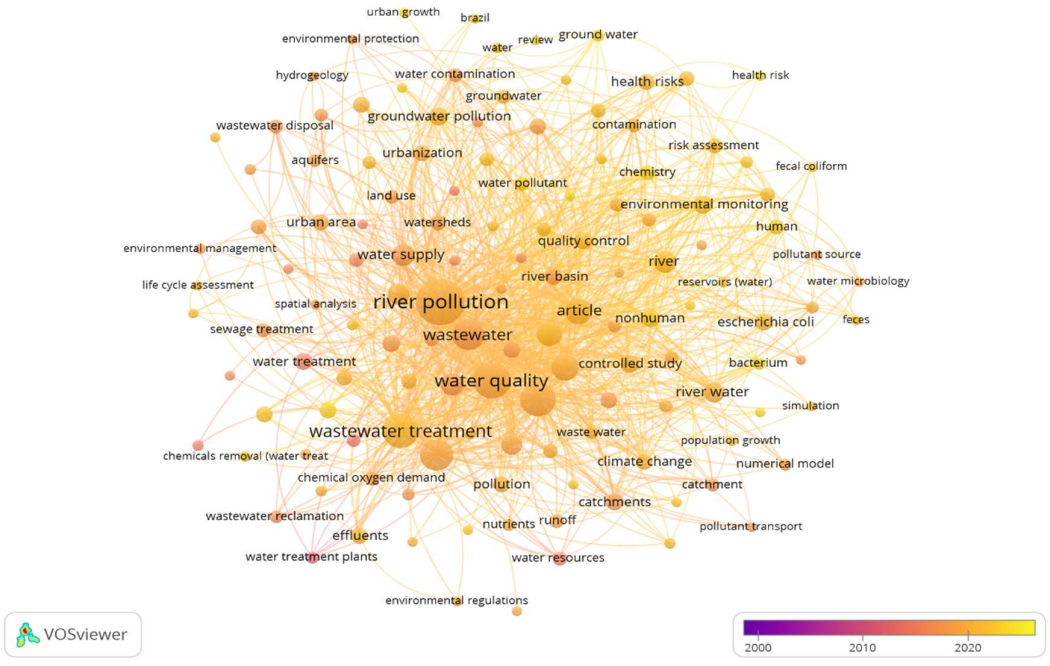

Figure 6 Co-occurrence overlay visualization of keywords. *Source-Vosviewer*

In the recent period (2018–2024), warmer colours highlight emerging themes, including pollutant transport modelling, climate change impacts, microbial risk assessment, and numerical modelling. These developments demonstrate a move toward advanced, data-

driven, and climate-resilient approaches, consistent with global sustainability and public health priorities.

Overall, the evolving keywords indicate a transition from isolated studies of pollution and sanitation toward integrated, system-wide approaches. The rising focus on microbial contamination underscores the urgency of improving sanitation in river-side cities, while the growing attention to hydrological processes and climate risks signals the need for adaptive and resilient planning frameworks. The convergence of engineering, environmental science, public health, hydrology, and urban planning highlights increasing demand for interdisciplinary integration, which is essential for developing a comprehensive sanitation–river health framework for river-side urban environments.

2.3 Case Studies

Indian Case Studies

Dravyavati River Rejuvenation Project, Jaipur, Rajasthan

Jaipur had launched the Dravyavati River Rejuvenation Project to clean the heavily-polluted Dravyavati River, once known as Amanishah Nallah. The river starts from the Nahargarh hills and passes through Jaipur before merging with the Dhund River. Rapid development and lack of sanitation facilities caused the river to slowly turn into a sewage carrying drain. To combat this situation, the rejuvenation project was taken up by Jaipur Development Authority (JDA) in 2016 under Public-Private Partnership (PPP) format. The principal implementing agency were Tata Projects Limited and Shanghai Urban Construction Group.

The project spread over a 47.5 km section of the river with an anticipated investment of close to ₹1,676 crore. The intervention was not merely a river clean-up exercise but a confluence of sanitation infrastructure, flood management, ecological restoration and public space development under a coherent urban planning framework (Kaushik et al., 2026).

Core Problem

The biggest problem linked with Dravyavati River was continual flow of untreated sewage and municipal trash into the river. The fast expansion in population, illegal settlements, industrial effluent and insufficient drainage systems have led to serious

degradation of the river ecology over the years. The river ceased to be a natural water body and started behaving like an open sewer carrying domestic wastewater, industrial effluents and solid garbage (Randhawa & Tarush, 2017).

The worsening state of the river gave rise to various environmental and urban problems. Water contamination polluted neighboring groundwater sources and created bad odor and terrible living conditions in the surrounding villages. Encroachment along the river banks had diminished the natural carrying capacity of the river and had increased the possibility of urban floods during monsoon periods. In several portions, the river had almost lost its biological character and had become a symbol of inadequacies in urban sanitation and drainage management (Sharma & Gupta, 2021).

Strategy / Intervention

The project utilized an integrated river-sensitive urban management approach by combining sanitation, engineering, ecological, and landscape initiatives. One of the most important procedures was the interception and diversion of sewage flowing into the river through several drains. To assure treatment of wastewater before discharge into the river system, several Sewage Treatment Plants (STPs) with a combined treatment capacity of roughly 170 MLD were set up/upgraded. The treated wastewater was also reused for maintaining the flow of the river, which was a crucial aspect under the semi-arid climatic conditions of Jaipur (Singh et al., 2023).

The project also involved extensive flood management measures, including enlarging and desilting the river channel, constructing retaining walls and embankments and developing hydraulic structures to increase stormwater flow. These modifications were intended at restoring the carrying capacity of the river and reducing the flood vulnerability of nearby urban areas (Sharma & Gupta, 2021).

Ecological restoration was another key component of the project. Plantation drives, biodiversity parks, landscaped green areas, bicycle tracks, walkways and recreational spaces were constructed along the river corridor. Unlike typical beautifying initiatives, the Dravyavati River project tried to combine sanitation infrastructure with ecological restoration and urban livability (Randhawa & Tarush, 2017).

Planning Relevance

Dravyavati River Rejuvenation Project is particularly relevant from the view point of urban planning and river sensitive sanitation. The project highlights the tight connection between the pollution of urban waterways and failures in sewerage infrastructure, land-use control, drainage systems and environmental governance. The project combines waste water treatment, flood prevention, ecological restoration and creation of public space and is in accordance with concepts of Integrated Water Resource Management (IWRM) and sustainable urban planning (Singh et al., 2023).

The project also illustrates the importance of multi-agency collaboration and PPP-based governance for the implementation of large-scale urban environmental initiatives. Simultaneously, it shows issues on long term sustainability and maintenance. Reports suggest that untreated sewage continues to flow into some portions of the river due to illegal sewer connections and operational failures. Excessive concreting and artificial modification of the river channel have also been challenged by researchers, who argue that ecological sustainability may be compromised if river restoration becomes too infrastructure-oriented (Sharma & Gupta, 2021).

The project is an excellent example of integrated urban river restoration and also a reminder that sustainable river management is an ongoing process of governance, ecological sensitivity and efficient operation of sanitation infrastructure.

The Dravyavati River Rejuvenation Project is an excellent example of how urban river restoration is strongly related with sanitation planning and waste water management for the present study on river sensitive urban sanitation. The project clearly shows that the rejuvenation of the river cannot be done by attractiveness alone unless it is backed by appropriate measures of sewage interception, wastewater treatment, flood management and ecological restoration.

The case study also points to the significance of combining sewage infrastructure development with environmental planning and governance processes. Results imply that successful river restoration requires not only physical infrastructural construction but also long-term maintenance, institutional coordination, ecological balance, and community-oriented planning approaches. Thus, the Dravyavati River project is a noteworthy Indian example of integrated urban sanitation planning that is attentive to rivers.

Sabarmati Riverfront Development Project, Ahmedabad, Gujarat

Sabarmati riverside Development Project in Ahmedabad is one of the largest urban riverside redevelopment projects in India. The Sabarmati River runs through Ahmedabad and has been an essential factor in the social, cultural and economic development of the city. However, with increased urbanisation, discharge of untreated sewage, encroachments and seasonal variations in water flow, the river progressively became a dirty and under-utilised urban environment.

To mitigate these problems, the Sabarmati Riverfront Development Corporation Limited (SRFDCL), a special purpose vehicle created by the Ahmedabad Municipal Corporation (AMC), started the riverfront development project in the late 1990s and major implementation started after 2003. The project encompassed around 11.5 km on both sides of the river in the city region and incorporated large-scale river channeling, embankment construction, public space development, and sanitation infrastructure enhancement. The project was anticipated to cost approximately ₹1,200 crore and would be funded by a combination of public investment and land-value capture (Desai, 2012).

The project sought to turn the damaged river corridor into a planned urban waterfront, addressing flood management, sewage interception, environmental enhancement and urban infrastructure development.

Core Problem

The Sabarmati River in Ahmedabad before re-development was facing serious environmental and urban management issues. The river received huge volumes of untreated home sewage and industrial effluents straight through several drains resulting in substantial water pollution and ecological damage. In the non-monsoon periods, the river typically dried up due to the low natural flow, while in the periods of heavy rainfall, it posed the risk of flooding to the adjacent villages (Mahadevia, 2011).

The riverbanks were highly encroached by informal communities lacking basic sanitation and drainage systems. The communities helped in additional contamination through open defecation, dumping of solid waste and direct discharge of wastewater into the river. Besides, the riverfront regions were mostly inaccessible and unused even though they are located in the center of Ahmedabad city. The Sabarmati River's pollution, therefore, was

a coalesced failure of urban sanitation systems, floodplain management, environmental governance and equitable urban planning (Desai, 2012).

Strategy / Intervention

The Sabarmati Riverfront Development Project utilized an integrated approach to urban regeneration by combining river management, sanitary infrastructure, flood protection, and public space development. One of the primary interventions was the construction of continuous retaining walls and embankments on both banks of the river. These engineering solutions restricted and stabilized the river channel, and reclaimed huge tracts of land for urban development and public usage (Mahadevia, 2011).

A major sanitation solution includes interception and diversion of sewage flows entering the river through existing drains. New sewer pipes and pumping infrastructure were installed to reroute effluent to sewage treatment facilities rather than allowing for direct discharge into the river. This considerably eliminated visible sewage pollution throughout the urban portion of the Sabarmati River (Desai, 2012).

The project includes significant urban design and landscape interventions as well, such as promenades, parks, gardens, walkways, bike tracks, public plazas and leisure areas. Roads and municipal infrastructure were created along the riverfront to provide accessibility and boost economic development. Moreover, the Vasna Barrage and controlled water flow from the Narmada Canal system helped retain water in the river channel, assuring its availability throughout the year (Mahadevia, 2011).

The project also entailed the rehabilitation and relocation of thousands of slum inhabitants on the banks of the river. Resettlement housing was given but this aspect of the project remains one of the most disputed because of concerns about displacement and social equality.

Planning Relevance

The Sabarmati riverside Development Project assumes great significance in the context of urban planning, riverside rehabilitation and sanitation-linked environmental management. The project illustrated how riverfront rehabilitation can be a driver for urban transformation by integrating environmental improvement, flood management, public infrastructure and economic development under a single planning framework.

From the sanitation perspective, the project demonstrated the significance of sewage interception and drainage management in enhancing urban river conditions. The reduction in direct wastewater discharge to the river demonstrated the key function of sanitary infrastructure in river restoration. The project also showed new urban financing strategies, including the utilization of reclaimed riverside land for commercial development to partially finance project implementation (Desai, 2012).

But the proposal has also been criticized by planners, environmentalists and social scientists. Excessive concretization and channelization, scholars contend, changed the natural ecology and hydrology of the river. Critics also observe that the water levels were maintained by diverting water from the Narmada Canal outside, so creating an artificial waterfront environment, rather than restoring the river's natural flow system (Mahadevia, 2011).

Another key worry is the displacement of informal settlements on the riverbanks. Although rehabilitation housing was given, research show that relocation often disrupted livelihoods, accessibility and social networks of displaced communities. The Sabarmati project, therefore, brings to the fore both possibilities as well as constraints of large-scale urban riverfront redevelopment initiatives.

The Sabarmati Riverfront Development Project shows how important river restoration and urban sanitation facilities are to each other. The experiment reveals that limiting sewage discharge and strengthening drainage systems are key precondition to improve river health in rapidly urbanizing towns.

Meanwhile, the project highlights that riverside development should not just be limited to visual improvement but also incorporate ecological sustainability, social inclusivity and long-term environmental management. The Sabarmati project has been successful in changing the urban face of Ahmedabad and improving sanitation infrastructure along the river corridor. But it also shows issues of ecological modification, artificial river maintenance, and displacement of vulnerable groups.

The Sabarmati Riverfront Project is a key example of integrated urban river redevelopment that also provides essential lessons in sustainability, governance and socially inclusive river sensitive planning approaches.

Kham River Restoration Initiative, Chhatrapati Sambhajinagar, Maharashtra

The Kham River, a seasonal tributary of Godavari River had gradually been changed into a filthy urban drain due to untreated sewage, industrial discharge and continual dumping of municipal solid waste.

The project was taken by the Chhatrapati Sambhajinagar Municipal Corporation, Aurangabad Cantonment Board, EcoSattva, industries, organizations including the Varroc Foundation and local community groups. The project was designed to address the core causes of river deterioration through sanitation and ecological planning (EcoSattva, 2022) as opposed to numerous riverfront initiatives that focused primarily on appearance.

Core Problems Before Intervention

Before rehabilitation, huge parts of the Kham River were acting as an open drain due to dumping of solid waste, debris, untreated sewage and industrial effluents in an unregulated manner. Some “garbage vulnerable points” were formed along river banks and garbage was piling up constantly.

Studies on water quality have indicated that anthropogenic contamination and untreated discharge of wastewater caused a significant deterioration of physico-chemical parameters (Shaikh & Ali, 2020). Siltation, encroachment, loss of riparian vegetation and modification of the channel diminished the ecological functions of the river, increasing the risk of flooding during monsoon seasons.

The deteriorated river ecology also impacted the surrounding people through unpleasant odour, mosquito breeding, unsafe access and deteriorating environmental quality.

Planning and Implementation Approach

The initiative was social-ecological and systems-based for river rehabilitation. Through a six-month-long diagnostic investigation including orthophoto mapping and field assessments, the sewage inlets, waste hotspots and environmental stress sites were discovered along the river corridor (EcoSattva, 2022).

The project was not about cosmetic cleaning but about upstream and preventive interventions, such as:

- enhancing solid waste management,
- campaigns to raise awareness,

Local and regional efforts for the treatment of wastewater.

Physical repair involved:

- Mechanical cleanup of about 15 kms of river and nala segments,
- legacy waste clearance and desiltation,

Stabilization and stabilization of about 5 km of riverbanks through pitching and embankment protection operations.

Nearly 54 acres of riparian land were recovered through planting and habitat improvement efforts.

Sanitation and Waste Management Measures

The project directly linked sanitation systems with the improvement of river health.

- garbage Collection Integration: Formal municipal garbage collection services were extended to cover over 25,000 houses, thereby cutting down direct dumping into the river corridor.
- Garbage susceptible locations: 44 to 110 garbage susceptible locations were discovered and removed through infrastructure development, waste-management planning and enforcement methods.
- Sewage management: Settlements along the river were gradually tied into sewage networks, diverting wastewater to treatment plants instead of letting it flow directly into the river.
- Physical Barriers and Traps: Garbage traps, floating barriers and bridge barricades have been erected to intercept floating debris and to prohibit direct dumping into the river channel.

These projects show that restoring rivers is possible through sewer connection, waste logistics management and urban planning strategies.

Governance and Community Participation

Community and institutional involvement was a key aspect of the effort. Approximately 600 sanitation workers participated in coordinated municipal restoration activities and almost 100 people were trained for sanitation and upstream restoration activities.

Public participation was promoted through awareness campaigns, waterfront events and cultural activities with local artists and locals. According to reports, about one million people were involved in activities related to the restoration program (WRI India, 2023).

The project thus illustrates the significance of collaborative governance involving municipal agencies, cantonment boards, NGOs, private organizations, industries and local communities.

Ecological Restoration and River Health Outcomes

Restoration efforts concentrated on improving ecological conditions along the river corridor. The 54-acre riparian zone was cleaned and regenerated biologically using plantation drives and habitat improvement strategies.

Local reports suggested slow recovery in aquatic biodiversity, such as increased diversity of phytoplankton and zooplankton after restoration measures (WRI India, 2023). It is also stated that river cleaning, desiltation and bank stabilization techniques resulted in better stormwater flow and less flood susceptibility during the recent monsoon periods.

Urban Planning and Governance Significance

The Kham River effort is essential in demonstrating how river restoration may be combined with sanitary infrastructure, solid waste management, ecological restoration and community participation.

The project's one of the key achievements is that the Kham River became one of the first seasonal urban rivers in India to acquire an Urban River Management Plan (URMP) under the River Cities Alliance framework. This implies that river-sensitive planning approaches can be used to smaller, seasonal urban rivers, and not just to huge perennial rivers (WRI India, 2023).

The project is also an example of basin scale and systems based design, by understanding the link between sanitary infrastructure, drainage systems, waste management, ecology and urban administration.

Key figures in figures

- Better river conditions for about 1.3 million residents.
- Restored approximately 54 acres of riparian area.
- Almost 25,000 residences are now connected to upgraded rubbish collection systems.
- About 600 sanitation workers were involved in restoration works.
- Removed around 44-110 trash susceptible locations.
- Almost 15 km of river and nala lengths cleaned and about 5 km of banks stabilized.

Sanitation-led river restoration in mid-sized Indian cities: The Kham River Restoration Initiative A case of a good practice

The investigation reveals that without tackling problems in solid waste management, sewage systems and urban administration, river health cannot be improved. It also points to the necessity of integrated planning approaches to sustainable river restoration that include sanitation infrastructure, ecological restoration, flood resilience, and community participation, instead of interventions focused primarily on beautification.

Most significantly, the effort shows that Urban River Management Plans and river sensitive planning frameworks can be successfully applied to smaller and seasonal urban rivers across India.Quantitative Highlights

Musi River Restoration Proposals, Hyderabad, Telangana

Historically, the river played an important part in the formation and development of Hyderabad metropolis. However, increased urbanization, population growth, industrialization and poor sanitation infrastructure slowly turned the Musi into a seriously polluted urban river. (CPCB, 2021).

With the passage of time the river environment was badly degraded by untreated sewage, industrial effluents, encroachments and dumping of solid waste. Many sections of the Musi today look like sewer channels, not river systems. The Government of Telangana and some planning authorities have proposed a number of Musi River Restoration and Riverfront Development programs, to improve water quality, restore ecological conditions, manage floods and revitalize the river corridor. (HMDA, 2022.

Core Problems Before Intervention

The biggest problem faced by the Musi River has been the continual inflow of untreated and poorly treated sewage from Hyderabad metropolis. The fast growth of the city has not been matched by the sewage infrastructure and treatment capacity, resulting in a significant percentage of the city's wastewater entering the river through several nalas and drainage channels (Central Pollution Control Board [CPCB], 2021).

Industrial pollution has aggravated the situation in the rivers. Effluents from pharmaceutical industries, manufacturing units and commercial activity released chemical pollutants and heavy metals into the river system. Repeated water-quality investigations found high biological oxygen demand (BOD), low dissolved oxygen levels, and significant pollution in downstream parts of the river (Reddy & Kumar, 2019).

Development of the riverbanks had diminished the natural floodplain and impeded the flow of water, increasing the likelihood of flooding during high rainfall events. Furthermore, large volumes of municipal solid waste and construction debris were also dumped into the river and nearby drains which resulted in siltation and ecological degradation(TSPCB, 2021).

The bad condition of the river damaged the health of the communities living nearby due to bad smell, proliferation of mosquitoes, polluting of ground water, unsafe environmental conditions and decreasing public health. The aquatic biodiversity in the river also reduced dramatically due to pollution and habitat degradation (Reddy & Kumar, 2019).

Restoration Strategy and Proposed Interventions

The restoration solutions for the Musi River employed a multi-sectoral approach that integrated sewage infrastructure, riverside planning, ecological restoration and urban

redevelopment. The Improvement of sewerage infrastructure and increasing the sewage treatment capacity across Hyderabad city was one of the primary intervention measures (HMDA, 2022).

The recommended interventions were:

- intercept and divert wastewater entering the river,
- up-gradation and extension of Sewage Treatment Plants (STPs),
- strengthening of drainage systems and nalas,
- and improved sewer connections in under-served communities.

The ideas stressed that river rehabilitation would be impossible without regulating sewage flow at source. Some programmes such as the Strategic Nala Development Programme (SNDP) and Musi Riverfront Development have concentrated on upgrading wastewater diversion and stormwater management systems (HMDA, 2022).

The planning framework also provided for riverfront redevelopment and ecological restoration. Suggested therapies were:

- stabilization of riverbanks,
- establishment of green buffers,
- public parks and recreation space,
- pedestrian and cycle infrastructure,
- and removal of encroachment in flood prone areas.

Some of the concepts also included reuse of wastewater and decentralized treatment facilities to reduce contamination to the river. Hyderabad has been experiencing urban flooding repeatedly due to encroachments and obstructed drainage channels and the focus was on flood-resilient infrastructure.

Sanitation and Waste Management Relevance

The Musi River scenario is a good example of the interlinkages between urban sanitation systems and river health . The deterioration of the river is directly related to:

- poor sewerage infrastructure,
- lack of wastewater treatment capacity,

- poor solid waste management methods;
- Fast uncontrolled urban growth.

The restoration approaches recognise that enhancing river quality requires:

- extension of the sewerage network,
- pretreatment of wastewater before to discharge,
- better drainage planning,
- Prevention of dumping of solid trash in nalas and river corridors.

The project consequently embodies the concept that urban rivers cannot be restored via appearance alone, and that sanitation infrastructure is the basis for river restoration.

Planning and Governance Significance

The Musi River restoration projects are important because they aim to integrate sanitary planning, flood management, ecological restoration and urban redevelopment within a metropolitan planning framework.

This project underlines the intricacy of restoring rivers in fast developing cities where:

- informal settlements are located on floodplains,
- sewage networks are incomplete,
- industrial pollution persists,
- and overlapping jurisdiction of several authorities.

For execution, institutional cooperation is required between agencies like Hyderabad Metropolitan Development Authority (HMDA), Greater Hyderabad Municipal Corporation (GHMC), irrigation departments, pollution-control authorities and sewage boards.

At the same time, the Musi River instance is also illustrative of the complexities of large-scale riverside revitalization. There are concerns about displacement of vulnerable groups, ecological repercussions of excessive concretization, and the risk of real-estate development taking precedence over ecological restoration (Reddy and Kumar, 2019).

So the Musi River gives both:

- an example of planning for river restoration related to sanitation,
- and a critical case study illustrating governance and sustainability problems in urban river revitalization.

The Musi River restoration solutions suggest that the degradation of urban waterways is essentially related to the failure of sanitation infrastructure and wastewater treatment systems. The instance shows the need for integration of sewage planning, drainage systems, flood management, ecological restoration and governance mechanisms in urban river restoration projects.

The Musi River is also a case study of the need to balance infrastructure-led redevelopment with ecological sustainability and social inclusion. The initiative thus offers crucial lessons for the development of integrated planning frameworks for fast urbanizing river-side communities experiencing severe sanitary and environmental demands.

International Case Studies

Cheonggyecheon Stream Restoration Project, Seoul, South Korea

The Cheonggyecheon was a natural creek that ran through the centre of Seoul, but industrialization and urbanization following the Korean War resulted in serious pollution and deterioration of the stream. The stream was covered with concrete by the mid-20th century and an elevated highway was built over it as part of the urban infrastructure expansion (Cho, 2010).

The Seoul Metropolitan Government in 2003 began a large restoration project to uncover and restore the stream as part of a broader agenda of ecological recovery, urban regeneration and environmental improvement.

Core Problems Before Intervention

Before the restoration, the Cheonggyecheon area was suffering from serious environmental degradation, including traffic congestion, pollution, poor air quality and loss of natural ecological systems. The creek itself had been covered over with concrete infrastructure and used largely as an underground drainage route.

Rapid urbanization and poor environmental planning had led to:

- a decline in the quality of the urban environment,
- enhanced urban heat island impacts,
- reduction of biodiversity,
- inadequate public areas in central Seoul (Lee & Anderson, 2013).

It was a time of road infrastructure supremacy and the breakdown of ecological design, which separated inhabitants from natural water systems and limited the city's environmental resilience.

Restoration Strategy and Interventions

The restoration project involved demolition of the elevated highway and removal of concrete structures covering the stream. The natural water corridor was re-established through ecological restoration, riverbank landscaping, and development of pedestrian-friendly public spaces (Cho, 2010).

Key interventions included:

- restoration of the stream channel,
- development of green corridors and riparian vegetation,
- pedestrian walkways and pedestrian bridges,
- Water management infrastructure,
- and enhancement of water circulation system.

Water from adjacent river systems and treated sources was supplemented to sustain continuous flow in the stream. The synergy between urban design and ecological planning was used to enhance the environmental quality and public accessibility.

The project also entailed extensive transport-planning reforms, including enhancements in public transportation to compensate for lost road capacity as a result of highway elimination.

Planning and Governance Significance

The Cheonggyecheon project is important because it shows how ecological restoration can be a core part of urban design and revitalization. The project brought together:

- environmental restoration,
- creation of public spaces;
- control of flooding,
- mobility planning;
- urban design responding to climate.

The initiative also boosted biodiversity, lowered the surrounding temperature and improved the air quality. Socially, the restored stream became a key public and recreational place in Seoul (Lee & Anderson 2013).

The project further demonstrated the significance of political leadership, public participation and integrated governance to the implementation of large scale urban environmental projects.

An example of this is the Cheonggyecheon Stream Restoration Project, which suggests that urban rivers and streams should be treated as not simply drainage infrastructure but also ecological and public assets. The project demonstrates the contribution of ecological restoration, green infrastructure and sustainable urban design to environmental quality and urban resilience.

The topic is especially useful for understanding how river restoration can help with climate sensitive planning, biodiversity enhancement and increased urban livability. It also shows the importance of linking transportation and public-space policy with environmental planning in dense metropolitan settings.

Singapore River Cleanup Programme, Singapore

In the 1960s and 1970s, the Singapore River and the adjacent Kallang Basin were grossly polluted due to the direct discharge of raw sewage, industrial waste, livestock agricultural activities and dumping of solid debris. Moreover, contamination in the river system was aggravated by rapid urbanization and dense population patterns (Tortajada & Joshi, 2013).

As the state of the river worsened, the Government of Singapore, led by Prime Minister Lee Kuan Yew, initiated a massive cleanup programme in 1977. The programme lasted for close to a decade and was targeted at integrating sanitation infrastructure, pollution

control, resettlement planning, drainage enhancement and riverside reconstruction in a holistic urban management framework (PUB Singapore, 2021).

Core Problems Before Intervention

Before restoration, the Singapore River was heavily polluted with untreated sewage and rubbish dumped directly into the river. The wastewater and solid waste from informal settlements, street hawkers, boatyards, animal farms and small industries along the banks of the river were directly released into the river system (Tortajada & Joshi, 2013).

Lack of efficient sewerage infrastructure and weak waste-management systems led to foul odour, low water quality, and deteriorating ecological conditions. Polluted river water also led to serious public-health problems and degraded the environmental quality of core metropolitan districts.

Siltation, garbage accumulation and unregulated development along the riverbanks led to further deterioration of the river environment and reduction of its social and recreational value.

Restoration Strategy and Interventions

The Singapore River Cleanup Programme took a long term and carefully coordinated planning strategy. One of the most significant interventions was the extension of the sewerage system and the redirection of effluent away from the river. Polluting activities and informal settlements along the river banks were shifted to planned housing and industrial zones connected to proper sanitation systems (PUB Singapore, 2021).

The programme also featured:

- building and extension of sewerage systems,
- Moving street hawkers and livestock farms,
- improved drainage systems,
- Desilting and dredging of the river,
- And stringent pollution-control measures.

Solid waste management procedures were upgraded to avoid dumping into the river and adjacent drains. Later, the reconstruction of the riverbank and enhancements to the public

space were introduced to bring people back into contact with the restored environment of the river.

Short-term beautifying initiatives were undertaken but the Singapore model first addressed sanitation and pollution avoidance before moving on to riverside rehabilitation.

Planning and Governance Significance

The Singapore River Cleanup Programme is of great significance as it indicates that urban river restoration is rooted in sanitary infrastructure and institutional cooperation. The plan was about collaborating across several government departments on sewage, housing, drainage, transport, waste management and environmental control (Tortajada & Joshi, 2013).

The project also shows the necessity of long term planning and good governance in river restoration. Strict environmental rules, efficient implementation methods and coordinated infrastructure investments made the initiative a success.

Ecological restoration led to significant increases of the river's water quality and biodiversity. The rebuilt riverfront thereafter became an important recreational, cultural and tourism space within Singapore city from a social perspective.

In the case of the Singapore river, sanitation has to be the first step in the planning for sustainable river restoration. The investigation found that untreated sewage, poor waste management systems and unchecked urban expansion are major causes for river degradation.

The case also demonstrates how integrated planning that includes sewage systems, resettlement policy, waste management, drainage infrastructure, and environmental governance can successfully rehabilitate urban river ecosystems. As such, it is an important international example of sanitation-led river-restoration for fast urbanizing riverside cities.

Chapter 3

Indicators of Urban sanitation and River health.

3.1 Indicators of Urban Sanitation & Solid Waste Management

1. Coverage of Toilets

This indicator evaluates universal access to sanitation facilities. It includes:

- household toilets,
- community toilets,
- and public toilets.

A city achieving 100% coverage is considered Open Defecation Free (ODF). This indicator is of critical importance for public health, dignity and protection of the environment.

Significance for River Health

The absence of bathrooms forces people to defecate in the open along drains and riverbanks, contaminating rivers directly with faecal matter and germs.

2. Coverage of Sewerage Network

This measures how much of the city is connected to underground sewer systems. Areas not connected generally depend on septic tanks or discharge wastewater into open drains.

Importance to River Health

- Low coverage of sewerage leads to:
- untreated discharge of wastewater into rivers, groundwater pollution,
- and urban environmental degradation.

3. Collection Efficiency of Wastewater

Even where sewerage networks exist, not all wastewater reaches treatment plants due to:

- leakages,
- illegal connections,
- damaged pipelines,
- or incomplete networks.

This indicator measures the real efficiency of the waste water collection systems.

Importance for River Health

Poor collection efficiency leads in sewage spills into storm drains and waterways.

4. Adequacy of Treatment Capacity

This assesses whether sewage treatment plants (STPs) can handle the quantity of sewage generated.

Formula

$$Treatment\ Capacity\ Adequacy = \frac{Installed\ STP\ Capacity}{Wastewater\ Generated} \times 100$$

Importance for River Health

Limited capacity of STP results in untreated sewage flowing into rivers.

5. Quality of Treatment

This indicator measures whether treated wastewater meets environmental standards prescribed by CPCB and pollution control authorities.

Important parameters include:

- BOD (Biological Oxygen Demand),
- COD (Chemical Oxygen Demand),
- TSS (Total Suspended Solids),
- Faecal Coliform.

Importance for River Health

Even treated wastewater can harm rivers if the quality of treatment is poor.

6. Extent of Reuse/Recycling

This evaluates sustainable wastewater management practices by measuring reuse of treated wastewater.

Common reuse applications:

- landscaping,
- irrigation,
- industrial cooling,
- construction,
- flushing.

Importance for River Health

- Reuse of wastewater
- minimizes freshwater withdrawal
- reduces river pollutant burdens
- and promotes circular water economy.

7. Efficiency in Redressal of Complaints

This governance indicator measures municipal responsiveness toward:

- sewer overflows,
- blocked drains,
- public toilet maintenance,
- sanitation grievances.

Importance for River Health

Delay in redressal typically results in long-drawn sewage leakage and damage to the environment.

8. O&M Cost Recovery

Sanitation systems require continuous operation and maintenance (O&M) expenditure for:

- sewer cleaning,
- electricity,
- manpower,
- chemical treatment,
- sludge management.

This indicator assesses financial sustainability.

Importance for River Health

Poor financial recovery results in:

- non-functional STPs,
- insufficient maintenance,
- decay of infrastructure, and
- discharge of untreated sewage into rivers.

9. Household Dependent on Septic Tanks

This indicator assesses the extent to which households rely on onsite sanitation systems rather than centralized sewerage networks.

In many Indian cities, especially:

- medium-sized towns,
- peri-urban settlements,
- and river-side cities,

septic tanks are the dominant sanitation system due to limited sewerage infrastructure.

Importance

This indicator helps determine:

- the need for FSM infrastructure,
- desludging services,
- treatment facilities,
- and environmental risk.

Relevance to River Health

- Often wrong septic tanks
- leach into the ground water,
- flow into drains, or
- run directly into rivers.

In cities like Narmadapuram, located on the banks of rivers, a strong reliance on septic tanks without scientific FSM can have a huge impact on the river environment.

Benchmark

There is no general "ideal percentage" because dependency varies by type of city. But:

- sewered cities → less reliance desirable,
- non-sewered towns → robust FSM systems needed.

10. Desludging Frequency

This measures how frequently septic tanks are emptied to maintain proper functioning.

According to the National FSSM Policy and CPHEEO guidelines:

- septic tanks should ideally be desludged every 3 years.

Why is it important?

Reasons for irregular desludging:

- overflow,
- blockage,
- groundwater contamination,
- septic leakage and
- direct discharge into drains or waterways..

Relevance to River Health

In settlements along the side of rivers, poorly maintained septic tanks often overflow and seep:

- stormwater runoff,
- open watercourses, and
- rivers

The National Faecal Sludge and Septage Management (FSSM) Policy and CPHEEO guidelines recommend that septic tanks should preferably be desludged at regular intervals of once every three years to ensure their efficient operation, prevent overflow and limit environmental damage.

11. Safe Collection & Transport

This indicator evaluates whether faecal sludge is:

- collected mechanically,
- transported safely,
- and handled through authorized operators.

It measures the percentage of sludge managed without:

- manual scavenging,
- illegal dumping,
- or environmental contamination.

Importance

Unsafe collection tactics may:

- expose workers to infections,
- pollute soils and water bodies
- and pose serious public-health hazards.

Relevance to River Health

Illegal dumping of septage into:

- drains,
- vacant land,
- or riverbanks is a major source of river pollution in Indian towns.

All i.e. 100% faecal sludge must be collected and delivered by safe, mechanized and authorized means without any leakage, manual handling or unlawful disposal.

12. Treatment of Septage

This indicator measures the percentage of collected faecal sludge scientifically treated at:

- Faecal Sludge Treatment Plants (FSTPs),
- Sewage Treatment Plants (STPs),
- or co-treatment facilities.

Importance

This treatment removes:

- pathogens,
- organic pollutants,
- nutrients
- and toxic substances.

Relevance to River Health

Discharge of untreated septage into rivers causes:

- high BOD,
- faecal coliform pollution,
- eutrophication
- and ecological deterioration.

As per National Faecal Sludge and Septage Management (FSSM) Policy and CPHEEO sanitation guidelines, all the collected septage should be scientifically treated at authorized treatment facilities like Faecal Sludge Treatment Plants (FSTPs) or Sewage Treatment Plants (STPs) before disposal or reuse so as to prevent environmental contamination and protect public health.

13. Disposal Compliance

This indicator evaluates whether treated sludge and liquid waste are:

- disposed safely,
- reused sustainably,
- and compliant with environmental regulations.

Compliance is assessed according to:

- CPCB standards,
- pollution-control norms,
- and environmental safety guidelines.

Importance

Improper disposal can reintroduce pollution into the:

- groundwater,
- rivers,
- agricultural land
- and urban ecosystems

Relevance to River Health

In river-side cities, safe disposal is necessary where untreated or partially treated sludge ends up in river systems by runoff or direct discharge.

The National Faecal Sludge and Septage Management (FSSM) Policy and the CPCB environmental norms specify that treated faecal sludge and wastewater should be disposed of or reused only as per the prescribed environmental standards to prevent contamination of rivers, groundwater, soil and the surrounding ecosystems.

3.2 Indicators of River Health

River health assessment is commonly carried out using physio-chemical and microbial water quality indicators that reflect the impact of urban sanitation systems, wastewater discharge, and anthropogenic activities on river ecosystems. Parameters such as Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), and Dissolved Oxygen (DO) are widely used to evaluate organic pollution, oxygen depletion, and ecological condition of rivers (CPCB, 2021; NMCG, 2020). Nutrient indicators including nitrate, ammoniacal nitrogen, and phosphate help assess eutrophication risks caused by sewage discharge and urban runoff. Similarly, Total Suspended Solids (TSS) and turbidity indicate sediment load and water clarity conditions affecting aquatic habitats. Microbial indicators such as Faecal Coliform (FC) and Total Coliform (TC) are

extensively used to identify sewage contamination and public health risks in urban rivers (WHO, 2017). These parameters have been widely applied in studies related to river pollution, urban sanitation, and river health assessment in Indian river systems, including the Ganga and Narmada river basins, to establish the relationship between urban wastewater management and river ecosystem degradation. The selected river health indicators and their acceptable limits considered for the present study are summarized in Table 1.

Table 2 Indicators for River Health

Category	Parameter	Definition and Importance	Acceptable Limit
Physio-Chemical Indicators	BOD (Biochemical Oxygen Demand)	Measures the amount of oxygen required by microorganisms to decompose organic matter in water. It indicates the level of organic pollution and sewage contamination.	≤ 30 mg/L
	COD (Chemical Oxygen Demand)	Represents the amount of oxygen required to chemically oxidize pollutants present in water. It helps assess the overall pollution load in wastewater.	≤ 250 mg/L
	DO (Dissolved Oxygen)	Refers to the amount of dissolved oxygen available in water for aquatic organisms. Low DO indicates polluted and poor-quality water conditions.	≥ 5 mg/L
	Ammoniacal Nitrogen / Nitrate	Nitrogen compounds originating from sewage, fertilizers, and organic waste. Excess concentration may lead to eutrophication and health hazards.	Nitrate ≤ 45 mg/L
	Phosphate	A nutrient entering water through detergents, sewage, and runoff. High phosphate concentration promotes algal growth and eutrophication.	< 0.1 mg/L
	Suspended Solids (TSS)	Fine particles of silt, organic matter, and waste suspended in water. High TSS reduces water clarity and affects aquatic ecosystems.	≤ 100 mg/L
	Turbidity	Indicates the cloudiness of water caused by suspended particles. It affects water quality and treatment efficiency.	1–5 NTU

Category	Parameter	Definition and Importance	Acceptable Limit
Microbial and Pathogen Indicators	Faecal Coliform (FC)	Indicates contamination from human or animal fecal matter and possible presence of disease-causing pathogens.	0 MPN/100 mL
	Total Coliform (TC)	Serves as an indicator of overall microbial contamination and sanitary quality of water.	0 MPN/100 mL

Chapter 4

Understanding the linkages between indicators of urban sanitation, Community health and river health.

Urban ecological systems are interconnected through urban sanitation systems, Solid Waste Management (SWM), Faecal Sludge Management (FSM) and river health. In river-side cities like Narmadapuram, sanitary infrastructure, wastewater management, septage handling and waste disposal practices directly affect the physical, chemical, biological and ecological aspects of River Narmada. Thus, the selected indicators for the current study are not independent measures of performance, but interconnected environmental variables that together dictate the health and sustainability of the urban-river system.

Studies on urban river systems have invariably found that the lack of appropriate sanitation infrastructure is a key factor in river pollution, such as direct discharge of untreated wastewater, sewage overflow, faecal contamination, nutrient enrichment and solid waste accumulation in river corridors (CPCB, 2021; NMCG, 2020). Thus, parameters like BOD, COD, DO, Total Coliform and Faecal Coliform are considered as significant indicators to examine the ecological impacts of urban sanitation systems on river environment.

Urban Sanitation and Organic Pollution Linkages

Direct implications for the organic pollution load entering river systems are associated with indicators such as toilet coverage, sewerage network coverage, efficiency of collection of wastewater and treatment capacity. Inadequate sewerage infrastructure and inefficient collection of wastewater often leads to the discharge of untreated sewage into open drains and natural water channels. This leads to an increase in the concentration of organic materials in river water which causes a rise in Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) levels.

A high BOD means that microbes are breaking down a lot of organic waste, using up the dissolved oxygen that fish and other animals in the water need to survive. High COD, at the same time, indicates rise in chemical and industrial pollution loads in the river system. The rise in organic pollution decreases the Dissolved Oxygen (DO) levels resulting in

ecological stress, loss of biodiversity and degradation of river self-purification capacity (Singh et al., 2004).

The shortcomings in urban sanitation might therefore be directly attributed to the declining quality of the river water and to the destruction of the ecology.

Wastewater Treatment and River Ecosystem Health

The appropriateness and efficiency of Sewage Treatment Plants (STPs) is a determining factor for the level of removal of waste water pollutants before discharge into rivers. Treatment capacity is inadequate or treatment infrastructure is not functional leading to release of partially treated or untreated sewage into River Narmada. Such discharges result in:

- increased nutritional loading,
- microbiological contamination;
- eutrophication;
- sediment deposition,
- Degraded health of the aquatic ecosystem.

Nutrients like nitrate, ammoniacal nitrogen and phosphate entering rivers from sewage and urban runoff cause excessive algal growth and eutrophication. This also leads to a further reduction of DO concentration and breakdown of aquatic biological balance (UNEP, 2016).

Thus, measures of river health are environmental representations of the efficacy of urban wastewater management.

Faecal Sludge Management and Microbial Contamination

Septic tanks and onsite sanitation are the principal sanitation technologies in medium-sized Indian cities with limited sewerage penetration. However, the absence of scientific Faecal Sludge Management (FSM) solutions results in hazardous confinement, irregular desludging, illegal dumping and direct discharge of faecal sludge into drains and riverbanks.

Poorly maintained septic tanks are a major contributor to:

- Faecal Coliform (FC)
- Total Coliforms (TC)
- contamination with pathogens,
- groundwater contamination,
- and threats to public health.

A substantial link has been established between weak septage management systems, sanitation governance and faecal pollution in the studies of Indian riverine communities (WHO, 2017). In towns close to rivers, overflow from septic tanks often enters rivers through stormwater drains and open channels, causing increased microbial pollution in river ecosystems.

Hence, indices of desludging frequency, safe collection and transport, septage treatment and disposal compliance are closely connected to river microbiological water quality indicators.

Solid Waste Management and River Degradation

The Solid Waste Management parameters such as collection efficiency, segregation, transportation, scientific processing and disposal compliance are highly related to the river health conditions. The improper disposal of municipal solid waste in drains, floodplains and riverbanks leads to:

- pinching of drainage paths,
- leaching,
- sediment deposition,
- contamination of surface run off,
- environmental degradation.

Unscientific waste disposal often contains organic contaminants, nutrients, heavy metals and pathogens in its leachate, which is carried to river systems by rainfall and stormwater flows. This results in rise in turbidity, suspended particles, nutrient concentration and microbiological pollution in river water (CPCB, 2021).

Along river corridors, the accumulation of solid waste also affects the morphology of the river, impacts riparian ecosystems and decreases the aesthetic and socio-cultural value of urban riverfronts.

Governance, Institutional Capacity, and Environmental Outcomes

Institutional sustainability of sanitation systems is reflected through governance related measures such as grievance redressal efficiency and O&M cost recovery. insufficient institutional coordination, lack of financial recovery and insufficient maintenance often result in:

- sewer overflows,
- faulty sewage treatment plants,
- bowel habits – irregular,
- Infrastructure deterioration.

According to studies by NIUA (2020) and NMCG (2020), urban river pollution is not controllable through infrastructure building alone, but needs to be backed by good governance, long-term monitoring, financial sustainability and integrated institutional coordination.

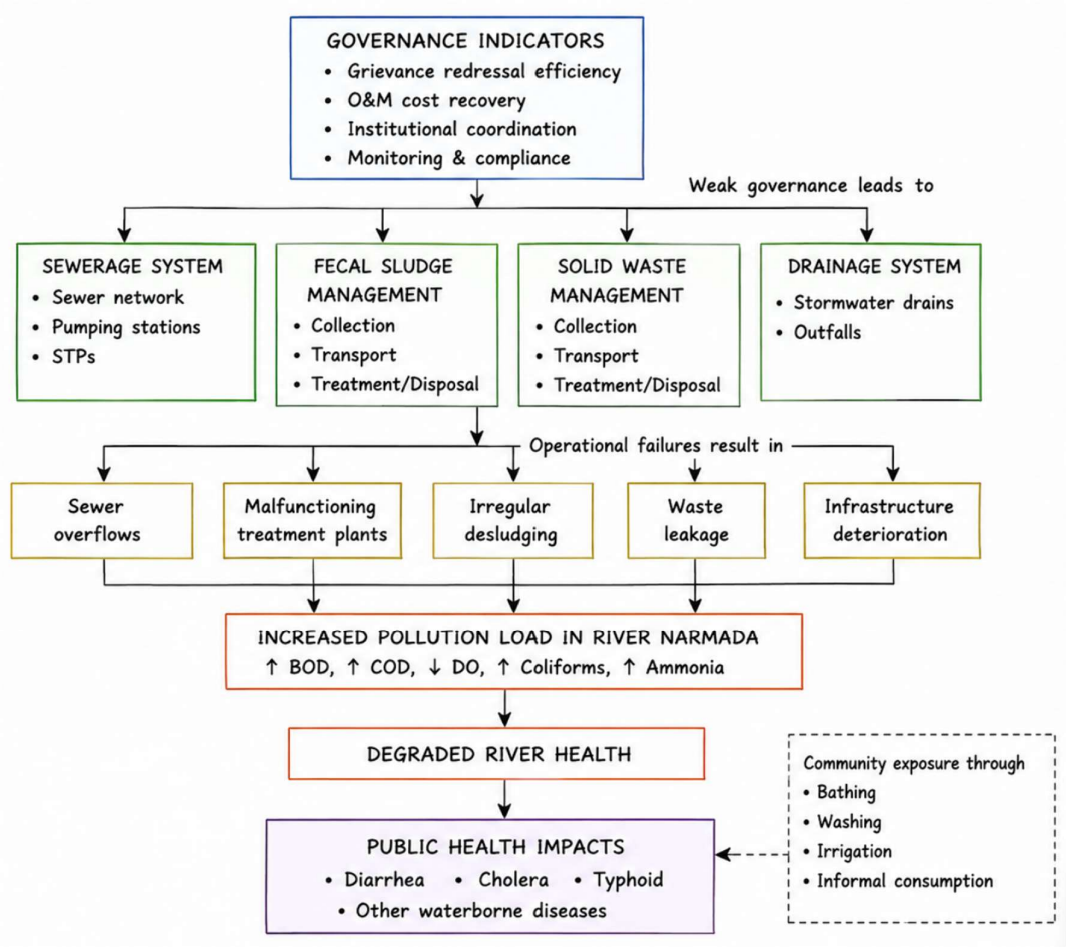

Figure 7 Conceptual Framework Showing the Linkages between Governance, Urban Sanitation Systems, River Health, and Public Health *Source- By Author*

Figure 7 above shows the inter-relationship between governance, urban sanitation systems, river health and public health results. Effective governance is the key element of efficient operation of sewerage, fecal sludge management, solid waste management and drainage systems, which includes institutional coordination, grievance redressal, financial sustainability and monitoring. Bad governance can cause sewer overflows, treatment plant breakdowns, erratic desludging, waste leakage and infrastructure deterioration. These shortcomings have resulted in increased pollution loads in River Narmada that have increased BOD, COD, coliform bacteria and ammonia level and decreased dissolved oxygen. This loss of river health increases community exposure to contaminated water and contributes to water-borne diseases such as diarrhea, cholera and typhoid.

Therefore, governance variables indirectly affect the health of rivers since they affect the operational efficiency and sustainability of municipal sanitation systems.

The chosen urban sanitation, SWM, FSM and river health indicators are interlinked and have integrated effect on the ecological status of River Narmada. Table 2 . Functional links between these indicators and their environmental effects. Poor river health directly increases the exposure of communities to dirty water through bathing, washing, irrigation and informal drinking, resulting in greater occurrences of diarrhoea, cholera, typhoid and other waterborne diseases.

All these indicators collectively point to sanitation failures causing river pollution, polluted rivers affecting community health and poor health and socio-behavioral factors further overburden the sanitation systems, hence the necessity for an integrated sanitation-river health framework.

Table 3 Linkages Between Urban Sanitation Indicators and River Health Indicators

S. No	Urban Sanitation / FSM / SWM Indicator	River Health Parameter Affected	Linkages	Environmental Impact
1	Toilet Coverage	FC, TC	Open defecation increases microbial contamination	Public health risk and faecal pollution
2	Sewerage Network Coverage	BOD, COD, DO	Untreated sewage enters river systems	Organic pollution and oxygen depletion

3	Wastewater Collection Efficiency	BOD, TSS, Turbidity	Leakage and overflow contaminate drains and rivers	Reduced water quality
4	Adequacy of STP Capacity	BOD, COD, Nutrients	Insufficient treatment leads to direct discharge	River pollution and eutrophication
5	Quality of Treatment	FC, BOD, COD	Poor treatment efficiency releases pollutants	Ecological degradation
6	Wastewater Reuse/Recycling	Nutrient Load, Water Stress	Reduced reuse increases freshwater extraction	Reduced ecological sustainability
7	Septic Tank Dependence	FC, TC, Nitrate	Leakage and overflow contaminate water bodies	Groundwater and river contamination
8	Desludging Frequency	FC, BOD	Irregular desludging causes septic overflow	Microbial contamination
9	Safe Collection & Transport	FC, TC, Turbidity	Illegal dumping contaminates drains and rivers	Environmental and health hazards
10	Treatment of Septage	BOD, COD, FC	Untreated sludge discharge increases pollution	Ecological stress
11	Disposal Compliance	Nutrients, FC, TSS	Unsafe disposal contaminates ecosystems	River and soil degradation
12	Solid Waste Collection & Disposal	TSS, Turbidity, Nutrients	Waste dumping blocks drains and pollutes rivers	Habitat degradation
13	Grievance Redressal Efficiency	All Indicators	Poor maintenance increases contamination risk	Infrastructure failure
14	O&M Cost Recovery	All Indicators	Financial weakness affects sanitation services	Long-term environmental deterioration

Source-WHO, CPCB, USEPA, UNEP.

Chapter 5

Identification of Study Area

The Narmada River is one of the important west flowing rivers of India and flows through Madhya Pradesh supporting a network of 21 Urban Local Bodies (ULBs) along its banks. These communities differ enormously in scale, typology, population growth and sanitation facilities. Among these ULBs, selection of a good case region is important for the present study to establish a replicable and contextually appropriate planning framework to combine urban sanitation with river health management.

The choice of the study area is based on a multi-criteria analytical approach, in line with the objectives of integrating urban sanitation systems with the management of river ecosystems. The theoretical framework is based on the following principles:

1. **Hydrological Connectivity** – The physical and functional relationship of the city to the Narmada river is a major determinant of its wastewater discharge, solid waste runoff and overall impact on river health. ULBs located immediately along the river route are so preferred.
2. **Urban Typology and Scale** – The typology of urban areas should be proportionally represented to help comprehend the relationships between sanitation and rivers in diverse urban contexts. Towns are classed according to population size and kind of settlement (MT-I, MT-II, ST-I, ST-II).
3. **Sanitation Infrastructure Status** – The status of existing sanitation infrastructure like ODF++, IHHL coverage, Solid Waste Management (SWM) and Door to Door Collection etc. under Swachh Bharat Mission (SBM) components determines the readiness of the ULB for integrated management.
4. **River Health and Environmental Sensitivity** – Depending upon the level of environmental stress including open discharge, riverfront dumping and ghat pollution, the choice is made. Preference would be given to ULBs working in Namami Devi Narmade, riverside or clean river efforts, since they have active linkage with programs to improve river health.
5. **Institutional and Project Readiness** – Institutional readiness for sanitation and infrastructure improvement is shown by inclusion under AMRUT or other

state/centrally financed programs, assuring data availability and implementation feasibility.

6. **Representativeness and Replicability** – The ULB selected should be representative of a typical urban settlement along a river, providing insights that can be extrapolated to other towns along the Narmada or comparable river systems in India.

Table 4 List of Urban Local Bodies along River Narmada in Madhya Pradesh.

S. N	District	ULB	Population 2011	Population 2025	Type of Settlement	Latitude	Longitude	SBM	AMRUT Projects	OTHER PROJECTS
1	Anooppur	Amarkantak	8416	10500	MTR	22.6822	81.7532	ODF, public toilets, SWM (door-to-door, compost pits)	Not in AMRUT	Namami Devi Narmade: ghat sanitation, pilgrimage
2	Dindori	Dindori	21323	27026	ST-II	22.9418	81.0768	ODF, IHHL, SWM system, awareness	Not in AMRUT	water supply augmentation
3	Mandla	Mandla	55133	66917	MT-I	22.5979	80.3714	ODF+, solid waste segregation, toilets	Not in AMRUT	River cleaning & Narmada related sanitation
4	Jabalpur	Jabalpur	1081677	1445322	MT-I	23.1686	79.9339	ODF++, waste-to-energy, smart bins, compost plants	Water supply 24x7, sewerage STPs, parks	Smart City Mission: riverfront, underground bins
5	Jabalpur	Bhedaghat	6657	9449	ST-I	23.1306	79.8024	Toilet facilities, SWM near tourist spots	Not in AMRUT	Tourism & pilgrimage ghat sanitation
6	Narsinghpur	Narsinghpur	59966	76498	MT-I	22.9473	79.1923	IHHL, SWM door-to-door collection	Not in AMRUT	State urban dev. schemes for water supply
7	Narsinghpur	Saikheda	9602	14112	ST-II	22.9622	78.5831	Basic SBM coverage, IHHL, SWM	Not in AMRUT	
8	Narmadapuram	Narmadapura	117988	149340	MT-I	22.7519	77.7289	ODF+, waste management	Water intake from Narmada, pipelines, sewerage STP	Namami Devi Narmade: riverfront sanitation
9	Sehore	Budhni	16808	24500	ST-II	22.7746	77.6826	IHHL, SWM, ODF+	Not in AMRUT	Pilgrimage sanitation works (Narmada river)
10	Sehore	Bhairunda	23788	31800	ST-II	22.6819	77.2717	IHHL, SWM door-to-door collection	Not in AMRUT	
11	Dewas	Nemawar	5978	7897	ST-I	22.4971	76.9801	IHHL, SWM	Not in AMRUT	Narmada ghat cleanliness projects
12	Khandwa	Omkareshwar	10063	13043	ST-I	22.2418	76.1494	Pilgrim toilets, ODF++, SWM at ghats	Not in AMRUT	Namami Devi Narmade: riverfront dev., sewage
13	Khargone	Sanavad	38740	47457	ST-II	22.1764	76.0682	ODF+, SWM	Not in AMRUT	water supply projects
14	Khargone	Badwah	26459	34153	ST-II	22.2532	76.0408	ODF, SWM	Not in AMRUT	Urban water supply augmentation
15	Khargone	Mandleshwar	12343	15000	ST-I	22.1769	75.6601	ODF, SWM	Not in AMRUT	Pilgrimage ghat sanitation works
16	Khargone	Maheshwar	24411	33802	ST-II	22.1773	75.583	ODF+, SWM, public toilets	Not in AMRUT	Heritage & pilgrimage dev., sewage
17	Dhar	Dhamnod	32093	38540	ST-II	22.2139	75.4723	IHHL, SWM	Not in AMRUT	
18	Dhar	Dharampuri	16363	20850	Small	22.1582	75.3499	IHHL, SWM	Not in AMRUT	
19	Barwani	Anjad	26289	31971	ST-II	22.0431	75.0538	IHHL, SWM	Not in AMRUT	
20	Barwani	Barwani	55504	73210	MT-I	22.0363	74.9033	ODF+, SWM	Water supply pipelines, sewerage under AMRUT	
21	Barwani	Sendhwa	56485	72109	MT-I	21.6819	75.0943	ODF, SWM	Water supply projects under AMRUT	

Source- Compile by author

Figure 8 shows the spatial distribution of selected Urban Local Bodies (ULBs) located on the banks of River Narmada in Madhya Pradesh. The prominent communities are the main urban nodes in the corridor of the Narmada River, from Amarkantak, where the river originates in the east, to downstream cities like Barwani and Anjad in the west.

The plotted ULBs are key municipalities and municipal corporations including Amarkantak, Dindori, Mandla, Jabalpur (Bhedaghat), Narsinghpur, Saikheda, Narmadapuram, Nemawar, Omkareshwar, Maheshwar, Barwaha, Sanawad, Dharampuri, Dhamnod, Barwani, Anjad and Sendhwa. These villages rely directly on the river for water supply, cultural activities, agriculture, tourism and economic development.

The picture illustrates the continuous urban–river interface along the Narmada and the aggregate effect of urban sanitation, wastewater management and solid waste practices in these ULBs on the river water quality and ecological health. The mapped communities provide a regional framework for assessment of urban impacts on the Narmada River system and help development of river-sensitive planning and sanitation management initiatives.

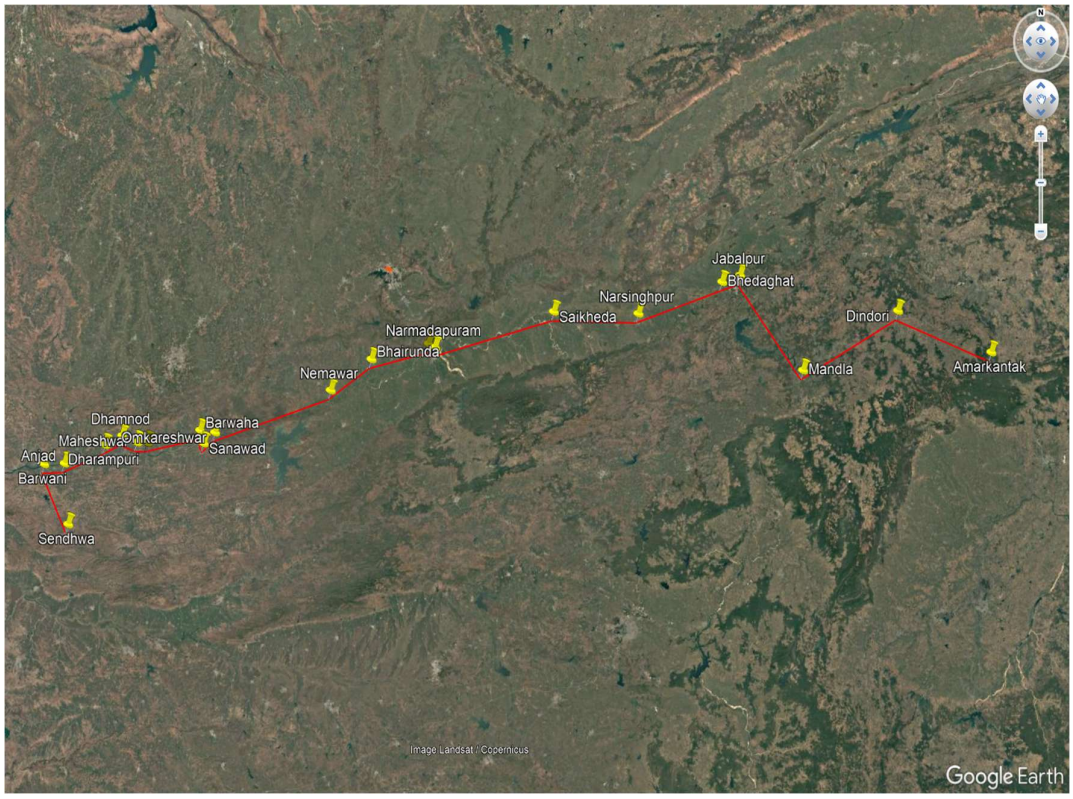

Figure 8 Location of Urban Local Bodies along River Narmada in MP *Source- Google Earth*

The reason for selecting Narmadapuram as a study area is its unique socio-environmental setting on the Narmada River and the severe issues faced in urban sanitation, wastewater management and river health. As the statistics shows, Narmadapuram is a fast-growing Class-I town with an expected population of over 1.49 lakh by 2025, which puts mounting demand on sanitation facilities and river-dependent systems. The city has a mixed sanitation profile and efforts are ongoing under Swachh Bharat Mission (SBM) including IHHL coverage, solid waste management and initiatives for obtaining ODF+ status. But there are still unsewered dwellings, limited waste management and direct river input for water delivery, which indicates the continued infrastructure and environmental weaknesses. Narmadapuram is also intimately tied to several riverbank development and sanitation initiatives under Namami Devi Narmade, which is indicative of the active governmental involvement in restoring the health of the river, but also exposes the disconnect between policy aim and on-ground results. The city's strategic location on the Narmada River, together with visible sanitation–river interactions such as wastewater discharge points, pilgrimage-driven waste loads, and emerging urban expansion, makes it an ideal and representative case for studying the integrated relationship between urban sanitation systems, community health, and river ecosystem health in river-side cities.

Chapter 6

Data Analysis

6.1 Study Area Profile

Location and regional context

Narmadapuram (previously hoshangabad) is a famous river side city located in the central section of the state of Madhya pradesh. The city is situated on the southern bank of the narmada river, one of the most important west flowing rivers in india.

Geographically it is located at around 22.75° N latitude and 77.72° E longitude and falls in lush narmada valley region. The city is an important administrative and cultural center of central India.

As to Draft Master Plan 2035, the overall planning area of Narmadapuram is 13,005.28 Hectare as demarcated on the basis of satellite imageries and revised cadastral boundaries. The planning area is the municipal area, consisting of 33 municipal wards that form the urban center and 26 adjacent villages that form the peri-urban and rural edge.

Physical, climate and cultural significance

Narmadapuram is a flat to gently sloping alluvial tract with an elevation of about 300-350 meters above mean sea level with fertile alluvial soils. The hydrological regime of the area is controlled to a large extent by the Narmada River and its tributaries. The city has a tropical climate and three seasons: scorching summers, moderate to high monsoon rains (about 1000-1200 mm yearly) and warm winters. The Narmada River maintains great cultural value, with many ghats functioning as religious, bathing, and festival sites, consequently defining local customs and impacting cleanliness along the riverbank.

The location of Narmadapuram city in Madhya Pradesh and Narmada Valley region with the planning boundary, transportation network and adjoining stretch of River Narmada considered for the present study is shown in Fig. 9.

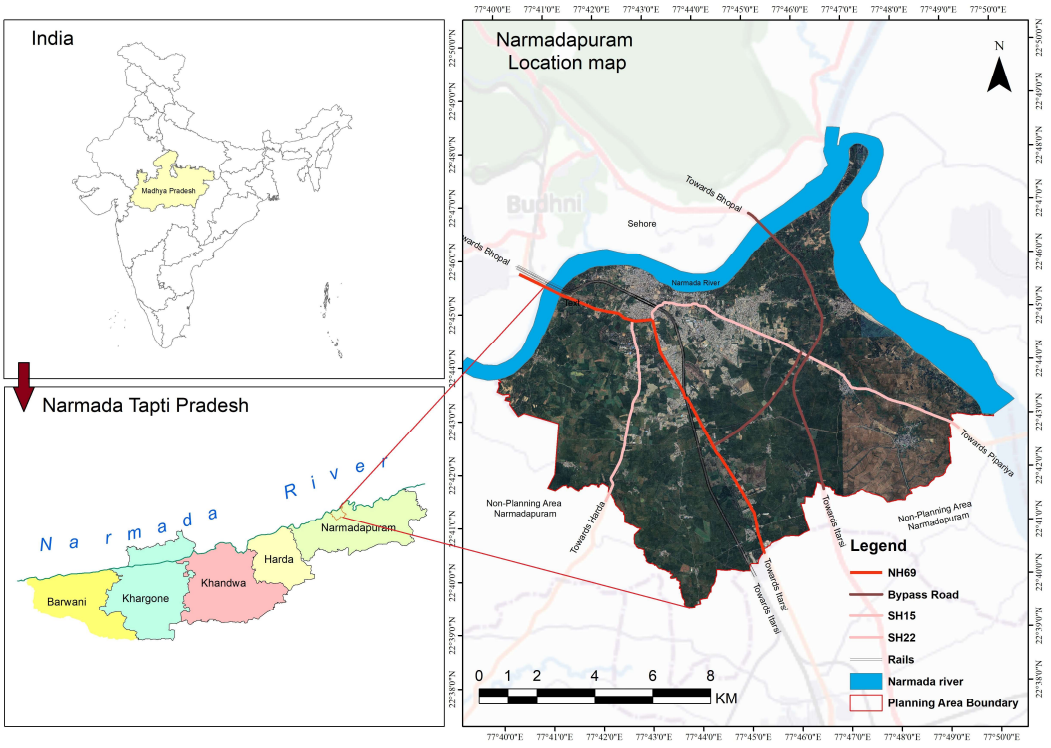

Figure 9 Location Map of Narmadapuram *Source- By Author (ArcMap)*

Evolution of sanitation in Narmadapuram (Hoshangabad)

The evolution of sanitation in Narmadapuram (Hoshangabad) is a significant paradigm to understand the change of small to medium Indian towns from river-dependent, open-drain systems to integrated, mission-led urban utilities. For the purposes of our study, evolution can be divided into two distinct paradigms: Baseline/Planning Era (Pre-2014) and Mission/Infrastructure Era (Post-2014).

Phase 1: Pre-2014 (Baseline & Planning Era)

Before the 2014 national policy change, sanitation in Hoshangabad was mainly decentralized, with no treatment facilities. The city depended on the Narmada River's "self-purification" capacity, which was increasingly inundated.

- Dependence on Natural Drainage: The domestic sewage was let out through three big open nalas namely Kori Ghat, Lendia and Sukh Tawa nalas, which drained directly into the Narmada. In the 1980s, a diversion plan was developed to transfer

the flow of the Kori Ghat downstream of the bathing places, but it remained untreated (WSP, 2009).

- Deficit of Infrastructure (2008-2010): According to Hoshangabad City Sanitation Plan (2010), around 15% of households were practising open defecation and 85% were using individual pits or septic tanks. However, septic tank management was "grossly inadequate" as the municipality was removing only roughly 180 tanks a year with one vacuum vehicle.
- Zero-Treatment Status: Only 70-75% of solid garbage was collected and disposed of by open dumping at the Idgah dump site while 100% of the city's 9.2 MLD of wastewater was untreated (Hoshangabad Municipality, 2010).

Phase 2: Post-2014 (Mission & Integrated Era)

The establishment of Swachh Bharat Mission (SBM) in 2014 and Madhya Pradesh Urban Services Improvement Project (MPUSEP) in 2017 has acted as a catalyst for change towards centralized infrastructure and behavioural change.

- Integrated Sewerage Expansion: The city was moving towards a complete underground sewer network under MPUSEP, supported by the Asian Development Bank (ADB). The project was to lay over 196 km of sewer pipelines and connect over 14,000 dwellings replacing the existing 'open nala' system (ADB, 2024).
- Treatment and Recovery: Modern Sewage Treatment Plants (STPs) have been commissioned for treating urban discharges. By 2025-2026, the city was transitioning from a "disposal-first" approach to a "reuse-first" approach, in which treated wastewater is increasingly considered as a resource for peri-urban agriculture to reduce nutrient loading (nitrogen and phosphorus) in the river basin (Kansara & Lakshmi, 2021).
- Certification and ODF certification: Narmadapuram acquired ODF++ certification by 2025 through strict digital monitoring and the Swachhata Green Leaf Rating system. This implies secure containment, conveyance and scientific treatment of all faecal sludge and septage besides elimination of open defecation (Ministry of Jal Shakti, 2025).

6.2 Spatial Analysis Maps

6.2.1 Narmadapuram Boundaries Map

Figure 10 illustrates delineation of the administrative structure of Narmadapuram, showing municipal limits, ward divisions, and the planning boundary. The municipal area is compact and primarily concentrated along the northern side adjoining the Narmada River. The ward boundaries indicate a relatively dense administrative subdivision in the central region, suggesting higher governance focus and urban concentration. The planning boundary extends significantly beyond the municipal limits, especially towards the southern side, indicating provision for future urban expansion. The proximity of the town to the Narmada River highlights both opportunities (water availability, tourism potential) and constraints (flood risk, restricted development zones).

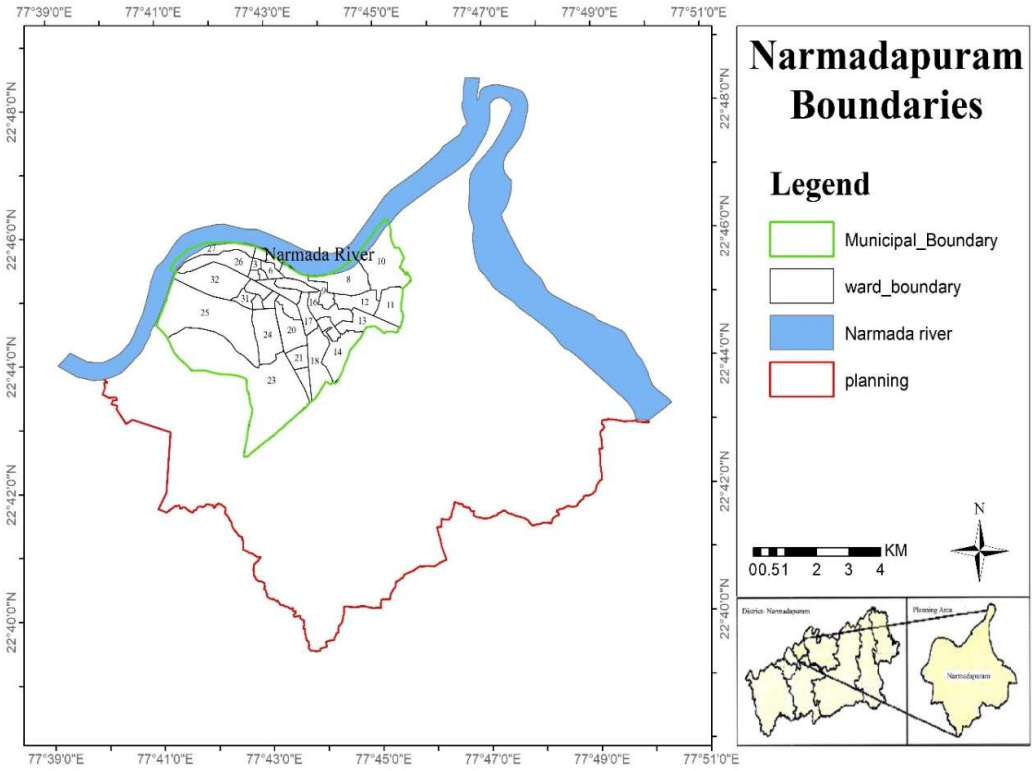

Figure 10 Administrative boundaries of Narmadapuram Source- By Author (ArcMap)

6.2.2 Narmadapuram Connectivity Map

The connectivity map reveals a well-developed road network concentrated in the central urban core, gradually becoming sparse towards the peripheral areas. Major roads act as

primary spines connecting different parts of the town and linking it with surrounding regions. The presence of a railway line crossing the planning area enhances regional accessibility and supports economic activities. However, the outer areas show limited connectivity, indicating potential gaps in infrastructure development. The overall pattern suggests a radial-cum-linear network influenced by the river alignment and existing settlement structure.

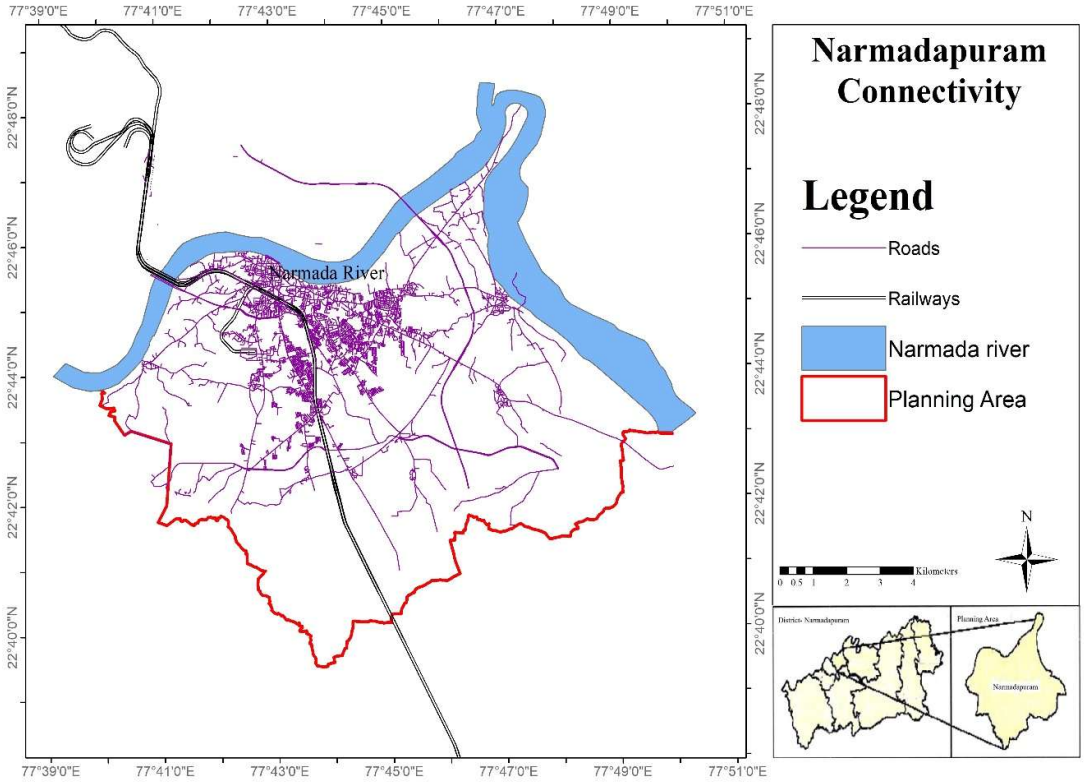

Figure 11 Narmadapuram Connectivity Map *Source- By Author (ArcMap)*

6.2.3 Narmadapuram Contour Map

The contour map, with a 1-meter interval, indicates that the study area has relatively gentle terrain with minor elevation variations. Slightly higher elevations are observed towards certain peripheral zones, while lower elevations are closer to the river basin. This gentle slope condition is suitable for urban development but requires careful planning for drainage and flood management. The dense clustering of contour lines in some areas

suggests localized undulations, which may influence construction practices and infrastructure design.

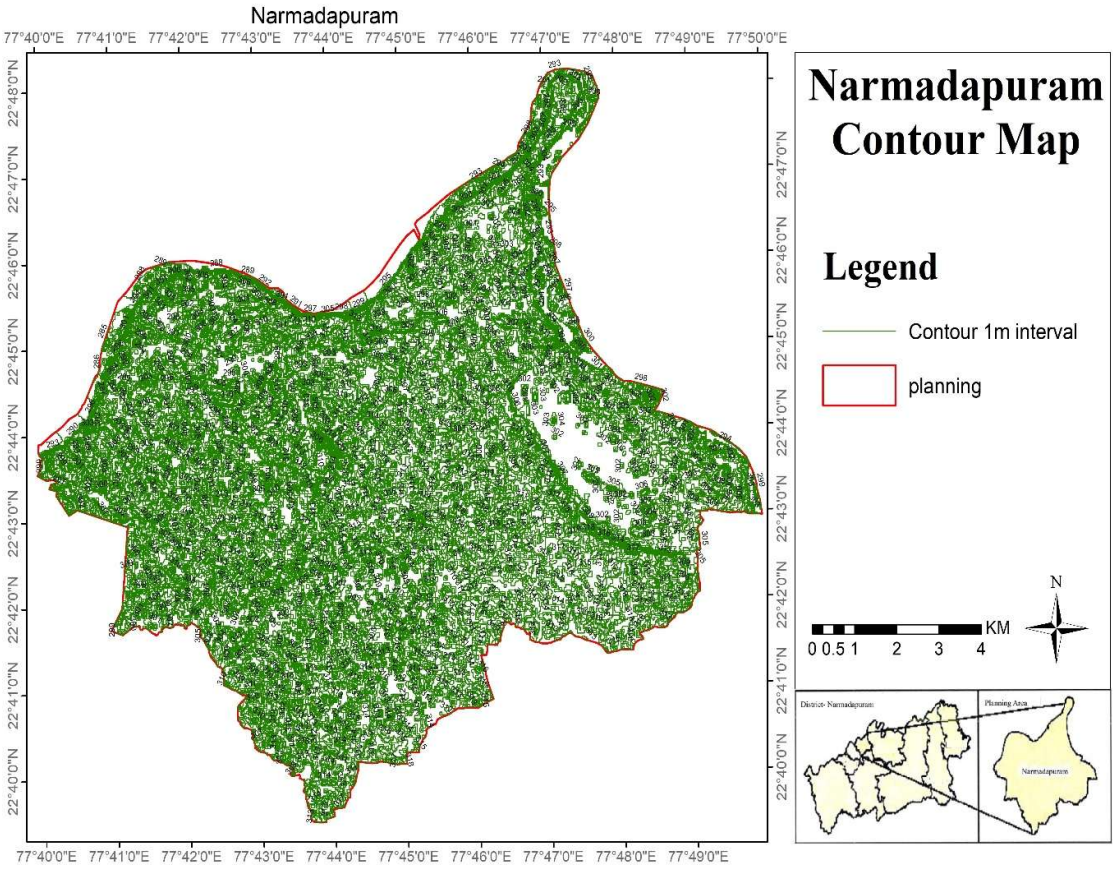

Figure 12 Narmadapuram Contour Map *Source- By Author (ArcMap)*

6.2.4 Narmadapuram Drainage Map

Figure 13 drainage map shows a hierarchical stream network classified into different orders. Lower-order streams are widely distributed across the planning area, feeding into higher-order channels that ultimately connect to the Narmada River. The drainage pattern appears dendritic, indicating relatively uniform geological conditions. Areas with higher drainage density may be more prone to water accumulation and require efficient stormwater management systems. The direct connection of drainage channels to the river emphasizes the importance of maintaining natural flow paths to prevent flooding and waterlogging.

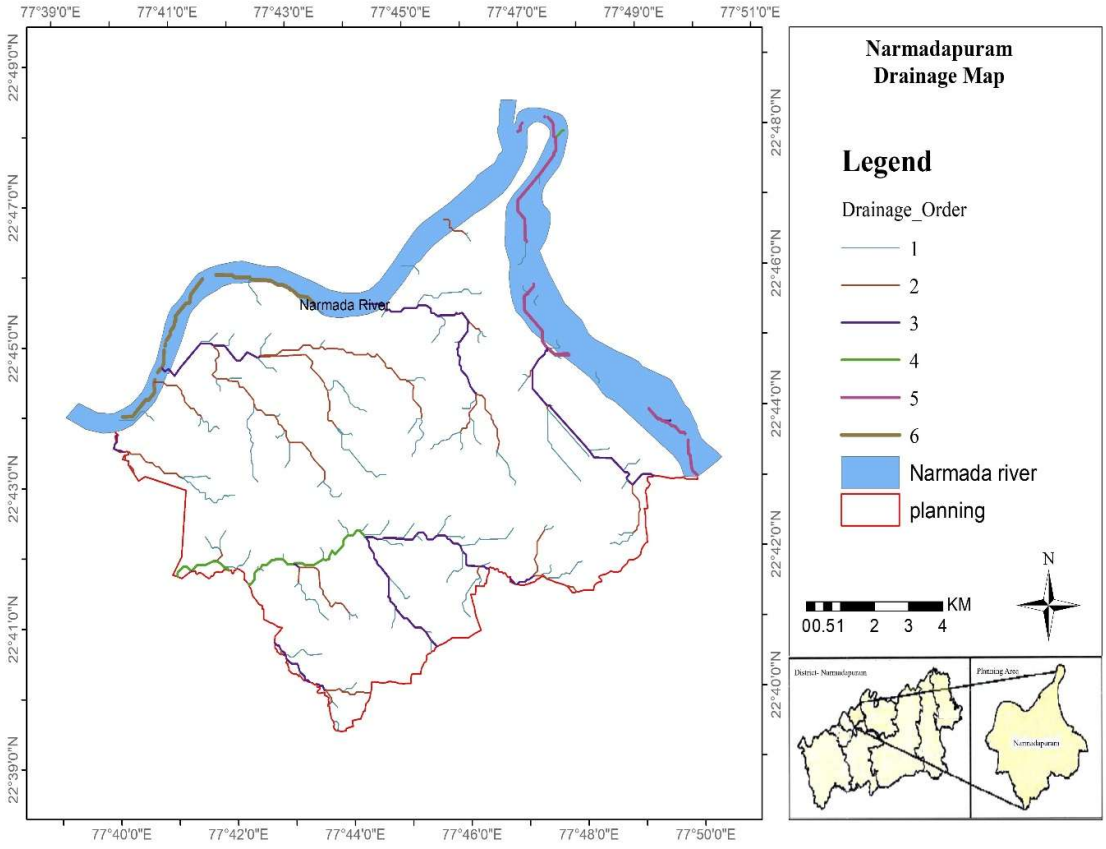

Figure 13 Narmadapuram Drainage Map *Source- By Author (ArcMap)*

6.2.5 Narmadapuram Population Density Map

The figure 14 shows the population density of Narmadapuram, reveals a pronounced concentration of population within the central urban wards located adjacent to the River Narmada, while peripheral areas exhibit comparatively lower population densities. The highest-density wards are clustered within the core city area, indicating increased pressure on urban infrastructure, sanitation services, wastewater management systems, and solid waste handling facilities. This spatial pattern suggests that densely populated river-adjacent zones are likely to generate greater quantities of domestic wastewater, faecal sludge, and municipal solid waste, thereby increasing the risk of pollutant discharge into the River Narmada.

From a river-sensitive urban sanitation perspective, the concentration of population near the river highlights the need for prioritized investments in sewerage connectivity,

wastewater treatment, faecal sludge management, and riverfront sanitation infrastructure. The map further indicates that population pressure is greatest in wards located within the immediate influence zone of the river, making these areas critical intervention zones for reducing pollution loads and improving river health. Therefore, population density emerges as an important spatial indicator for identifying sanitation demand hotspots and guiding targeted planning interventions aimed at protecting the ecological health of River Narmada while supporting sustainable urban development in Narmadapuram.

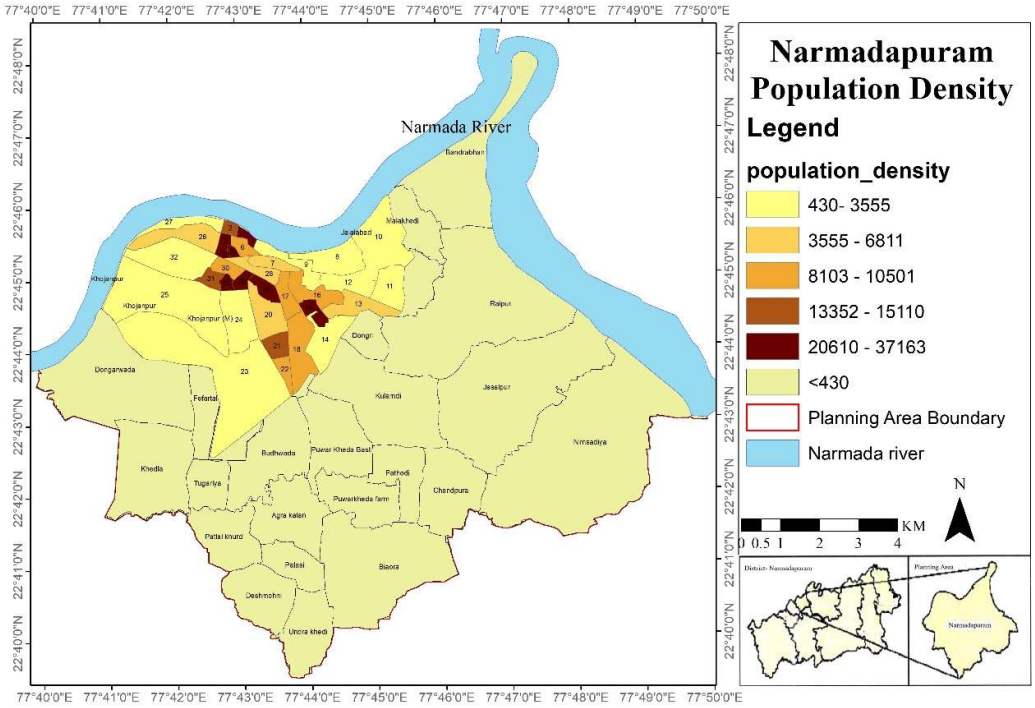

Figure 14 Narmadapuram Population Density Map *Source- By Author (ArcMap)*

6.2.6 Narmadapuram Satellite Image

The satellite imagery provides a real-world visualization of land use and land cover within the planning area. Built-up areas are concentrated in the central region, while agricultural lands and open spaces dominate the outskirts. The Narmada River forms a prominent natural feature, influencing settlement patterns and land use distribution. The image also shows transportation corridors and scattered settlements, indicating ongoing urban expansion. This map is essential for validating spatial analysis and understanding ground realities.

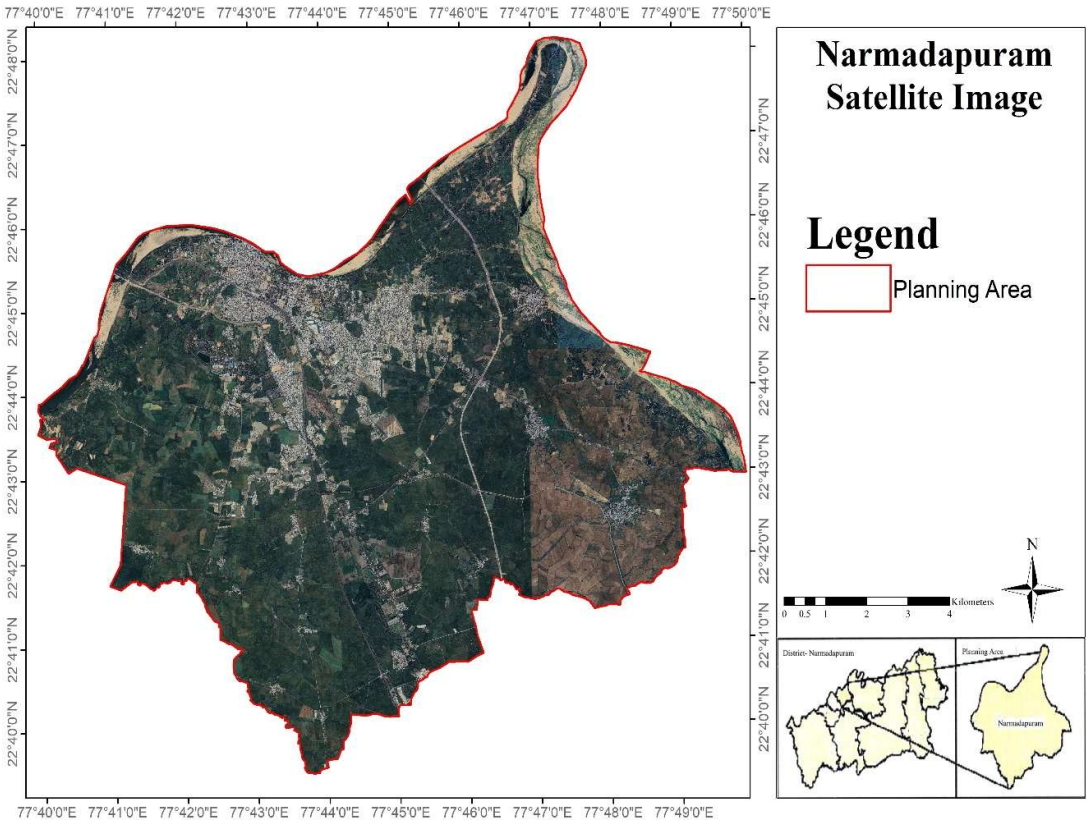

Figure 15 Narmadapuram Satellite Map *Source- By Author (ArcMap)*

6.2.7 Narmadapuram Slope Map

The slope map categorizes the terrain into very gentle, gentle, and moderate slopes. A majority of the area falls under very gentle slopes, making it highly suitable for urban development and infrastructure expansion. Moderate slopes are limited and mostly located near riverbanks or specific terrain features. These areas may require special engineering considerations and should be avoided for dense construction. Overall, the terrain supports planned development with minimal topographical constraints.

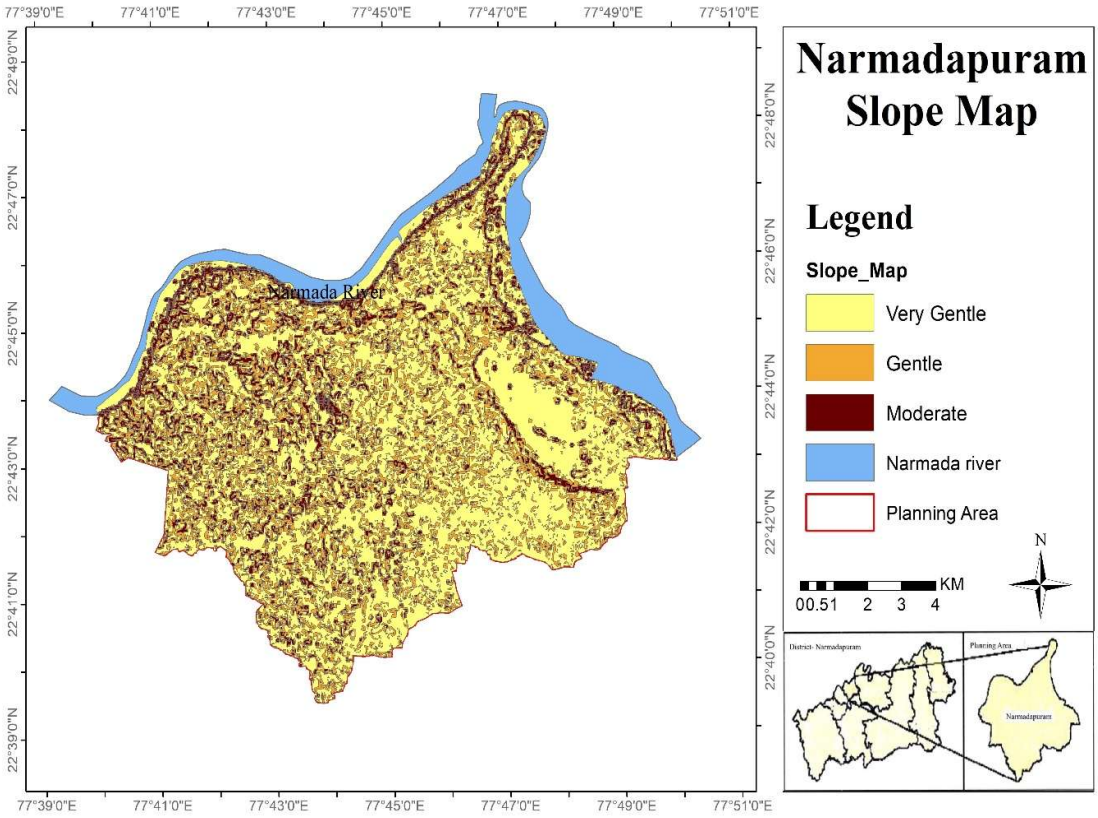

Figure 16 Slope Map of Narmadapuram *Source- By Author (ArcMap)*

6.2.8 Narmadapuram Ward Map

Figure 17 ward map illustrates the administrative structure of Narmadapuram Municipal Council, comprising 33 municipal wards distributed across the planning area. While all wards were considered for understanding the overall urban context and spatial distribution of the city, the primary field survey and questionnaire-based data collection were conducted in selected wards located along the River Narmada. These riverfront wards were chosen because they represent the zones of direct interaction between urban sanitation systems and the river ecosystem. The selected wards provided critical insights into sanitation infrastructure, wastewater disposal practices, faecal sludge management, solid waste management, riverfront usage patterns, and public perceptions regarding river health. The ward-level analysis enabled identification of river-sensitive sanitation challenges and pollution hotspots within the immediate influence zone of the Narmada River, thereby supporting the development of targeted planning interventions for river health improvement.

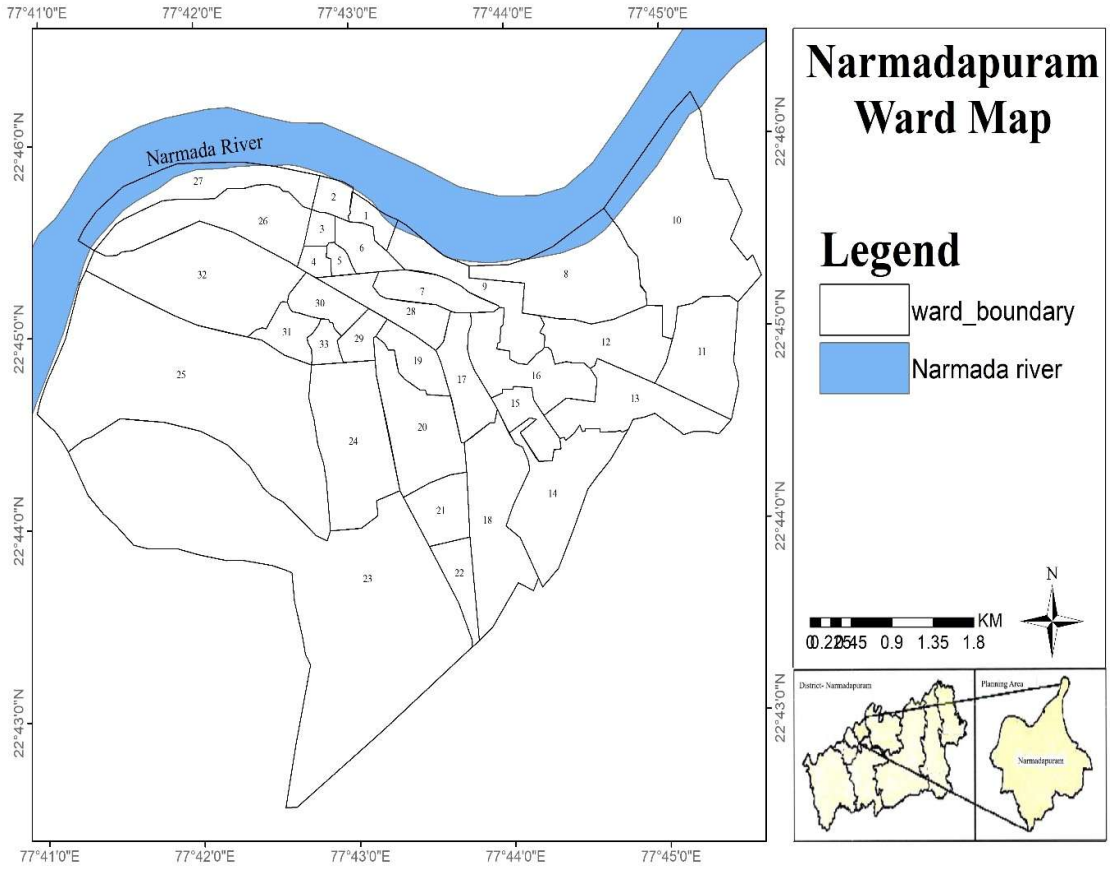

Figure 17 Ward Map of Narmadapuram ULB *Source- By Author (ArcMap)*

6.3 Assessment of Urban Sanitation and Solid Waste Management infrastructure

Assessment of Urban Sanitation, Solid Waste Management (SWM), and Faecal Sludge Management (FSM) can be undertaken using the Service Level Benchmarks (SLBs) prescribed by the Government of India. These benchmarks provide a framework to evaluate the efficiency, coverage, sustainability, and environmental performance of urban sanitation systems. The SLB-based assessment helps in identifying service gaps, infrastructure deficiencies, environmental concerns, and governance-related challenges. Such an assessment supports evidence-based planning and facilitates the formulation of river-sensitive urban sanitation interventions for sustainable urban and environmental management.

Table 5 projected population considered for the assessment has been derived from the Draft Master Plan 2035 for Narmadapuram city. Based on standard urban planning norms,

water demand and sewage generation have been calculated considering 150 LPCD water supply, UFW provisions, and sewage generation at 80% of total water supplied.

Table 5 Projected Sewage Generation

Total population of Narmadapuram city 2035	2,50,000
Adding Floating Population 6% (As per Master Plan)	15,000
Total water supply @150 Ipcd	47.7
Total sewage/sullage generation @80% of supply (MLD)	38.16

Source: By Author

Evaluation of urban sanitation indicators in Narmadapuram reveals that there are significant deficiencies in sewerage infrastructure, wastewater collection and treatment systems despite relatively high sanitation access coverage. Table 6 shows that the reported toilet coverage in the city is 96.3%, suggesting significant progress towards universal sanitation access and reduction of open defecation. However, the total sanitation system is ineffective due to lack of sewerage connectivity and absence of functional wastewater treatment facilities.

More than 90% of sewer laying work is claimed to be complete, while the coverage of sewerage network is said to be just 35.8%. Field investigations and site observations show that large parts of the sewerage network are now not functioning. This has resulted in a low efficiency of 32.1% in wastewater collection, which means a large amount of sewage and sullage is either dumped into open sewers or released untreated into the surrounding environment. Such situations in riverside towns such as Narmadapuram lead to direct contamination of the River Narmada from drain outfalls and storm water channels.

The existing treatment capacity is presently 0% enough as projected 21 MLD Sewage Treatment Plant (STP) is under construction and not operational as given in Table 6. The quality of wastewater treatment could not be evaluated due to the absence of a functional treatment facility. The lack of operable treatment facilities considerably increases the likelihood of untreated sewage discharge into the River Narmada, consequently contributing to increased organic pollution, nutrient loading, microbiological contamination and ecological deterioration.

The report also says that there is no data available on wastewater reuse/recycling, efficiency of grievance redressal and O&M cost recovery. This points towards institutional, monitoring and governance weaknesses in the municipal sanitation system. The paucity of data also points to the need to improve urban environmental monitoring systems and sanitation governance procedures.

The results in Table 6 show that while access to sanitation has increased significantly, there are still major shortcomings in the collection, treatment, operational efficiency and institutional management of wastewater. These deficiencies directly affect the health conditions of the river and call for the urgent need of integrated river-sensitive urban sanitation planning interventions including the operationalization of sewerage infrastructure, decentralized wastewater management, treatment facilities, and strengthened governance systems for sustainable management of River Narmada and adjoining urban settlements.

Table 6 Service Level Benchmark values for Narmadapuram

Urban Sanitation					
S.No	Indicator	Definition	Unit	Actual Value	Remarks
1	Coverage of Toilets	% households with access to toilets	%	96.3	
2	Coverage of Sewerage Network	% area served by sewer network	%	35.8	>90% Sewers laying work is completed, but are not operational a
3	Collection Efficiency of Wastewater	Wastewater collected vs generated	%	32.1	
4	Adequacy of Treatment Capacity	Installed STP vs required	%	0	21 MLD STP in construction Stage
5	Quality of Treatment	Compliance with standards (BOD/COD)	%	No Treatment	As there is no treatment Facility
6	Extent of Reuse/Recycling	% treated wastewater reused	%	NA	Data not available
7	Efficiency in Redressal	Complaint resolution time	%	NA	Data not available
8	O&M Cost Recovery	Cost recovered from users	%	NA	Data not available

Source: Survey

Assessment of Faecal Sludge Management (FSM) indicators in Narmadapuram revealed heavy reliance on onsite sanitation systems and no scientific septage management infrastructure. Table 7 indicates the relevance of decentralized sanitation systems in the city, showing that around 39.51% of houses rely on septic tanks. This is indicative of the low coverage of sewerage network and a growing dependence on onsite containment systems for wastewater control.

The study also finds that septic tanks are generally desludged every 3-5 years, more or less consistent with national FSSM guidelines that prescribe periodic desludging for safe functioning of septic tanks. However, in some regions, irregular desludging techniques can raise the chances of septic overflow, groundwater contamination and the release of untreated septage into neighboring drains and river systems.

As indicated in Table 7, statistics on safe collection and transport of faecal sludge are currently unavailable, pointing to deficiencies in monitoring, institutional documentation and regulation of desludging operations. Improper monitoring systems could lead to higher chances of harmful disposal activities such as illicit dumping of septage into open drains, vacant land and environmentally sensitive riverbank regions.

The study also finds that the scientific treatment of septage is not functional as the projected Faecal Sludge Treatment Plant (FSTP) is still under construction and not functioning. The efficiency of treatment is almost nil and thus poses a serious environmental threat to the river Narmada and its bordering ecosystems. Untreated faecal sludge may result in an increase in Biochemical Oxygen Demand (BOD), faecal coliform contamination, fertilizer loading and ecological degradation of river systems.

Moreover, there is no data on disposal compliance, suggesting governance and institutional constraints to monitor ecologically safe disposal and reuse methods. The results in Table 7 indicate the need for urgent strengthening of city-wide FSM systems through operationalization of FSTP infrastructure, scientific septage treatment, regulated desludging services, monitoring mechanisms and integrated river-sensitive sanitation planning interventions to reduce pollution risks to River Narmada.

Table 7 Service Level Benchmark values for Narmadapuram

Faecal sludge Management				
S.No	Indicator	Unit	Actual Value	Remarks

1	Household dependent on septic tanks	%	39.51	
2	Desludging frequency	Years	3-5 years	
3	Safe collection & transport	%	No Data Available	
4	Treatment of septage	%	0	FSTP is Under Construction & Inoperational
5	Disposal compliance	%	No Data Available	

Source: Survey

Assessment of Solid garbage administration (SWM) indicators in Narmadapuram city shows reasonable development in municipal garbage collection services, but huge gaps still remain in segregation, scientific processing and institutional administration. As shown in Table 8, the door-to-door waste collection coverage is stated to be 85.19%, which implies a relative improvement in the accessibility of garbage collection services at the household level. Similarly the collection efficiency of municipal solid trash is rather high (88.89%) showing that a good percentage of waste created is being collected by the urban local authority.

Despite the advances in collection systems, the segregation at source is restricted to 48.15%. This indicates that the methods for segregation of waste for wet and dry waste are not being implemented properly. Poor segregation affects the efficiency of recycling, composting and scientific waste processing systems and increases dependence on landfill disposal. The evaluation further reveals that currently 100% of the garbage collected is destined for disposal to landfills, which highlights the lack or limited implementation of sustainable approaches for waste recovery and resource management.

Table 8 further highlights the non-availability of data linked to scientific processing, cost recovery and complaint redressal methods which indicates institutional and monitoring flaws in the SWM system. Absence of scientific waste processing may lead to environmental damage through leachate formation, open dumping and pollution of local drains and aquatic bodies. Poor solid waste management can impact River Narmada

adversely in cities along rivers such as Narmadapuram through stormwater runoff, drain blockage and disposal of rubbish along river banks and floodplain areas.

The results in Table 8 highlight the need to develop integrated solid waste management systems by better source segregation, scientific processing infrastructure, decentralized waste treatment, strengthened monitoring methods, and sustainable landfill management practices. Such initiatives are crucial to minimize environmental contamination and facilitate river-sensitive urban sanitation planning in Narmadapuram.

Table 8 Service Level Benchmark values for Narmadapuram

Solid Waste Management					
S.No	Indicator	Definition	Unit	Actual Value	Remarks
1	Door-to-Door Collection	HH covered by collection	%	85.19	
2	Segregation at Source	Waste segregated (wet/dry)	%	48.15	
3	Collection Efficiency	Waste collected vs generated	%	88.89	
4	Scientific Processing	Waste processed scientifically	%	No Data Available	
5	Landfill Disposal	Waste sent to landfill	%	100	
6	Cost Recovery	SWM user charges recovery	%	No Data Available	
7	Complaint Redressal	Complaints resolved	%	No Data Available	

Source: Survey

The evaluation of Narmadapuram Draft Master Plan 2035 has been undertaken to assess the extent of integration of river-sensitive planning components and river-health issues within the statutory planning framework. Table 9 shows the evaluation of different planning aspects for river-sensitive urban development, including river vision and objectives, river zone delineation, urban flooding, groundwater augmentation, river pollution, development control regulations and land-use planning.

The research shows that while the Draft Master Plan 2035 does recognize some river-related characteristics, there are other essential dimensions related to integrated river-sensitive urban sanitation and ecological planning that are not sufficiently specified or are

missing. Other elements such as land use planning, development control rules and river water consumption are partially addressed, but overall methods for river pollution management, floodplain regulation, sanitation integration and ecological restoration seem to be restricted.

In addition, critical factors such as river-sensitive zoning, groundwater protection, urban floods resilience and river health management need to be better integrated spatially and in terms of policy within the planning framework as shown in Table 9. The insufficient integration of river-sensitive design principles may result in continuous environmental strain on the River Narmada due to unregulated development, wastewater discharge, expansion of the floodplain and poor ecological safeguards.

The report stresses the importance of integrating river sensitive urban sanitation planning concepts into statutory planning instruments such as the Draft Master Plan 2035. Strengthening these planning features can help in sustainable urban growth, ecological conservation, climatic resilience and long-term protection of River Narmada and its bordering urban communities.

Table 9 Consideration of River in Master Plan

Planning Dimensions	Narmadapuram Draft Master Plan 2035		
	Mentioned in Detail	Mentioned without Detail	Not Mentioned
River Sensitive Vision/Objectives			
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: Compile by Author

The assessment further shows that the river-related planning in the Draft Master Plan 2035 is predominantly infrastructure-oriented and lacks a comprehensive river-sensitive urban sanitation approach. As indicated in Table 9, there has been little emphasis on

integrated wastewater management, ecological buffers, floodplain protection and riverfront environmental management. This shows the necessity to incorporate the principles of river-health based planning in future statutory planning frameworks to enable sustainable urban growth and long-term ecological protection of River Narmada.

Chapter 7

Result and discussion

Here results and discussion derived from the assessment of urban sanitation systems, Solid Waste Management (SWM), Faecal Sludge Management (FSM), river health indicators, and planning framework analysis for Narmadapuram city. The analysis establishes the relationship between urban sanitation conditions and the ecological health of River Narmada. The findings are based on Service Level Benchmark (SLB) assessment, water quality analysis, field observations, secondary data, institutional review, and planning document analysis.

The chapter further evaluates how deficiencies in sanitation infrastructure, wastewater management, solid waste disposal, and governance mechanisms contribute to river pollution and ecological degradation. The findings collectively support the need for integrated river-sensitive urban sanitation planning approaches for river-side cities.

Urban Sanitation Assessment

The assessment of urban sanitation indicators reveals substantial gaps in sewerage infrastructure, wastewater collection, and treatment systems despite relatively high sanitation access coverage in Narmadapuram.

The analysis indicates that toilet coverage in the city is relatively high, suggesting considerable progress toward achieving universal sanitation access and reduction of open defecation. However, the effectiveness of the sanitation system remains constrained due to limited sewerage network connectivity and absence of operational treatment infrastructure.

Although significant sewer laying work has reportedly been completed under ongoing infrastructure projects, field observations indicate that large portions of the network remain non-operational. Consequently, wastewater collection efficiency remains comparatively low, resulting in discharge of untreated wastewater into open drains and stormwater channels.

The assessment further reveals that the city currently lacks an operational Sewage Treatment Plant (STP), as the proposed treatment facility remains under construction. This results in direct environmental risks for River Narmada due to untreated wastewater discharge. The absence of wastewater reuse systems, limited monitoring mechanisms, and inadequate grievance redressal systems reflect governance and institutional gaps within the sanitation sector.

Discussion

The findings indicate that sanitation access alone is insufficient for ensuring environmental sustainability unless supported by effective wastewater conveyance, treatment, and disposal systems. The results align with national urban sanitation studies that identify infrastructure implementation gaps as a major challenge in medium-sized Indian cities.

In the context of Narmadapuram, inadequate wastewater management directly affects River Narmada through increased organic pollution, microbial contamination, and deterioration of ecological conditions. The findings therefore reinforce the need for integrated sanitation planning approaches that combine sewerage infrastructure, decentralized treatment systems, and river-sensitive environmental management.

Solid Waste Management Assessment

The assessment of Solid Waste Management indicators demonstrates moderate improvement in municipal waste collection services; however, substantial deficiencies persist in segregation, scientific processing, and sustainable disposal practices.

Door-to-door waste collection coverage and collection efficiency are comparatively high, indicating improved municipal service delivery. However, segregation at source remains limited, reducing the effectiveness of recycling and resource recovery systems.

The analysis further reveals significant dependence on landfill disposal and absence of sufficient scientific processing infrastructure. Limited availability of institutional data regarding scientific processing, cost recovery, and grievance redressal indicates governance and monitoring limitations.

Discussion

Improper solid waste management contributes significantly to environmental degradation in river-side cities. In Narmadapuram, disposal of waste along drains, floodplains, and river-adjacent areas may contribute to leachate generation, drain blockage, and contamination of River Narmada.

The findings suggest that existing SWM systems remain largely disposal-oriented rather than resource-recovery-oriented. Strengthening segregation, decentralized waste processing, scientific landfill management, and monitoring mechanisms is therefore essential for reducing environmental stress on river ecosystems.

Faecal Sludge Management Assessment

The assessment of Faecal Sludge Management indicators highlights substantial dependence on onsite sanitation systems within Narmadapuram. A significant proportion of households rely on septic tanks due to limited sewerage coverage.

The findings indicate that desludging practices occur at intervals broadly aligned with national guidelines; however, lack of systematic monitoring and scientific treatment infrastructure remains a major concern.

The proposed Faecal Sludge Treatment Plant (FSTP) is currently under construction and remains non-operational. Consequently, treatment efficiency is effectively absent, increasing the possibility of unsafe disposal and environmental contamination.

The assessment also indicates lack of institutional data regarding safe collection, transport, and disposal compliance, reflecting governance and regulatory gaps within the FSM system.

Discussion

In river-side cities, poorly managed onsite sanitation systems contribute significantly to microbial contamination and nutrient loading in nearby water bodies. Overflow and leakage from septic tanks often enter stormwater drains and eventually discharge into River Narmada.

The absence of scientific FSM systems therefore increases environmental and public-health risks. The findings demonstrate the urgent requirement for operationalization of

FSTP infrastructure, regulated desludging services, and scientific septage management systems.

River Health Assessment

The river water quality assessment was carried out using key physio-chemical and microbial indicators including Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Faecal Coliform, and Total Coliform at upstream and downstream locations of the urban stretch.

The BOD analysis indicates relatively higher values at downstream locations compared to upstream locations, reflecting increased organic pollution within the urban stretch. Similarly, COD levels remain consistently higher downstream, indicating increasing chemical and organic pollution load due to urban wastewater discharge.

DO levels remain relatively stable; however, declining downstream values in recent years indicate increasing ecological stress and reduction in river self-purification capacity.

Microbial indicators including Faecal Coliform and Total Coliform demonstrate higher downstream contamination levels, indicating sewage intrusion and public-health risks associated with untreated wastewater discharge.

Discussion

The river-health assessment establishes a direct relationship between urban sanitation conditions and river water quality degradation in Narmadapuram. The higher downstream pollution levels indicate the influence of urban wastewater discharge, sewage overflow, and inadequate treatment infrastructure.

The findings reveal that deficiencies in wastewater management, FSM systems, and solid waste disposal practices collectively contribute to deterioration of river ecology. Elevated BOD and COD levels indicate increasing organic and chemical pollution, while high coliform concentrations reflect microbial contamination caused by untreated sewage.

The results demonstrate that river health cannot be addressed independently from urban sanitation systems. Instead, integrated river-sensitive planning approaches are required to reduce pollution load and improve ecological resilience.

Linkages Between Urban Sanitation and River Health

The study establishes strong interconnections between urban sanitation systems and river ecosystem conditions. Indicators related to sewerage coverage, wastewater collection efficiency, treatment capacity, FSM infrastructure, and SWM systems directly influence river-health parameters such as BOD, COD, DO, turbidity, and microbial contamination.

Inadequate sewerage infrastructure and absence of operational treatment facilities increase discharge of untreated wastewater into River Narmada. Similarly, unsafe septage management and poor solid waste disposal contribute to nutrient loading, suspended solids, and microbial pollution.

Discussion

The findings reinforce that urban sanitation systems and river ecosystems function as interconnected environmental systems rather than isolated sectors. River degradation in Narmadapuram is therefore not only an environmental issue but also a consequence of infrastructural, institutional, and planning deficiencies.

The study demonstrates the need for integrated urban sanitation planning frameworks that combine:

- Sewerage infrastructure
- Wastewater treatment
- Faecal sludge management
- Solid waste management
- Riverfront environmental management
- Floodplain protection
- Governance strengthening
- Community participation

Such integrated approaches are essential for achieving long-term ecological sustainability and river-sensitive urban development.

Planning Framework Assessment

The assessment of the Draft Master Plan 2035 indicates limited integration of river-sensitive planning principles within the statutory planning framework. Although certain river-related components are acknowledged, several ecological and sanitation-related dimensions remain insufficiently addressed.

The analysis reveals limited emphasis on river-sensitive zoning, floodplain protection, integrated wastewater management, ecological restoration, and river-health-based planning approaches.

The findings indicate that existing planning approaches remain largely infrastructure-oriented and do not adequately integrate ecological and sanitation dimensions within urban planning processes. Absence of detailed river-sensitive regulations may contribute to continued environmental pressure on River Narmada through unregulated development, floodplain encroachment, and pollution discharge.

The study therefore highlights the necessity for incorporating river-sensitive urban sanitation principles within statutory planning instruments to ensure sustainable management of river-side cities.

One of the six guiding principles of the NMCG (2024) SOP states that management of river-related activities cannot be the responsibility of a single department and requires collective, coordinated action among multiple agencies.

The SOP therefore proposes a River Management Task Force (RMTF) comprising:

- District Administration
- Urban Local Bodies
- Pollution Control Board
- Water Supply and Sewerage Agencies
- Health Departments
- Fisheries Department
- Forest Department
- NGOs and Community Organizations
- Remote Sensing Agencies
- Tourism and Education Departments

with clearly defined responsibilities before, during, and after events.

Overall Findings

The overall findings of the study indicate that:

- Urban sanitation infrastructure in Narmadapuram remains partially developed and operationally inadequate.
- Limited sewerage coverage and absence of operational treatment infrastructure contribute to river pollution.
- Significant dependence on septic tanks increases the need for scientific FSM systems.
- Solid waste management systems remain largely disposal-oriented.
- River water quality deteriorates downstream due to urban pollution load.
- Existing planning frameworks inadequately integrate river-sensitive urban sanitation principles.
- Governance, monitoring, and institutional coordination gaps significantly affect environmental management outcomes.

Conclusion

The results and discussion establish that the ecological health of River Narmada is closely associated with the performance of urban sanitation systems in Narmadapuram. Deficiencies in wastewater collection, sewage treatment, faecal sludge management, and solid waste management contribute directly to river pollution and ecological degradation. The study further indicates that socio-cultural activities along riverbanks, inadequate environmental monitoring, fragmented institutional responsibilities, and insufficient sanitation facilities at riverfront locations can intensify pollution pressures on river ecosystems. Effective river management therefore requires coordinated governance, baseline environmental assessment, public participation, and protection of biodiversity and floodplain areas. The findings demonstrate the necessity for integrated river-sensitive urban sanitation planning approaches that combine infrastructure development, ecological conservation, governance strengthening, and sustainable urban planning interventions. Such approaches are essential for improving river health, enhancing urban environmental sustainability, and strengthening the relationship between cities and river ecosystems.

Chapter 8

Proposals & Recommendations

Proposal Framework for River-Sensitive Urban Sanitation Planning

Based on the analysis of urban sanitation indicators, Solid Waste Management (SWM), Faecal Sludge Management (FSM), river water quality assessment, field observations, and planning framework review, a multi-level proposal framework has been developed for Narmadapuram city along River Narmada. The proposed framework, illustrated in Figure 18, aims to establish a river-sensitive and environmentally sustainable urban system that integrates sanitation infrastructure, ecological conservation, riverfront management, and community participation within the urban planning process.

The assessment findings presented in previous sections and summarized in Tables revealed that although toilet coverage in the city is relatively high, significant deficiencies continue to exist in sewerage connectivity, wastewater collection efficiency, scientific treatment infrastructure, faecal sludge management systems, and solid waste processing mechanisms. Further, the river health assessment discussed in previous chapter demonstrated increasing downstream pollution levels in terms of BOD, COD, Faecal Coliform, and Total Coliform, indicating the direct influence of urban wastewater discharge and inadequate sanitation systems on River Narmada. Similarly, the review of the Draft Master Plan 2035 presented in Table 8 highlighted limited integration of river-sensitive planning principles within the statutory planning framework.

According to National Mission for Clean Ganga (NMCG). (2024). *Standard Operating Procedure (SOP)* "River health cannot be protected through infrastructure provision alone. Effective river-sensitive urban sanitation requires integrated governance, scientific monitoring, wastewater and solid waste management, ecological conservation, carrying-capacity assessment, and community participation within a coordinated planning framework."

In response to these identified gaps, the proposal framework shown in Figure 18 has been structured at three interconnected planning levels, namely River Level, River Fringe Level, and City Level. The framework integrates environmental, infrastructural, socio-cultural, governance, and ecological dimensions to strengthen the relationship between urban sanitation systems and river health.

At the River Level, the proposal focuses on broad ecological and riverfront-scale interventions intended to improve overall river health and environmental sustainability. The river health analysis indicated increasing pollution loads, riverbank vulnerability, and ecological stress within the urban river stretch. Therefore, interventions at this level include river protection measures such as waste removal, riverbank stabilization, and flood protection strategies to reduce environmental degradation and flood-related risks. Water-security interventions focus on improving river water quality by reducing untreated wastewater discharge into the river system.

The proposal also recognizes the socio-cultural significance of River Narmada in Narmadapuram. Field observations and ghat-level assessments discussed in earlier sections indicated that ghats and riverfront areas function as important cultural, religious, and community spaces. Accordingly, socio-cultural interventions emphasize preservation of ghats, inclusive riverfront design, and support for spiritual and community activities while ensuring environmental sustainability. Ecological interventions such as pollution reduction and vegetative buffer development are proposed to improve biodiversity, strengthen riparian ecosystems, and enhance ecological resilience along the river corridor. River-connectivity proposals including riverfront development, pedestrian bridges, viewing decks, and public recreational spaces aim to improve public accessibility while promoting environmentally sensitive riverfront management.

At the River Fringe Level, the proposal addresses the transitional zone between the river and the urban settlement where direct interaction between urban activities and river ecosystems occurs. The findings related to floodplain encroachment, inadequate drainage systems, and river pollution discussed and field observations indicate that unregulated activities within the river corridor significantly contribute to ecological degradation. Therefore, river-sensitive zoning regulations are proposed to regulate activities within environmentally sensitive river buffer zones.

Floodplain protection measures including No Construction Zones (NCZ), encroachment removal, and rehabilitation strategies are proposed to reduce flood vulnerability and protect natural river functions. Infrastructure proposals focus on interception and conveyance systems for wastewater management, along with sanitation amenities at ghats and riverfront areas to reduce direct sewage discharge into River Narmada. River buffer zoning based on High Flood Level (HFL) delineation is proposed to control environmentally harmful development activities within vulnerable riverfront areas.

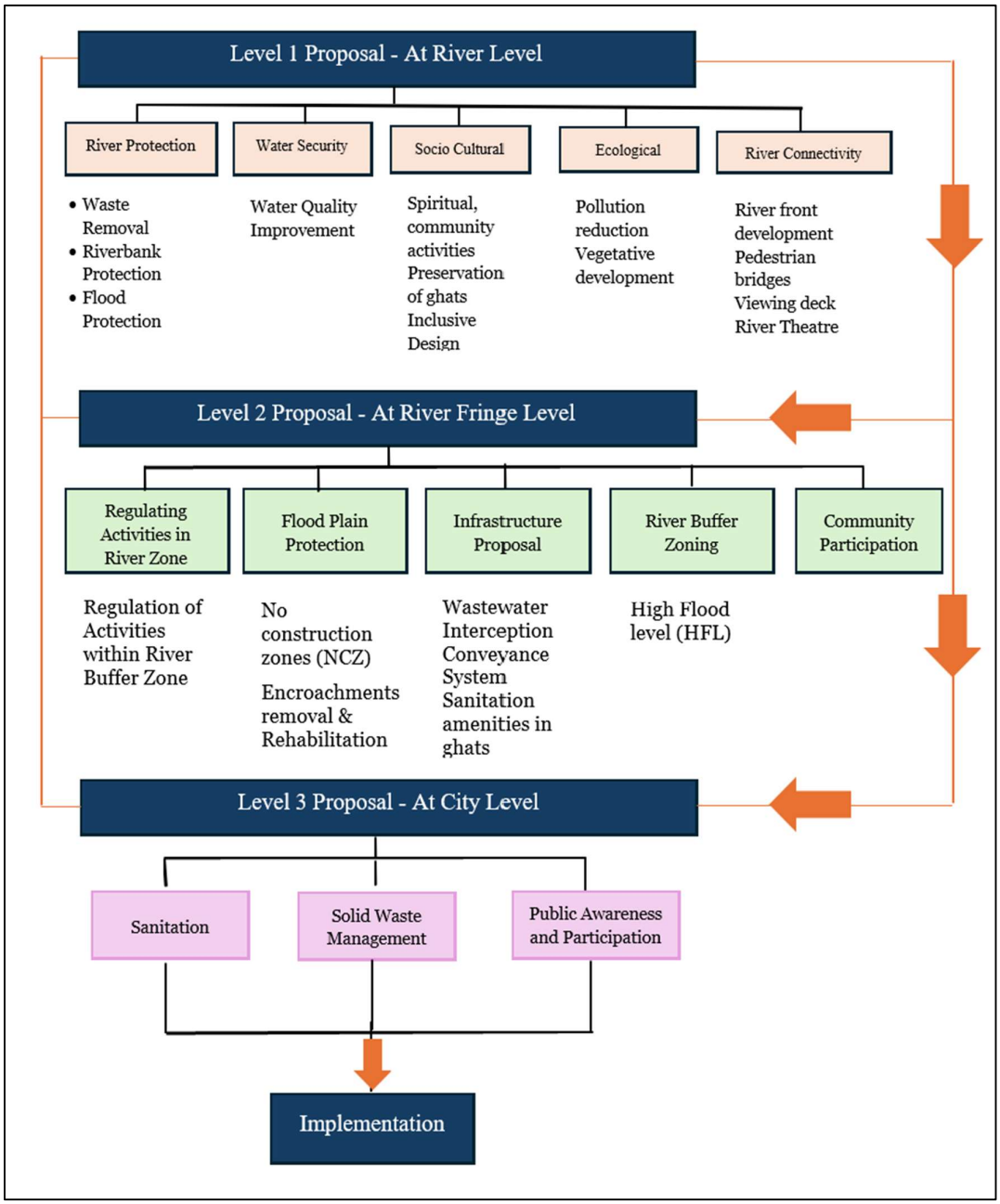

Figure 18 Approaches for proposals *Source- By Author*

The proposal further emphasizes community participation mechanisms as a critical component of river-sensitive urban sanitation planning. The governance and institutional assessment indicate gaps in monitoring systems, public participation, and institutional coordination within sanitation management systems. Therefore, involvement of local communities, NGOs, and stakeholders is proposed to strengthen awareness, monitoring, behavioral change, and long-term sustainability of river conservation initiatives.

Table 10 Consideration of River related planning component in Master Plan

Integrated River-Sensitive Urban Sanitation Planning Proposals	
Study Area: Narmadapuram (Hoshangabad), Madhya Pradesh	
At the River Level	
Planning Components	**Proposed Interventions**
Interception and Diversion of Drains	Untapped drains discharging into River Narmada to be intercepted and diverted toward STPs to prevent direct wastewater discharge into the river. (Wastewater Interception Conveyance System)
Ghat Sanitation Infrastructure	Provision of toilets, changing rooms, hygiene facilities, and drainage systems at ghats.
Vegetation Development and Microfiltration	Development of riparian vegetation buffers and microfiltration zones.
Riverfront Solid Waste Management	Installation of segregated waste collection points along ghats, Floating Plates.
Pedestrian and Green Corridor Development	Development of pedestrian pathways and green buffers.
Ritual Waste Management	Dedicated collection systems for ritual waste and floral offerings.
Decentralized Wastewater Treatment	Development of DEWATS near major outfalls and dense river-edge settlements.
Riverbank Desilting and Restoration	Periodic desilting of riverbanks and drainage channels.
Bio-remediation of Drains	Bio-remediation and phytoremediation techniques at secondary drains.
At River Fringe Area Level	
Planning Components	**Proposed Interventions**
River Buffer Zoning	Establishment of river-sensitive zoning regulations.
No Development Zone (NDZ)	Proposal for environmentally sensitive No Development Zones.
Encroachment Removal & Rehabilitation	Removals of all encroachment up to HFL and NDZ
Green Buffer Development	Development of green vegetation buffers along river edges.
Socio-Cultural Activities	Control of these activities like Bathing, ceremonial activities, religious gatherings, Evening aarti and spiritual activities.
Informal Settlement Sanitation	Provision of community toilets and FSM infrastructure.
Economic activities	Organic farming, riparian agriculture practices, and livelihood activities
Community Participation Mechanisms	Inclusion of local communities and NGOs in river sanitation programmes.
At City Level	
Planning Components	**Proposed Interventions**
Immediate Phase (2026–2029)	100% HH coverage of sewer pipelines, STP commissioning at required capacity, drain desilting, sanitation mapping, Formal waste treatment system.
Phase II (2029–2033)	Wastewater Interception Conveyance System, FSTP development, drain interception, SCADA systems.
Phase III (2033-41)	Expansion of sewerage networks, STP upgradation, 100 % wastewater reuse systems.

Source: By Author

At the City Level, the proposal addresses broader urban sanitation systems and city-wide environmental management mechanisms. The urban sanitation and FSM assessments presented in Table 6 and Table 7 revealed operational deficiencies in sewerage infrastructure, inadequate wastewater treatment systems, high dependence on onsite sanitation systems, and limited scientific solid waste management practices. Accordingly, city-level interventions focus on strengthening sanitation infrastructure, improving sewerage and wastewater treatment systems, enhancing Faecal Sludge Management (FSM) infrastructure, and promoting decentralized wastewater management approaches.

The proposal also emphasizes strengthening Solid Waste Management systems through source segregation, scientific processing, decentralized waste treatment, and environmentally safe disposal mechanisms to reduce river pollution caused by solid waste dumping and stormwater contamination. Public awareness and participation programs are proposed to improve sanitation behaviour, environmental responsibility, and community engagement in river conservation activities.

The implementation strategy illustrated in Figure 18 is categorized into two complementary approaches: Active Restoration and Passive Restoration. Active restoration includes physical and infrastructure-based interventions such as wastewater interception systems, sewerage infrastructure, ecological restoration, riverfront improvement, vegetative buffers, and sanitation facilities. Passive restoration includes policy reforms, river-sensitive zoning regulations, development control measures, institutional strengthening, floodplain protection guidelines, and governance-based interventions required for long-term environmental sustainability.

Overall, the proposed framework aims to improve river water quality, strengthen urban sanitation systems, reduce pollution load entering River Narmada, enhance ecological sustainability, and promote sustainable urban-river integration. The framework establishes an integrated river-sensitive urban sanitation planning approach that combines infrastructure development, ecological restoration, governance strengthening, and community participation to support long-term environmental resilience and sustainable urban development in Narmadapuram.

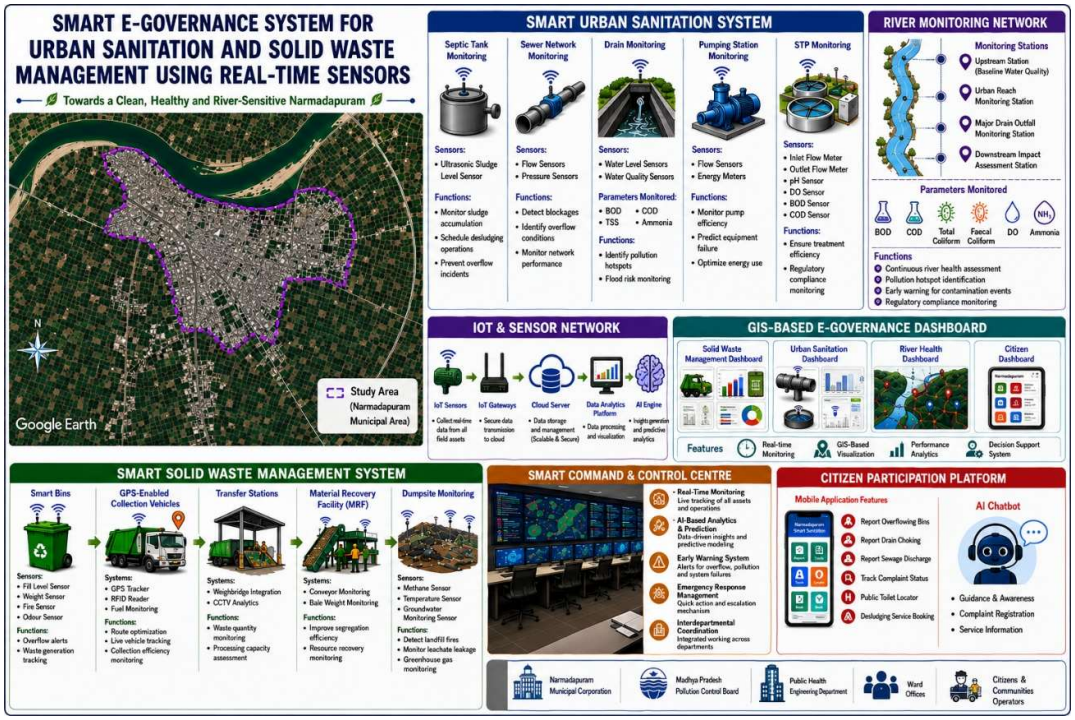

Figure 19 Smart E-governance System for Urban Sanitation and Solid Waste Management
Source- Compile by Author

The proposed Smart E-Governance System for Urban Sanitation and Solid Waste Management has been developed based on the findings of the study, which identified critical gaps in sanitation infrastructure, wastewater management, solid waste handling, monitoring mechanisms, and institutional coordination affecting the health of the River Narmada. The analysis revealed that conventional sanitation management practices are largely reactive, fragmented, and dependent on periodic inspections, resulting in delayed responses to pollution events, operational inefficiencies, and limited accountability. To address these challenges, the study proposes an integrated digital governance framework that combines IoT-enabled monitoring, GIS-based decision support, real-time data analytics, and citizen participation mechanisms.

Framework shown in figure 19, introduces a Smart Urban Sanitation System wherein key sanitation assets such as septic tanks, sewer networks, drainage systems, pumping stations, and sewage treatment plants are equipped with real-time sensors. These sensors continuously monitor operational parameters including sludge levels, flow rates, water levels, pressure conditions, and treatment efficiency. Such monitoring enables early detection of sewer blockages, overflow incidents, drain pollution, pump failures, and treatment plant inefficiencies, thereby reducing the risk of untreated wastewater entering the river system.

Recognizing the direct relationship between sanitation performance and river health established during the study, a dedicated River Monitoring Network is proposed along the urban stretch of the Narmada River. Real-time monitoring stations located upstream, within the urban reach, at major drain outfalls, and downstream of the city continuously assess key water quality parameters including BOD, COD, Dissolved Oxygen (DO), Ammonia, Total Coliform, and Faecal Coliform. This system enables timely identification of pollution hotspots and supports evidence-based environmental management and regulatory compliance.

To address deficiencies observed in solid waste management practices, the framework incorporates a Smart Solid Waste Management System consisting of sensor-based community bins, GPS-enabled collection vehicles, digitally monitored transfer stations, material recovery facilities, and landfill monitoring systems. Smart bins equipped with fill-level sensors help optimize collection schedules, while GPS-enabled vehicles improve route efficiency and service accountability. Monitoring of recovery facilities and disposal sites supports resource recovery, landfill safety, and reduction of environmental pollution.

A key component of the proposed framework is the establishment of an integrated IoT and Sensor Network, which acts as the digital backbone of the system. Data generated from sanitation infrastructure, waste management facilities, and river monitoring stations are transmitted through IoT gateways to a centralized cloud platform where they are processed using advanced analytics and artificial intelligence tools.

The collected information is visualized through a GIS-Based E-Governance Dashboard, enabling municipal authorities to monitor service delivery, infrastructure performance, river health indicators, and citizen grievances in real time. The dashboard facilitates spatial analysis of pollution hotspots, infrastructure gaps, and operational inefficiencies, thereby strengthening planning, monitoring, and decision-making processes.

To ensure effective governance and interdepartmental coordination, the framework proposes a Smart Command and Control Centre that functions as the central decision-support platform. The center integrates data from sanitation systems, waste management operations, and river monitoring networks to generate alerts, predict operational failures, support emergency response actions, and facilitate coordinated interventions among municipal departments.

The framework further strengthens public participation through a Citizen Participation Platform, allowing residents to report overflowing bins, drain blockages, sewage discharges, and sanitation-related issues using mobile applications and AI-assisted grievance systems. This promotes transparency, accountability, and community engagement in urban environmental management.

Overall, the proposed Smart E-Governance Framework represents a transition from conventional infrastructure-focused sanitation management to a data-driven, river-sensitive, and performance-oriented governance model. By integrating real-time monitoring, digital technologies, institutional coordination, and citizen participation, the framework supports the long-term sustainability of urban sanitation systems while contributing to the protection and restoration of the ecological health of the River Narmada. This approach aligns with the principles of River-Sensitive Urban Planning (RSUP), National Mission for Clean Ganga (NMCG), and Smart City governance frameworks, providing a replicable model for river-dependent urban settlements across India.



Figure 20 Various Interventions *Source- Compile by Author*

Figure 19 illustrates multiple interventions that have been suggested at different levels.

Based on the assessment of urban sanitation indicators, river-health analysis, field observations, stakeholder consultations, and spatial planning studies conducted in Narmadapuram, a comprehensive set of river-sensitive planning interventions is proposed to strengthen the relationship between urban sanitation systems and the ecological health of River Narmada. The findings revealed that deficiencies in wastewater collection, untreated drain outfalls, inadequate riverfront sanitation infrastructure, solid waste accumulation near ghats, and ecological degradation along the river corridor contribute significantly to declining river health. Therefore, the proposed framework adopts an integrated approach that combines sanitation infrastructure, ecological restoration, climate resilience, community participation, and sustainable urban development.

The proposal prioritizes water and sanitation interventions such as interception and diversion of untreated drains to sewage treatment facilities, inspection and rehabilitation of sewer networks, pumping infrastructure for wastewater conveyance, floating waste collection systems, and treatment of currently unmanaged wastewater entering the river. These interventions directly address the pollution sources identified during the river-health assessment and aim to reduce pollutant loads entering River Narmada.

Recognizing the ecological significance of the river corridor, the framework incorporates nature-based and ecological interventions, including aquatic and riparian habitat restoration, wetland development, bio-swales, rain gardens, detention landscapes, sponge-city elements, and nala rejuvenation measures. These interventions support biodiversity conservation, improve water retention, enhance groundwater recharge, and strengthen the ecological resilience of the riverfront environment.

The study also identified the need for improved public accessibility and environmentally sensitive riverfront development. Accordingly, urban design and mobility interventions such as pedestrian bridges, viewing decks, river theatres, green corridors, permeable pavements, and non-motorized connectivity routes are proposed to improve public interaction with the river while minimizing environmental impacts.

Considering the strong socio-cultural relationship between Narmadapuram and River Narmada, the framework further proposes social and community interventions, including educational spaces, community integration areas, social inclusion zones, and river-awareness programs. These interventions aim to promote environmental stewardship,

encourage responsible riverfront use, and strengthen community participation in river conservation efforts.

In addition, flood-resilient landscape strategies involving seasonal farming, organic agriculture, vegetative buffers, and controlled floodplain utilization are proposed to enhance climate resilience, reduce flood risks, improve local livelihoods, and support sustainable land-use practices along the river corridor.

Collectively, these interventions translate the findings of the study into a practical river-sensitive urban sanitation framework that integrates physical planning, environmental management, governance mechanisms, and community participation. The proposed approach seeks not only to improve sanitation service delivery but also to restore ecological functions, enhance river health, and promote sustainable urban development in Narmadapuram.

REFERENCES

1. Kaushik, N., Pandey, A. K., & Agrawal, A. (2026). The Dravyavati River Rejuvenation Project: A case study. Springer Nature.
2. Randhawa, A., & Tarush, C. (2017). Revitalization of Dravayawati River, Jaipur, India: A water-front development project. Journal of Geography and Regional Planning, 10(3), 28–38.
3. Sharma, K., & Gupta, P. (2021). Hydrological challenges in riverfronts: A case study of Dravayawati Riverfront Project in Jaipur, Rajasthan.
4. Singh, et al. (2023). River rejuvenation in urban India for enhancing living conditions through integrated water resources management. Environmental Science and Pollution Research.ase Studies
5. Desai, R. (2012). Governing the urban through riverfront development and displacement in Ahmedabad. Economic and Political Weekly, 47(47–48), 49–56.
6. Mahadevia, D. (2011). Branded and renewed? Policies, politics and processes of urban development in the reform era: The case of Ahmedabad. Working Paper, Centre for Urban Equity, CEPT University.
7. Sabarmati Riverfront Development Corporation Limited (SRFDCL). (2020). Sabarmati Riverfront Development Project Reports. Ahmedabad Municipal Corporation.
8. Datta, A. (2015). New urban utopias of postcolonial India: 'Entrepreneurial urbanization' in Dholera smart city, Gujarat. Dialogues in Human Geography, 5(1), 3–22.
9. EcoSattva. (2022). Kham River Restoration Initiative: Project documentation and restoration framework. Pune: EcoSattva Environmental Solutions.
10. Central Pollution Control Board (CPCB). (2021). Polluted River Stretches for Restoration of Water Quality. Ministry of Environment, Forest and Climate Change, Government of India. New Delhi, India.
11. National Mission for Clean Ganga (NMCG). (2020). Framework for River Rejuvenation and River-Sensitive Urban Planning. Ministry of Jal Shakti, Government of India, New Delhi.
12. World Health Organization (WHO). (2017). Guidelines for Drinking-Water Quality (4th ed.). Geneva: World Health Organization.
13. Atal Bihari Vajpayee Institute of Good Governance and Policy Analysis. (2024). Narmada Ghat Survey Report. Government of Madhya Pradesh.
14. Central Pollution Control Board. (2021). Polluted river stretches assessment report. Ministry of Environment, Forest and Climate Change, Government of India.

15. Ministry of Housing and Urban Affairs. (2021). Swachh Bharat Mission-Urban 2.0 guidelines. Government of India.
16. Ministry of Jal Shakti. (2021). National river conservation and wastewater management report. Government of India.
17. National Institute of Urban Affairs. (2020). Urban sanitation governance and institutional framework in India. NIUA, New Delhi.
18. National Mission for Clean Ganga. (2020). Namami Gange programme: Framework for river rejuvenation. Ministry of Jal Shakti, Government of India.
19. Narain, V. (2016). Urbanization, peri-urban water insecurity and human development. Water International, 41(5), 676–693.
20. Prasad, C. S. J. (2013). Urban environmental governance and sanitation planning challenges in India. Indian Journal of Public Administration, 59(3), 527–541.
21. Singh, N., Basu, S., & Vashishtha, P. (2020). Urban rivers in India: Challenges and restoration approaches. Current Science, 119(4), 610–617.
22. UN Women. (2022). Gender, sanitation and urban inclusion. United Nations.
23. WaterAid India. (2021). The state of urban sanitation in India: Gender and inclusion perspectives. WaterAid.
24. World Bank. (2021). Urban sanitation and wastewater management in India. World Bank Group.
25. Black, M., & Fawcett, B. (2008). The last taboo: Opening the door on the global sanitation crisis. Earthscan.
26. Brown, R. R., Keath, N., & Wong, T. H. F. (2009). Urban water management in cities: Historical, current and future regimes. Water Science and Technology, 59(5), 847–855.
27. United Nations Environment Programme. (2016). A snapshot of the world's water quality: Towards a global assessment. UNEP.
28. Shaikh, R., & Ali, S. (2020). Assessment of water quality degradation in Kham River due to urban and industrial pollution in Aurangabad city. International Journal of Environmental Sciences, 11(3), 145–152.
29. WRI India. (2023). Urban River Management Plan for Kham River under River Cities Alliance. New Delhi: World Resources Institute India.
30. Varroc Foundation. (2022). Community engagement and ecological restoration initiatives along Kham River. Aurangabad.
31. References (APA Style)
32. Central Pollution Control Board (CPCB). (2021). Polluted river stretches in India: Restoration and monitoring reports. New Delhi: CPCB.
33. Hyderabad Metropolitan Development Authority (HMDA). (2022). Musi Riverfront Development Project Reports. Hyderabad.

34. Reddy, M., & Kumar, S. (2019). Assessment of water quality degradation in Musi River due to urbanization and industrial pollution in Hyderabad. International Journal of Environmental Studies, 76(4), 602–615.
35. Telangana State Pollution Control Board (TSPCB). (2021). Water quality status of Musi River. Hyderabad.
36. References (APA Style)
37. Cho, M. (2010). The politics of urban nature restoration: The case of Cheonggyecheon restoration in Seoul, Korea. International Development Planning Review, 32(2), 145–165.
38. Lee, J., & Anderson, C. (2013). The restoration of Cheonggyecheon stream in Seoul and its social and ecological impacts. Journal of Urban Design, 18(2), 257–276.
39. References (APA Style)
40. PUB Singapore. (2021). Clean rivers: Singapore River and Kallang Basin cleanup. Singapore: Public Utilities Board.
41. Tortajada, C., & Joshi, Y. K. (2013). The Singapore water story: Sustainable development in an urban city-state. International Journal of Water Resources Development, 29(4), 638–647.
42. Benson, D., & Ak, M. Y. (2022). Assessing the water security effectiveness of integrated river basin management: Comparative case study analysis for lesson-drawing. Frontiers in Water, 4, Article 1013588.
43. UNESCO. (2009). Integrated water resources management in action: The United Nations World Water Assessment Programme Dialogue Paper (No. SC.2009/WS/03).
44. Ministry of Housing and Urban Affairs, Government of India. (2020). River Centric Urban Planning Guidelines. https://www.mohua.gov.in/upload/uploadfiles/files/RCUP%20Guidelines.pdf
45. Urban Design Lab (2022, August 4). Integration of rivers in urban development.
46. Earth5R (2020). Urban River Defense Strategy: A Step-by-step Community Protocol.
47. UNESCO. (2009). Integrated water resources management in action: The United Nations World Water Assessment Programme Dialogue Paper (No. SC.2009/WS/03), Section: Better and sustainable water resources management.
48. Ministry of Housing and Urban Affairs, Government of India. (2020). River Centric Urban Planning Guidelines: Highlight the need for river centric master planning.
49. Earth5R (2020). United Nations Environment Programme (UNEP) emphasizes the need for integrated river management.

50. Ministry of Housing and Urban Affairs, Government of India. (2020). River Centric Urban Planning Guidelines: River health needs to be mainstreamed into urban planning.
51. National Mission for Clean Ganga (NMCG). (2020). Urban River Management Plan Framework.
52. Urban Design Lab (2022, August 4). Rivers have been at the receiving end of unprecedented urbanization.
53. National Mission for Clean Ganga (NMCG). (2020). Mainstreaming Urban River Report.
54. India Rivers Forum. (n.d.). Advisories and guidelines: River Regulation Zones (RRZ) as an advisory for state/UTs.
55. Benson, D., & Ak, M. Y. (2022). Assessing the water security effectiveness of integrated river basin management: Comparative case study analysis for lesson-drawing. Frontiers in Water, 4, Article 1013588.

ANNEXURES

1. Plagarism report