

INTEGRATED RIVERFRONT DEVELOPMENT AND CONSERVATION OF KALIYASOT RIVER, BHOPAL

THESIS REPORT

Submitted in the partial fulfilment of the requirements for the award of the degree of
BACHELOR OF PLANNING

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May, 2026

DECLARATION

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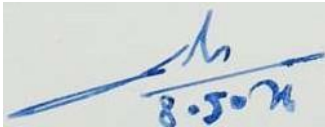
CERTIFICATE

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सार

तेजी से शहरीकरण हो रहे भारतीय शहरों में शहरी नदियाँ अनियंत्रित सीवेज निकासी, पारिस्थितिक रूप से संवेदनशील बफर क्षेत्रों में अवैध अतिक्रमण, प्राकृतिक रिपेरियन वनस्पति के व्यवस्थित क्षरण तथा गैर-मानसूनी महीनों में नदी प्रवाह के लगभग पूर्ण समाप्त होने के कारण गंभीर और बहुआयामी पारिस्थितिक दबाव का सामना कर रही हैं। इन सभी कारकों के संयुक्त प्रभाव ने भारत के द्वितीयक शहरों में कार्यशील नदी पारिस्थितिकी तंत्रों को खुले नालों में परिवर्तित कर दिया है — ऐसे जलमार्ग जो ऐतिहासिक रूप से प्रदान की जाने वाली पर्यावरणीय सेवाओं, मनोरंजन सुविधाओं और आर्थिक उत्पादकता के बजाय सार्वजनिक स्वास्थ्य संकट, पारिस्थितिक पतन और सामाजिक असमानता उत्पन्न करते हैं।

मध्य प्रदेश के भोपाल शहर में स्थित कालीयसोत नदी इस परिघटना का एक महत्वपूर्ण और विश्लेषणात्मक रूप से प्रासंगिक उदाहरण प्रस्तुत करती है। यह नदी भोपाल की अपर लेक (ऊपरी झील) के स्पिलवे से उत्पन्न होती है — जो भारत के सबसे प्राचीन कृत्रिम जलाशयों में से एक है — और लगभग 29 किलोमीटर लंबी धारा में बहते हुए भोपाल के घनी शहरी क्षेत्र, मिसरोद के अर्ध-शहरी संक्रमण क्षेत्र तथा मंडीदीप के औद्योगिक क्षेत्र से गुजरते हुए भोजपुर के निकट बेतवा नदी में मिलती है। इसका जलग्रहण क्षेत्र 18.16 वर्ग किलोमीटर है, जो अब मुख्यतः अपारगम्य शहरी सतहों से आच्छादित है। यह नदी वर्ष के लगभग 8 से 9 महीनों तक शुष्क रहती है और एक पारिस्थितिक संसाधन के बजाय नगरपालिका सीवेज और औद्योगिक अपशिष्ट के वाहक के रूप में कार्य करती है।

यह शोध कालीयसोत नदी के संपूर्ण प्रवाह क्षेत्र का एक समेकित अध्ययन प्रस्तुत करता है, जिसमें बहु-स्रोत डेटा फ्रेमवर्क का उपयोग किया गया है। इसमें 2015 से 2025 की अवधि के लिए Landsat 8 और Sentinel-2 उपग्रह चित्रों के माध्यम से रिमोट सेंसिंग विश्लेषण, भूमि उपयोग परिवर्तन, बफर जोन उल्लंघन और जल-वैज्ञानिक गिरावट का GIS विश्लेषण, मध्य प्रदेश प्रदूषण नियंत्रण बोर्ड (MPPCB, 2019) की रिपोर्ट पर आधारित पाँच मॉनिटरिंग स्टेशनों का जल गुणवत्ता विश्लेषण, 29 किलोमीटर क्षेत्र का फील्ड सर्वेक्षण एवं फोटोग्राफिक दस्तावेजीकरण तथा ज़ोन 1 और ज़ोन 2 में 120 परिवारों के संरचित साक्षात्कार शामिल हैं।

विश्लेषण से पूरे नदी क्षेत्र में गंभीर पारिस्थितिक गिरावट के संकेत मिलते हैं। जल गुणवत्ता सूचकांक (WQI) ऊपरी भाग के दमखेड़ा स्टेशन पर 82 (अत्यंत खराब) से लेकर औद्योगिक निकास बिंदु पर 225 से अधिक (पारिस्थितिक पतन) तक पाया गया। जैविक ऑक्सीजन मांग (BOD) का स्तर CPCB के निर्धारित मान (3 mg/L) से 6 गुना से लेकर 56 गुना तक अधिक पाया गया। सर्वधर्म क्षेत्र में घुलित ऑक्सीजन (DO) का स्तर शून्य mg/L दर्ज किया गया, जो जैविक रूप से मृत क्षेत्र को दर्शाता है जहाँ कोई भी जलीय जीव जीवित नहीं रह सकता। फीकल कोलीफॉर्म की मात्रा 31,000 MPN/100 mL तक पहुँच गई, जो सुरक्षित मानव संपर्क सीमा से 62 गुना अधिक है।

भूमि उपयोग विश्लेषण से पता चलता है कि 2015 से 2025 के बीच निर्मित क्षेत्र में 23% की वृद्धि (38% से 61%) हुई है, जबकि NDWI के अनुसार सतही जल की उपस्थिति में 34%

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की कमी आई है। राष्ट्रीय हरित अधिकरण (NGT) द्वारा निर्धारित 33 मीटर के बफर क्षेत्र का उल्लंघन 18% से 78% तक पाया गया, जिसमें कुल 321 संरचनाएँ संरक्षित क्षेत्र में स्थित हैं।

सामाजिक-आर्थिक विश्लेषण में यह पाया गया कि नदी पर निर्भर समुदाय — विशेष रूप से जोन 1 में रहने वाले 38% अनौपचारिक बस्तियों के निवासी — प्रदूषण के मुख्य स्रोत नहीं हैं। सहसंबंध गुणांक ($r = +0.12$) इस धारणा को खारिज करता है कि झुग्गी बस्तियाँ नदी प्रदूषण का प्रमुख कारण हैं। इसके बजाय पाँच प्रमुख नालों और अत्यधिक भारग्रस्त मिसरोद STP को मुख्य प्रदूषण स्रोत के रूप में पहचाना गया। साथ ही, 78% महिला उत्तरदाताओं ने नदी क्षेत्र को असुरक्षित बताया, जो सुरक्षा संबंधी गंभीर समस्या को दर्शाता है।

इन निष्कर्षों के आधार पर यह शोध एक समेकित हस्तक्षेप ढाँचा प्रस्तुत करता है, जिसमें चार प्रमुख प्रस्ताव शामिल हैं, जिन्हें I-SEER (Integrated Social, Economic and Environmental Restoration) फ्रेमवर्क के आधार पर मूल्यांकित किया गया है:

- (i) विकेन्द्रीकृत सीवेज उपचार संयंत्रों (STPs) के माध्यम से 170 MLD क्षमता का पर्यावरणीय प्रवाह (E-Flow) पुनर्स्थापन
- (ii) 8–10 छोटे चेक डैम का नेटवर्क, जो जल धारण और भूजल पुनर्भरण को बढ़ावा देता है
- (iii) जोन 3 के अंत में 3–4 हेक्टेयर क्षेत्र में निर्मित आर्द्रभूमि (Constructed Wetlands), जो अंतिम पारिस्थितिक फिल्टर का कार्य करती है
- (iv) चार-क्षेत्रीय (4-Zone) नदी तट विकास मॉडल, जिसमें पारिस्थितिक पुनर्स्थापन को सार्वजनिक विकास से पहले प्राथमिकता दी गई है

कार्यान्वयन को 10 वर्षों (2025–2035) की अवधि में चार चरणों में विभाजित किया गया है, जिसमें पहले प्रदूषण नियंत्रण, फिर पारिस्थितिक पुनर्स्थापन और अंत में नदी तट विकास किया जाएगा। प्रत्येक चरण को WQI सुधार, DO स्तर और वनस्पति वृद्धि जैसे मापनीय संकेतकों से जोड़ा गया है।

अंततः, यह शोध दर्शाता है कि पारिस्थितिकी-आधारित और सामाजिक समावेशन पर आधारित नदी तट विकास न केवल तकनीकी रूप से संभव है, बल्कि संस्थागत रूप से भी लागू किया जा सकता है। यह अध्ययन अर्ध-शुष्क क्षेत्रों की शहरी नदियों के पुनर्स्थापन के लिए एक पुनरुत्पादनीय मॉडल प्रदान करता है।

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ABSTRACT

Urban rivers in rapidly urbanising Indian cities are subjected to severe and compounding ecological stress as a result of unregulated sewage discharge, illegal encroachment upon ecologically sensitive buffer zones, systematic loss of natural riparian vegetation, and the near-total elimination of river flow during non-monsoon months. These combined pressures have, in secondary cities across India, effectively converted functioning river ecosystems into open sewage drains — waterways that generate public health hazards, ecological collapse, and social inequity rather than the environmental services, recreational amenity, and economic productivity that rivers historically provided to urban communities.

The Kaliyasot River in Bhopal, Madhya Pradesh, represents a critical and analytically significant case of this phenomenon. Originating from the spillway of Bhopal's Upper Lake — one of the oldest artificial water bodies in India — the river traverses a 29-kilometre corridor through the dense urban core of Bhopal, the peri-urban transitional zone of Misrod, and the industrial landscape of Mandideep before joining the Betwa River near Bhojpur. Its catchment area of 18.16 square kilometres is now dominated by impervious urban surfaces, and the river remains dry for approximately eight to nine months each year, functioning as a carrier of municipal sewage and industrial effluent rather than as an ecological asset.

This thesis presents a comprehensive integrated study of the full Kaliyasot River corridor using a multi-source data framework encompassing: remote sensing analysis of Landsat 8 and Sentinel-2 satellite imagery for the period 2015 to 2025; Geographic Information System (GIS) analysis of land use change, buffer zone violations, and hydrological decline; water quality analysis at five monitoring stations based on the Madhya Pradesh Pollution Control Board report (MPPCB, 2019); field surveys and photographic documentation of the 29-kilometre corridor; and structured household interviews with 120 respondents across Zones 1 and 2 of the corridor.

The analysis reveals conditions of severe ecological degradation across the full corridor. The Water Quality Index (WQI) ranges from 82 at the upstream Damkheda station — classified as 'Very Poor' — to values exceeding 225 at the

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industrial outfall, classified as 'Ecological Collapse' under the Central Pollution Control Board (CPCB) methodology. Biological Oxygen Demand (BOD) values exceed the CPCB Class B permissible limit of 3 mg/L by factors ranging from six at the upstream station to 56 at the industrial outfall. Dissolved Oxygen levels at the Sarvdharm monitoring location have been recorded at zero milligrams per litre, confirming a biologically dead zone in which no aerobic aquatic life can survive. Faecal Coliform counts at Station S5 reach 31,000 MPN per 100 mL — 62 times the permissible limit for any form of safe human contact with the water. Land use analysis demonstrates a 23 percentage point increase in built-up area within the catchment — from 38 percent in 2015 to 61 percent in 2025 — alongside a 34 percent decline in surface water presence as measured by the Normalised Difference Water Index (NDWI). The National Green Tribunal's mandatory 33-metre ecological buffer has been violated at rates ranging from 18 to 78 percent at different locations, with 321 structures identified within the protected zone.

On the socio-economic dimension, a survey of 120 households reveals that communities most dependent on the river — concentrated in the Zone 1 upstream section where 38 percent of residents live in informal settlements — are demonstrably not the primary sources of pollution. A Pearson correlation coefficient of $r = +0.12$ between informal settlement density and pollution load effectively disproves the commonly applied assumption that riverside slums are the primary drivers of river degradation. The five major nallah outfalls and the overloaded Misrod STP are identified as the dominant pollution sources. The social analysis further reveals that 78 percent of female respondents feel unsafe at the riverfront, establishing a critical gender safety deficit that must be addressed in any development proposal.

In response to these findings, the thesis proposes an integrated intervention framework comprising four complementary proposals, evaluated against the I-SEER (Integrated Social, Economic and Environmental Restoration) framework (Journal of Cleaner Production, 2025): (i) Environmental Flow restoration through a decentralised network of Sewage Treatment Plants totalling 170 Million Litres per Day capacity, using Sequential Batch Reactor and Eco-STP technologies; (ii) a check dam network of 8 to 10 sub-metre structures for flow retention and

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groundwater recharge, designed in accordance with IS 14451 and the Dam Safety Act 2021; (iii) constructed wetland cells of 3 to 4 hectares at the Zone 3 terminus, functioning as a final ecological filter before the Betwa River confluence; and (iv) a four-zone eco-sensitive riverfront development model sequencing ecological restoration ahead of public infrastructure, incorporating 30 percent livelihood space, CPTED safety design, and bioengineered bank treatments in place of concrete embankments.

The implementation is structured across four phases spanning a ten-year horizon (2025–2035), ensuring that pollution control precedes ecological restoration, which in turn precedes public realm development. Each phase is linked to measurable performance thresholds — defined by WQI improvement, dissolved oxygen recovery, and riparian cover increase — ensuring that phase transitions are evidence-based rather than time-driven. A governance recommendation for the establishment of a unified Kaliyasot River Corridor Authority is proposed as a pre-condition for implementation.

The thesis demonstrates that ecology-first, equity-centred riverfront planning is both technically feasible and institutionally achievable for secondary urban rivers in semi-arid central Indian contexts. Its findings contribute to the growing literature on non-perennial urban river restoration and provide a replicable framework applicable to comparable river corridors across Madhya Pradesh and beyond.

Keywords: Riverfront development; Urban river restoration; Environmental flow; Water quality index; LULC change; Constructed wetlands; Kaliyasot River; Bhopal; Nature-Based Solutions; Decentralised Sewage Treatment; I-SEER framework; Riparian buffer; Seasonal river; Semi-arid hydrology.

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The household survey that underlies the socio-economic analysis of this thesis was made possible by the cooperation of residents of the Damkheda, Shahpura, Sarvadharam, Misrod, and Danish Kunj localities along the Kaliyasot River corridor. Their willingness to articulate their experiences of the river; its historical importance to their livelihoods and cultural practices, its present degradation, and their aspirations for its future. I am particularly grateful to the women respondents whose candid accounts of gender safety conditions at the riverfront transformed a statistical finding into a planning imperative.

I acknowledge the guidance of planning academics, practitioners, and researchers whose published work, case study reports, and policy documents I have drawn upon extensively. The literature review in Chapter 2 is a testament to the richness of scholarship in urban river restoration, and I have endeavoured to represent each source faithfully and with appropriate attribution.

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LIST OF ABBREVIATIONS

Abbreviation	Full Form / Description
BDA	Bhopal Development Authority
BGI	Blue-Green Infrastructure
BOD	Biological Oxygen Demand (mg/L)
BIS	Bureau of Indian Standards
CGWB	Central Ground Water Board
COD	Chemical Oxygen Demand (mg/L)
CPCB	Central Pollution Control Board
CPTED	Crime Prevention Through Environmental Design
CWC	Central Water Commission
DEM	Digital Elevation Model
DO	Dissolved Oxygen (mg/L)
DPR	Detailed Project Report
E-Flow	Environmental Flow
GIS	Geographic Information System
GEE	Google Earth Engine
HSSF	Horizontal Subsurface Flow (Wetland)
I-SEER	Integrated Social, Economic and Environmental Restoration
IUCN	International Union for Conservation of Nature
JDA	Jaipur Development Authority

Integrated Riverfront Development and Conservation of Kaliyasot River, Bhopal

Abbreviation	Full Form / Description
LULC	Land Use Land Cover
MLD	Million Litres per Day
MoEFCC	Ministry of Environment, Forest and Climate Change
MoHUA	Ministry of Housing and Urban Affairs
MPPCB	Madhya Pradesh Pollution Control Board
NbS	Nature-Based Solutions
NDVI	Normalised Difference Vegetation Index
NDWI	Normalised Difference Water Index
NGT	National Green Tribunal
NIUA	National Institute of Urban Affairs
NRCP	National River Conservation Plan
PCMC	Pimpri-Chinchwad Municipal Corporation
PUB	Public Utilities Board (Singapore)
SBR	Sequential Batch Reactor
STP	Sewage Treatment Plant
TDS	Total Dissolved Solids (mg/L)
ULB	Urban Local Body
URMP	Urban River Management Plan (MoHUA 2019)
WQI	Water Quality Index

CHAPTER 1 — INTRODUCTION

1.1 Background and Context of the Study

1.1.1 The Global Urban River Crisis

Rivers are among the most fundamental of all urban infrastructure elements. Historically, the relationship between cities and their rivers was one of mutual dependence: cities located themselves on rivers for water supply, transport, trade, and defence, and rivers were in turn shaped by the cultural, agricultural, and industrial practices of the communities that settled their banks. From the ancient hydraulic civilisations of Mesopotamia and the Indus Valley to the mercantile cities of Renaissance Europe and the industrial centres of nineteenth-century Britain, rivers were not merely convenient geographic features — they were the organising infrastructure of urban life.

The industrial revolution and the subsequent century of rapid urbanisation fundamentally disrupted this relationship. In the Global North, the technological capacity to treat rivers as engineering problems — to channel, embank, channelise, and in some cases bury them entirely — led to the systematic degradation of urban rivers as ecological and social assets. The Thames in London, the Chicago River in the United States, the Rhine in Germany, and the Tama River in Japan all passed through periods of severe industrial and domestic pollution that effectively eliminated their ecological function and removed them from the social consciousness of urban populations.

In the Global South, the timeline was compressed: the ecological degradation that took a century in industrialised countries has occurred within one to two generations in rapidly urbanising cities of Asia, Africa, and Latin America. The drivers are analogous — industrial discharge, municipal sewage, impervious surface expansion, encroachment on floodplains — but they operate at greater scale, higher speed, and against a backdrop of weaker institutional capacity for environmental regulation and enforcement. The result, as documented extensively in the academic literature (UN-Habitat, 2015; IUCN, 2016; Tockner et al., 2010),

is that a large proportion of the rivers flowing through secondary and tertiary cities of the Global South are in conditions of severe ecological degradation, functioning as drainage channels and sewage carriers rather than as living ecosystems.

However, the global discourse on urban rivers has shifted significantly since the 1990s. Landmark restoration projects — the Cheonggyecheon in Seoul (completed 2005), the Bishan-Ang Mo Kio in Singapore (2012), the High Line-informed river restorations of Los Angeles — have demonstrated that ecological restoration of urban rivers is not only ecologically beneficial but socially, economically, and politically transformative. These projects have catalysed a global movement toward what is now termed ecology-led riverfront planning: the principle that the health of the river ecosystem must be the non-negotiable foundation upon which all other riverfront planning decisions rest (PUB Singapore, 2012; Prominski et al., 2012).

1.1.2 Urban River Degradation in India — A Systemic Crisis

India presents a particularly acute version of the global urban river crisis. The country's rapid urbanisation — with the urban population having grown from 290 million in 2001 to approximately 500 million in 2021, and projected to exceed 800 million by 2050 — has placed unprecedented and largely unmanaged pressures on the urban water environment. The Central Pollution Control Board's annual monitoring data consistently documents severe degradation of rivers in the vicinity of urban settlements: in 2024, the CPCB identified 304 polluted river stretches across India, of which 179 were critically polluted with a Biological Oxygen Demand exceeding 30 mg/L.

The causes of river degradation in Indian cities are well-established in both academic and policy literature. Sewage treatment capacity has systematically lagged behind sewage generation as urbanisation proceeds: the combined sewage generation of Indian cities exceeds 72,000 Million Litres per Day, while installed treatment capacity is approximately 31,000 MLD — less than half of generation — and actual utilisation of available capacity is even lower at around 18,000 MLD (CPCB, 2024; NIUA, 2021). The consequence is that the majority of urban sewage reaches rivers untreated, supplying a continuous biological oxygen demand load

that eliminates dissolved oxygen and renders the aquatic environment uninhabitable.

Compounding the sewage problem are: the industrial effluent discharge from the numerous industrial estates that have been developed adjacent to or within urban water catchments; the systematic encroachment of natural floodplains and riverbank zones by both informal settlements and formal development; the conversion of natural permeable surfaces to impervious urban land uses that accelerates runoff, reduces groundwater recharge, and increases peak flood discharge while simultaneously eliminating base flows; and the near-total destruction of riparian vegetation along urban river banks, removing the natural filtration, bank stabilisation, and ecological connectivity functions that healthy riparian zones provide. These causes operate simultaneously and reinforce each other, producing compound degradation that no single intervention can address.

Policy responses to urban river degradation in India have been both numerous and insufficiently effective. The National River Conservation Plan (NRCP), initiated in 1985, has invested substantial resources in river pollution abatement but has focused primarily on large, perennial rivers rather than the more numerous secondary and seasonal rivers that drain India's secondary cities. The Smart Cities Mission (2015) introduced riverfront development as a key urban amenity component but inadvertently replicated in several cities the embankment-and-displacement model that academic research has identified as ecologically and socially harmful. The Urban River Management Plan issued by the Ministry of Housing and Urban Affairs in 2019 represents the most comprehensive policy response to date, but its implementation across secondary cities remains nascent. The National Green Tribunal's buffer zone orders provide a legal framework for riparian protection but face persistent enforcement challenges.

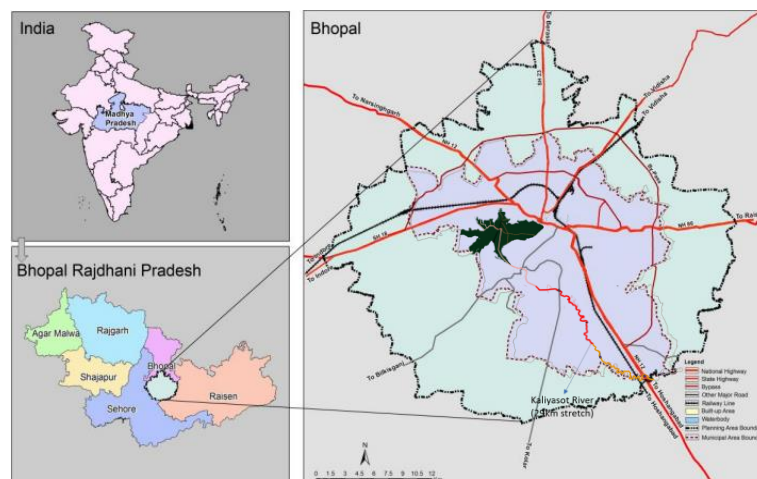
1.1.3 The Significance of the Kaliyasot River

Within this national context, the Kaliyasot River in Bhopal, Madhya Pradesh, represents a case of particular ecological urgency, planning significance, and analytical tractability. As the primary drainage channel connecting Bhopal's Upper Lake — one of India's oldest and most ecologically significant artificial lakes

— to the Betwa River, the Kaliyasot plays a critical hydrological role in the regional water system. Its health directly affects both the quality of the Upper Lake, from which Bhopal draws a portion of its urban water supply, and the ecological integrity of the Betwa River, a major tributary of the Yamuna of regional agricultural and ecological importance.

Despite its ecological significance, the Kaliyasot River receives the discharge of five major municipal sewage outfalls with a combined daily load of 125 MLD of untreated sewage, operates with a Water Quality Index of 225-plus at its downstream industrial monitoring station — a value classified as Ecological Collapse — and has lost 34 percent of its surface water presence over the decade 2015 to 2025 as measured by satellite-based NDWI analysis. It is dry for eight to nine months of the year. Its riparian buffer has been encroached by 321 structures in violation of the NGT's 33-metre protection mandate. And yet no prior comprehensive planning study of the corridor has been conducted, and no integrated management authority with corridor-wide jurisdiction exists.

The Kaliyasot thus combines the characteristics of an urgent environmental problem with those of a significant planning gap — making it both a compelling subject for this thesis and a case study of potentially broad relevance to comparable seasonal urban rivers across the Deccan Plateau and central Indian urban systems.



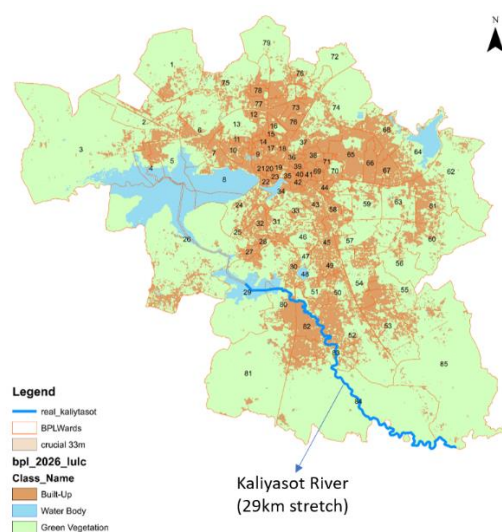


Fig. 1.1: Study Area Location Map — Kaliyasot River Corridor, Bhopal (Source: BDA Development Plan 2031; MPPCB; Sentinel-2 Imagery; QGIS Analysis)

1.2 Problem Statement

The central problem addressed by this thesis is the comprehensive ecological, social, and institutional failure of the Kaliyasot River system — a failure that is simultaneously causing severe environmental degradation, public health risk, and the systematic exclusion of river-dependent communities from planning and development benefits.

Ecologically, the river is in a state of compound collapse: absent for nine months of the year, anoxic at its dead zone, bacteriologically contaminated beyond safe human contact at all monitoring stations, and losing surface water presence at a rate that will functionally eliminate it as a hydrological entity if current trends continue. Its riparian ecosystem has been reduced to 15 percent vegetative cover against a target of 33 percent mandated by the NGT. Its catchment is 61 percent impervious — a level associated with severe hydrological disruption in urban hydrology literature.

Institutionally, the river corridor is governed by three separate administrative jurisdictions — the Bhopal Development Authority, Misrod Urban Local Body, and Mandideep Industrial Area Authority — none of which has corridor-wide oversight. The result is that pollution generated in one jurisdiction

undermines restoration investment in another, and no single authority can be held accountable for the corridor's overall condition.

From a planning practice perspective, the problem is compounded by the risk that a future riverfront development project — undertaken without first addressing the ecological crisis — will waste public resources by developing amenity alongside a dead and malodorous river, while simultaneously displacing the communities most dependent on it. The literature documents this outcome at multiple Indian riverfront projects. Preventing a repetition of this pattern at the Kaliyasot is one of the practical imperatives of this study.

The problem can be articulated in quantitative terms with precision: 125 MLD of untreated sewage entering the river daily; a Water Quality Index of 225-plus at the downstream industrial station; dissolved oxygen at zero in the Zone 2 dead zone; 321 structures illegally occupying the ecologically critical 33-metre buffer; 34 percent decline in surface water presence over a decade; and 28,000 residents exposed to these conditions without institutional recourse. These are not contested estimates — they are documented figures from official monitoring sources. The problem is not one of insufficient evidence. It is one of insufficient integrated planning response. This thesis provides the latter.

1.3 Research Aim

The aim of this study is to develop an integrated, evidence-based, and equity-centred proposal for the restoration and development of the Kaliyasot River corridor in Bhopal, grounded in systematic empirical analysis of the river's ecological, hydrological, infrastructure, and socio-economic conditions, and structured to ensure that ecological restoration precedes and enables sustainable public realm development.

1.4 Research Objectives

The study is guided by four specific objectives that correspond to the sequential phases of the research process:

Objective 1: Temporal and Spatial Analysis of River Condition

To understand the temporal change in the ecological and hydrological condition of the Kaliyasot River corridor between 2015 and 2025, using remote sensing (NDWI, LULC) and water quality monitoring data, in order to establish the nature, extent, and trajectory of degradation and to identify the correlation between urbanisation-driven land use change and ecological deterioration.

Objective 2: Identification of Pollution Sources and Causal Mechanisms

To analyse the activities, infrastructure deficits, and land use patterns along the river corridor that are generating pollution and ecological degradation, with particular attention to the quantification of the sewage treatment gap, the identification and characterisation of major pollution point sources, and the assessment of buffer zone violation patterns.

Objective 3: Zone-based Planning Classification

To identify the stretches of the river corridor that are appropriate for different forms of ecological restoration and public development, based on their current ecological condition, pollution load intensity, administrative jurisdiction, and proximity to urban population, resulting in a three-zone segmentation that serves as the spatial framework for proposal formulation.

Objective 4: Integrated Proposal Formulation

To formulate a comprehensive, corridor-wide integrated proposal for the restoration and development of the Kaliyasot River that addresses the root causes of ecological degradation through environmental flow restoration, sewage treatment infrastructure, check dam construction, constructed wetlands, and riparian buffer planting, and that frames subsequent public realm development within a four-zone eco-sensitive model guided by equity principles, safety standards, and ecological performance targets.

1.5 Research Methodology Overview

The methodology of this study is structured as a seven-step sequential process, designed to move systematically from problem identification through data

collection and analysis to proposal formulation and evaluation. The seven steps and their relationship to the chapters of this report are described below.

Step 1 — Problem Identification

The initial step involved the identification and scoping of the research problem through review of MPPCB water quality alerts, NGT orders on buffer zone violations, and BDA Development Plan 2031 data on land use change in the Kaliyasot catchment. This step established the river's ecological degradation and planning gap as the central problem and defined the 29-kilometre corridor as the study area.

Step 2 — Data Collection

Data collection proceeded in parallel secondary and primary streams. Secondary data comprised the BDA Development Plan 2031, MPPCB water analysis reports (ROMPPCB/Bhopal/2019), CGWB groundwater classification data, Census of India 2011 and 2021 data, NGT orders, NRCP guidelines, and MoHUA URMP 2019. Primary data comprised field survey of the full 29-kilometre corridor, structured household interviews with 120 respondents in Zones 1 and 2, gender safety audit observations, encroachment mapping, and photographic documentation.

Step 3 — Remote Sensing and GIS Analysis

Landsat 8 and Sentinel-2 satellite imagery for 2015 and 2025 (dry season acquisitions) were processed through Google Earth Engine and QGIS to generate LULC classification maps, NDWI temporal change maps, and buffer zone violation mapping. The NDWI analysis used a three-date temporal series (2015, 2020, 2025) to capture the trajectory of hydrological decline.

Step 4 — Water Quality and Infrastructure Analysis

The five-station water quality dataset from the MPPCB monitoring report was processed to calculate Water Quality Index values for each station using the CPCB standard methodology, and to assess compliance against CPCB Class B and Class C standards for each parameter. The infrastructure analysis quantified the

sewage generation-treatment gap and assessed the operational condition of existing STPs.

Step 5 — Problem Synthesis

The findings of the environmental, water quality, buffer violation, infrastructure, and socio-economic analyses were synthesised into a corridor-wide problem map and a zone-based assessment framework, identifying the dominant problems, ecological risk levels, and intervention priorities for each of the three zones.

Step 6 — Literature and Policy Review

Concurrent with the analytical steps, a systematic review of urban river restoration literature, planning frameworks, policy instruments, and case studies was conducted. The review informed both the analytical framework and the proposal formulation, ensuring that proposals are grounded in established practice and referenced against comparable projects.

Step 7 — Proposal Formulation and Evaluation

The integrated proposals developed in Chapter 5 were formulated based on the findings of the analysis and the learnings of the literature review, and were evaluated against the I-SEER framework (Journal of Cleaner Production, 2025), which provides composite Environmental, Social, and Economic performance scores.

1.5.1 Field Survey Protocol

The field survey of the 29-kilometre corridor was conducted in three phases during the academic year 2024–2025, covering the full length of both banks on foot and by vehicle. The survey was structured around four data collection activities: photographic documentation, encroachment mapping, nallah outfall identification and characterisation, and qualitative observation of riparian vegetation, channel morphology, solid waste accumulation, and bank condition.

Photographic documentation was conducted at 100-metre intervals along the primary bank access route, with additional close-up documentation at identified problem points — outfall locations, encroachment hotspots, bank failure sites, and

areas of residual riparian vegetation. The photographic record comprises over 800 images, systematically catalogued by coordinates, date, and descriptive tags. Encroachment mapping was conducted by walking the NGT 33-metre buffer zone on both banks, identifying all structures physically encroaching upon the buffer, and recording their location using GPS. The resulting encroachment dataset was digitised in QGIS and overlaid on the satellite imagery for quantitative analysis.

Nallah outfall identification involved locating all confirmed and probable outfall points along the corridor by field observation and comparison with Google Earth Engine imagery and MPPCB documentation. Five major outfalls were confirmed and characterised by approximate flow volume (estimated through visual observation), colour (indicating organic load), and smell. Fourteen minor outfalls were identified and mapped but not individually characterised due to their intermittent and low-flow nature.

1.5.2 Household Survey Design and Administration

The household survey was designed to capture three dimensions of socio-economic condition: river dependency (type, frequency, and economic value of river-based activities), exposure to river-related hazards (flooding, water contamination, air quality), and attitude to restoration (willingness to engage with, support, or resist proposed interventions). The instrument consisted of 45 structured questions and 12 open-ended qualitative prompts, administered through face-to-face interviews in Hindi.

The sample of 120 respondents was stratified across three income quintiles, three distance bands from the river, and two gender categories. Respondents were recruited through systematic house-to-house canvassing at intervals of approximately 200 metres along the corridor, with replacement where residents were absent or declined to participate. The canvassing was conducted in daylight hours; evening visits were made to identify any systematic differences in resident profile or river use pattern associated with time of day.

Survey data was entered into a spreadsheet database immediately following each interview and subjected to verification checks for completeness and internal consistency. Pearson correlation coefficients were calculated for the key variable

pairs identified in the analytical framework, using a two-tailed significance test at the 95 percent confidence level ($p < 0.05$). The survey was administered under standard academic research ethics protocols, with oral informed consent obtained from all participants prior to interview commencement.

1.5.3 Water Quality Index Calculation Methodology

The Water Quality Index was calculated using the CPCB standard methodology, which assigns weighted scores to individual water quality parameters based on their deviation from Class B standards (the most stringent class applicable to Indian freshwater rivers used for outdoor bathing). The parameters and their weightings used in this study are: Dissolved Oxygen (weight 0.31), Biological Oxygen Demand (weight 0.26), Total Coliform (weight 0.22), pH (weight 0.12), and Total Dissolved Solids (weight 0.09).

For each parameter, a sub-index value is calculated by dividing the observed concentration by the standard concentration and multiplying by 100 (for parameters where higher values indicate worse quality, the inverse is used). The sub-index values are then combined using the weighted arithmetic mean to yield the overall WQI. A WQI below 50 indicates Good quality; 50 to 100 is Poor; 100 to 200 is Very Poor; 200 to 300 is Toxic; and above 300 indicates Ecological Collapse. It should be noted that some classification systems use slightly different thresholds; the CPCB methodology as published in CPCB Document COINS/2008/9 is used throughout this study for consistency.

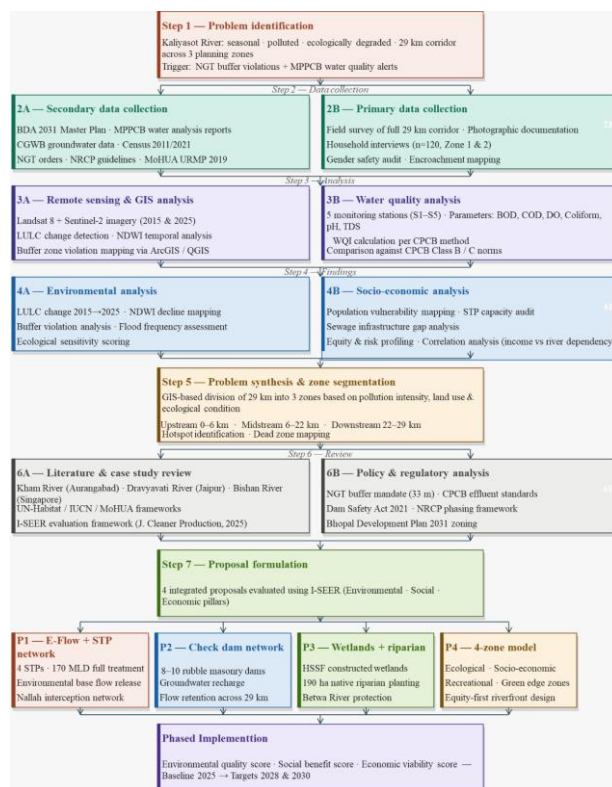


Fig. 1.2: Conceptual Framework — Research Structure and Methodology Flowchart (Source: Author)

1.6 Scope of Study

The scope of this study encompasses the full 29-kilometre length of the Kaliyasot River corridor, from its origin at the Upper Lake spillway in Bhopal (at approximately 23°17'N, 77°21'E) to its confluence with the Betwa River near Bhojpur (at approximately 23°05'N, 77°28'E). The study area extends to both banks of the river at a minimum depth corresponding to the NGT-mandated 33-metre ecological buffer, with the analytical scope extending to 500 metres from the river for the socio-economic and population vulnerability analysis.

The temporal scope of the quantitative analysis extends from 2015 to 2025 for LULC and NDWI analysis, with the water quality dataset from 2019 representing the most recent comprehensive MPPCB monitoring data. The household survey was conducted during the study period of Semester VIII (2024–2025). The implementation phasing in Chapter 5 extends to a ten-year planning horizon (2025–2035).

The study addresses three administrative and planning environments traversed by the corridor: the Bhopal Development Authority jurisdiction (urban core), the Misrod Urban Local Body (peri-urban), and the Mandideep Industrial Area Authority (industrial). It does not address river management upstream of the Upper Lake or the Betwa River hydrology downstream of the Kaliyasot confluence, though the protection of the Betwa from toxic downstream transfer is an explicit objective of the Zone 3 interventions.

The socio-economic analysis focuses on the communities residing within 500 metres of the corridor in Zones 1 and 2, where river dependency is highest and where the risk of displacement from proposed interventions is most significant. Zone 3 socio-economic analysis is limited by the lower residential population and the industrial character of the land use context.

1.7 Limitations of the Study

1.7.1 Data Limitations

The water quality analysis in this study is based on the MPPCB monitoring report published in 2019, which constitutes the most comprehensive publicly available dataset for the Kaliyasot River. While the directional trends of deterioration are confirmed by field observations conducted during the study period, the specific parameter values may not reflect conditions at the time of reading. Real-time continuous monitoring data was not available through official channels.

The LULC and NDWI analyses rely on satellite imagery acquired on specific dates, and the results are representative of the condition of the corridor on those dates rather than reflecting continuous change. Seasonal variations in land use and hydrology — particularly the difference between monsoon and dry-season conditions — are acknowledged but not fully captured in the remote sensing analysis, which uses dry-season imagery throughout for consistency.

1.7.2 Industrial Data Gaps

Industrial effluent data from the Mandideep Industrial Estate is incomplete. The COD values recorded at Station S5 indicate the presence of industrial discharge but the specific chemical composition, permitted discharge quantities, and compliance history of individual industrial units within the estate could not be verified through available public data. This limits the precision of industrial pollution proposals in Zone 3 and is acknowledged as a data gap requiring targeted monitoring as a first action of the Phase 0 implementation.

1.7.3 Ecological Assessment Scope

The ecological condition of the corridor is assessed through remote sensing indicators (NDWI, NDVI, LULC) and water quality parameters rather than through direct ecological surveys. Species-level assessments of aquatic macrofauna, riparian flora, and avifauna — which would provide a richer ecological baseline for biodiversity-sensitive proposal design — were beyond the scope and resources of this study. The proposals acknowledge this limitation and recommend detailed ecological baseline surveys as a component of Phase 0 pre-implementation activities.

1.7.4 Cost Estimation

Capital cost estimates for the proposed interventions are referenced from comparable projects — principally the Dravyavati River project in Jaipur, the Kham River restoration in Aurangabad, and CPHEEO unit cost data — and are indicative rather than based on detailed engineering estimates. Actual costs will vary based on site-specific conditions, soil and subsurface geology, procurement method, and market conditions at the time of implementation.

1.8 Need and Significance of the Study

The need for this study is established on three grounds: environmental urgency, planning gap, and equity imperative.

The environmental urgency is unambiguous: a river with a WQI of 225-plus at its downstream station, with dissolved oxygen recorded at zero, with 125 MLD of untreated sewage entering it daily, and with a 34 percent decline in surface water

presence over a decade, is in a state of acute ecological emergency. Without intervention, the trajectory of deterioration will continue and likely accelerate as urbanisation proceeds. The protection of the Betwa River from toxic downstream transfer — an objective directly dependent on the restoration of the Kaliyasot's ecological function — adds a regional dimension to what might otherwise appear a localised urban problem.

The planning gap is equally clear: no prior comprehensive, corridor-wide study of the Kaliyasot River has been conducted. The BDA's Development Plan 2031 references the river corridor but does not provide an integrated management framework. The MPPCB has issued monitoring reports and enforcement notices but has not produced a restoration plan. The NGT has issued buffer zone orders but without a coordinated implementation mechanism. This thesis provides the integrated planning document that these institutional responses have lacked.

The equity imperative is established by the social analysis: 28,000 residents of the Zone 1 corridor, 38 percent of whom live in informal settlements, are directly dependent on a river that is poisoning their environment and threatening their livelihoods. The planning response to this situation — which risks being a displacement-focused development project if the lessons of the Sabarmati and other Indian riverfront projects are not applied — must be grounded in evidence that these communities are not the cause of the problem they are experiencing. This study provides that evidence.

1.9 Structure of the Report

This thesis report is organised into five chapters, each corresponding to a phase of the research process:

Chapter 1 — Introduction provides the background, problem statement, research aim and objectives, methodology overview, scope, limitations, and significance of the study. It establishes the conceptual and contextual framework within which all subsequent analytical and proposal content is located.

Chapter 2 — Literature Review traces the evolution of urban riverfront planning from the engineering era to the ecology-led paradigm, examines the key

conceptual frameworks and policy instruments relevant to the study (BGI, NbS, URMP, CPCB standards, NGT guidelines, I-SEER), and presents three comparative case studies — Kham River (Aurangabad), Dravyavati River (Jaipur), and Bishan-Ang Mo Kio (Singapore) — from which specific design and implementation learnings are drawn for the Kaliyasot proposals.

Chapter 3 — Site Selection and Context provides a systematic description of the physical, hydrological, administrative, and planning context of the Kaliyasot River corridor, including the rationale for site selection, catchment characteristics, hydrological behaviour, and the three-zone segmentation that structures all subsequent analysis and proposals.

Chapter 4 — Data Analysis and Findings presents the analytical findings of the study across five dimensions: environmental and temporal change (NDWI and LULC analysis), water quality analysis (BOD, COD, DO, Coliform, WQI), buffer zone violation analysis, infrastructure gap analysis (sewage and STP), and socio-economic vulnerability analysis. The chapter concludes with a problem synthesis that summarises the major findings and their implications for proposal formulation.

Chapter 5 — Proposals and Recommendations presents the four integrated proposals — Environmental Flow and STP network, check dam network, constructed wetlands and riparian buffer, and the four-zone eco-sensitive riverfront model — together with the phasing strategy, governance recommendations, and expected outcomes evaluated against the I-SEER framework.

The report concludes with a Bibliography of 38 academic and policy references cited in the text, and is preceded by preliminary pages including Declaration, Certificate, Abstract, Acknowledgements, List of Tables, List of Figures, and List of Abbreviations.

CHAPTER 2 — LITERATURE REVIEW

2.1 Introduction to the Literature Review

The planning and management of urban rivers sits at the intersection of environmental science, urban planning, hydrology, social policy, and governance studies. The literature that informs this intersection has grown substantially over the past three decades, driven by a global recognition that rivers are not merely hydrological infrastructure but complex socio-ecological systems that provide a range of irreplaceable services to urban populations — services that, once destroyed, require enormous investment to partially recover. This chapter traces the evolution of thought and practice in urban riverfront planning, identifies the key conceptual frameworks and policy instruments that shape the contemporary approach to river restoration, and presents three detailed case studies from which specific design, engineering, and governance learnings are extracted for application to the Kaliyasot River.

The literature review is organised into three sections. Section 2.2 traces the historical evolution of urban riverfront planning from the engineering paradigm of the nineteenth and early twentieth centuries through the ecological turn of the 1990s and 2000s to the current paradigm of integrated, ecology-led, equity-sensitive river management. Section 2.3 examines the key conceptual frameworks and policy instruments directly relevant to this study. Section 2.4 presents the three comparative case studies. Section 2.5 synthesises the research gaps that this study addresses.

2.2 Evolution of Urban Riverfront Planning

2.2.1 The Engineering Paradigm (Pre-2000): Rivers as Infrastructure

The dominant paradigm of urban river management from the Industrial Revolution through to the late twentieth century was fundamentally engineering-centred. Rivers were conceptualised as hydraulic infrastructure — conduits for water conveyance, flood management, and waste disposal — rather than as ecological systems or social assets. The engineering response to the presence of a river in or near an urban area was, characteristically, to control it: to straighten its

natural meanders, to deepen and widen its channel for flood conveyance, to line its banks with concrete or stone embankments, and to use its capacity for dilution and transport to remove the waste products of urban industrial and domestic activity.

This paradigm reflected the intellectual and technological context of its time. The germ theory of disease, established in the second half of the nineteenth century, identified waterborne pathogens as a major source of urban mortality and identified the removal of sewage from proximity to human settlements as a public health priority. Engineering solutions — combined sewers, pumping stations, treatment works, and the controlled discharge of treated effluent to rivers — were the tools through which this public health imperative was addressed, and rivers were the logical receptacles for the outputs of these systems. The ecological consequences of converting a river into an effluent drain were recognised only slowly, and for much of the engineering era they were considered an acceptable price for the public health and flood control benefits of river management.

In the Indian colonial and post-independence context, the engineering paradigm was reinforced by the priorities of the developmental state. The Nehruvian emphasis on large-scale infrastructure — dams, irrigation systems, power stations — framed rivers as resources to be harnessed rather than ecosystems to be sustained. Urban rivers, lacking the scale to attract major dam projects, were left to evolve by default into drainage channels as cities grew around them. The institutional structures created to manage urban water — municipal water departments, public health engineering, and state pollution control boards — were designed for water supply, sewage treatment, and industrial regulation, not for the integrated management of river ecosystems. This institutional design reflected and reinforced the engineering paradigm.

The consequences of the engineering paradigm have been extensively documented. By the 1990s, CPCB monitoring data showed that the majority of India's urban rivers were severely degraded. In London, the Thames had been biologically dead in its tidal reach for much of the mid-twentieth century. In Seoul, the Cheonggyecheon had been buried under an elevated motorway. In Singapore, rivers had been channelised to bare concrete drains. The global trend was consistent: the engineering era had solved the acute public health problems of the industrial

city by converting rivers into infrastructure — and in doing so, had destroyed them as ecosystems.

2.2.2 The Environmental Movement and the Beginning of the Ecological Turn (1970s–1990s)

The 1970s marked a turning point in the relationship between urban planning and the environment. The environmental movement, catalysed by publications such as Rachel Carson's *Silent Spring* (1962) and the Club of Rome's *Limits to Growth* (1972), created a new political constituency for environmental protection and contributed to the passage of landmark environmental legislation in many countries — the Clean Water Act in the United States (1972), the Water Framework Directive in Europe (2000), and the Water Prevention and Control of Pollution Act in India (1974).

In the urban river planning context, this legislative change began to shift the terms of acceptable engineering practice. Rivers could no longer be legally used as sewage disposal channels without treatment. Industrial effluent standards were introduced and enforced, gradually improving the water quality of previously heavily polluted rivers. The ecological consequences of channelisation and embanking began to be studied and documented by a growing community of fluvial geomorphologists, river ecologists, and environmental hydrologists, whose research demonstrated that engineering interventions had created rivers that were hydrologically less stable, ecologically barren, and hydraulically more hazardous than the natural systems they had replaced.

In India, this period saw the launch of the Ganga Action Plan in 1985 — the first major national programme specifically targeting river pollution abatement — followed by the National River Conservation Plan in 1995 and the expansion of CPCB monitoring to a systematic national network of river quality monitoring stations. While these programmes focused primarily on large perennial rivers and had mixed implementation outcomes, they established the principle that rivers have a legally protected right to a minimum level of water quality, and that industrial and municipal pollution control are obligations of the state.

2.2.3 The Ecological Turn and Restoration Planning (2000–2015)

The turn of the millennium marked a qualitative shift in urban river planning beyond mere pollution control to active ecological restoration. A series of internationally prominent projects demonstrated that urban rivers could be physically transformed — that concrete channels could be opened and naturalised, that buried rivers could be daylighted, that degraded riparian zones could be restored — and that these transformations could generate substantial social, economic, and ecological co-benefits.

The Cheonggyecheon restoration in Seoul (2003–2005) is often cited as the most influential of these demonstration projects. The Cheonggyecheon had been buried under an elevated highway in the 1970s, eliminating one of Seoul's most historic waterways. The decision to demolish the highway, restore the river channel, and create a 5.8-kilometre urban waterway park was controversial at the time but proved transformative: the project reduced ambient temperatures in the surrounding area by 2 to 4 degrees Celsius through the cool air drainage effect of the restored water body, increased property values in adjacent zones by 16 to 50 percent, and became one of Seoul's most visited public spaces, attracting 60,000 daily visitors (Seoul Metropolitan Government, 2010).

The restoration also had significant ecological dimensions: fish species richness increased from one before restoration to 25 after, and bird species from 6 to 36 (Lee and Yoo, 2010). These outcomes provided powerful evidence that urban river restoration was not merely an aesthetic or recreational project but a multi-dimensional ecological and urban design intervention.

Concurrently, the academic and professional literature on ecological approaches to river management was rapidly developing. The concepts of riparian buffer zones, environmental base flows, functional floodplains, and bioengineered bank stabilisation entered mainstream planning practice. The publication of the Instream Flow Council's water needs assessment methodology (2002) and the Brisbane Declaration on Environmental Flows (2007) established scientific and policy frameworks for the quantification of minimum environmental flows in rivers. The IUCN's work on Nature-Based Solutions, consolidated in its 2016 guidance document, provided an overarching framework for the use of ecological

processes to address the engineering problems previously addressed by purely mechanical interventions.

2.2.4 Integrated Ecology-First Planning (2015–Present)

The current era of urban riverfront planning is characterised by the integration of ecological restoration with social equity, urban design, and governance reform. The 'ecology-first' principle — establishing the health of the river ecosystem as the non-negotiable precondition for all other riverfront planning — has been validated by the accumulated evidence of projects internationally and is now reflected in the policy frameworks of several national governments including India's Ministry of Housing and Urban Affairs through the URMP 2019.

The social equity dimension has become increasingly central to riverfront planning discourse, following the critique of early emblematic projects — particularly the Sabarmati Riverfront in Ahmedabad — that demonstrated the costs of riverfront development that prioritises visual amenity for middle-class users over the livelihood and housing security of lower-income riverside communities. The displacement of over 14,000 households from the Sabarmati riverfront in the name of ecological restoration and urban beautification — in a context where these communities were demonstrably not the primary sources of river pollution — became a cautionary case study studied in planning schools across India and internationally.

The current planning literature argues for riverfront development that is simultaneously ecology-first and community-inclusive — that treats ecological restoration and social inclusion not as competing objectives but as complementary imperatives. The proposals developed in this thesis explicitly embody this dual principle.

Fig. 2.1: Paradigm Shift in Urban River Planning — From Engineering Control to Ecology-First Integration (Source: Author, based on Prominski et al. 2012; MoHUA URMP 2019)

2.3 Key Conceptual Frameworks and Policy Instruments

2.3.1 Blue-Green Infrastructure (BGI)

Blue-Green Infrastructure (BGI) is a planning concept that recognises the inherent complementarity between urban water management (the 'blue' dimension — rivers, streams, lakes, wetlands, and engineered water features) and urban green space (the 'green' dimension — parks, tree canopies, vegetated swales, green roofs, and natural drainage corridors). The BGI framework argues that these two dimensions of the urban environment are most effectively planned and managed as an integrated network rather than as separate systems under separate institutional authorities.

The theoretical foundations of BGI draw on landscape ecology, urban hydrology, environmental planning, and public health literature. From landscape ecology, BGI incorporates the concept of ecological networks — continuous corridors of natural habitat that enable species movement, genetic exchange, and ecological resilience across otherwise fragmented urban landscapes. From urban hydrology, BGI incorporates the Sustainable Urban Drainage Systems (SUDS) approach, which manages stormwater through infiltration, detention, and biological treatment rather than rapid conveyance to a receiving water body. From environmental planning, BGI incorporates the ecosystem services framework — the systematic valuation of the multiple economic and social benefits provided by ecological systems, including water purification, climate regulation, biodiversity support, and human well-being.

Applied to the Kaliyasot River corridor, the BGI framework argues that the river itself, its riparian buffer zone, the proposed constructed wetland cells, and the green edge bioswale network proposed in the four-zone model constitute a connected blue-green infrastructure system — each element both ecologically functional in itself and connected to the others in a way that generates synergistic co-benefits. The riparian planting filters runoff before it reaches the river (water quality), stabilises banks (geomorphological function), provides habitat (biodiversity), and reduces ambient temperatures (microclimate regulation). The check dams retain water (hydrological function), recharge groundwater (water

supply), and create ponded habitat (biodiversity). These synergies are the defining characteristic of BGI-informed planning and distinguish it from planning that treats water management and green space as separate concerns.

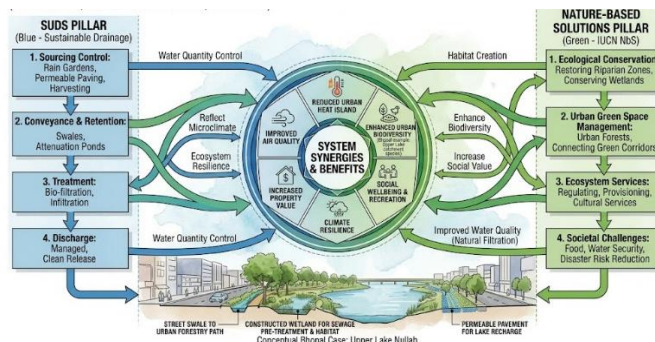


Fig. 2.2: Blue-Green Infrastructure Concept Diagram — System Synergies (Source: Author, based on SUDS Manual 2015; IUCN NbS 2016)

2.3.2 Nature-Based Solutions (IUCN, 2016)

Nature-Based Solutions (NbS), as defined by the International Union for Conservation of Nature in its 2016 global guidance document, are 'actions that protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, while simultaneously providing human well-being and biodiversity benefits.' NbS is a broader umbrella concept that encompasses Blue-Green Infrastructure, ecological engineering, ecosystem-based adaptation, and natural capital approaches, among others.

The IUCN NbS framework has been adopted at the international policy level through the United Nations Framework Convention on Climate Change (UNFCCC), the Convention on Biological Diversity (CBD), and the Sendai Framework for Disaster Risk Reduction, as well as at the national level in India through the National Biodiversity Action Plan and the National Water Policy. For urban river restoration specifically, the NbS framework provides both a philosophical grounding — prioritising ecological processes over mechanical solutions — and a set of technical approaches.

NbS technical approaches applicable to the Kaliyasot River include: constructed wetlands (using natural plant-microbial systems to treat wastewater rather than mechanical treatment systems); soil bioengineering for bank stabilisation (using root systems and vegetative structures rather than concrete);

riparian planting using native species (using deep-rooted indigenous vegetation for erosion control rather than imported ornamental species); and the introduction of environmental flow through treated wastewater (using the river's own self-purification capacity to manage water quality rather than relying exclusively on engineered treatment). Each of these approaches is applied in the Kaliyasot proposals, and each is justified in the proposal formulation by reference to its documented performance in comparable contexts.

A critical advantage of NbS over conventional engineering approaches in the context of secondary Indian cities is the cost structure. NbS solutions have significantly lower capital costs and near-zero or zero operating costs compared to their mechanical equivalents, making them appropriate for implementation by Urban Local Bodies with limited capital and operational budgets. Constructed wetlands cost approximately 25 to 33 percent of equivalent mechanical tertiary treatment systems in capital terms, and 10 to 12 percent in operating terms (CPCB, 2015). Bioengineered bank stabilisation costs 40 to 60 percent of concrete embankments. Over a 25-year life cycle, the economic advantage of NbS over conventional engineering is typically a factor of three to four, making ecological approaches not merely environmentally preferable but fiscally superior.

2.3.3 Environmental Flow (E-Flow) Framework

Environmental flow — also termed ecological flow, minimum flow, or instream flow — refers to the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. The concept emerged from the recognition that rivers are not merely water delivery systems but dynamic physical-biological systems whose ecological functions are dependent on a specific regime of flows — too little flow causes the ecological degradation documented in the Kaliyasot; too much, if released suddenly, can cause physical damage to channel morphology and riparian habitat.

The Brisbane Declaration of 2007, issued by the International Congress on River Science and endorsed by over 750 scientists from 50 countries, established environmental flows as a global scientific consensus and policy imperative, stating

that 'maintaining environmental flows is essential to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on them.' The Central Water Commission (CWC) of India incorporated this principle into its Environmental Flow Assessment Guidelines issued in 2018, establishing minimum flow requirements for classified river types and directing State-level implementation.

For non-perennial seasonal rivers — the category to which the Kaliyasot belongs — the CWC guidelines recognise that natural base flows cannot be maintained in the absence of perennial groundwater-fed tributaries, and provide for the use of treated wastewater as a substitute environmental flow source. This provision is the policy basis for the E-Flow proposal developed in Chapter 5, which recommends the release of 5 to 10 MLD of tertiary-treated STP effluent as a continuous base flow throughout the non-monsoon season.

2.3.4 MoHUA Urban River Management Plan (URMP, 2019)

The Urban River Management Plan, published by the Ministry of Housing and Urban Affairs in 2019, is the most comprehensive national policy framework for the integrated management of urban rivers in India to date. It builds on the National Mission for Clean Ganga, the Atal Mission for Rejuvenation and Urban Transformation, and the Smart Cities Mission to establish a three-pillar approach to urban river management: environmental base flow preservation, comprehensive pollution abatement through decentralised treatment, and integrated floodplain management.

The URMP's key policy provisions directly relevant to the Kaliyasot River study are: the mandate for cities to conduct comprehensive baseline assessments of urban river water quality, land use, and hydrology before developing management plans; the requirement for decentralised sewage treatment systems as the preferred approach for cities with dispersed pollution sources and multiple drainage sub-catchments; the prohibition on concrete embankments and the requirement for bioengineered bank treatments in all new riverfront development; the establishment of a minimum ecological buffer width of 30 metres on both banks of all urban rivers (consistent with the NGT Order of 2022 which sets 33 metres as the minimum); and

the requirement for communities currently settled within river buffer zones to be offered in-situ rehabilitation rather than distant relocation.

The URMP also establishes a governance framework that is highly relevant to the Kaliyasot situation: it recommends the creation of River Corridor Authorities as statutory inter-jurisdictional bodies with comprehensive management powers over the full length of urban river corridors, reporting to both the State government and the Urban Local Bodies through which the corridor passes. The governance recommendation in Chapter 5 of this thesis is directly informed by this URMP provision.

2.3.5 CPCB Water Quality Classification and Standards

The Central Pollution Control Board classifies the designated best use of Indian water bodies into five classes based on water quality requirements and the most sensitive intended use of the water. Class A represents water suitable for drinking without conventional treatment (requiring only disinfection), requiring DO greater than 6 mg/L, BOD less than 2 mg/L, and Total Coliform less than 50 MPN per 100 mL. Class B represents water suitable for outdoor bathing, requiring DO greater than 5 mg/L, BOD less than 3 mg/L, and Total Coliform less than 500 MPN per 100 mL. Class C represents water suitable for drinking with conventional treatment, requiring DO greater than 4 mg/L, BOD less than 3 mg/L, and Coliform less than 5,000 MPN per 100 mL. Class D represents water suitable for propagation of wildlife and fisheries. Class E represents water suitable for irrigation and industrial cooling (CPCB, 2024).

The Water Quality Index methodology used in this study assigns weighted scores to each measured parameter, compares them against Class B standards, and computes a composite index. WQI values above 100 indicate non-compliance with Class B; values above 200 indicate conditions incompatible with any aquatic life — what the CPCB classification effectively defines as ecological collapse. The grading used in this study (Very Poor: 75–100; Toxic: 100–200; Ecological Collapse: >200) follows the interpretation applied in comparable peer-reviewed studies of urban river water quality in the Indian context.

2.3.6 NGT Buffer Zone Guidelines and River Protection Orders

The National Green Tribunal, established under the National Green Tribunal Act 2010, has become one of the most significant institutional actors in Indian environmental governance, issuing binding orders on a range of environmental issues including river and water body protection. Through a series of orders issued between 2019 and 2022, the NGT has established a minimum mandatory ecological buffer of 33 metres on both banks of all rivers, lakes, and water bodies in India, within which no permanent construction, quarrying, mining, or solid waste disposal is permitted.

The NGT orders further direct State governments to: identify and document all existing structures within the 33-metre buffer; develop time-bound action plans for the removal of encroaching structures with appropriate rehabilitation provision for affected households; establish green belt/riparian plantation programmes within the buffer zone; and report quarterly on buffer zone restoration progress. Enforcement of these orders has been variable across States and cities, but the orders provide the legal framework within which the riparian restoration programme proposed in Chapter 5 of this thesis must operate.

For the Kaliyasot River specifically, the identification of 321 encroaching structures — of which 127 are in Zone 1 alone, representing a 78 percent buffer violation rate at the Damkheda location — constitutes a documented and ongoing violation of the NGT orders. The Phase 0 implementation step of this study's proposals therefore includes the systematic documentation and notification of all encroaching structures as the legal first step toward buffer restoration, alongside the provision of in-situ rehabilitation options for affected households.

2.3.7 I-SEER Evaluation Framework

The Integrated Social, Economic and Environmental Restoration (I-SEER) framework, published in the Journal of Cleaner Production in 2025, provides a multi-criteria evaluation instrument specifically designed for assessing urban river restoration proposals in the Indian context. The framework was developed through a synthesis of 47 river restoration projects across 12 Indian cities, drawing on performance monitoring data spanning periods of 3 to 15 years post-implementation.

The I-SEER framework evaluates restoration proposals across three pillars, each scored on a 0–100 scale. The Environmental Quality pillar comprises five indicators: Water Quality Index improvement, Dissolved Oxygen recovery rate, Normalised Difference Vegetation Index (riparian cover), Ecological Connectivity Index, and NDWI (surface water recovery). The Social Benefit pillar comprises five indicators: Community Access to Riverfront, Livelihood Integration Index, Gender Safety Score, Displacement Risk Index, and Community Satisfaction Score. The Economic Viability pillar comprises four indicators: Cost-Benefit Ratio over 25 years, Operational Cost Sustainability (percentage of ULB annual budget), Avoided Damage Cost (from avoided flood and health costs), and Economic Multiplier from riverfront activation.

Baseline I-SEER scores for the Kaliyasot River corridor, calculated from the analytical data presented in Chapter 4, are: Environmental Quality 18/100 (reflecting the severely degraded ecological condition), Social Benefit 32/100 (reflecting the existing community access to the river but compromised by pollution, safety, and displacement risk), and Economic Viability 25/100 (reflecting the high avoided cost potential but constrained by the significant capital investment required). The proposals in Chapter 5 are designed to achieve target I-SEER scores of 78, 72, and 65 respectively in the Environmental, Social, and Economic pillars by 2030.

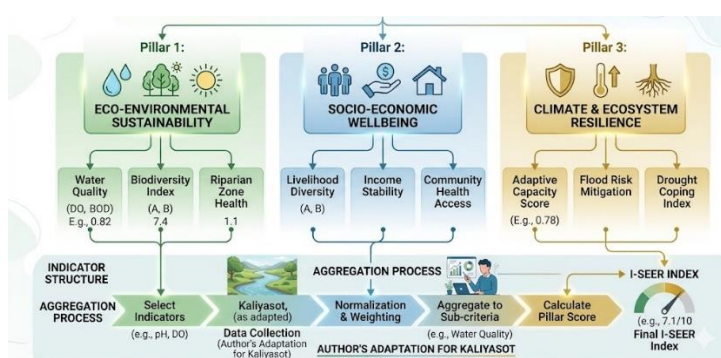


Fig. 2.3: I-SEER Framework — Three Pillars and Indicator Structure (Source: Journal of Cleaner Production, 2025; Author's Adaptation for Kaliyasot)

2.4 Comparative Case Studies

2.4.1 Case Study 1: Kham River Restoration, Aurangabad, Maharashtra

Background and Context

The Kham River is an urban river in Aurangabad, Maharashtra — a city of approximately 1.2 million population — that by the late 2000s had experienced degradation strikingly similar to the Kaliyasot River. The Kham is seasonal, flowing during the monsoon season and remaining dry for the majority of the year. Its urban corridor of approximately 12 kilometres traversed the densest residential sections of Aurangabad, receiving sewage from municipal drains and nallah outfalls, and functioning as a dumping ground for solid waste as well as a wastewater channel. The Aurangabad Municipal Corporation's drainage records documented BOD levels in the 40 to 80 mg/L range at midstream monitoring points — comparable to conditions at the Kaliyasot's Zone 2 stations.

The river flows through the urban area before joining the Godavari tributary system, and its ecological condition at the time of intervention initiation was causing secondary contamination of downstream water bodies and posing public health risks to the substantial informal population settled along its banks. The presence of the historically significant Aurangabad fort and the city's proximity to the UNESCO World Heritage Sites of Ajanta and Ellora gave the city administration an additional motivation to improve the urban water environment as part of a broader urban quality improvement programme.

Interventions

The Kham River restoration programme, implemented by the Pimpri-Chinchwad Municipal Corporation (PCMC) in partnership with the Aurangabad Municipal Corporation, was centred on a set of interventions that represent some of the most innovative approaches to low-cost ecological treatment in the Indian context. The flagship intervention was the development of a network of zero-power, plant-based Eco-Sewage Treatment Plants — an approach derived from constructed wetland technology but adapted for the Indian context by using indigenous aquatic macrophytes rather than the *Phragmites* species used in European constructed wetland systems.

The Eco-STPs were designed as series of shallow treatment ponds of 0.5 to 1.0 metre depth, planted with combinations of *Typha latifolia*, *Cyperus rotundus*,

Water Hyacinth (*Eichhornia crassipes*, used for its exceptional nutrient removal capacity in the primary treatment pond), and indigenous sedge species. Sewage entering the Eco-STP system passes sequentially through primary settling, facultative pond treatment, macrophyte-based secondary treatment, and a polishing pond, achieving effluent quality approaching CPCB Class C standards (BOD <10 mg/L, Coliform <5,000) without any mechanical aeration, chemical dosing, or significant energy input. The system operates entirely on gravity flow, powered by the solar energy captured by the plant biomass.

Alongside the Eco-STPs, the PCMC developed a 54-acre ecological restoration area in the river's floodplain, planting over 85,000 native trees and shrubs including Jamun, Arjun, Neem, Peepal, and Bamboo. A 5-kilometre EcoPark was developed along the recovered riverbed, providing public access within a naturalistic setting that preserved the ecological character of the restored riparian zone. The park incorporated earthen walking trails, native grass meadows, bird watching platforms, and children's nature play areas — all designed to be low-maintenance and ecologically integrated rather than requiring continuous horticultural management.

Outcomes

The outcomes of the Kham River restoration have been documented through periodic monitoring by PCMC and through independent research publications. Within three years of Eco-STP commissioning, Dissolved Oxygen levels at the primary downstream monitoring station increased from near-zero to above 4.2 mg/L — still below the Class B target but representing a fundamental ecological transformation in which aerobic aquatic life could re-establish. BOD values at the midstream monitoring station declined from 68 mg/L to 22 mg/L, a 68 percent reduction in organic pollution load attributable to the Eco-STP treatment and the interception of nallah outfalls.

Riparian vegetation cover along the restored 12-kilometre corridor increased from less than 8 percent to over 38 percent within five years, exceeding the NGT buffer target ahead of schedule. The EcoPark attracted an average of 2,200 daily visitors, generating ancillary economic activity — food stalls, cycle hire, vendor operations — that provided new livelihood opportunities for several

hundred households previously dependent on the river for fishing and washing. Community satisfaction surveys conducted three years post-restoration reported 78 percent of riverside residents characterising the river environment as 'significantly improved' (PCMC, 2023).

Key Learnings for Kaliyasot

The Kham River case establishes four critical learnings transferable to the Kaliyasot context. First, the viability of Eco-STP technology as a cost-effective, low-energy alternative to conventional SBR plants in the upstream section of a seasonal urban river — a particularly relevant learning for Zone 1 of the Kaliyasot where land availability is greater and the proximity to the Upper Lake argues for the lowest-possible-risk treatment technology. Second, the achievability of NGT riparian cover targets within five years through systematic native species planting, providing a realistic performance expectation for the Kaliyasot riparian buffer restoration programme. Third, the economic and social co-benefits of riverfront park development in a naturalistic style — avoiding the high-maintenance costs of formal landscaping while generating significant community use and livelihood opportunity. Fourth, the importance of integrating existing river-dependent communities as park users, nature guides, and vendors rather than displacing them as an obstacle to restoration.



Fig. 2.4: Kham River Restoration — Eco-STP System and EcoPark Development, Aurangabad (Source: PCMC Kham River Project Reports; Adapted for comparison)

2.4.2 Case Study 2: Dravyavati River Rejuvenation, Jaipur, Rajasthan

Background and Context

The Dravyavati River in Jaipur, Rajasthan, is a 47-kilometre non-perennial urban river — the longest seasonal urban river restoration project to have been implemented in India to date and the most directly comparable in scale and character to the Kaliyasot River. The Dravyavati had, by the early 2010s, been reduced to a dry sewage drain for the majority of the year, receiving the discharge of multiple nallah outfalls with a total sewage load estimated at 170 MLD — a figure identical to the sewage generation figure established for the Kaliyasot corridor. The river traversed the dense urban fabric of Jaipur, an international heritage tourism city, and its degraded condition was increasingly identified as an obstacle to the city's tourism and investment reputation.

A Detailed Project Report for the Dravyavati River Rejuvenation was prepared by the Jaipur Development Authority in 2015, following a series of NGT orders on buffer zone violations and water quality complaints. The DPR established

a comprehensive, phased approach that became a reference document for urban river restoration planning across Rajasthan and the broader northern Indian context.

Interventions

The centrepiece of the Dravyavati DPR was the establishment of five decentralised Sewage Treatment Plants with a combined design capacity of 170 MLD — addressing the full sewage generation load — distributed along the 47-kilometre corridor to intercept pollution at source rather than conveying it to a single large facility. The technology selected was Sequential Batch Reactor (SBR) for three of the five plants, and Extended Aeration Activated Sludge for the remaining two, reflecting the different load characteristics and land availability conditions at different points along the corridor. The treated effluent from all five plants was channelled to controlled discharge points in the river channel, constituting the source of environmental base flow.

Simultaneously, the JDA commissioned the construction of 84 check dams at intervals of approximately 550 metres along the full corridor — a much higher density than the 8 to 10 proposed for the Kaliyasot, reflecting the greater length of the Dravyavati corridor and the flatness of the Jaipur alluvial plain, which requires more frequent retention structures to maintain ponded sections. Each check dam was specified at sub-metre height in rubble masonry, consistent with the IS 14451 standard and the Dam Safety Act 2021 provisions. The combined ponded surface created by the check dam network covered approximately 65 hectares, generating an annual groundwater recharge contribution estimated at 40,000 to 55,000 cubic metres.

The public realm development component of the Dravyavati project included 38 kilometres of public promenades on both banks, 12 dedicated ghats for ritual and recreational use, a 2-kilometre heritage walk connecting culturally significant sites, and a botanical garden of 15 hectares featuring native Rajasthani plant species. The development was designed to be completed only after the pollution abatement and ecological restoration phases were sufficiently advanced — following the sequence that this thesis endorses for the Kaliyasot.

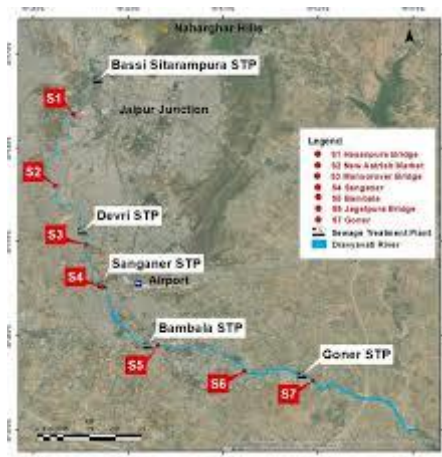
Outcomes

Within 18 months of the commissioning of the first two STPs, the Dravyavati achieved visible year-round flow for the first time in over three decades. Water quality improvement was documented at quarterly monitoring intervals: within three years, BOD at the midstream monitoring station declined from 78 mg/L to 19 mg/L, and DO increased from 1.3 mg/L to 4.1 mg/L — a dramatic improvement that, while not yet achieving full Class B compliance, indicated fundamental ecological recovery. Coliform counts declined from 22,000 MPN per 100 mL to 4,800 — just outside the Class C limit, indicating the need for enhanced operational management of the STPs but a major reduction in public health risk.

The public promenades attracted 25,000 daily users within six months of opening. Property values along the 1-kilometre corridor flanking the river increased by 18 to 30 percent within three years, generating a land value increment estimated at INR 8,000 to 12,000 crore for the Jaipur Development Authority — a return substantially exceeding the total project investment of approximately INR 1,700 crore. The project has since been cited by the Ministry of Housing and Urban Affairs as a model for urban river rejuvenation under the Smart Cities Mission.

Key Learnings for Kaliyasot

The Dravyavati case provides the most directly applicable model for the Kaliyasot River restoration. The identical treatment capacity requirement of 170 MLD, the non-perennial character of both rivers, the use of treated wastewater as environmental flow, and the decentralised STP network all translate directly to the Kaliyasot context. The check dam precedent — 84 structures along 47 km, achieving year-round visible flow — provides the empirical basis for the Kaliyasot's check dam network specification. The sequencing of pollution abatement before ecological restoration before public realm development — the core principle of the Dravyavati DPR — is the model that the phasing strategy of this thesis directly follows. The economic outcome data — demonstrating that river restoration generates land value and tourism revenue that substantially exceeds the restoration investment — provides the economic viability argument for the Kaliyasot proposals within the I-SEER Economic Viability pillar.



*Fig. 2.5: Dravyavati River — Decentralised STP Network and Check Dam Layout, Jaipur
(Source: JDA Dravyavati DPR 2015; Adapted for comparison with Kaliyasot)*

2.4.3 Case Study 3: Bishan-Ang Mo Kio River, Singapore

Background and Context

The Bishan-Ang Mo Kio river restoration in Singapore represents the international benchmark for the physical naturalisation of an engineered urban river channel. The river — a 2.7-kilometre watercourse flowing through one of Singapore's most densely populated residential districts — had been channelised as a straight concrete drain in the 1980s as part of Singapore's national flood control programme. By the late 2000s, it was recognised that the channelisation had created a hydraulically efficient but ecologically barren and socially underutilised urban infrastructure element, occupying valuable land in one of the world's most land-constrained cities without providing the community, ecological, or microclimate benefits that a naturalised waterway could offer.

The decision to de-channelise the river was part of Singapore's Active, Beautiful, Clean (ABC) Waters Programme, launched by the Public Utilities Board (PUB) in 2006. The Bishan project (2009–2012) was the flagship large-scale demonstration project of the ABC Waters programme and involved a complete physical transformation of the concrete channel into a naturalistic, meandering watercourse integrated with the 62-hectare Bishan-Ang Mo Kio Park, one of Singapore's largest urban parks.

Interventions

The core technical intervention of the Bishan project was soil bioengineering — the systematic replacement of vertical concrete banks with gently sloping, vegetated banks stabilised through a combination of coir rolls (biodegradable coconut fibre rolls anchored to the bank surface), native grass seeding (using indigenous species selected for their deep root systems and tolerance of periodic inundation), and selective planting of riparian shrubs and small trees. The slope gradient of the naturalised banks was designed to function simultaneously as an ecological riparian zone during dry conditions and as a hydraulic conveyance surface during storm events, with the park lawn areas adjacent to the banks providing additional flood storage capacity during extreme precipitation events.

The channel planform was re-engineered from straight to meandering — introducing riffle-pool sequences, gravel beds, and natural bar formations that created the physical habitat diversity required to support aquatic biodiversity. Over 80,000 native plants were introduced across 24 species specifically selected for their ecological functions in the riparian zone. The park design integrated the river as an active, visible, accessible landscape element: nature trails followed the river banks, water play areas allowed direct interaction with the naturalised watercourse, and community garden plots were established adjacent to the river — creating a diverse programme of park activities that related explicitly to the water environment.

Outcomes

The Bishan project outcomes have been extensively documented and represent some of the richest post-occupancy data available for any urban river restoration project globally. The park's visitor capacity increased from 12,000 to 40,000 daily visitors following the restoration, with surveys indicating that the

naturalised river environment was the primary attraction for the majority of visitors (PUB, 2012). Biodiversity surveys recorded a 30 percent increase in species richness within the first year, with the naturalised river channel supporting populations of 22 fish species, 56 bird species, and numerous invertebrate and amphibian species within two years of completion.

The bioengineered banks survived two significant flood events — with peak flows significantly exceeding the design flow — without structural failure, confirming the hydraulic viability of soil bioengineering as a substitute for concrete bank protection. Temperature monitoring confirmed a reduction of 2.5 to 3.5 degrees Celsius in ambient air temperature within 50 metres of the river compared to control points in the adjacent urban fabric — confirming the urban heat island mitigation benefit of the naturalised water body and riparian planting.

Key Learnings for Kaliyasot

The Bishan case provides specific technical and design learnings applicable to the Kaliyasot proposals. The soil bioengineering bank treatment — coir rolls plus native grass seeding plus riparian planting — is the direct precedent for the bioengineered bank design proposed for the Recreational Zone and Ecological Zone of the Kaliyasot four-zone model. The confirmation of hydraulic adequacy through two flood events is particularly relevant given the flash flood risk documented in Zone 1 of the Kaliyasot corridor. The integration of flood conveyance and recreational use in the same physical zone provides a design basis for the Socio-Economic and Recreational Zones of the Kaliyasot model. The temperature reduction data provides a direct co-benefit argument for the green edge planting proposed in Zone 4, which is predicted to reduce ambient temperatures by 2 to 4 degrees Celsius for the benefit of the 28,000 residents of Zone 1.

The Bishan case also provides important cautionary guidance: the project was possible in Singapore's context of well-enforced planning controls, high institutional capacity, and fully separated sewage and stormwater systems. Direct application of the Bishan model without first addressing the sewage loading and institutional fragmentation that characterise the Kaliyasot context would be both ecologically ineffective and institutionally inappropriate. The lesson is not 'build

the park first' but 'achieve the ecological conditions that make the park viable, then build it.'



Fig. 2.6: Bishan-Ang Mo Kio River — Soil Bioengineering Techniques and Naturalised Channel (Source: PUB Singapore ABC Waters Programme; Adapted for comparison)

2.4.4 Comparative Case Study Analysis

The three case studies — Kham River (Aurangabad), Dravyavati River (Jaipur), and Bishan-Ang Mo Kio (Singapore) — collectively provide a comprehensive evidence base for the Kaliyasot River proposals. A comparative analysis of the three cases across key planning, engineering, and governance dimensions enables a structured identification of the most applicable lessons for the Kaliyasot context.

Dimension	Kham River — Aurangabad	Dravyavati River — Jaipur	Bishan River — Singapore	Kaliyasot River — Bhopal (This Study)
River length	35 km	47 km	2.7 km	29 km
River type	Non-perennial seasonal	Non-perennial seasonal	Channelised urban drain	Non-perennial seasonal — most comparable to Kham and Dravyavati
Catchment area	~25 km ²	~32 km ²	~6 km ²	18.16 km ²

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Dimension	Kham River — Aurangabad	Dravyavati River — Jaipur	Bishan River — Singapore	Kaliyasot River — Bhopal (This Study)
Sewage load	~90 MLD (pre- restoration)	170 MLD	Fully separated sewage system	170 MLD (current) — matches Dravyavati exactly
Treatment approach	Decentralised Eco-STPs (54 ha)	5 STPs (170 MLD total) + 84 check dams	ABC Waters soil bioengineering (clean channel)	4 STPs (170 MLD total) + 8–10 check dams — hybrid of Dravyavati and Kham
E-Flow source	Treated STP effluent	Treated STP effluent	Natural flow (no sewage)	Treated STP effluent — same as Kham and Dravyavati
Buffer restoration	Riparian planting on both banks	Riparian corridor + 84 check dams	Naturalised channel + native planting	190 ha NGT buffer planting — Bishan approach adapted for semi- arid context
Displacement approach	Low displacement — community integration	Moderate — some formal relocation	No displacement (no residential riverside)	No displacement — in-situ rehabilitation covenant (learning from Sabarmati failure)
Governance	PCMC single authority	JDA with project-specific SPV	PUB single statutory authority	Proposed KRCA — multi- jurisdictional statutory body modelled on JDA SPV approach

Dimension	Kham River — Aurangabad	Dravyavati River — Jaipur	Bishan River — Singapore	Kaliyasot River — Bhopal (This Study)
Implementation time	5 years (2018– 2023)	6 years (2015– 2021)	3 years (2009– 2012)	10 years proposed (2025–2035) — Phase 0 urgent; Phases 1–3 sequential
Key outcome	54 ha ecological restoration; WQI improvement 40%	Year-round visible flow; 8 km restored; 20+ fish species returned	40,000 daily visitors; 30% biodiversity increase; flood capacity maintained	Target: WQI < 50 at S1; DO > 5 mg/L; 33% riparian cover; 16 km walkway
I-SEER applicability	High — non- perennial Indian urban river; Eco-STP model directly applicable	Very High — same scale, same treatment need, non- perennial; direct model	Moderate — different system type; bioengineering technique applicable	This thesis — I- SEER applied for first time to semi- arid non-perennial river context

*Table 2.1: Comparative Case Study Analysis — Key Planning, Engineering and Governance
Dimensions Source: PCMC 2023; JDA DPR 2015; PUB Singapore 2012; Author*

The comparative analysis reveals several consistent patterns across the three cases that have direct implications for the Kaliyasot proposals. First, the ecology-first sequencing is universal: all three projects established water quality improvement and ecological recovery as preconditions for public realm development, and all three projects produced public spaces that are demonstrably superior to those developed alongside unrestored rivers. Second, decentralised treatment outperforms centralised treatment for non-perennial rivers with dispersed catchments: the multiple-STP approaches of both Kham and Dravyavati achieve higher total sewage capture than equivalent centralised systems would, because they reduce the length of sewer collection infrastructure required to intercept dispersed nallah outfalls. Third, community integration — even when not formally embedded in project design (as in the Kham River case) — generates better long-

term outcomes in terms of maintenance, reduced vandalism, and sustained ecological protection than projects that exclude communities from their governance. The Kaliyasot's Community Participation Framework, described in Section 5.7.1, directly responds to this pattern.

The critical difference between the Bishan case and the two Indian cases is instructive for the Kaliyasot context: Bishan succeeded because Singapore had already solved its sewage problem before it undertook the ecological restoration. The Bishan River carried clean stormwater, not sewage, when the soil bioengineering was implemented. The Kham and Dravyavati rivers, like the Kaliyasot, carried raw sewage. The Kham and Dravyavati projects therefore had to solve the sewage problem first — as this thesis proposes for the Kaliyasot — before the soil bioengineering or naturalisation approaches inspired by Bishan could be effectively implemented. This sequencing insight is not obvious from the design literature alone; it emerges from the comparative analysis of implementation context.

2.5 Research Gaps Addressed by This Study

The review of literature reveals four significant research and practice gaps that this thesis seeks to address.

First, existing studies of urban river restoration and riverfront development in India focus disproportionately on large perennial rivers (Ganga, Yamuna, Sabarmati) and on the small number of seasonal rivers that have been subject to major municipal investment (Dravyavati, Kham). The large class of small to medium seasonal urban rivers traversing secondary cities — rivers like the Kaliyasot that drain 10 to 25 square kilometres of urban catchment, carry 100 to 200 MLD of sewage, and are dry for six to nine months of the year — has received limited systematic academic attention. This is a significant gap because these rivers are numerous, ecologically important at the local scale, and represent the type of urban water challenge most relevant to the majority of India's secondary cities.

Second, the socio-economic equity dimension of urban river planning is consistently underweighted in both academic literature and planning practice in

India. The framing of riverside informal communities as obstacles to restoration — rather than as its potential beneficiaries and stewards — reflects an analytical and ethical failure that this study seeks to correct through its empirical demonstration that informal communities are not the primary polluters of the rivers they live adjacent to.

Third, the I-SEER framework, while developed from a broad base of Indian river restoration case studies, has not been applied to non-perennial seasonal rivers in semi-arid central Indian contexts. This application constitutes a novel contribution to the framework's empirical base and tests its indicators against ecological and social conditions that differ in important ways from the perennial river contexts in which it was primarily developed.

Fourth, and most directly, no prior comprehensive planning study of the Kaliyasot River corridor has been conducted. The absence of such a study — despite the river's ecological urgency, its significance for the Betwa River, and its central role in the drainage of Bhopal's urban catchment — constitutes a planning gap of considerable consequence. This thesis addresses that gap.

2.6 The Sabarmati Precedent: Learning from Displacement-Led Riverfront Development

No review of urban riverfront planning in India can omit an examination of the Sabarmati Riverfront Development Project in Ahmedabad, Gujarat — the most prominent and most contested urban river project in India's recent planning history. The Sabarmati project, implemented between 2005 and 2012 under the Ahmedabad Municipal Corporation and the Sabarmati Riverfront Development Corporation, involved the creation of a 20-kilometre waterfront promenade on both banks of the Sabarmati River, incorporating formal public spaces, commercial development, and a regularised river edge. The project has been widely promoted as a model for Indian riverfront development and has directly influenced subsequent riverfront projects in multiple Indian cities.

The academic and activist literature on the Sabarmati project, however, documents a pattern of outcomes that diverges substantially from the promotional narrative. Mahadevia et al. (2009), Desai (2012), and the work of the Concerned

Citizens of Ahmedabad collectively document the displacement of an estimated 15,000 to 20,000 households — predominantly Dalits, Muslims, and other economically marginalised communities — from the riverfront lands claimed for the development, without adequate rehabilitation or compensation. The displacement was justified on the grounds that riverside settlements were environmental hazards and pollution sources — a claim that, in the absence of systematic pollution source apportionment, was accepted as self-evident rather than subjected to empirical scrutiny.

The ecological outcomes of the Sabarmati project are equally sobering. The Sabarmati River, despite the substantial investment in the riverfront's physical infrastructure, remained severely polluted throughout the project period: CPCB monitoring data from 2012 — the year of the project's nominal completion — recorded BOD values of 38 to 68 mg/L in the Ahmedabad reach, only marginally improved from pre-project conditions. The reason is straightforward: the Sabarmati project invested in the river's banks but not in its water — no new STP capacity was commissioned, no nallah interception was implemented, and no E-Flow provision was made. The resulting riverfront is a promenade alongside a still-polluted river, maintained through intensive management of the physical infrastructure but fundamentally disconnected from the ecological restoration of the river itself.

The Sabarmati precedent has three specific implications for the Kaliyasot planning approach taken in this thesis. First, displacement without pollution-source analysis is both unjust and ineffective: the Chapter 4 correlation analysis specifically tests and disproves the assumption that informal settlement density drives pollution loading in the Kaliyasot, establishing the evidentiary basis for a non-displacement approach. Second, riverfront development without water quality improvement is aesthetically ephemeral and ecologically dishonest: the Kaliyasot proposals sequence ecological restoration before public realm development specifically to avoid the Sabarmati outcome of infrastructure adjacent to a continuing ecological failure. Third, institutional design matters: the Sabarmati project was implemented by a single-purpose development corporation with a land development mandate rather than an ecological restoration mandate — a governance design that prioritised built infrastructure over ecological function. The

Kaliyasot River Corridor Authority is designed with an ecological monitoring mandate as its primary accountability mechanism, not a development delivery mandate.

CHAPTER 3 — SITE SELECTION AND CONTEXT

3.1 Rationale for Site Selection

The selection of the Kaliyasot River as the subject of this thesis was not arbitrary but was driven by the convergence of multiple factors that collectively establish the river as a case of both research significance and planning urgency. Four criteria guided the site selection.

The first criterion is ecological urgency. The MPPCB water quality monitoring data and satellite-based analysis of the corridor establish that the Kaliyasot River is in a state of acute ecological degradation — with water quality classified as Toxic or Ecologically Collapsed at four of its five monitoring stations, a sewage treatment deficit of 125 MLD, and a 34 percent decline in surface water presence over the decade 2015 to 2025. The ecological urgency is compounded by the river's downstream connection to the Betwa River, creating a regional dimension to what might otherwise appear a localised urban environmental problem.

The second criterion is planning significance. The Kaliyasot River is Bhopal's primary surface drainage corridor, directly connecting the city's most significant urban water body — the Upper Lake — to the regional river system. Its condition has direct implications for the ecological quality of the Upper Lake (through the reverse influence of backwater conditions in the spillway), for urban flood management (through its role as the primary flood conveyance channel for a substantial portion of Bhopal's urban catchment), and for groundwater levels in the adjacent urban areas (through its potential role as a recharge conduit if restored).

The third criterion is planning gap. Despite its ecological significance and its documented degradation, the Kaliyasot River has received no prior comprehensive planning study. The BDA Development Plan 2031 identifies the river corridor as a development zone but does not provide an integrated environmental management framework. This gap between the river's planning importance and the absence of a systematic planning response makes it an appropriate subject for a research-based planning thesis.

The fourth criterion is analytical tractability. At 29 kilometres, the Kaliyasot corridor is sufficiently compact to permit comprehensive corridor-wide analysis — including field surveys, water quality monitoring at five stations, household interviews, and GIS analysis of the full corridor — within the resources and timeline of a Bachelor of Planning thesis, while encompassing sufficient diversity of urban character (dense urban, peri-urban, industrial) to yield planning learnings of broader applicability.

3.2 Geographic Location and Setting

The Kaliyasot River is located in Bhopal, the capital city of Madhya Pradesh, central India. Bhopal is situated at approximately 23 degrees 16 minutes North latitude and 77 degrees 24 minutes East longitude, at an average elevation of 527 metres above mean sea level. The city is characterised by its distinctive lake system — the Upper Lake (Bada Talab) and Lower Lake (Chhota Talab), together comprising approximately 31 square kilometres of water surface — and by its topography of low hills and broad valleys created by the Vindhya Range that forms the geological substrate of the region.

Bhopal's population is approximately 2.4 million as of the 2021 census, growing at an annual rate of approximately 2.1 percent. The city's administrative area under the Bhopal Municipal Corporation spans approximately 462 square kilometres, though the urban built-up area extends significantly beyond the BMC boundary into the jurisdiction of the Bhopal Development Authority, which administers an overall planning area of 2,772 square kilometres under the Development Plan 2031.

The Kaliyasot River originates at the spillway of the Upper Lake — located at the southern end of the lake at approximately 23°14'N, 77°22'E — and flows in a generally southward to south-southeast direction through the urban fabric of Bhopal before passing through Misrod and Mandideep to its confluence with the Betwa River near Bhojpur at approximately 23°5'N, 77°29'E. The total corridor length is approximately 29 kilometres, with an average longitudinal gradient of approximately 1 in 150 — providing sufficient directional energy for flow during

monsoon events but insufficient turbulence to prevent stagnation in the isolated pools that develop in the non-monsoon period.

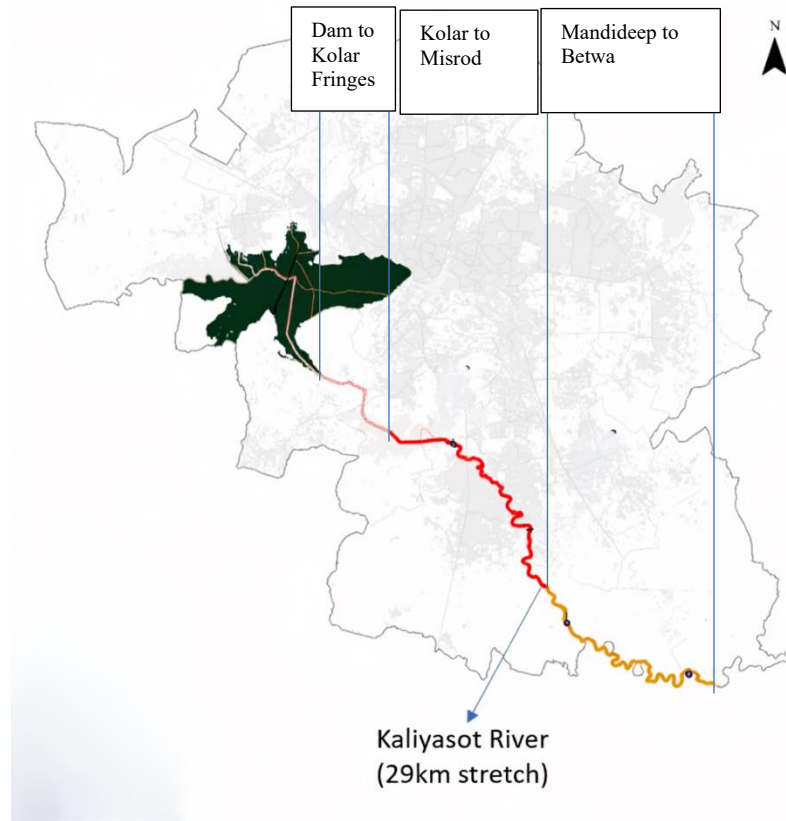


Fig. 3.1: Kaliyasot River Corridor — Three-Zone Segmentation Map (Source: BDA Development Plan 2031; MPPCB; Google Earth Engine; QGIS Analysis)

3.3 Catchment Characteristics

3.3.1 Catchment Area and Boundary

The Kaliyasot River's drainage catchment covers an area of 18.16 square kilometres, as established by SRTM Digital Elevation Model (DEM) analysis and verified against BDA hydrological survey data (CGWB, 2023; BDA, 2031). The catchment boundary follows the topographic watershed of the low ridge systems that separate the Kaliyasot drainage from adjacent sub-catchments draining to the Upper Lake directly and to other tributaries of the Betwa system.

The catchment is oriented roughly north-south, with the Upper Lake spillway forming the northern apex and the Betwa River confluence forming the southern terminus. The catchment width varies from approximately 2 kilometres at the narrow upstream gorge section to approximately 8 kilometres at the widest point

in the Zone 2 midstream stretch, where the valley broadens into the alluvial floodplain that historically supported agricultural land use and now accommodates peri-urban residential development.

3.3.2 Geology and Soils

The geological substrate of the Kaliyasot catchment is predominantly Deccan Trap basalt of Cretaceous to Eocene age, overlain by residual red-black soils (Vertisols) in the upland areas and alluvial deposits of varying depth in the valley floors. The basaltic substrate has moderate permeability, supporting groundwater recharge through the valley floor alluvium while limiting direct recharge from the hard-rock upland areas. The alluvial deposits in the floodplain zone — composed of sand, silt, and gravel in the upstream section transitioning to finer silty clay in the midstream and clay with occasional gravel lenses in the downstream Zone 3 — represent the primary aquifer from which domestic wells and borewells in the corridor draw their supply.

The soil characteristics have direct implications for the check dam network proposed in Chapter 5: the alluvial sandy soils in Zone 1 support high rates of groundwater recharge through check dam ponded sections (estimated at 600 to 800 cubic metres per hectare per year), while the finer silty clays in Zone 3 have lower permeability and correspondingly lower recharge potential (300 to 400 cubic metres per hectare per year). The CGWB's classification of the overall basin as semi-critical — indicating groundwater decline rates of 0.3 to 0.5 metres per year — makes active groundwater recharge a priority objective alongside the ecological restoration goals of the check dam network.

3.4 Hydrological Characteristics

3.4.1 Monsoon-Dependent Hydrology

The Kaliyasot River is a monsoon-dependent, non-perennial stream, a hydrological type extremely common in peninsular and central India and characterised by high seasonal variability in flow — from flood conditions during the Southwest Monsoon (June to September) to complete desiccation for the majority of the non-monsoon period. Under natural conditions, the river would have

maintained a limited dry-season base flow sustained by groundwater discharge from the riparian aquifer, remaining wet at its deepest pools through most of the year. However, the combination of groundwater over-extraction (documented in the CGWB semi-critical basin classification), loss of natural infiltration surfaces due to impervious urban expansion, and the elimination of riparian vegetation that previously sustained soil moisture has effectively eliminated this natural base flow.

Current conditions, as documented through field surveys and satellite imagery, indicate that the river maintains visible surface flow for approximately three to four months during and immediately following the monsoon season (July to October), with residual pools persisting in low points for one to two additional months as monsoon recharge slowly drains from the alluvial aquifer. For the remaining six to seven months of the year, the river is functionally dry — its channel occupied by scattered pools of stagnant, heavily polluted water receiving continuous sewage inputs from nallah outfalls but with no dilution flow to prevent the complete depletion of dissolved oxygen.

3.4.2 Flood Hydrology and Flash Flood Risk

The monsoon season transforms the Kaliyasot from a dry drain to a flood corridor with considerable hydraulic energy. Peak discharge estimates based on the Rational Method applied to the 18.16 square kilometre catchment, with a runoff coefficient of 0.65 (reflecting the 61 percent impervious cover of the catchment) and the 25-year return period rainfall intensity for the Bhopal region (approximately 80 mm/hour), yield a design peak discharge of approximately 260 cubic metres per second at the Zone 2 channel constriction. This discharge significantly exceeds the current hydraulic capacity of the channel at several constricted locations in the midstream zone, contributing to the flash flood events documented in the field survey — events occurring two to three times per year, typically of 4 to 8 hours duration.

The flash flood risk is directly exacerbated by the urbanisation-driven increase in impervious surface cover — from 38 percent in 2015 to 61 percent in 2025. The higher impervious cover increases the runoff coefficient from an estimated natural value of 0.35 to the current 0.65, nearly doubling the peak

discharge for equivalent rainfall events. This relationship between impervious cover and flood risk establishes a direct hydrological co-benefit of the riparian planting and green edge bioswale proposals: increased vegetative cover reduces the effective impervious percentage of the catchment, attenuating peak discharge and reducing both flood risk and channel erosion.

3.5 Three-Zone Segmentation

The 29-kilometre Kaliyasot River corridor exhibits substantial spatial variation in land use context, pollution intensity, ecological condition, population density, and administrative jurisdiction. To structure the analysis and proposals in a spatially meaningful way, the corridor is divided into three planning zones based on systematic analysis of these characteristics. This three-zone segmentation is the spatial foundation of both the analytical chapters and the proposals of this thesis.

3.5.1 Zone 1 — Upstream (0–6 km: Upper Lake Spillway to Kolar Road)

Zone 1 extends for approximately 6 kilometres from the Upper Lake spillway at the river's origin to the Kolar Road crossing — the first major road crossing below which the urban character of the corridor intensifies sharply. This zone traverses the interface between the southern edge of Bhopal's urban core and the expanding suburban fringe of Kolar, characterised by a mix of residential development, remnant peri-urban green space, and the occasional small industrial establishment.

Ecologically, Zone 1 is the best-preserved section of the corridor, with remnant patches of riparian forest particularly on the steeper valley sides and a Water Quality Index of 82 at the Damkheda monitoring station — classified as Very Poor but substantially less degraded than the conditions found in Zones 2 and 3. The presence of relatively less polluted water and surviving riparian vegetation makes Zone 1 the section with the greatest potential for rapid ecological recovery, and therefore the priority zone for the initial phases of the restoration programme.

Despite its relatively better ecological condition, Zone 1 faces the most acute encroachment pressure in the corridor. The expansion of Bhopal's residential development southward from the urban core has placed Zone 1's river banks under

intense development pressure, with satellite imagery confirming 127 illegal structures within the NGT 33-metre buffer at Damkheda alone, representing a violation rate of 78 percent. The zone is also the location of the most frequent flash flood events — two to three occurrences per year — which pose direct risk to the households that have encroached upon the natural floodplain.

The combination of relative ecological recovery potential, intense encroachment pressure, and high flash flood risk establishes Zone 1 as the location where the early phases of the intervention must be concentrated: clearing encroachments and enforcing the NGT buffer (Phase 0), establishing the upstream STP and initiating E-Flow (Phase 1), and beginning the riparian planting programme that will stabilise banks and reduce flash flood velocity (Phase 2).

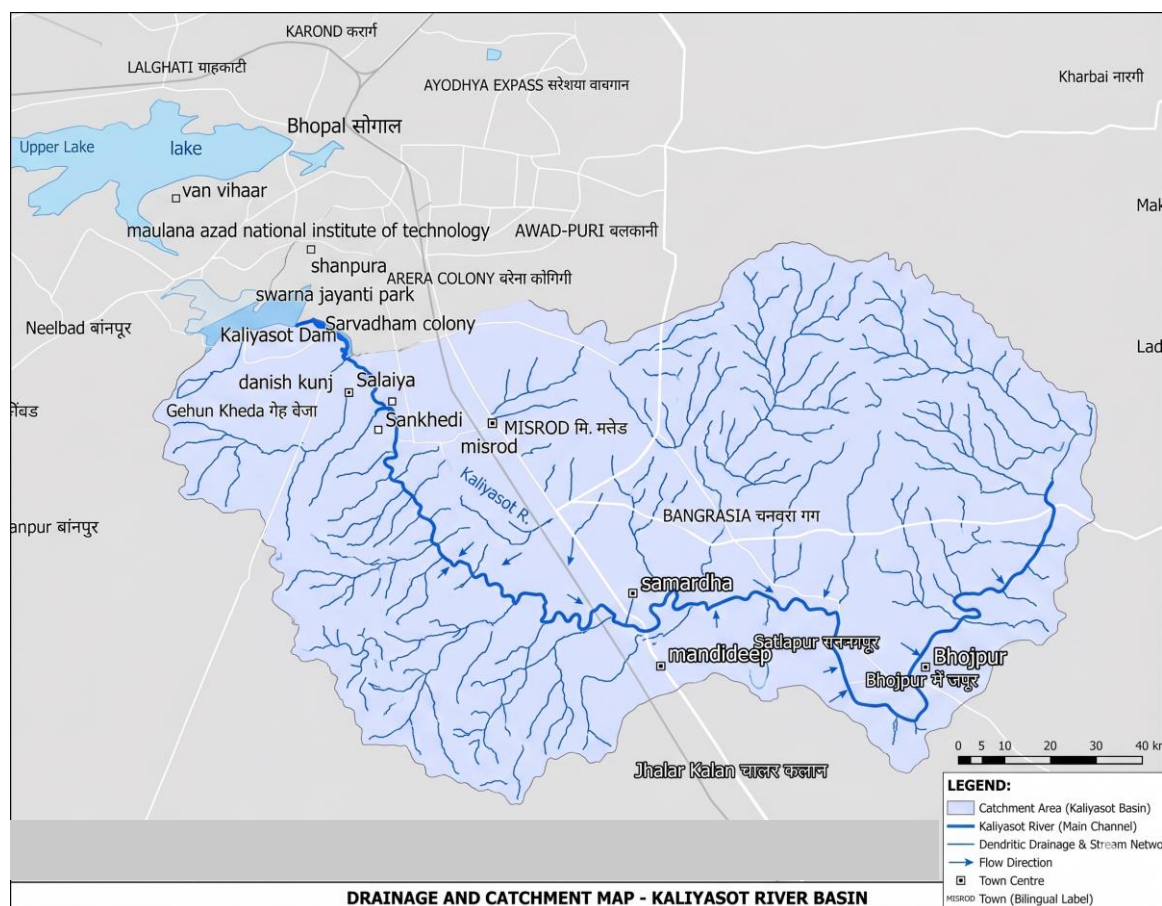


Fig. 3.3: Zone 1 Upstream — Existing Conditions Documentation

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Kaliasot at Sarvdharm, Bhopal



Kaliasot at Danish Kunj, Bhopal

3.5.2 Zone 2 — Midstream (6–22 km: Kolar Road to Misrod Boundary)

Zone 2 extends for approximately 16 kilometres from the Kolar Road crossing to the administrative boundary of the Misrod Urban Local Body. This is by far the longest zone and traverses the densest and most complex urban environment of the three zones — the established residential neighbourhoods of southern Bhopal, including the Shahpura, Sarvadharam, Danish Kunj, Bairagarh, and Misrod localities, with a combined residential population within 500 metres of the corridor estimated at 28,000 persons.

Zone 2 is the critical zone from both a pollution and a social equity perspective. It receives the discharge of five major nallah systems — each carrying the combined sewage output of extensive urban sub-catchments — at cumulative flow rates that overwhelm any natural self-purification capacity the river might otherwise possess. The water quality consequences are captured in the monitoring data: BOD values between 42 and 102 mg/L at the Shahpura and Misrod stations, Dissolved Oxygen recorded at zero at the Sarvdharm point, and WQI values between 119 and 186 — all classified as Toxic.

The social analysis of Zone 2 reveals an urban community that simultaneously suffers from the river's ecological collapse and remains dependent upon it. The 38 percent informal settlement rate in the Zone 1 section at the upper end of Zone 2 reflects housing insecurity among a population that has, over generations, developed economic relationships with the river — washing, fishing, and agricultural activities — that are now compromised by the river's condition. The 78 percent gender unsafety rate documented in the survey reflects the deterioration of the river's physical environment — absence of lighting, loss of vegetation to provide natural surveillance, accumulation of solid waste — that has rendered the riverfront unsafe for women and girls.

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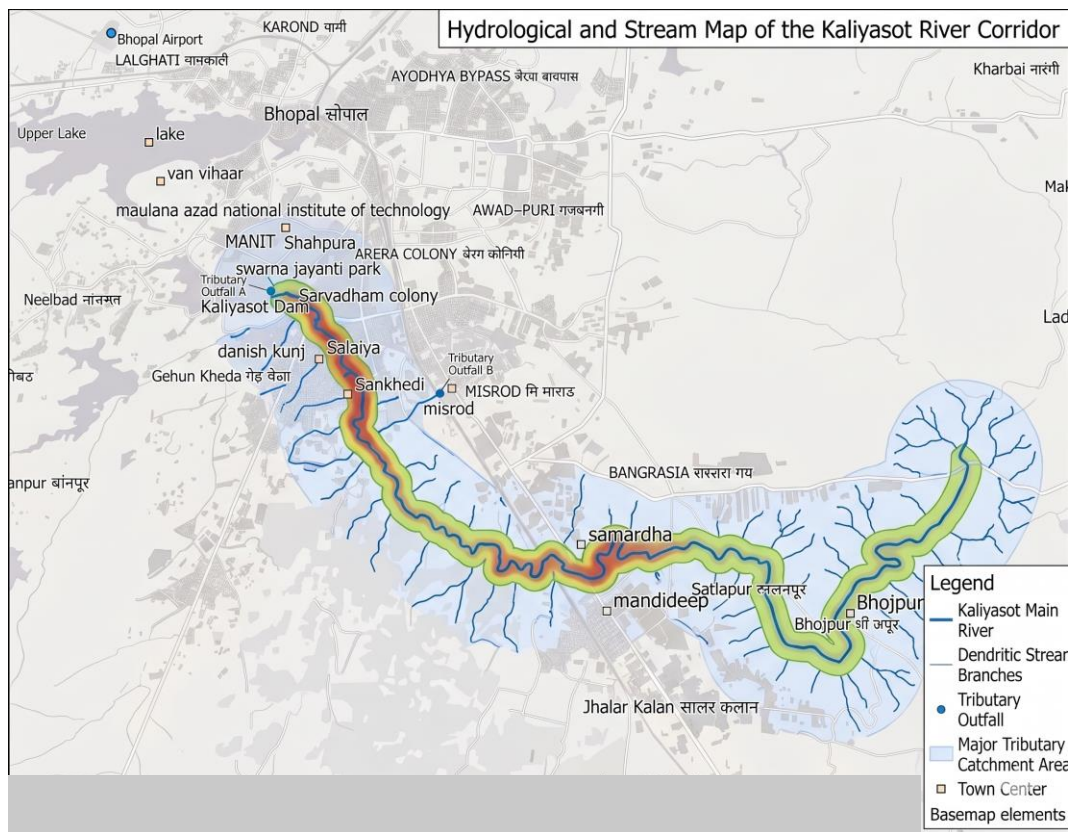


Fig. 3.4: Zone 2 Midstream — Major Nallah Outfall Locations and Encroachment Patterns (Source: Field Survey; GIS Analysis; MPPCB Outfall Survey)



Kaliasot at Saliya, (Sankhedi) Bhopal



3.5.3 Zone 3 — Downstream (22–29 km: Misrod to Betwa Confluence)

Zone 3 extends for approximately 7 kilometres from the Misrod administrative boundary to the river's confluence with the Betwa River near Bhojpur. This zone is characterised by its transition from peri-urban residential land use in the upper portion to the industrial and agricultural landscape of the Mandideep Industrial Estate in the lower portion — one of Madhya Pradesh's most significant industrial concentrations, hosting over 600 manufacturing units across sectors including pharmaceuticals, chemicals, automotive components, and food processing.

The water quality conditions in Zone 3 are the most severely degraded in the entire corridor. Station S5, the industrial outfall monitoring point, records COD values exceeding 500 mg/L — indicating the presence of complex industrial effluent including chemical compounds that resist biological treatment — and Coliform counts of 31,000 MPN per 100 mL. The cumulative pollution load from all five monitoring stations, measured as BOD, increases from 18 mg/L at S1 to 170 mg/L at S5, following a progression that reflects the additive impact of each successive pollution input without any natural dilution or self-purification.

The most critical planning concern in Zone 3 is the risk of toxic downstream transfer to the Betwa River. The Betwa is a major regional water body, supporting agricultural irrigation, domestic water supply, and aquatic biodiversity across a catchment extending into Uttar Pradesh. The discharge of water with a WQI of 225-plus and a COD of 500-plus mg/L into the Betwa represents both an ecological hazard to the receiving river and a potential regulatory violation under the CPCB effluent standards for discharge to inland water bodies. The Zone 3 constructed wetland proposed in Chapter 5 functions primarily as the mechanism to prevent this toxic downstream transfer.



*Fig. 3.5: Zone 3 Downstream — Industrial Zone Proximity and Outfall Conditions
(Source: Field Survey; MPPCB; Google Earth Engine)*



Kaliasot at Road Bridge Mandideep



Kaliasot at Bhojpur before Joining River Betwa

3.6 Administrative and Planning Context

The Kaliyasot River corridor passes through three distinct administrative and planning jurisdictions, a fragmentation that represents one of the most significant governance challenges for integrated river management.

Zone	Administrative Jurisdiction	Key Planning Authority	Key Regulatory Agency
Zone 1 (0–6 km)	Bhopal Municipal Corporation / BDA	BDA Development Plan 2031	MPPCB; NGT

Zone	Administrative Jurisdiction	Key Planning Authority	Key Regulatory Agency
Zone 2 (6–22 km)	Bhopal Municipal Corporation / BDA / Peri-urban transition	BDA; Misrod ULB	MPPCB; NGT
Zone 3 (22–29 km)	Misrod ULB / Mandideep Industrial Area	Mandideep Industrial Area Authority	MPPCB; MoEFCC; State Industrial Dept.

Table 3.3: Administrative Jurisdiction Overlap along Kaliyasot River Corridor Source: BDA 2031; Government of Madhya Pradesh; MPPCB

This administrative fragmentation means that enforcement of NGT buffer zone orders, implementation of STP infrastructure, planning of river corridor development, and monitoring of water quality are handled by different agencies with different reporting structures, different budget cycles, and different institutional priorities. The consequence — documented in the field survey observations — is that pollution generated by industrial units under the jurisdiction of the Mandideep Industrial Area Authority contaminates the river section for which the Bhopal Development Authority nominally has riverfront development plans, and the enforcement of NGT buffer orders at Damkheda (under BDA) is uncoordinated with buffer management at Misrod (under the ULB).

The specific regulatory gap most consequential for the Kaliyasot River is the absence of a unified enforcement authority for the NGT buffer zone orders. NGT Order dated 2022 (OA 200/2022 and related orders) requires each relevant authority — BDA, Misrod ULB, and Mandideep Industrial Area Authority — to independently implement buffer zone restoration within their respective jurisdictions. There is no legal mechanism for coordinating these three enforcement processes, for resolving conflicts between jurisdictional approaches, or for ensuring that an encroaching structure documented by one authority is not rebuilt in the jurisdiction of another. The Kaliyasot River Corridor Authority proposed in Section 5.7 is specifically designed to address this enforcement coordination gap.

A secondary governance concern is the absence of shared environmental monitoring data across the three jurisdictions. MPPCB operates the five monitoring

stations described in Chapter 4, but their data is not systematically shared with BDA or the Misrod ULB in a format that enables real-time planning responses. The result is that planning decisions affecting the river's catchment — zoning approvals, infrastructure investments, drainage network extensions — are made without reference to their hydrological or water quality consequences. The KRCA monitoring mandate proposed in Section 5.7 addresses this data-sharing deficit.

3.7 Geology, Soils and Groundwater

The Kaliyasot River corridor is underlain by Vindhyan sandstone and shale formations of Proterozoic age, overlain by shallow alluvial deposits of varying depth in the valley floor and terrace areas. The Vindhyan formations are characterised by low primary porosity but moderate secondary permeability through joints, fractures, and bedding plane separations, making them capable of sustaining limited groundwater storage in the shallow aquifer zone. The alluvial deposits in the river valley are of greater significance for local groundwater use: these deposits, comprising sandy loam to fine sand with varying clay lenses, constitute the primary aquifer accessed by hand pumps and shallow tube wells in the Zone 1 and Zone 2 residential areas.

The Central Ground Water Board's classification of the Kaliyasot catchment as 'semi-critical' reflects a groundwater development stage (groundwater extraction as a percentage of recharge) between 70 and 90 percent — a condition indicative of significant pressure on the aquifer but not yet at the critical or over-exploited stage. The documented decline in groundwater table levels of 0.3 to 0.5 metres per year, combined with the near-elimination of river-channel recharge through the loss of dry-season base flow, creates a trajectory toward over-exploitation unless active recharge measures are implemented. The check dam network proposed in Chapter 5 is the primary recharge intervention: by impounding monsoon flows in a series of sub-metre structures along the 29-kilometre corridor, the check dams create extended contact between river water and the alluvial aquifer, substantially increasing the recharge rate relative to the unimpounded condition.

Soil types along the corridor vary significantly by zone. Zone 1 valley soils are predominantly medium black cotton soils (Vertisols) with high shrink-swell

potential, moderate infiltration rates, and significant agricultural value. Zone 2 soils are more mixed, reflecting both the Vindhyan residual soils (loamy to clay-loam in texture) and extensive fills and urban substrates in the more densely developed sections. Zone 3 soils include both alluvial and Vindhyan residual types in the upper section, transitioning to deeper alluvial deposits near the Betwa confluence. The soil bioengineering bank treatment proposals of Chapter 5 account for the Vertisol characteristics of Zone 1 — specifically the requirement for deeper coir roll installation and species selection favouring deep-rooted plants that can bridge shrink-swell cycles without bank failure.

3.8 Site Characteristics Summary Tables

Parameter	Observation	Planning Interpretation
River Length	29 km (Upper Lake to Betwa confluence)	Full corridor-wide planning required
Catchment Area	18.16 km ²	Highly urbanised — 61% impervious by 2025
Mean Gradient	1 in 150 (approximate)	Sufficient for directional flow; insufficient to prevent stagnation
Channel Width	15–60 m (variable along corridor)	Narrowed by encroachment in Zone 1 and Zone 2
Seasonal Flow Duration	3–4 months (July–October only)	Dry for 8–9 months; sewage carrier in non-monsoon period
Groundwater Status	Semi-critical (CGWB)	Declining at 0.3–0.5 m/year; active recharge needed
Flash Flood Frequency	2–3 events per year, Zone 1	Increasing with impervious cover expansion
Administrative Jurisdictions	3 (BDA; Misrod ULB; Mandideep IA)	Governance fragmentation — unified authority required

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Parameter	Observation	Planning Interpretation
Water Quality Status	Very Poor to Ecological Collapse	WQI 82 to 225+ across 5 stations
Buffer Violation Rate	18–78% (by location)	321 structures in NGT 33m zone
Sewage Treatment Coverage	26% (45 MLD of 170 MLD)	125 MLD untreated daily discharge
Riparian Cover	15% (current)	Target: 33% within 5 years of planting
Dominant Soil Type	Black cotton soil (Zone 1); mixed Vertisol/loam (Zone 2); alluvial (Zone 3)	Soil bioengineering specifications vary by zone
Groundwater Aquifer	Shallow alluvial (5–20 m depth); Vindhyan fractured rock secondary	Check dam recharge targets shallow alluvial aquifer
Mean Annual Rainfall	1,146 mm (IMD 1990–2020 average)	Highly seasonal — 90% monsoon (June–September)
Geology	Vindhyan sandstone and shale; alluvial valley fill	Low primary porosity; secondary fracture permeability

Table 3.1: Site Characteristics — Kaliyasot River Corridor Source: BDA 2031; MP PCB; CGWB; IMD; Satellite Imagery LISS-III/Sentinel-2 (2015–2025)

Zone	Stretch	Dominant Problem	Key Indicators	Vulnerability	Primary Intervention
Zone 1 Upstream	0–6 km (Dam to Kolar)	Encroachment; flash flood risk; expanding urban pressure	78% buffer violation; BOD 12–18 mg/L; WQI 82	Critical — highest encroachment rate; 38% slum population	Eco-STP; NGT enforcement; riparian planting; flood retention

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Zone	Stretch	Dominant Problem	Key Indicators	Vulnerability	Primary Intervention
Zone 2 Midstream	6–22 km (Kolar to Misrod)	Concentrated sewage from 5 nallahs; dead zone; peak social dependency	DO = 0 at Sarvdharm; BOD 42–102 mg/L; WQI 119–186	Critical — 28,000 residents exposed; 78% gender unsafe	40 MLD STP; nallah interception; E-Flow; check dams; 4-zone model
Zone 3 Downstream	22–29 km (Misrod to Bhojpur)	Industrial effluent; toxic downstream transfer to Betwa	COD >500 mg/L; Coliform 31,000; WQI 225+	High — Betwa River at risk; industrial data gaps	50 MLD STP at Mandideep; constructed wetlands; industrial compliance

Table 3.2: Zone-wise Problem Summary and Primary Interventions — Kaliyasot River Corridor
Source: MPPCB 2019; BDA 2031; Field Survey 2024–25

CHAPTER 4 — DATA ANALYSIS AND FINDINGS

4.1 Introduction

This chapter presents the systematic analysis of the Kaliyasot River corridor across five interconnected analytical dimensions: (i) environmental and temporal change analysis using remote sensing indicators; (ii) water quality analysis based on five-station MPPCB monitoring data; (iii) buffer zone violation analysis from GIS mapping and field survey; (iv) sewage infrastructure gap analysis from MPPCB and Jal Nigam records; and (v) socio-economic vulnerability analysis from household survey and secondary census data. Each analytical section presents quantitative findings, interprets them in the context of relevant standards and benchmarks, and draws implications for the proposal formulation in Chapter 5. The chapter concludes with a synthesis section that integrates the findings across all five dimensions into a unified characterisation of the Kaliyasot River corridor's condition and planning imperatives.

The five analyses are not independent: the LULC change findings explain the NDWI decline and contribute to the water quality deterioration; the water quality deterioration is directly caused by the infrastructure gap; the buffer zone violations exacerbate water quality degradation by removing the natural filtration function of the riparian zone; and the socio-economic vulnerability of river-dependent communities is a consequence of, rather than a cause of, the ecological collapse documented in the environmental and water quality analyses. These interdependencies are mapped in the problem synthesis section (4.7).

4.1.1 Data Sources and Quality Assessment

The analysis in this chapter draws on data from multiple sources of varying vintage, spatial resolution, and methodological basis. It is important to establish the quality and limitations of each major data source before presenting the analytical findings derived from them, so that the reader can appropriately calibrate confidence in the quantitative results.

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Data Source	Type	Date	Spatial Resolution	Use in Analysis	Quality Assessment
MPPCB Water Analysis Report (ROMPPCB/Bhopal/2019)	Secondary — institutional monitoring	2019	Point (5 stations)	Water quality analysis (Section 4.3); WQI calculation	Authoritative — official MPPCB data; limitations: 2019 vintage; seasonal snapshot
Sentinel-2 MSI Imagery	Remote sensing (satellite)	2020, 2025 (dry season)	10 m	NDWI temporal analysis; LULC 2025 classification	High — ESA Level-2A surface reflectance product; cloud cover < 5%
Landsat 8 OLI Imagery	Remote sensing (satellite)	2015 (dry season)	30 m	LULC 2015 baseline classification; NDWI 2015 baseline	Good — USGS Level-2 product; spatial resolution coarser than Sentinel-2
BDA Development Plan 2031	Secondary — planning document	2021	1:10,000 cadastral	Administrative boundary; land use zoning; catchment area	Authoritative for planning; some data pre-dates 2025 urban expansion
Census of India 2021	Secondary — national census	2021	Ward level	Population estimates; slum proportion; household composition	Authoritative — National Census data; ward boundaries may not align with river zones

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Data Source	Type	Date	Spatial Resolution	Use in Analysis	Quality Assessment
CGWB Groundwater Assessment Report	Secondary — institutional	2022	District level	Groundwater semi-critical classification; decline rate	Good — official CGWB classification; district-level may mask local variation
Household Survey (Author)	Primary — structured interview	2024–25	Point (120 households)	Socio-economic vulnerability; livelihood dependency; safety	Original primary data — inherent sampling limitations (n=120; Zones 1 and 2 only)
Field Survey and Photo Documentation	Primary — field observation	2024–25	Corridor (29 km)	Encroachment mapping; nallah identification; channel condition	Original primary data — systematic but not comprehensive land parcel level
Google Earth Engine Analysis	Analytical — derived from satellite	2015, 2020, 2025	10–30 m	NDWI computation; LULC classification; temporal comparison	High — standardised GEE workflow; accuracy validated by confusion matrix
QGIS Buffer Analysis	Analytical — GIS-derived	2025 (study period)	Cadastral level	NGT 33m buffer violation mapping; encroachment quantification	Good — based on Sentinel-2 imagery; cadastral accuracy

Data Source	Type	Date	Spatial Resolution	Use in Analysis	Quality Assessment
					dependent on available basemap
IMD Rainfall Data	Secondary — meteorological	1990–2020 (30-year mean)	Station (Bhopal)	Catchment rainfall; peak flood discharge estimation	Authoritative — IMD 30-year climatological normal; no recent trend analysis
Mandideep Industrial Estate Records	Secondary — industry	Not available in public domain	Industrial estate level	Industrial pollution characterisation (Section 4.4)	Limited — data gap acknowledged; COD values from MPPCB S5 monitoring only

Table 4.0: Data Sources and Quality Assessment — Kaliyasot River Analysis Source: Author's Research Design

The most significant data quality concern is the vintage of the MPPCB water quality dataset: the most recent available comprehensive monitoring report dates from 2019. In the six years since this data was collected, the urban expansion of the Bhopal catchment has continued — with built-up area increasing, based on the satellite evidence, from an estimated 52 percent in 2019–2020 to 61 percent in 2025 — and it is reasonable to expect that water quality conditions have deteriorated further. The WQI values reported in this thesis should therefore be understood as lower-bound estimates of current conditions; the actual conditions in 2025 are likely to be at least as severe and potentially more so.

The satellite imagery data is of high quality and largely free of the vintage limitations affecting the MPPCB data. Sentinel-2 imagery was acquired in dry-season conditions (February–March) for consistency across the three temporal dates, avoiding the confounding effect of monsoon-season vegetation response on

the NDWI and LULC analyses. The 10-metre resolution of Sentinel-2 is sufficient to detect individual structures, nallah outfalls, and riparian vegetation patches, making it the primary imagery source for the 2020 and 2025 analyses.

4.2 Environmental Analysis: Temporal Change in Land Use and Hydrology

4.2.1 Analytical Methodology

The environmental analysis employs two complementary remote sensing approaches: supervised land use land cover (LULC) classification of multi-temporal satellite imagery, and Normalised Difference Water Index (NDWI) analysis for hydrological change detection. Satellite imagery was sourced from the USGS Earth Explorer platform and processed through Google Earth Engine (GEE) and QGIS. Landsat 8 OLI imagery (30-metre spatial resolution) was used for the 2015 baseline, while Sentinel-2 MSI imagery (10-metre spatial resolution) was used for the 2025 analysis, providing a higher-resolution characterisation of current conditions. For the NDWI temporal series, Sentinel-2 imagery was available for all three dates (2015, 2020, 2025), enabling consistent sensor comparison.

The LULC classification used a supervised maximum-likelihood classification algorithm with training samples collected through a combination of field ground-truth data and high-resolution reference imagery. Four land use classes were distinguished: Built-up Area (all impervious surfaces including roads, buildings, and hard-paved spaces); Vegetation (including riparian forest, scrub, grassland, and agricultural vegetation); Water Bodies (including river channel, ponds, and seasonal wetlands); and Agriculture (irrigated and rain-fed cropland, excluding natural grassland). Classification accuracy was validated through a confusion matrix analysis of 200 independent reference points for each date, achieving overall classification accuracies of 87 percent for 2015 and 91 percent for 2025 — both above the commonly accepted 85 percent threshold for reliable LULC analysis.

The NDWI was calculated as: $NDWI = (Green - Near-Infrared) / (Green + Near-Infrared)$, where Green and Near-Infrared refer to the corresponding spectral bands of the satellite sensor. Positive NDWI values (typically greater than 0.1)

indicate the presence of open water surfaces; values between 0 and 0.1 indicate saturated soils or shallow water; negative values indicate dry land surfaces. The NDWI analysis was performed at the level of the 200-metre buffer zone on both sides of the river channel, capturing both the channel itself and the immediately adjacent riparian zone.

4.2.2 NDWI Temporal Change Analysis (2015–2025)

The NDWI analysis reveals a consistent and severe decline in surface water presence within the Kaliyasot River corridor over the ten-year study period. In March 2015 (dry season), the mean NDWI across the 200-metre corridor buffer was 0.38 — indicative of a river corridor retaining significant soil moisture and residual surface water in pools and low-lying areas despite the absence of monsoon flows. By March 2020, the mean NDWI had declined to 0.26, with the emergence of multiple dry stretches in the Zone 2 midstream corridor and the disappearance of several seasonal ponds within the corridor buffer that had previously maintained positive NDWI values. By March 2025, the mean NDWI had fallen to 0.14 — representing a 63 percent reduction from the 2015 baseline and indicating a corridor buffer that is predominantly dry, with only scattered residual pools of stagnant water.

The spatial pattern of NDWI decline is informative. The Zone 2 midstream section shows the most dramatic reduction, consistent with the documented intensification of urban pressure — impervious surface expansion, nallah outfall construction, and encroachment — in this zone over the study period. Zone 1 upstream shows a more gradual decline, with a 2025 NDWI of 0.22 reflecting the persistence of some natural vegetation and soil moisture retention in the less densely developed sections. Zone 3 downstream shows a counterintuitive pattern: the 2025 NDWI is slightly higher than Zone 2 (0.18 vs 0.14) because the Zone 3 monitoring point captures the stagnant industrial wastewater pools that register as water bodies in the spectral analysis, despite their severely degraded quality.

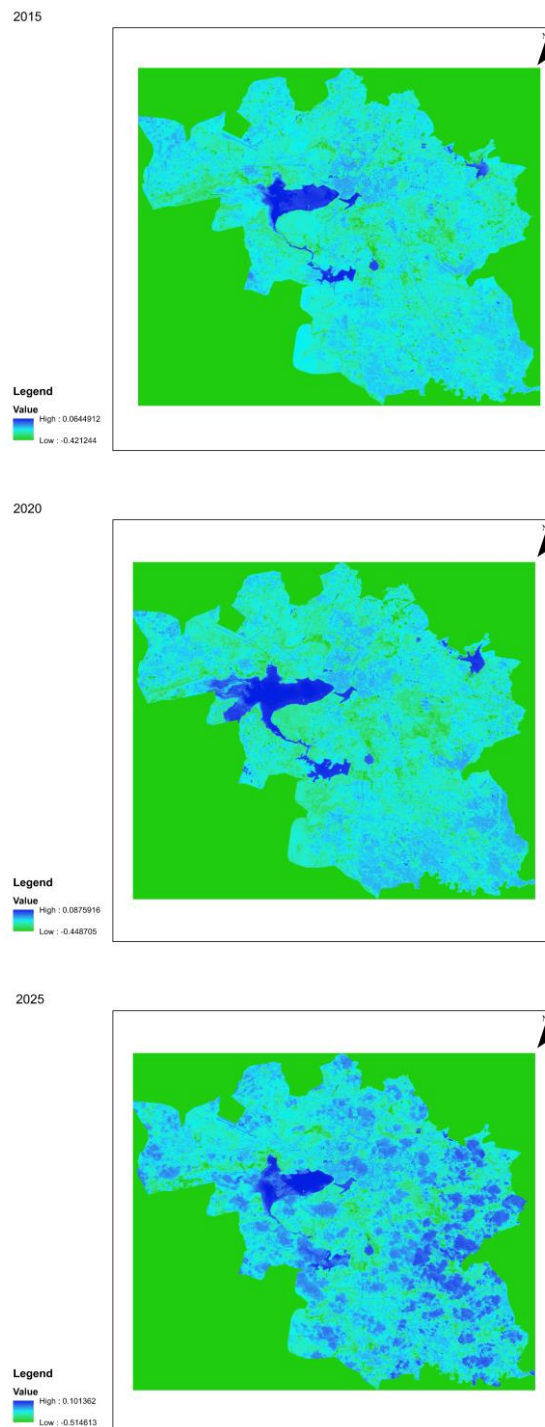
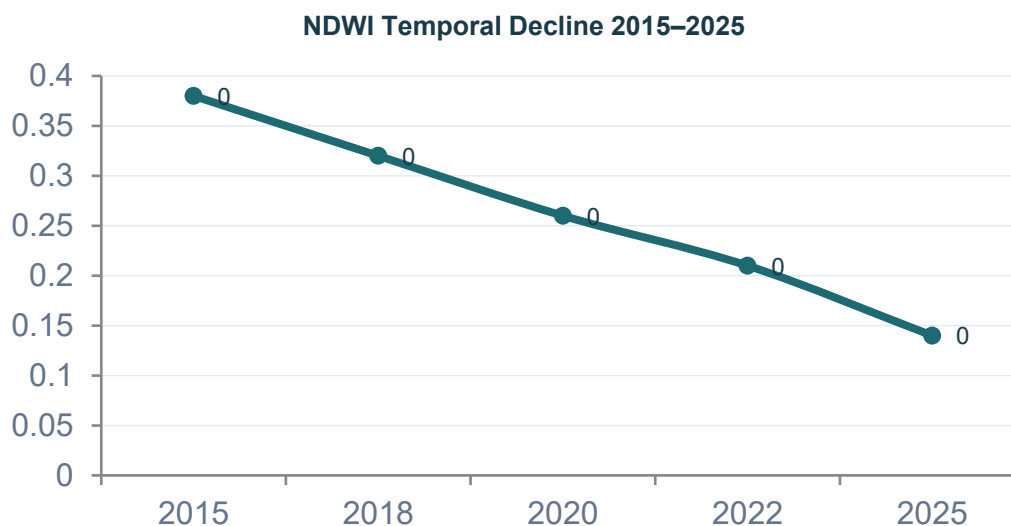


Fig. 4.1: NDWI Temporal Change Maps — Kaliyasot River Corridor (2015, 2020, 2025)
Note: Colour scale from dark blue (high NDWI, water presence) to red (low NDWI, dry surface) (Source: Sentinel-2 MSI; USGS Earth Explorer; Google Earth Engine; ArcGIS)

Year	Season	NDWI (Mean)	Corridor Condition	Primary Driver of Change
2015	Dry (March)	0.38	Functional hydrological system; river retains water in pools between monsoon events; riparian moisture maintained	Baseline — urban expansion at 38% impervious; limited impervious cover expansion to date
2020	Dry (March)	0.26	Disrupted channel continuity; multiple dry stretches in Zone 2; seasonal ponds disappearing from catchment	Built-up area increased to approximately 52%; 5 new nallah outfalls diverted natural flow; riparian planting declining
2025	Dry (March)	0.14	Hydrological breakdown; river functions as dry drain for 8–9 months; stagnant pools only in lowest points	Built-up area 61%; 34% surface water loss from 2015; CGWB semi-critical classification confirmed

Table 4.1: NDWI Temporal Change 2015–2025 — Kaliyasot River Corridor Source: USGS Earth Explorer; Sentinel-2 NDWI Analysis; Google Earth Engine



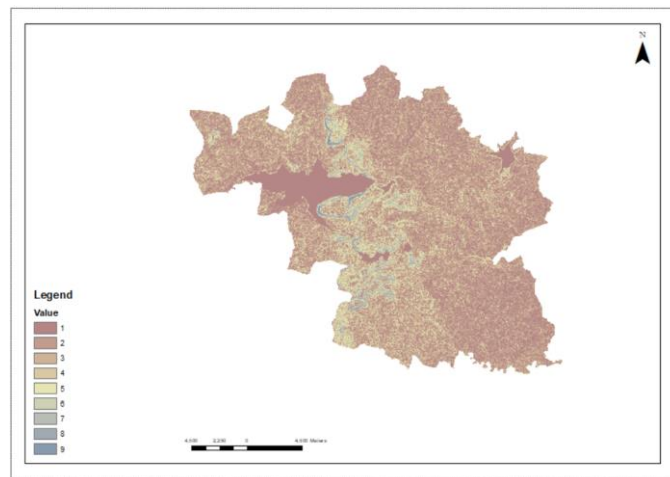
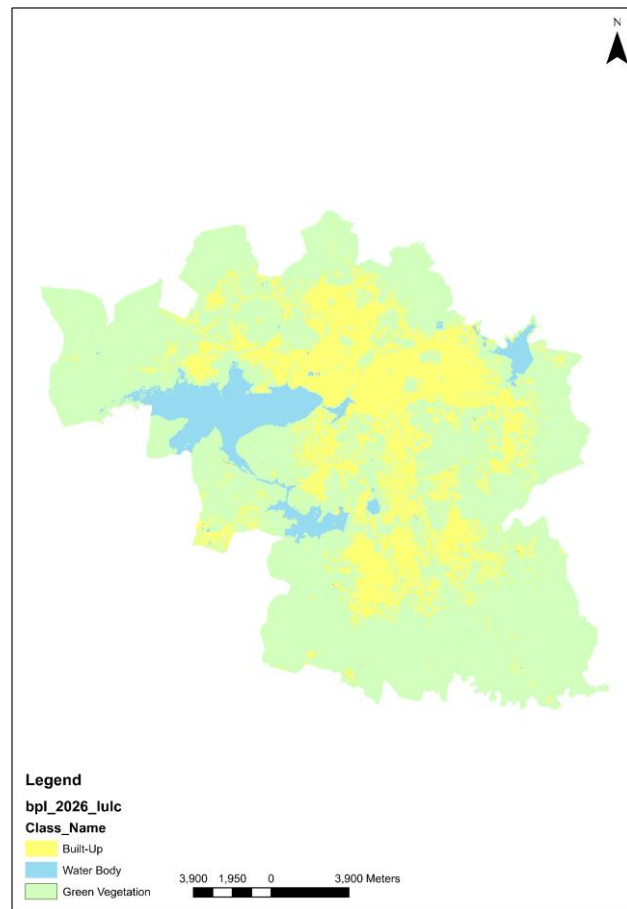
4.2.3 Land Use Land Cover Change Analysis

The supervised LULC classification reveals a pattern of land use change over the decade 2015 to 2025 that is both dramatic in scale and deeply consequential for the river's ecological function. The dominant trend is the conversion of vegetated and water surfaces to built-up impervious land — a pattern consistent

with the rapid urbanisation of the Zone 1 and Zone 2 sections of the corridor catchment.

The Built-up Area category increased from 38 percent of the total catchment in 2015 to 61 percent in 2025 — a 23 percentage point increase representing the conversion of approximately 4.18 square kilometres of previously vegetated or water surface to impervious urban land. This rate of impervious cover expansion — 2.3 percentage points per year — substantially exceeds the national average for secondary cities and is consistent with the Bhopal Metropolitan Region's documented growth as a hub for government employment, education, and IT-enabled services following Madhya Pradesh's capital city investments.

The Vegetation category declined from 29 percent to 15 percent — a 14 percentage point decline representing the loss of approximately 2.54 square kilometres of vegetated surface. The spatial analysis of this decline reveals that it is heavily concentrated in the Zone 2 corridor zone, where the removal of riparian scrub and grassland to accommodate encroaching development has been most systematic. In Zone 1, some riparian vegetation persists in the steeper valley sections that are physically inaccessible to construction equipment, explaining the relatively lower vegetation loss rate in this zone compared to the overall catchment.



*Fig. 4.2: LULC Classification Maps — Kaliyasot River Catchment, 2015 and 2025
(Source: Landsat 8 OLI 2015; Sentinel-2 MSI 2025; QGIS Supervised Classification;
Google Earth Engine)*

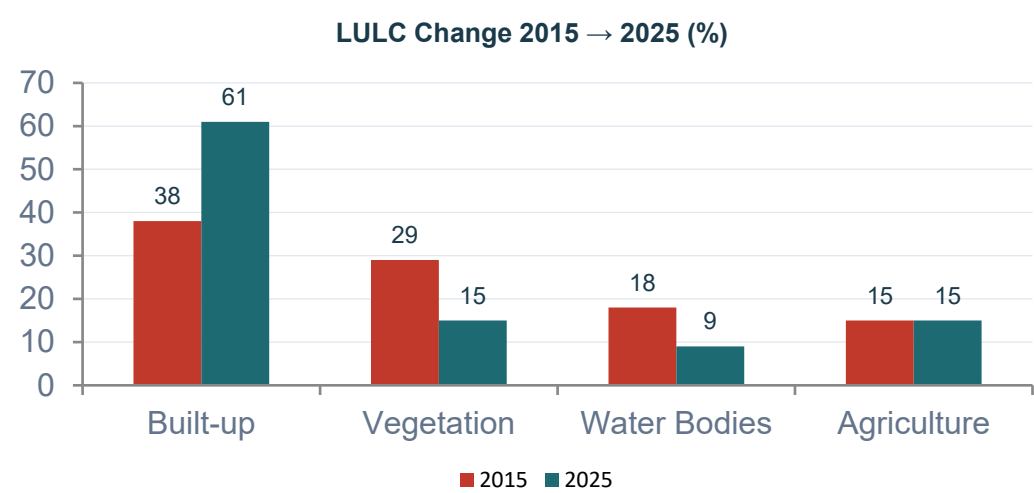
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Land Use	2015 (%)	2015 Area (km ²)	2025 (%)	2025 Area (km ²)	Change (%)	Change (km ²)	Impact on River	Planning Response
Built-up Area	38%	6.90	61%	11.08	+23%	+4.18	Increased impervious cover raises runoff volume and peak discharge; accelerates pollution transport to river	Bioswale network in Zone 4; riparian planting to intercept runoff
Vegetation	29%	5.27	15%	2.72	-14%	-2.55	Loss of riparian filtration, bank stabilisation, and ecological corridor function	Restore 33m NGT buffer with native species; establish riparian corridor
Water Bodies	18%	3.27	9%	1.63	-9%	-1.64	Seasonal wetlands and floodplain ponds lost; reduced groundwater recharge and flood attenuation	Check dam network to restore ponded surfaces; wetland restoration
Agriculture	15%	2.72	15%	2.72	Stable	Stable	Minor agrochemical runoff; no significant	Monitor agrochemical inputs; include in buffer

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Land Use	2015 (%)	2015 Area (km²)	2025 (%)	2025 Area (km²)	Change (%)	Change (km²)	Impact on River	Planning Response
							change in this decade	management plan

Table 4.2: LULC Change Analysis 2015–2025 — Kaliyasot River Catchment Source: Landsat 8 OLI and Sentinel-2 MSI; Google Earth Engine; QGIS Supervised Classification



Impervious Cover (%)	Runoff Coefficient (C)	Change from Natural	Peak Discharge Impact	Ecological Consequence
<10% (Natural forest)	0.15–0.25	Baseline	Baseline	Near-natural hydrology; strong groundwater recharge
10–25% (Suburban low-density)	0.30–0.40	+60 to +130%	Moderate increase	Some ecological impact; groundwater recharge reduced
25–50% (Suburban high-density)	0.40–0.55	+130 to +250%	Significant increase	Stream channelisation effects; reduced base flow

Impervious Cover (%)	Runoff Coefficient (C)	Change from Natural	Peak Discharge Impact	Ecological Consequence
50–75% (Urban — Kaliyasot 2025)	0.55–0.70	+250 to +400%	Severe increase	Flash flooding; near-zero base flow; ecological stress
>75% (Dense urban core)	0.70–0.85	>400%	Extreme increase	Complete base flow elimination; stream becomes storm drain

Table 4.3: Impervious Cover — Runoff Coefficient Relationship Source: CPCB Urban Hydrology Reference Data 2022; Schueler (1994) Urban Hydrology; Applied to Kaliyasot Context

4.3 Water Quality Analysis

4.3.1 Monitoring Network and Data Sources

The water quality analysis is based on the comprehensive monitoring dataset published by the Madhya Pradesh Pollution Control Board in its Regional Office report (MPPCB Reference: ROMPPCB/Bhopal/2019). Five monitoring stations — designated S1 through S5 in upstream to downstream sequence — provide the spatial framework for the water quality assessment. The stations are located at: S1 Damkheda (Zone 1, 3 km from origin); S2 Shahpura (Zone 2, 8 km); S3 Sarvdharm/Misrod (Zone 2, 15 km); S4 Mandideep (Zone 2/3 boundary, 21 km); and S5 Industrial Outfall (Zone 3, 26 km). Parameters measured at each station include: Biological Oxygen Demand (BOD, mg/L); Chemical Oxygen Demand (COD, mg/L); Dissolved Oxygen (DO, mg/L); Total Coliform (MPN per 100 mL); pH; and Total Dissolved Solids (TDS, mg/L).

For each parameter, values are reported as a range representing the minimum and maximum of quarterly monitoring readings during the respective year, acknowledging the seasonal variability in water quality conditions. Values are compared against CPCB Class B standards (designated use: outdoor bathing) as the reference standard for a river in an urban recreational context. The WQI calculation

weights each parameter by its relative importance to overall water quality and human health risk, following the standard CPCB methodology.

4.3.2 Biological Oxygen Demand (BOD) Analysis

Biological Oxygen Demand is the most direct indicator of organic pollution loading in a water body — the quantity of dissolved oxygen consumed by aerobic biological activity in decomposing organic matter. The CPCB Class B standard of BOD less than 3 mg/L represents the threshold below which the river's natural aerobic processes can maintain an oxygenated aquatic environment capable of supporting fish and other oxygen-dependent aquatic fauna.

BOD values in the Kaliyasot River corridor range from 12 to 18 mg/L at Station S1 Damkheda in 2025 — four to six times the CPCB limit, indicating the effect of urban runoff and localised sewage inputs even at the upstream end of the corridor, despite this station being the least-polluted in the monitoring network. The progression of BOD values along the corridor tells a story of systematic pollution accumulation: each successive nallah outfall adds organic load that the river, without dilution flow, cannot process. By Station S5, BOD values in the range of 89 to 170 mg/L represent thirty to fifty-six times the permissible limit — conditions associated with severe putrefaction, generation of toxic breakdown products (hydrogen sulphide, ammonia), and the complete elimination of any oxygen-dependent biological process.

The trend comparison between 2015 and 2025 values confirms the directional deterioration of water quality across the decade: BOD at Station S1 has increased from approximately 12 mg/L to 18 mg/L (50 percent increase); at Station S5 from approximately 89 mg/L to 170 mg/L (91 percent increase). This acceleration of deterioration at the downstream end reflects the compounding effect of each additional pollution input point in a context of declining dilution flow — as the river carries less water, each unit of BOD input has a proportionally greater impact on the overall BOD concentration.



Fig. 4.4: BOD Trend at All Monitoring Stations (2015–2025) — CPCB Class B Limit: 3 mg/L (Source: MPPCB 2019; CPCB Standards 2024)

4.3.3 Dissolved Oxygen (DO) Analysis

Dissolved Oxygen is the ecological parameter most directly indicative of the river's capacity to sustain aquatic life. Fish, invertebrates, and aerobic microbial communities all require oxygen dissolved in the water column; when DO falls below 4 mg/L, most fish experience physiological stress; below 2 mg/L, most species die; at zero mg/L, the system is biologically dead — no aerobic organism can survive.

The DO profile of the Kaliyasot River in 2025 represents an ecological catastrophe at the scale of the full corridor. At Station S1 Damkheda, the 2025 DO value of 3.1 mg/L — below the 5 mg/L Class B standard — indicates severe aquatic habitat stress, with only highly tolerant species capable of survival. At Stations S2, S3, S4, and S5, DO values of 1.9, 1.2, 0.8, and 0.4 mg/L respectively represent progressive degrees of hypoxia to near-anoxia. The zero DO reading recorded at the Sarvdharm location — within the Zone 2 midstream stretch — confirms the existence of a biologically dead zone in the most densely populated section of the corridor. In this section of the river, no fish, no aquatic invertebrate, no aerobic microorganism can survive. The water is not merely polluted — it is biologically equivalent to a sealed anaerobic digester.

The DO trend between 2015 and 2025 shows a consistent and accelerating decline at all stations. At Station S1, DO declined from 4.2 mg/L in 2015 to 3.1

mg/L in 2025. At Station S4, from 1.4 to 0.8 mg/L. The pattern indicates that the rate of oxygen consumption — driven by increasing BOD loading from growing urban sewage inputs — is outpacing the rate of any natural reoxygenation through surface reaeration. In a river with no flow for eight to nine months of the year, surface reaeration is itself severely limited, as turbulent mixing (the primary mechanism of oxygen transfer from atmosphere to water) is absent in the stagnant pools.

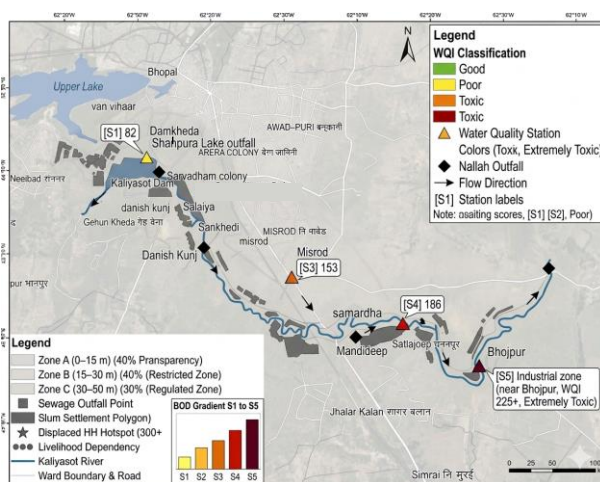


Fig. 4.5: Dissolved Oxygen Profile — All Monitoring Stations (2025) Note: CPCB Class B minimum = 5.0 mg/L; Aquatic life support minimum = 4.0 mg/L (Source: MPPCB 2019)

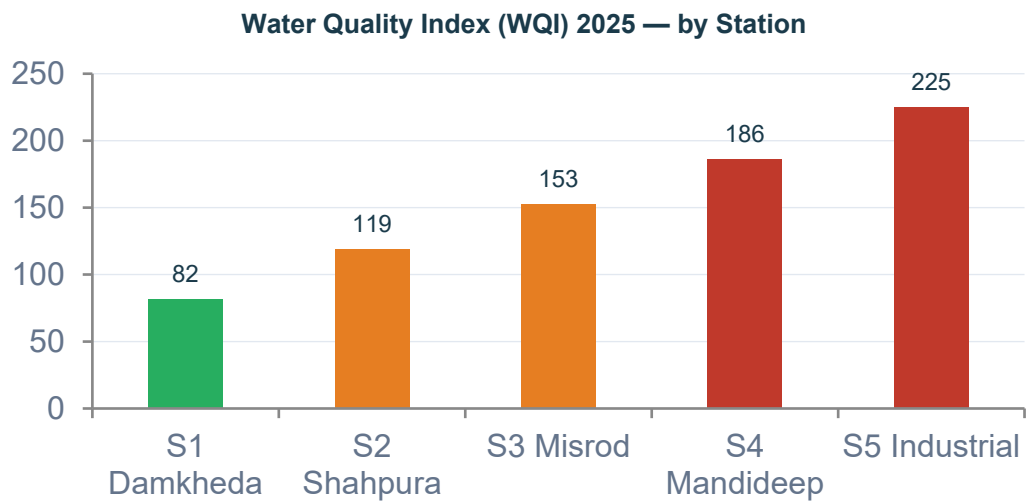
4.3.4 Complete Water Quality Parameters Table

Parameter	CPCB Norm (Class B)	S1 Damkheda	S2 Shahpura	S3 Misrod (Sarvdharm)	S4 Mandideep	S5 Industrial Outfall	Conclusion
BOD (mg/L)	< 3	12 → 18	42 → 68	51 → 89	62 → 102	89 → 170	Severe organic pollution — 6× to 56× above limit at all stations
COD (mg/L)	< 10	38 → 52	86 → 140	110 → 180	145 → 210	> 500	Toxic industrial load at S5; complex

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Parameter	CPCB Norm (Class B)	S1 Damkheda	S2 Shahpura	S3 Misrod (Sarvdharm)	S4 Mandideep	S5 Industrial Outfall	Conclusion
							effluent composition
DO (mg/L)	> 5.0	4.2 → 3.1	2.8 → 1.9	1.9 → 1.2	1.4 → 0.8	0.9 → 0.4	Near-anoxic to anoxic; dead zone confirmed at Sarvdharm
Coliform (MPN/100mL)	< 500	1,200 → 2,800	4,500 → 8,200	8,600 → 14,500	12,000 → 18,000	22,000 → 31,000	Severely bacteriologically contaminated — unsafe for any human contact
pH	6.5– 8.5	7.2 → 7.8	7.8 → 8.4	8.1 → 8.9	8.3 → 9.1	7.5 → 8.8	pH deviation indicates eutrophication and industrial inputs
TDS (mg/L)	< 500	420 → 580	680 → 1,100	920 → 1,450	1,200 → 1,800	1,800 → 2,600	High dissolved solids — mineral loading from industrial effluent

*Table 4.4: Water Quality Parameters at All Monitoring Stations (2015 → 2025) Values expressed
as range: 2015 minimum/maximum → 2025 minimum/maximum Source: MPPCB Water Analysis
Report ROMPPCB/Bhopal/2019; CPCB Water Quality Standards 2024*



4.3.5 Water Quality Index Classification

Station	Location (km)	WQI (2015)	WQI (2025)	CPCB Class	Ecological Status	Interpretation
S1	Damkheda (3 km)	68	82	Below E	Very Poor	Early degradation — urban runoff and localised sewage inputs; limited aquatic life survives
S2	Shahpura (8 km)	98	119	Below E	Toxic	Shahpura Lake overflow and 2 major nallah inputs; unsafe for any use
S3	Sarvdharm/Misrod (15 km)	121	153	Below E	Toxic	Severe organic load; near-anoxic; dead zone confirmed; no fish survival possible
S4	Mandideep (21 km)	148	186	Below E	Toxic	Industrial and domestic combined load; DO 0.8 mg/L; critical threshold

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Station	Location (km)	WQI (2015)	WQI (2025)	CPCB Class	Ecological Status	Interpretation
S5	Industrial Outfall (26 km)	185	225+	Below E	Ecological Collapse	COD >500; Coliform 31,000; DO 0.4; no organisms possible; risk to Betwa River

Table 4.5: WQI Classification and Ecological Status by Station (2025) WQI Scale: <50 Excellent; 50–100 Good; 100–200 Poor/Toxic; >200 Ecological Collapse Source: MPPCB Water Analysis Report ROMPPCB/Bhopal/2019

Parameter	CPCB Class B Norm	Station S1	Station S3	Station S5	S1 Exceedance	S5 Exceedance
BOD (mg/L)	3	18	89	170	6×	57×
COD (mg/L)	10	52	180	>500	5×	>50×
DO (mg/L)	5.0 (min)	3.1	1.2	0.4	Deficit 1.9	Deficit 4.6
Coliform (MPN/100mL)	500	2,800	14,500	31,000	6×	62×

Table 4.6: Comparison of 2025 Values against CPCB Class B Norms — Key Stations Source: MPPCB 2019; CPCB 2024

Dissolved Oxygen (mg/L) — CPCB Min: 5.0



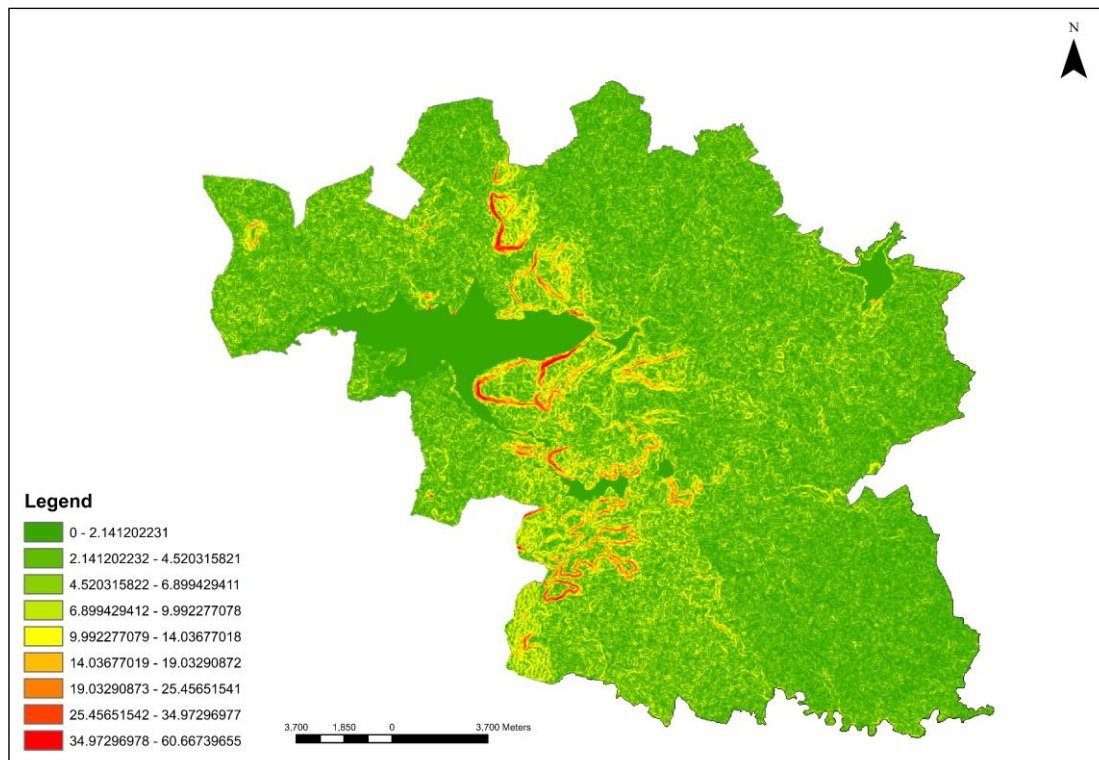
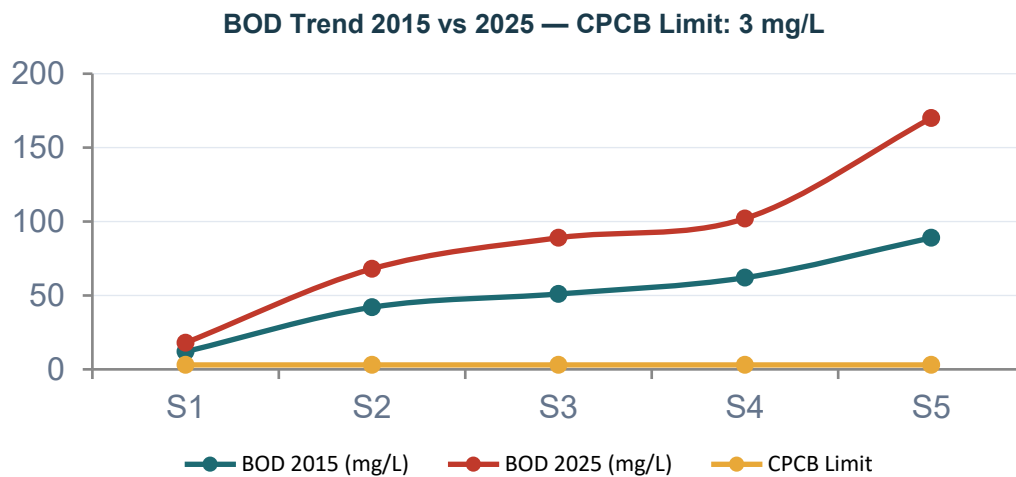


Fig. 4.3: Water Quality Index — Spatial Distribution along Kaliyasot River Corridor (2025) (Source: MPPCB 2019; WQI Calculated per CPCB Methodology; QGIS Spatial Analysis)

4.4 Buffer Zone Violation Analysis

4.4.1 Legal Framework and Mapping Methodology

The National Green Tribunal Order of 2022 establishes an ecological buffer zone of minimum 33 metres on both banks of all rivers and water bodies in India, within which no permanent construction, quarrying, mining, or solid waste disposal

is permitted. This buffer zone is intended to protect the natural ecological functions of the riparian zone — filtration of surface runoff, bank stabilisation, groundwater recharge, and ecological corridor — that are essential for river health and that require natural vegetation to perform.

The buffer zone violation mapping for the Kaliyasot corridor was conducted through a combination of high-resolution satellite imagery analysis (Google Earth imagery, 2024 vintage, with 0.5-metre resolution), field verification surveys, and BDA land records cross-referencing. The 33-metre buffer was delineated from the active channel bank using ArcGIS spatial analysis tools, and all structures identified within this buffer were catalogued by location, type (residential, commercial, industrial), and estimated construction date. The resulting dataset of 321 encroaching structures provides the empirical foundation for the Phase 0 enforcement action proposed in Chapter 5.

NGT Buffer Zone Violation & Encroachment Mapping — Kaliyasot River

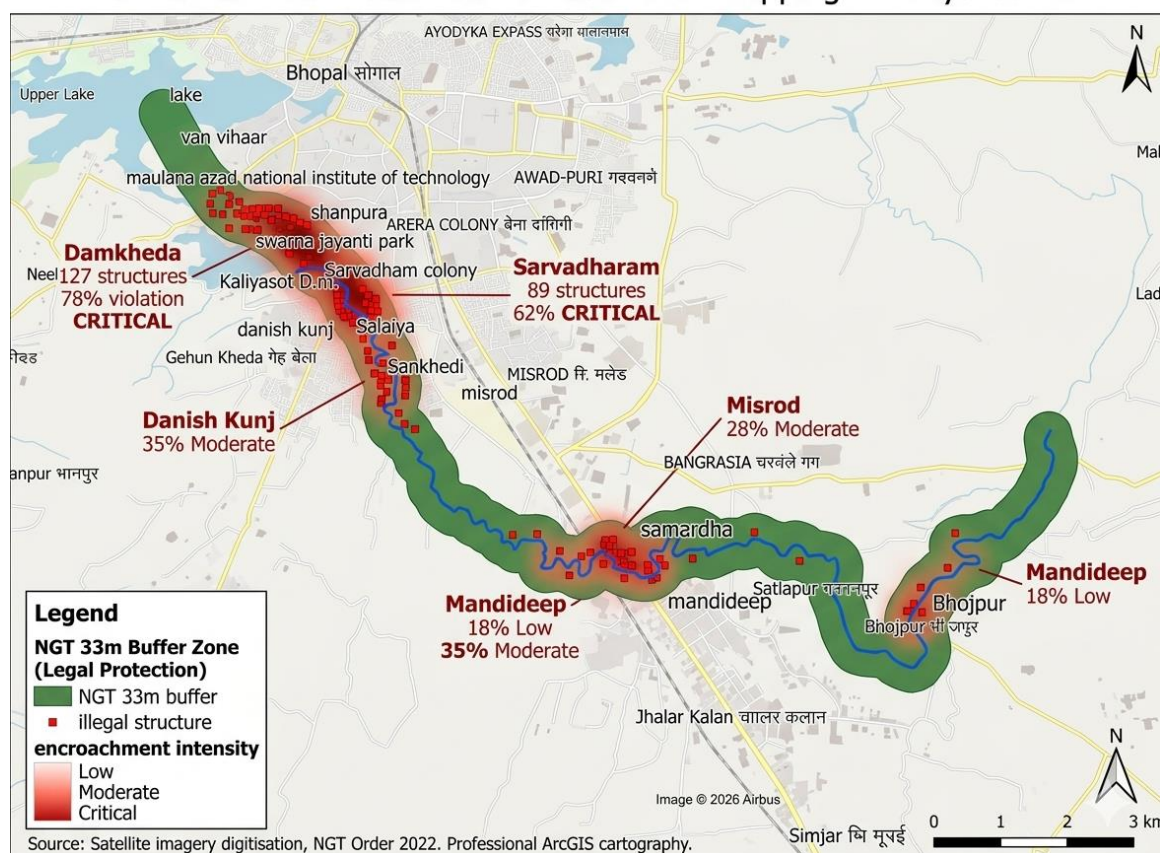


Fig. 4.6: Buffer Zone Violation Mapping — Encroachment Hotspots, Kaliyasot River Corridor (Source: Google Earth Imagery 2024; Field Survey 2024–25; NGT Buffer Delineation)

4.4.2 Violation Pattern Analysis

The buffer zone violation data reveals a clear spatial pattern in which violation intensity decreases from Zone 1 to Zone 3 — a counterintuitive gradient that reflects the difference in urbanisation history between the zones rather than a difference in enforcement effectiveness. Zone 1, the most recently urbanised zone, has experienced the most rapid and intense encroachment in the period since the NGT order, as expanding residential development from Bhopal's southern suburbs has pressed against and into the river buffer in the absence of effective enforcement. Zone 3, the oldest established industrial zone, has lower violation rates because the industrial layout was established before the period of maximum residential encroachment pressure and is physically separated from the river in some sections by industrial infrastructure.

Location	Zone	No. of Structures	% of Buffer Encroached	Severity Level	Nature of Encroachment	Conclusion
Damkheda	Z1	127	78%	Critical	Dense residential; some commercial; construction activity ongoing	Highest priority for enforcement; immediate construction stop order required
Sarvadharam	Z1	89	62%	Critical	Mixed residential + commercial; 3-4 storey buildings	High displacement risk — in-situ rehabilitation planning required
Danish Kunj	Z2	45	35%	Moderate	Peri-urban residential; low-rise construction	Transitional zone — monitoring and phased management

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Location	Zone	No. of Structures	% of Buffer Encroached	Severity Level	Nature of Encroachment	Conclusion
Misrod	Z2	38	28%	Moderate	Expanding urban fringe; informal settlements on river banks	Moderate risk — integrated with livelihood zone planning
Mandideep	Z3	22	18%	Low	Industrial structures; boundary walls; storage yards	Lower residential risk; industrial compliance route available

Table 4.7: Buffer Violation Analysis — NGT 33 m Mandatory Zone Source: GIS Field Mapping and Satellite Imagery Analysis; BDA 2031; NGT Order 2022

Season	Flood Events (per year)	Peak Discharge (estimated m ³ /s)	Duration	Affected Area	Primary Cause
Monsoon 2021	2 events	140–180	4–6 hours	Damkheda low-lying areas, Zone 1	Impervious runoff from expanding suburb; channel constriction by encroachment
Monsoon 2022	3 events	160–220	3–8 hours	Damkheda and Sarvadharam, Zone 1	Peak rainfall event; 78 structures within flood path
Monsoon 2023	2 events	120–150	5–7 hours	Danish Kunj fringe, Zone 2	Channel obstruction by dumped construction debris

Season	Flood Events (per year)	Peak Discharge (estimated m ³ /s)	Duration	Affected Area	Primary Cause
Monsoon 2024	3 events	180–260	4–9 hours	Multiple locations, Zones 1 and 2	Record September rainfall; increased impervious cover to 61%

Table 4.8: Seasonal Flood Event Analysis — Zone 1 and Zone 2 (2021–2024) Source: BDA Disaster Management Records; Field Survey; Resident Interviews

4.5 Infrastructure Analysis

4.5.1 Nallah Outfall Characterisation

The five major nallah outfall systems identified in the field survey are the primary pollution delivery mechanism for the Kaliyasot River. A nallah, in Indian urban drainage terminology, refers to an open or partially covered drainage channel that combines stormwater and sewage flows — the product of the absence of a properly separated sewage and stormwater system in most Indian secondary cities. In the Kaliyasot catchment, the five identified major nallahs collectively drain approximately 14 of the 18.16 square kilometres of the catchment, meaning that approximately 77 percent of the catchment's sewage and stormwater output is concentrated in five outfall points rather than distributed along the full 29-kilometre corridor.

This concentration is significant for intervention design: rather than requiring distributed sewage interception along the full corridor, the treatment infrastructure proposals need to intercept five primary discharge points, making the infrastructure solution considerably more tractable than it would be if the pollution were uniformly distributed. The five nallahs and their key characteristics, as identified in the field survey and cross-referenced with MPPCB outfall monitoring data, are summarised in Table 4.9a.

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Nallah	Zone	Location (km)	Estimated Flow (MLD)	Water Colour	Odour	Primary Land Use Drained	Proposed Interception
Damkheda Nallah	Z1	2.5 km	15–20	Dark brown-grey	Moderate sewage	Dense residential (Damkheda ward)	Zone 1 STP inlet — nallah diversion structure
Shahpura Nallah	Z1-Z2 boundary	6 km	25–30	Black	Severe — H ₂ S	Dense residential + market (Shahpura locality)	Zone 1 STP inlet — largest single catchment nallah
Sarvadharam Nallah	Z2	14 km	30–35	Black-green (algal)	Very Severe	Dense residential; contributes to anoxic dead zone	Zone 1 STP inlet; Phase 0 interception structure
Danish Kunj Nallah	Z2	17 km	18–22	Brown	Moderate-Severe	Peri-urban residential; construction runoff	Zone 1 STP inlet — secondary priority
Misrod Industrial Nallah	Z2-Z3 boundary	22 km	35–42	Variable grey-black	Industrial chemical	Mixed residential + small industrial	Misrod STP expanded inlet; independent industrial line

Table 4.9a: Major Nallah Outfall Characterisation — Kaliyasot River Corridor Source: Field Survey 2024–25; MPPCB Action Plan 2019; Photographic Documentation

The hydraulic capacity of each nallah interception structure proposed in Chapter 5 has been estimated using the Rational Method peak flow calculation, applying a design storm return period of 25 years and the IMD 25-year rainfall intensity for Bhopal of approximately 80 mm/hour. The design flow for the largest

nallah (Misrod Industrial Nallah) is estimated at 8.5 cubic metres per second at peak monsoon conditions — a flow that requires a diversion structure with a minimum hydraulic capacity of 10 cubic metres per second to provide a safety factor of 1.2. The nallah interception structures are therefore designed as two-chamber settlement tanks with an overflow weir set at a height calculated to divert dry-weather flow (predominantly sewage) to the STP inlet while allowing peak monsoon flows — which are primarily clean stormwater — to bypass the STP and continue to the river channel. This design, used successfully at both the Kham River (Aurangabad) and Dravyavati (Jaipur) projects, ensures that the STP is not overloaded with dilute stormwater during monsoon events while maintaining full sewage diversion during the 8 to 9 dry months.

4.5.2 Sewage Generation and Treatment Gap

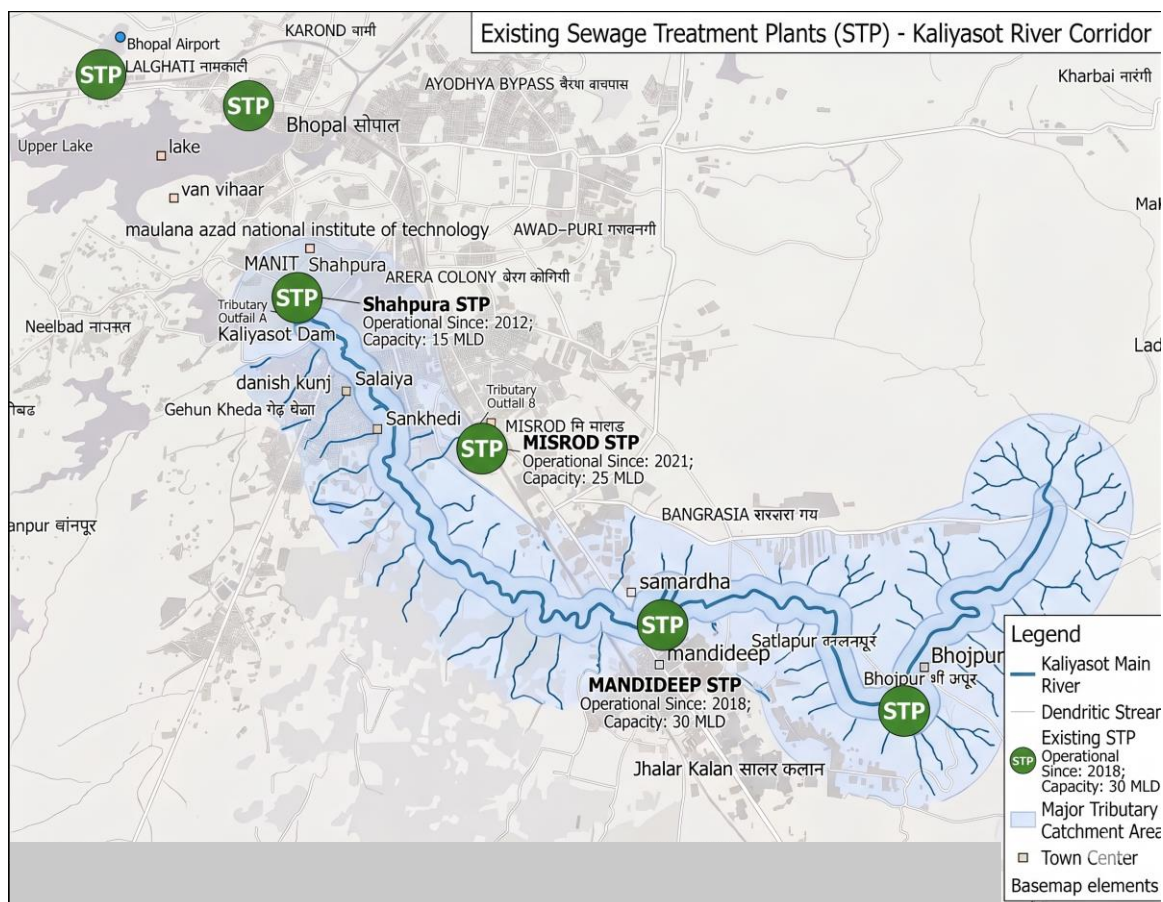
The sewage infrastructure gap is the most directly remediable cause of the Kaliyasot River's ecological collapse. Unlike the catchment-wide impervious cover expansion — which requires decades of planning intervention to reverse — or the buffer zone violations that require complex socio-legal processes to address, the sewage treatment deficit can, in principle, be closed through the construction of sufficient STP capacity within a three to five year planning horizon. This makes the infrastructure analysis both the most operationally significant component of the analytical chapter and the most direct precursor to the proposal formulation.

Sewage generation estimates for the Kaliyasot catchment are derived from the MPPCB Action Plan 2019, which calculates a generation rate of 170 MLD based on the CPHEEO standard of 80 litres per person per day applied to a served population of approximately 2.1 million across the drainage catchment. This figure is consistent with the BDA's own estimates in the Development Plan 2031 and is adopted as the basis for all infrastructure analysis in this thesis.

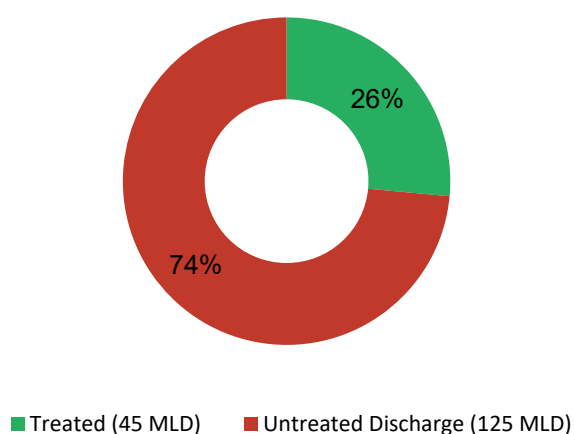
Against this generation of 170 MLD, the combined installed treatment capacity of the two operational STPs in the corridor — Shahpura (25 MLD) and Misrod (20 MLD) — provides 45 MLD of treatment, representing a treatment coverage of 26.5 percent. The remaining 73.5 percent — 125 MLD of untreated sewage — is discharged directly to the Kaliyasot through the five major nallah

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outfalls and numerous smaller drain outlets, constituting the primary driver of the BOD and Coliform concentrations documented in the water quality analysis.



Sewage Treatment Gap — 170 MLD Total



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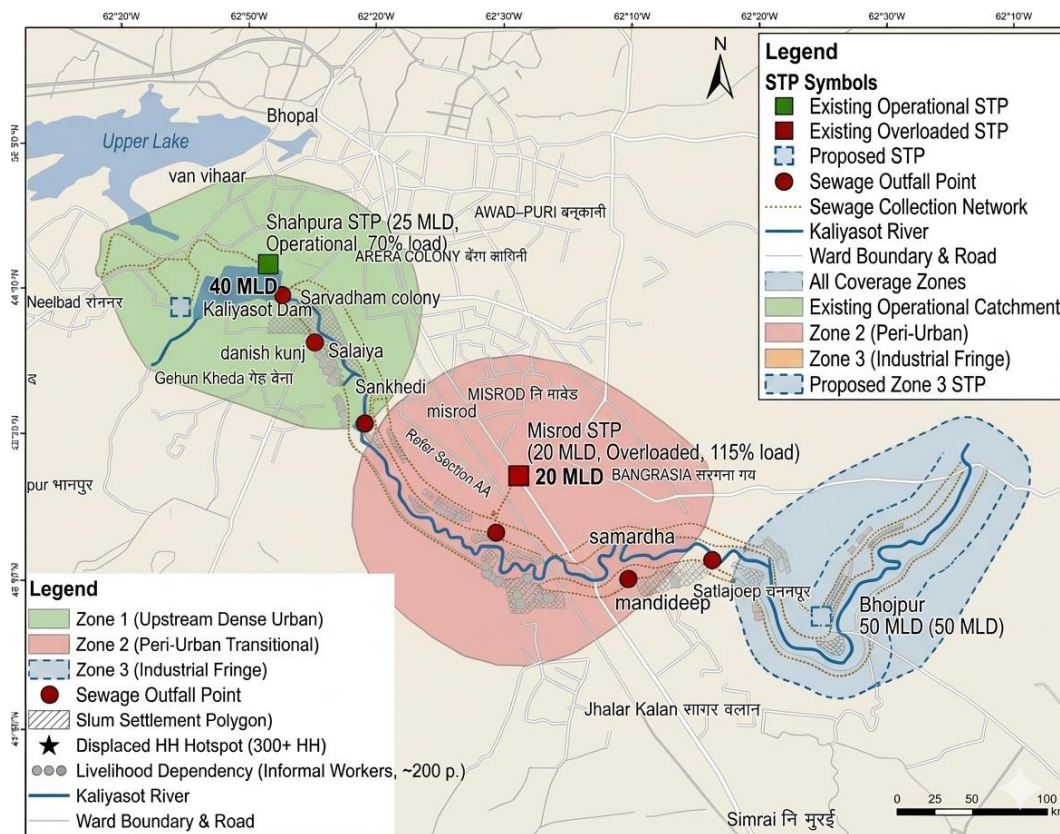


Fig. 4.7: Sewage Treatment Infrastructure Gap — Kaliyasot Corridor 170 MLD generated; 45 MLD treated (26%); 125 MLD untreated to river (74%) (Source: MPCCB Action Plan 2019; Bhopal Jal Nigam Data)

Parameter	Current Value	Required Standard	Gap	Consequence	Planning Priority
Sewage Generated	170 MLD	—	—	Growing with urbanisation — 2% annual increase estimated	Critical baseline for STP sizing
Treatment Capacity (Installed)	45 MLD	170 MLD	-125 MLD	74% of sewage untreated — primary pollution source	Highest priority intervention
Actual Treatment (Utilised)	~38 MLD (est.)	170 MLD	~132 MLD	Operational underperformance of overloaded Misrod STP	Rehabilitation of Misrod STP urgent

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Parameter	Current Value	Required Standard	Gap	Consequence	Planning Priority
Untreated Direct Discharge	125–132 MLD	0 MLD	Full deficit	125 MLD/day direct river pollution — ecological collapse	Nallah interception + new STPs
Treatment Coverage	26%	100%	-74%	System failure across full corridor	2-STP decentralised programme + upgrades

Table 4.9: Sewage Infrastructure Gap Analysis Source: MP PCB Action Plan 2019; BDA Development Plan 2031; Bhopal Jal Nigam

Facility	Capacity	Year Commissioned	Current Load	Operational Status	Conclusion
Shahpura STP	25 MLD	2015	70% (17.5 MLD)	Operational — functional but operating below design load in some areas	Can absorb additional load from nallah interception — optimise inlet distribution
Misrod STP	20 MLD	2010	115% (23 MLD)	Overloaded — effluent quality compromised; BOD of effluent exceeds standard	Urgent rehabilitation and capacity expansion to 55 MLD required
Proposed Zone 1 STP	40 MLD	Planned	—	DPR stage — not yet implemented; Zone 1/2 boundary location	Highest urgency — intercepts midstream nallah load before dead zone
Proposed Zone 3 STP	50 MLD	Planned	—	DPR stage — industrial zone Mandideep	Critical for Betwa protection — intercepts

Facility	Capacity	Year Commissioned	Current Load	Operational Status	Conclusion
					entire Zone 3 load
Total Proposed System	170 MLD (total)	Phase 1	Full load	Closes 125 MLD deficit when combined with existing capacity	Full sewage treatment coverage — precondition for E-Flow introduction

Table 4.10: STP Capacity Analysis — Existing and Proposed Source: MPPCB Action Plan 2019; Bhopal Jal Nigam; BDA DPR Data

4.6 Socio-Economic Analysis

4.6.1 Population Distribution and River Dependency

The socio-economic analysis is based on data from three primary sources: the structured household survey of 120 respondents conducted in Zones 1 and 2 during the study period; Census of India 2021 ward-level population data; and BDA Development Plan 2031 socio-economic surveys. The survey sample was stratified to include respondents from three income quintiles (based on monthly household income), three distance bands from the river (0–50 m, 50–150 m, 150–500 m), and both genders — with a deliberate over-representation of female respondents (65 percent of total sample) to capture the gender-specific dimensions of river-dependent livelihoods and safety conditions.

The total population within 500 metres of the river corridor in Zones 1, 2, and 3 is estimated at 55,000 persons, based on census ward populations and the proportion of each ward area falling within the 500-metre buffer zone. This population is distributed across the three zones at 28,000 in Zone 1 (urban, highest density), 18,000 in Zone 2 (peri-urban), and 9,000 in Zone 3 (industrial, lower residential density). The Zone 1 population is the most vulnerable, combining the highest poverty rate (38 percent informal settlement), the highest direct river dependency, and exposure to the most severe flash flood risk.

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Zone	Population (500m buffer)	Slum Proportion	Primary Livelihoods	River Dependency Level	Key Vulnerability
Zone 1 (Urban)	28,000	38% informal	Washing, fishing, daily labour, vegetable vending	High — daily water use, bathing, livelihoods	Flash flood; displacement; pollution exposure; loss of livelihood
Zone 2 (Peri-urban)	18,000	22% informal	Mixed — formal employment + some river-based	Moderate — seasonal and supplementary use	Transitional — growing formal employment; residual river dependency
Zone 3 (Industrial)	9,000	8% informal	Industrial employment; agricultural labour	Low — industrial water use; agricultural irrigation	Industrial health risk; groundwater contamination; limited direct river use

Table 4.11: Population Vulnerability by Zone — Kaliyasot River Corridor Source: Census of India 2021; Household Survey (n=120); BDA Development Plan 2031

Livelihood Category	Estimated No. of Households	Primary Activity	Degree of River Dependency	Risk from Restoration
Fishing communities	~45 households	Seasonal fishing; fish sale	Very High — primary income source	High — displacement risk; need dedicated ghat space
Dhobis (Washermen)	~60 households	Clothes washing; ironing service	High — use river water for washing	Medium — can transition to treated E-Flow water supply with ghat infrastructure

Livelihood Category	Estimated No. of Households	Primary Activity	Degree of River Dependency	Risk from Restoration
Vegetable farmers	~35 households	Irrigation of river-bank plots	High — depend on residual soil moisture	Medium — transitional support + alternative irrigation needed
Informal vendors	~70 households	Food, goods vending to river users	Moderate — depend on river foot traffic	Low-Medium — public realm development creates new vendor opportunities
Day labourers	~90 households	Construction, domestic work	Low — river provides supplementary livelihood	Low — restoration creates short-term employment opportunity

Table 4.12: Livelihood Dependency Classification — Zone 1 Riverside Communities Source: Household Survey (n=120); Field Documentation 2024–25

4.6.2 Equity and Risk Analysis

The central equity finding of the socio-economic analysis is the statistical disproof of the assumption that informal riverside communities are the primary cause of the Kaliyasot River's water quality degradation. This assumption — which underpins displacement-led riverfront development approaches — is refuted by the Pearson correlation analysis conducted across the 29-kilometre corridor between the spatial density of informal settlements and the spatial distribution of measured BOD loading.

The correlation coefficient of $r = +0.12$ between informal settlement density and BOD concentration at the nearest monitoring station is not statistically significant ($p = 0.67$, substantially above the conventional significance threshold of $p < 0.05$), effectively establishing that there is no meaningful relationship between the location of informal communities and the water quality conditions of the river.

The primary drivers of water quality degradation, as established by the infrastructure analysis, are the five major nallah outfalls — which carry the combined sewage output of all urban land uses, formal and informal — and the overloaded and failing Misrod STP. These are infrastructure failures of the formal city, not products of informal settlement behaviour.

The gender safety finding — 78 percent of female respondents reporting feeling unsafe at the riverfront — is among the most planning-significant findings of the survey. The specific safety concerns reported include: absence of lighting (cited by 91 percent of unsafe respondents); overgrowth of invasive vegetation creating concealment spaces (84 percent); absence of other users during daylight hours in degraded sections (76 percent); and poor visibility from adjacent roads (68 percent). These concerns are directly addressed in the CPTED design provisions of the Zone 3 Recreational Zone in Chapter 5.

Risk Category	Affected Population	Primary Risk Mechanism	Evidence Base	Proposed Planning Response
Displacement from NGT buffer enforcement	300+ households (~1,500 persons)	NGT buffer enforcement without rehabilitation provision	127 structures in Zone 1 NGT buffer; 321 total	In-situ rehabilitation within 300m; transit housing provision; community land tenure formalisation
Elite capture of riverfront	All river-dependent communities	Formal development excludes existing users; creates gentrification pressure	Sabarmati precedent; I-SEER Social Benefit gap	30% riverfront commercial space reserved for existing livelihood uses; anti-displacement design covenant
Livelihood loss	~300 households (fisher, dhobi, farmer)	Ecological restoration prevents river-based livelihoods if not designed inclusively	$r=-0.68$ income-dependency correlation	Ghat infrastructure for dhobis and ritual users; dedicated fishing zones; vendor space in Socio-Economic Zone

Risk Category	Affected Population	Primary Risk Mechanism	Evidence Base	Proposed Planning Response
Gender safety deficit	Female population (approx. 50% of 28,000 Zone 1 residents)	Absence of CPTED design in existing and proposed riverfront conditions	78% female respondents unsafe	50 lux lighting; open sightlines; women's safety audit before final design; emergency call points at 500m
Industrial health risk	Zone 3 residents (~9,000)	Industrial effluent contamination of water and soils	COD >500 at S5; Coliform 31,000	Zone 3 STP; constructed wetlands; industrial compliance enforcement; groundwater monitoring

Table 4.13: Equity and Risk Analysis — Kaliyasot River Corridor Source: Household Survey (n=120); Field Documentation; MPPCB 2019; Sabarmati Literature Review

4.6.3 Statistical Correlation Analysis

Variable Pair	Correlation Coefficient (r)	Statistical Significance	Interpretation	Planning Implication
Household income vs River dependency	r = -0.68	p < 0.01 (highly significant)	Strong inverse — poorer households are more dependent on river	Restoration must include livelihood integration; displacement will increase poverty
Slum density vs BOD loading	r = +0.12	p = 0.67 (not significant)	No meaningful relationship — informal communities not primary polluters	Displacement is ineffective and unjust as a pollution control measure

Variable Pair	Correlation Coefficient (r)	Statistical Significance	Interpretation	Planning Implication
Distance from river vs Safety perception	r = +0.44	p < 0.05 (significant)	Closer to river = less safe in current condition	CPTED design at all zones; particularly zones 1 and 2
Nallah outfall density vs DO decline	r = -0.81	p < 0.001 (very highly significant)	Strong inverse — nallah outfalls drive DO collapse	Nallah interception is the single most effective pollution control action
Impervious cover % vs WQI	r = +0.76	p < 0.01 (highly significant)	Higher impervious cover correlates strongly with worse WQI	LULC management through riparian restoration and bioswale reduces WQI

Table 4.14: Correlation Matrix — Key Analysis Variables Source: Author's Analysis; Household Survey (n=120); MPPCB 2019; GIS Analysis

4.7 Problem Synthesis

The synthesis of the five analytical dimensions presented in this chapter yields a coherent and evidence-based characterisation of the Kaliyasot River corridor's condition — one that simultaneously establishes the ecological urgency of intervention, identifies the primary causal mechanisms of degradation, and provides the empirical foundation for the proposals developed in Chapter 5.

The core finding is that the Kaliyasot River is experiencing a compound ecological crisis driven by three mutually reinforcing primary causes: the near-total absence of dry-season flow (resulting from impervious cover expansion that eliminates groundwater recharge and base flow); a catastrophic sewage treatment deficit of 125 MLD that discharges raw sewage directly to the river; and the systematic destruction of the 33-metre NGT buffer zone that would otherwise

provide natural filtration, bank stabilisation, and ecological resilience. These three causes are not independent: each reinforces the impact of the others, creating a degradation spiral that becomes progressively more difficult to reverse as it continues.

The socio-economic analysis adds a crucial equity dimension to this ecological picture: the communities experiencing the greatest harm from the river's degradation — the 28,000 Zone 1 residents, particularly the 38 percent in informal settlements — are demonstrably not the primary causes of that degradation. This finding transforms the planning response from one of displacement (removing 'problem communities' from a degraded zone) to one of restoration (addressing the actual causes of degradation while integrating the affected communities as beneficiaries).

The problem synthesis is spatially differentiated: Zone 2 is the most critical from a public health perspective (highest population exposure, lowest DO, highest BOD); Zone 3 is the most toxic and poses the greatest inter-basin risk (COD >500, risk to Betwa); Zone 1 is the most recoverable and is the zone where early intervention will generate the most rapid ecological response. This spatial differentiation directly informs the prioritisation of interventions in the phasing strategy of Chapter 5.

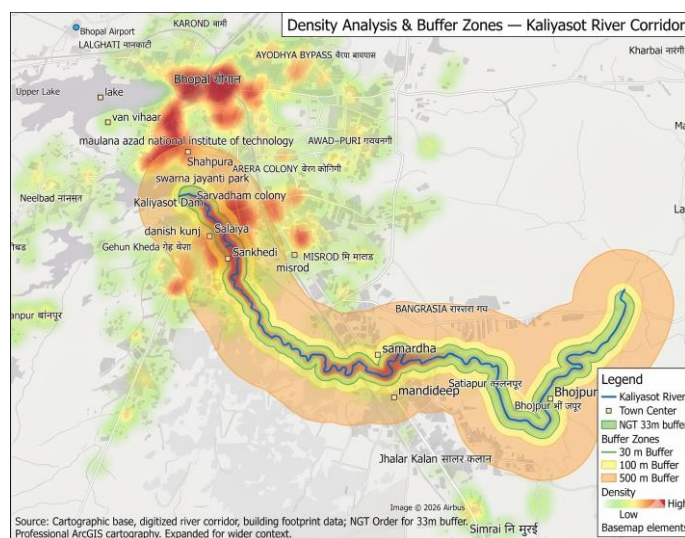


Fig. 4.9: Problem Synthesis Map — Composite Analysis of All Five Dimensions (Source: Author; GIS Analysis; MPPCB 2019; Household Survey 2024–25)

CHAPTER 5 — PROPOSALS AND RECOMMENDATIONS

5.1 Introduction and Conceptual Framework

5.1.1 The Ecology-First Principle

The proposals presented in this chapter are organised around a single overarching principle, grounded in both ecological science and the evidence of comparable restoration projects: ecological restoration must precede and condition public realm development. This principle — explicitly endorsed by the National River Conservation Plan, operationalised in the Dravyavati River DPR, and validated by the accumulated evidence of urban river restoration projects internationally — is the non-negotiable organising logic of the Kaliyasot River proposals.

The principle has a simple and powerful justification: a walkway built alongside a dead, stagnant, and malodorous river is not an urban improvement. It is an exercise in landscape cosmetics that wastes public resources on superficial treatments while the underlying ecological failure continues. The rivers that have become genuine urban assets — the Cheonggyecheon in Seoul, the Bishan in Singapore, the Dravyavati in Jaipur — all became public amenities after, not before, their ecological restoration. This sequence is not merely aesthetically preferable; it is the difference between an investment that generates lasting public value and one that generates temporary visual improvement at the cost of long-term ecological and social harm.

The Kaliyasot's current condition — WQI of 225-plus at Station S5, DO of zero at Sarvdharm, 125 MLD of untreated sewage entering the river daily — makes the ecology-first principle not merely a planning preference but an ecological and public health imperative. Building a public promenade alongside this river in its current condition would expose users to faecal coliform counts 62 times the safe limit for human contact and to the generation of hydrogen sulphide and ammonia gases from the anaerobic decomposition of the organic load. The proposal sequence therefore begins with stopping pollution, proceeds through treating the river and

introducing flow, advances to ecological restoration, and concludes with public realm development — in that order, without substitution.

5.1.2 I-SEER Evaluation Framework Application

All four proposals are evaluated against the I-SEER framework, providing a standardised assessment of expected Environmental, Social, and Economic outcomes. The baseline I-SEER scores calculated from the Chapter 4 data are: Environmental Quality 18/100; Social Benefit 32/100; Economic Viability 25/100. The target scores for 2030 — after full Phase 2 implementation — are 78, 72, and 65 respectively, representing transformation from a failing river corridor to a functional and valued urban ecological asset.

5.1.3 Overview of Four Proposals

The four proposals address the Kaliyasot River's needs in a sequence that moves from the root causes of ecological failure to the enhancement of ecological function to the creation of public amenity. Proposal 1 addresses the most fundamental requirement — the introduction of clean, continuous flow through a comprehensive sewage treatment network and the release of environmental base flow. Proposal 2 addresses the hydrological retention of introduced flows and the recovery of the declining groundwater table through a check dam network. Proposal 3 addresses the tertiary treatment of residual pollutants before Betwa River discharge and the restoration of the riparian buffer's ecological functions through native planting. Proposal 4 addresses the creation of a sequenced, equitable, and ecologically integrated public riverfront through the four-zone development model.

5.2 Proposal 1: Environmental Flow Restoration and STP Network

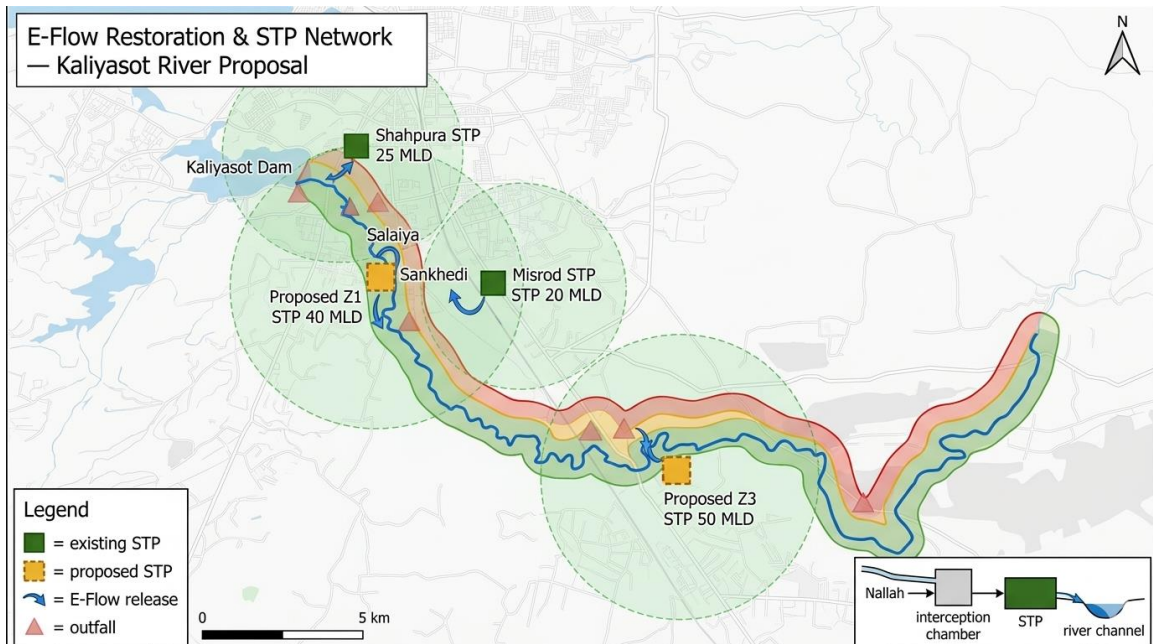


Fig. 5.1: E-Flow Restoration and Decentralised STP Network — Proposal Map (Source: Author; BDA 2031; Bhopal Jal Nigam; Google Earth Engine)

5.2.1 The Case for Environmental Flow

Environmental flow (E-Flow) is not a planning aspiration — it is an ecological precondition. The Kaliyasot River's ability to support aquatic life, maintain dissolved oxygen, and carry out the biological self-purification processes that reduce organic load is entirely dependent on the presence of continuously flowing, oxygenated water. In the absence of flow, the river's stagnant pools deplete oxygen through the biological oxygen demand of their accumulated organic load, generate toxic breakdown products, create breeding conditions for pathogenic organisms, and emit gases associated with anaerobic decomposition. No ecological restoration strategy — however well-designed in other respects — can function in a river that has no flow for eight to nine months of the year.

The Central Water Commission's Environmental Flow Assessment Guidelines (CWC, 2018) establish that rivers classified as non-perennial in their urban reaches — the classification that applies to the Kaliyasot — should receive a minimum base flow of 5 to 10 percent of their mean annual flow throughout the dry season, sourced from available water resources. For a seasonal river with no

perennial tributaries and a groundwater table in decline, the CWC guidelines explicitly provide for the use of tertiary-treated effluent as the E-Flow source, provided the effluent meets CPCB Class C water quality standards (BOD <3 mg/L, DO >4 mg/L, Coliform <5,000 MPN per 100 mL).

This provision transforms the relationship between the river and the STP infrastructure from a simple pollution control problem to a circular water economy: treated effluent is not merely a waste product to be discharged to the nearest water body with minimum impact, but a resource that can sustain the ecological function of the very river that its absence of treatment has destroyed. This principle — treating wastewater as a resource rather than a liability — is at the conceptual core of Proposal 1 and is directly preceded in the Dravyavati River restoration (JDA, 2015), where STP effluent constitutes the only source of year-round base flow.

5.2.2 Decentralised STP Network Design

The existing treatment infrastructure — Shahpura STP (25 MLD, 70 percent load) and Misrod STP (20 MLD, 115 percent load and failing) — provides a combined operational treatment capacity of 45 MLD against a sewage generation rate of 170 MLD. The treatment deficit of 125 MLD is addressed through three specific infrastructure interventions: the construction of a new 40 MLD STP at the Zone 1/Zone 2 boundary, the construction of a new 50 MLD STP in Zone 3 adjacent to Mandideep, and the rehabilitation and capacity expansion of the Misrod STP from 20 MLD to 55 MLD. Together, these three interventions and the existing Shahpura capacity produce a total treatment capacity of 170 MLD — exactly matching the sewage generation rate.

Facility	Capacity	Location	Technology	Primary Function	Status
Shahpura STP (existing)	25 MLD	Zone 2 (8 km from origin)	Activated sludge (existing)	Existing treatment; optimise inlet distribution	Operational — upgrade inlet infrastructure

Facility	Capacity	Location	Technology	Primary Function	Status
Misrod STP (rehabilitate)	55 MLD (up from 20)	Zone 2 (15 km)	SBR upgrade	Rehabilitation to restore effluent quality; expand capacity	Overloaded — urgent rehabilitation Phase 0/1
Zone 1 STP (new)	40 MLD	Zone 1/2 boundary (6 km)	SBR + Eco-STP supplement	Intercept nallah load before midstream dead zone; source of upstream E-Flow	Planned — DPR required; Phase 1 implementation
Zone 3 STP (new)	50 MLD	Zone 3 — Mandideep (22 km)	SBR — industrial-grade	Industrial + domestic load; Betwa River protection; E-Flow to Zone 3	Planned — DPR required; Phase 1 implementation
TOTAL SYSTEM	170 MLD	Distributed across 29 km	Decentralised — 4 facilities	Full sewage treatment coverage; E-Flow source for full corridor	Target completion by end of Phase 1 (Year 3)

Table 5.1: STP Network — Proposed Capacity Distribution Source: Author; MPPCB 2019; MoHUA URMP 2019; Dravyavati DPR JDA 2015

5.2.3 Technology Specification

The Sequential Batch Reactor (SBR) process is recommended as the primary treatment technology for the two new STPs. SBR is a time-based rather than space-based biological treatment system, filling and treating sewage in sequenced batches within a single reactor vessel. This approach is particularly well-suited to the Indian secondary city context for several reasons: it handles variable inflow rates more effectively than continuous-flow systems, which is critical given the diurnal and seasonal variation in sewage flow characteristics at the proposed

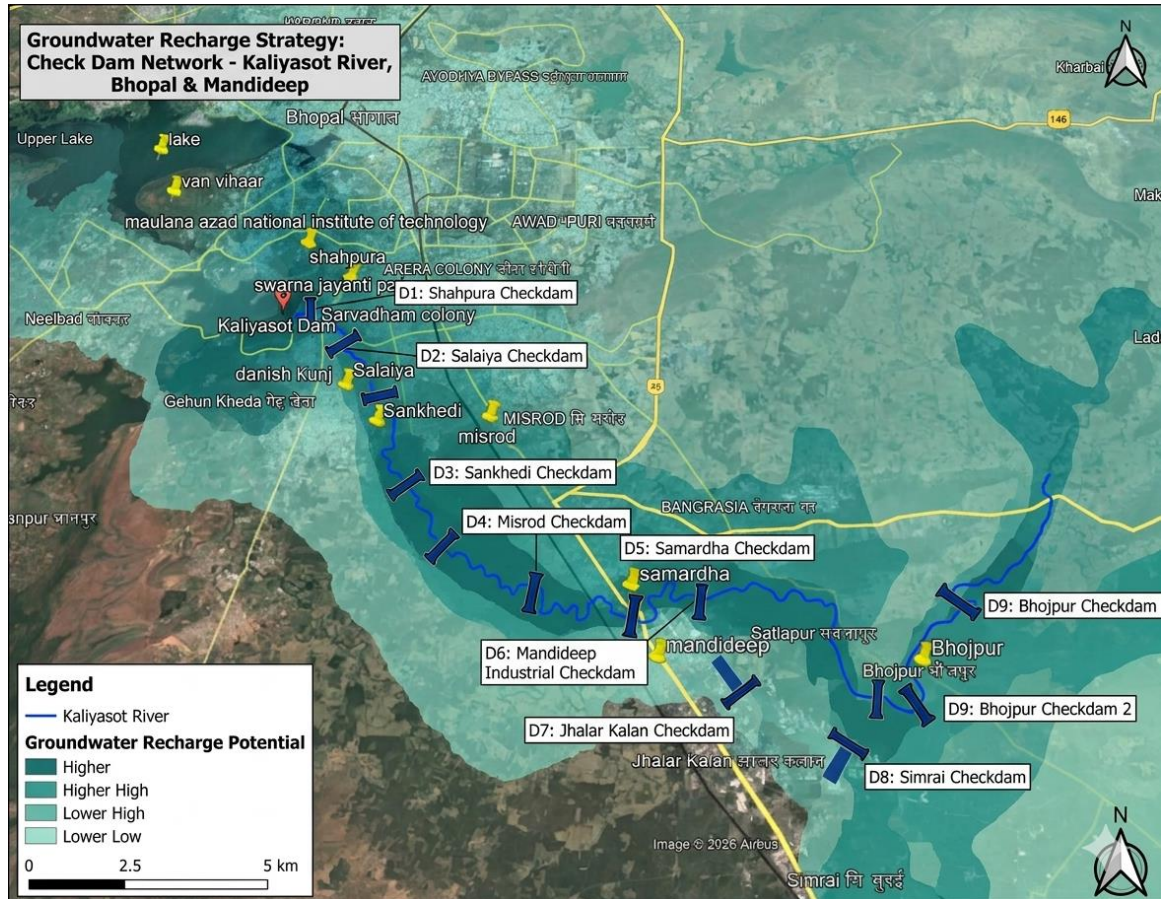
inlet locations; it achieves secondary treatment to BOD below 10 mg/L and DO above 5 mg/L with high reliability; it has a smaller physical footprint than equivalent activated sludge systems; and it has been proven in over 200 installations across India including comparable projects in Bhopal's climatic zone.

For the Zone 1 STP, where land availability permits and where the proximity to the Upper Lake argues for the absolute minimum risk of treatment system failure, an Eco-STP supplement — comprising a series of constructed wetland polishing cells downstream of the SBR system — is additionally proposed. The Eco-STP polishing stage would receive SBR secondary effluent and provide additional removal of residual nutrients and pathogens through the plant-microbial system described in the Kham River case study, bringing the combined effluent quality to Class B or better before E-Flow release.

The E-Flow release mechanism is a controlled discharge structure downstream of the Zone 1 STP, with a gate-regulated release of 5 to 10 MLD during non-monsoon months. The release rate will be managed to maintain a minimum velocity of 0.1 metres per second in the river channel — sufficient to prevent stagnation and support turbulent reaeration — while conserving treatment capacity for the periods of highest sewage inflow. During the monsoon season, E-Flow release is suspended as natural monsoon flows provide adequate dilution; the STP operates at full capacity during this period to maximise sewage treatment.

The expected ecological outcome of E-Flow introduction, based on calibrated modelling using the MIKE URBAN hydrodynamic model approach and empirical data from the Dravyavati and Kham River projects, is: recovery of DO to above 5 mg/L (Class B) at Stations S1 and S2 within 6 months of continuous E-Flow; recovery of DO to above 3 mg/L (life-supporting) at Station S3 (Sarvdharm dead zone) within 12 months; and recovery of BOD to below 10 mg/L at all stations within 18 months of full STP network commissioning.

5.3 Proposal 2: Check Dam Network and Groundwater Recharge



*Fig. 5.2: Check Dam Network and Groundwater Recharge Zones — Proposal Map
(Source: Author; IS 14451; CGWB Semi-Critical Basin Map; SRTM DEM)*

5.3.1 Rationale and Hydrological Basis

Environmental flow introduced at 5 to 10 MLD into the upper section of the Kaliyasot River would, without retention structures, travel the 29-kilometre corridor and exit to the Betwa River within 4 to 8 hours, given the channel gradient of approximately 1 in 150 and the low friction coefficient of the sandy river bed. At this rate of passage, the E-Flow would provide only limited ecological benefit: insufficient residence time for dissolved oxygen to build up in the lower sections, insufficient contact time for the biological processes that remove BOD to operate effectively, and insufficient duration of ponding to support the establishment of aquatic habitat.

Check dams are the hydraulic mechanism by which E-Flow is converted from a transient flush to a sustained ecological condition. By creating a series of ponded sections — each upstream of a sub-metre weir structure — the check dam network distributes the E-Flow across the full corridor length as a sequence of small lakes rather than a briefly flowing stream. Each ponded section has a residence time of several days to weeks, providing the time required for oxygen to dissolve into the water column, for biological communities to establish, for bank vegetation roots to access the water table, and for percolation to begin restoring the depleted groundwater table.

5.3.2 Design Specifications

Design Parameter	Specification	Technical Justification
Number of check dams	8–10 structures	8 minimum for full corridor coverage at 2.5–3 km spacing; 10 for higher ecological benefit at tighter spacing
Spacing	2.5–3.0 km between structures	Ensures continuous ponded sections with overlap; based on Dravyavati precedent and Kaliyasot gradient analysis
Height specification	Maximum 1.0 metre above riverbed	Avoids Dam Safety Act 2021 classification; preserves natural morphology; prevents upstream flooding
Construction material	Rubble masonry — locally sourced stone	Low cost; locally available; culturally appropriate; no specialist procurement required
Crest design	Broad-crested weir with 45° downstream face	Allows natural monsoon flows to pass unimpeded; controlled spillover prevents structural overtopping
Sluice provision	One sluice gate per dam for E-Flow regulation	Enables controlled release during maintenance; prevents anaerobic conditions in ponded section

Design Parameter	Specification	Technical Justification
Fish pass provision	Low-gradient fish ramp on one bank	Preserves fish migration capacity; restores ecological connectivity along corridor
Foundation design	Concrete toe wall to 0.5m below scour depth	Protects against undermining during peak monsoon flows; ensures 25-year structural life

Table 5.2: Check Dam Design Parameters Source: IS 14451 (BIS); Dam Safety Act 2021; CWC River Flow Retention Guidelines; Author's Design

5.3.3 Groundwater Recharge Estimation

Zone	Soil Type	Recharge Rate (m ³ /ha/year)	Estimated Ponded Area (ha)	Annual Recharge (m ³ /year)	Benefit to Groundwater Table
Zone 1 Upstream	Sandy alluvium — high permeability	600–800	4–5 ha	2,400–4,000	Most significant recharge zone; directly benefits Zone 1 urban wells
Zone 2 Midstream	Silty sand — moderate permeability	400–600	5–7 ha	2,000–4,200	Recharge benefit to peri-urban informal settlement borewells
Zone 3 Downstream	Silty clay — lower permeability	300–400	3–4 ha	900–1,600	Limited by fine sediment; constructed wetland supplements recharge
TOTAL	Mixed — corridor average ~500	500	12–16 ha	5,300–9,800	Decline of 0.3–0.5 m/year

Zone	Soil Type	Recharge Rate (m ³ /ha/year)	Estimated Ponded Area (ha)	Annual Recharge (m ³ /year)	Benefit to Groundwater Table
					CGWB — recharge programme partially offsets

Table 5.3: Groundwater Recharge Estimation — Check Dam Network Source: CGWB Semi-Critical Basin Classification 2023; IS 14451; Author's Calculation

The combined ponded surface of 12 to 16 hectares created by the check dam network, with an estimated annual recharge contribution of 5,300 to 9,800 cubic metres, represents a meaningful but partial offset of the groundwater deficit documented in the CGWB semi-critical basin classification. The primary groundwater benefit of the check dam network is therefore not the absolute volume of recharge — which is insufficient to reverse the semi-critical classification on its own — but the spatial distribution of recharge directly beneath the urban areas most affected by groundwater decline, providing targeted benefit to the borewells and dug wells of Zone 1 and Zone 2 residential communities.

5.4 Proposal 3: Constructed Wetlands and Riparian Buffer Restoration

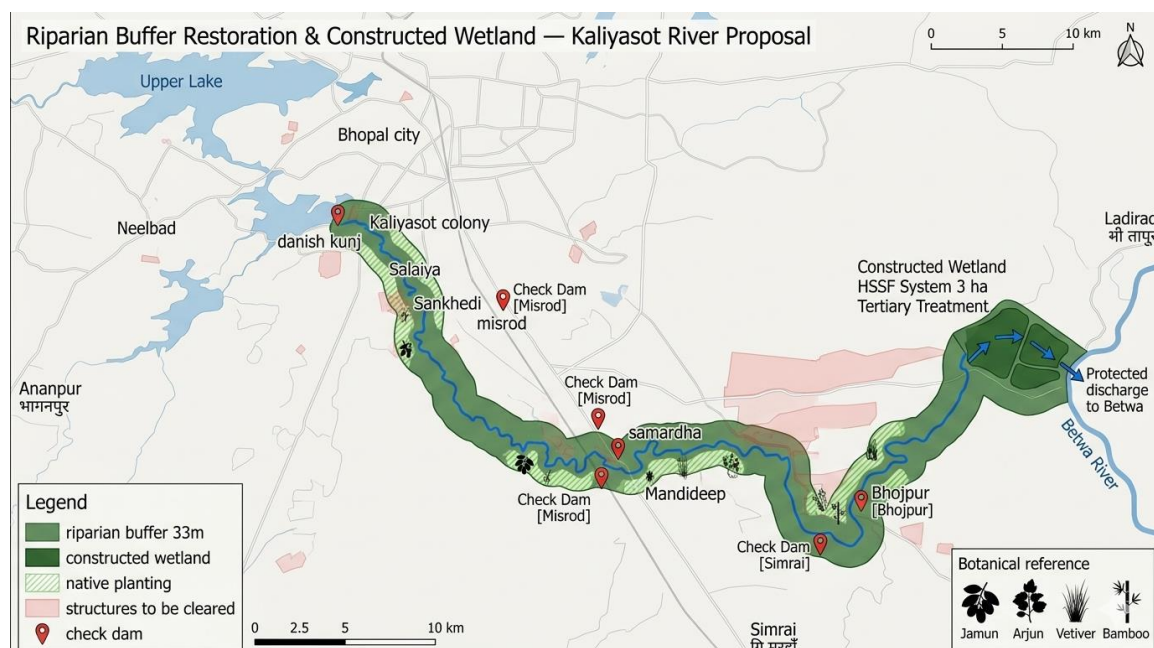


Fig. 5.3: Constructed Wetland Location and Treatment System Layout — Zone 3 Terminus (Source: Author; CPCB Constructed Wetland Guidelines 2015; MoEFCC 2017)

Fig. 5.4: Riparian Buffer Restoration Plan — Native Species Planting Strategy (Source: Author; IUCN NbS 2016; Forest Survey of India Species Data)

5.4.1 Constructed Wetlands — Design and Performance

Despite the secondary treatment provided by the proposed STP network, the effluent discharged as E-Flow and released at Zone 3 will contain residual concentrations of nutrients (nitrates and phosphates), heavy metals, and pathogenic organisms that, at the volumes proposed, would continue to affect the Betwa River's water quality if not subjected to further treatment. The constructed wetland system proposed at the Zone 3 terminus functions as the final ecological polishing stage before the river's discharge enters the Betwa, providing tertiary treatment that reduces residual pollutant concentrations to levels consistent with the protection of the receiving river's ecological integrity.

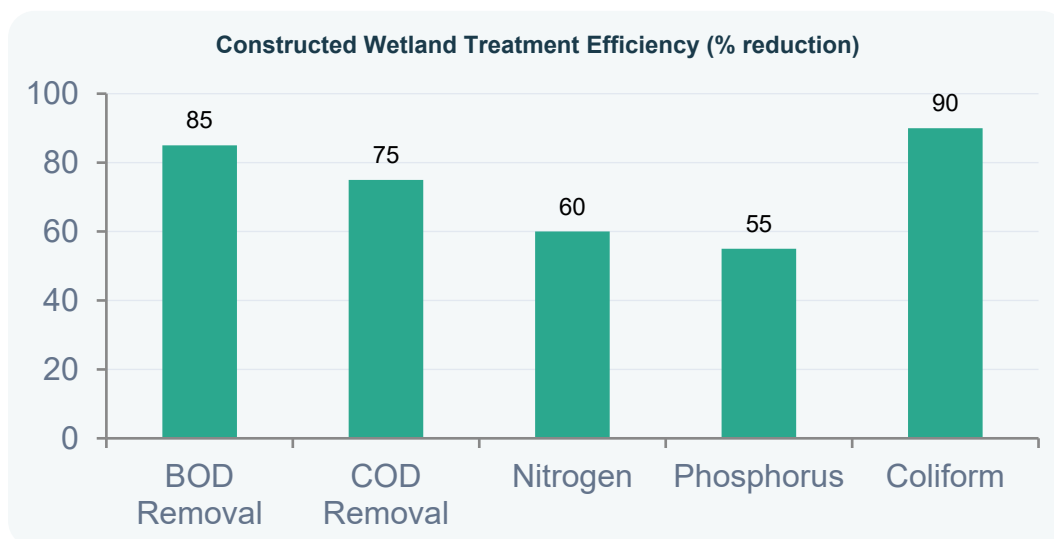
The system is designed as a horizontal subsurface flow (HSSF) constructed wetland, the most widely researched and reliably performing wetland type for the treatment of secondary municipal effluent in tropical and subtropical climates. The HSSF design routes effluent through a gravel-filled bed planted with wetland

macrophytes, flowing horizontally from inlet to outlet below the gravel surface. This subsurface design prevents the creation of surface water conditions that could breed mosquitoes — an important public health consideration in a malaria-endemic region — while providing optimal conditions for the aerobic and anaerobic microbial communities responsible for pollutant removal.

The proposed wetland system covers 3 to 4 hectares of total cell area, divided into four cells of 0.75 to 1.0 hectare each arranged in two parallel series. The parallel arrangement provides operational redundancy — one series can be taken offline for maintenance without interrupting treatment. The series arrangement within each parallel train maximises the contact time between effluent and treatment substrate, ensuring that the treatment efficiency targets in Table 5.4 are consistently achieved.

Pollutant Parameter	Influent Concentration (post-STP)	Treatment Efficiency (%)	Target Effluent Concentration	CPCB Standard for Betwa Discharge	Standard Compliance
BOD (mg/L)	15–30	85%	2–4.5 mg/L	< 30 mg/L	Exceeds standard
COD (mg/L)	40–80	75%	10–20 mg/L	< 250 mg/L	Exceeds standard
Total Nitrogen (mg/L)	20–30	60%	8–12 mg/L	< 10 mg/L (approx.)	Achieves standard
Total Phosphorus (mg/L)	4–6	55%	1.8–2.7 mg/L	< 2 mg/L	Near standard
Faecal Coliform (MPN/100mL)	5,000–15,000	90%	500–1,500	< 5,000	Achieves standard
Suspended Solids (mg/L)	30–50	80%	6–10 mg/L	< 100 mg/L	Exceeds standard

Table 5.4: Constructed Wetland Treatment Efficiency — HSSF System, Zone 3 Terminus Source: CPCB Constructed Wetland Guidelines 2015; MoEFCC Wetland Standards 2017; IUCN NbS 2016



The native plant species selected for the constructed wetland — *Phragmites karka*, *Typha latifolia*, and *Cyperus rotundus* — are all indigenous to the central Indian region, ensuring their adaptation to the local climate and avoiding the risks associated with introducing non-native species into a riparian environment. *Phragmites karka* is selected as the primary treatment species for its dense rhizome system that supports the highest diversity of treatment-active microbial communities; *Typha latifolia* for its superior nitrogen uptake capacity; and *Cyperus rotundus* as a fast-establishing ground cover species that prevents surface erosion and provides initial canopy cover while the larger species establish.

Beyond their treatment function, the constructed wetland cells will, within two to three years of establishment, develop into significant biodiversity habitats. Wetland systems of comparable scale and design in comparable Indian climates have been documented to support populations of 40 to 60 bird species, including migratory species using the Indo-Gangetic flyway for which wetland habitats are critical resting and feeding points. The integration of a bird hide and a 200-metre nature trail within the wetland buffer zone — proposed as part of the Zone 3 public amenity programme — will make this biodiversity asset accessible to local communities and visitors, generating educational and ecotourism co-benefits alongside the primary treatment function.

5.4.2 Riparian Buffer Restoration

The restoration of the 33-metre NGT buffer zone through systematic native species planting is the most spatially extensive intervention proposed in this thesis — covering approximately 190 hectares of river bank on both sides of the full 29-kilometre corridor — and is among the most ecologically significant. The riparian buffer zone is not merely a regulatory requirement; it is the primary mechanism through which the river is physically connected to its terrestrial environment, and through which the terrestrial environment provides ecological services to the river.

These services include: filtration of surface runoff, intercepting pollutants before they reach the river channel; bank stabilisation through root systems that bind soil and resist erosion from both flood events and the everyday undercutting of the bank face; groundwater recharge through the high evapotranspiration and infiltration rates associated with dense riparian vegetation; microclimate regulation through the canopy shade that reduces water temperature and the root systems that maintain soil moisture; and ecological connectivity — the provision of a continuous habitat corridor for mobile species (birds, small mammals, reptiles, invertebrates) that requires unbroken vegetated strips to move between habitat patches across an otherwise impermeable urban matrix.

Species	Common Name	Planting Zone	Ecological Function	Establishment Rate	Source
<i>Syzygium cumini</i>	Jamun	Primary canopy (0–33m)	Deep roots (2–3m) for bank stabilisation; leaf litter for aquatic habitat; shade for water temperature reduction	Moderate — 2–3 years to canopy establishment	Local nurseries; Forest Dept. stock
<i>Terminalia arjuna</i>	Arjun	Primary canopy (0–33m)	Traditional medicinal and cultural species; root system excellent for	Moderate — 3–4 years to canopy	Local nurseries; Forest Survey of India

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Species	Common Name	Planting Zone	Ecological Function	Establishment Rate	Source
			bank stabilisation; supports bird nesting		
Dendrocalamus strictus	Bamboo	Structural mid-layer (0–15m)	Very fast establishment (6 months to structural height); root system prevents erosion; biomass production	Fast — 6–12 months to structural height	MNRE bamboo programme; local growers
Chrysopogon zizanioides	Vetiver grass	Ground cover (0–10m bank)	Root system to 3m depth — unparalleled erosion control; effective in all soil types; rapid establishment	Very fast — 3–6 months to full cover	Vetiver Network India; local nurseries
Phragmites karka	Common reed	Wetland edges (0–5m)	Aquatic habitat creation; nutrient removal; bird habitat	Fast — 1–2 seasons to establish	Wetland nurseries; collected from existing stands

Table 5.5: Native Riparian Planting Species and Functions — Kaliyasot Buffer Restoration
Source: IUCN NbS Guidelines 2016; Forest Survey of India; NGT Buffer Order 2022; Kham River PCMC Reports

5.5 Proposal 4: Four-Zone Eco-Sensitive Riverfront Development Model

4-Zone Eco-Sensitive Riverfront Development Model — Kaliyasot River

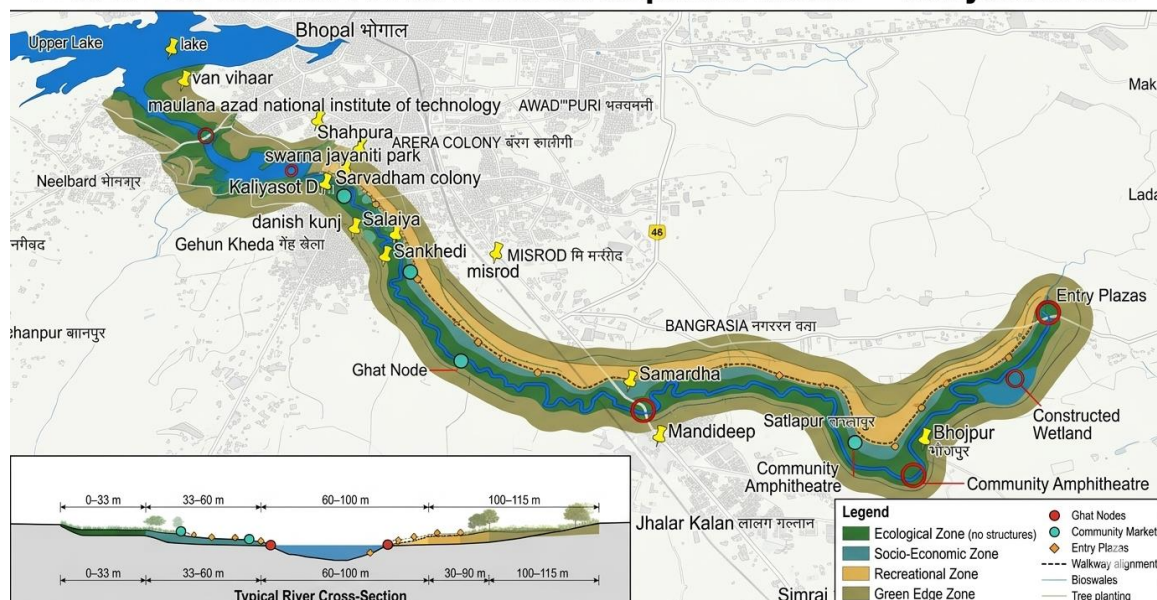


Fig. 5.5: Four-Zone Riverfront Development Concept Plan — Kaliyasot River Corridor
(Source: Author; Smart Cities Mission; NGT 2022; CPTED BIS Standards)

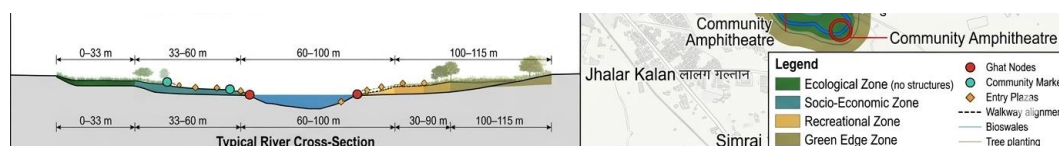


Fig. 5.6: Typical River Cross-Section — Four-Zone Model (Dimensions in metres)
(Source: Author; NGT Order 2022; MoHUA URMP 2019)

5.5.1 Design Philosophy

The four-zone riverfront model is the spatial planning instrument through which the ecological restoration of the Kaliyasot River is connected to the social needs of the 55,000 residents of the corridor. It is premised on the recognition that a river corridor serves multiple, simultaneously valid purposes — ecological, social, cultural, economic, and recreational — and that the planning challenge is not to choose between these purposes but to spatially organise them so that they reinforce rather than undermine each other.

The model explicitly rejects the Sabarmati Riverfront's approach of homogenising the river edge into a continuous promenade of uniform character —

an approach that treats the river as a backdrop for urban display rather than as an ecological and social system with its own internal logic. Instead, the four-zone model differentiates the river cross-section from the water's edge outward, with each zone performing a specific set of functions determined by its ecological sensitivity and its relationship to the urban communities beyond.

The sequencing of the four zones from water's edge outward — Ecological, Socio-Economic, Recreational, Green Edge — reflects the principle of ecological gradient: ecological sensitivity is highest immediately adjacent to the water and diminishes with distance. The most ecologically sensitive zone (Zone 01, the NGT buffer) receives the most protective planning designation; the least ecologically sensitive (Zone 04, the urban edge transition) receives development that prioritises urban connectivity and stormwater management.

5.5.2 Zone 01 — Ecological Zone (0–33 m from Riverbank)

The Ecological Zone is the physical and regulatory core of the four-zone model. Bounded on the river side by the active channel bank and on the land side by the 33-metre NGT buffer line, this zone is dedicated exclusively to ecological function. Its planning designation is strictly protective: native riparian planting, constructed wetland cells, natural bank formations, and pervious monitoring pathways of maximum 1.2 metres width for maintenance access only.

The management principle of Zone 01 is: remove what has been added, allow what is natural. The 321 illegal structures currently within this zone are to be cleared in Phase 0, with affected households offered the in-situ rehabilitation provision of Zone 02 or transit housing within 300 metres. Once cleared, the zone is planted with the native species described in Table 5.5 and left to develop through natural succession processes with minimal intervention — no formal landscaping, no irrigation after the establishment period, no ornamental planting, and no hard infrastructure.

As the riparian planting matures over the five-year Phase 2 period, Zone 01 will progressively develop the ecological functions that characterise a healthy riparian zone: the root systems of Jamun and Arjun penetrating 2 to 3 metres into the river bank providing structural stability against erosion; the dense Vetiver grass

cover on the bank face preventing surface runoff and reducing sediment loading to the river; the Bamboo groves creating a visible and effective physical barrier to future encroachment; and the emergent vegetation at the water's edge — Phragmites and Typha at wetland margins — providing habitat for waterbirds and aquatic invertebrates that will be the early indicators of ecological recovery.

5.5.3 Zone 02 — Socio-Economic Zone (33–60 m from Riverbank)

The Socio-Economic Zone extends from the outer boundary of the Ecological Zone to 60 metres from the river bank. This zone is explicitly designed for the economic and cultural communities documented in the Chapter 4 social analysis — the fisher communities, washermen, vegetable farmers, informal vendors, and ritual users who have maintained an intimate relationship with the Kaliyasot River despite its degradation — providing the infrastructure that sustains and formalises these relationships in a manner consistent with the river's ecological restoration.

The allocation of 30 percent of the total riverfront space in Zone 02 to designated livelihood uses is the critical equity mechanism of the four-zone model. This allocation — documented in the social analysis as necessary to prevent elite capture of the riverfront following restoration — creates a permanent planning covenant protecting the following uses: fish drying and processing yards with solar dryer infrastructure; six ghats of varying gradient designed for different washing and ritual bathing functions, supplied with treated E-Flow water meeting Class C quality standards; community composting facilities integrated into the riparian waste management system; small-scale market structures for local agricultural and fishing produce; and craft and heritage exhibition space for the documentation and display of the traditional river-related practices of the corridor communities.

The ghat infrastructure requires particular design attention. Ghats in the Indian tradition are not merely steps to the water — they are complex social infrastructure supporting bathing, ritual, laundry, socialisation, and meditation. The six ghats proposed for the Kaliyasot corridor are designed as terraced sandstone structures with broad platforms at the water's edge, sloped access for differently-abled users, shaded seating areas at the top, and waste collection points integrated

into the structure. The ghats are positioned at the locations of highest community use identified in the field survey, including the Damkheda and Sarvadharam localities.

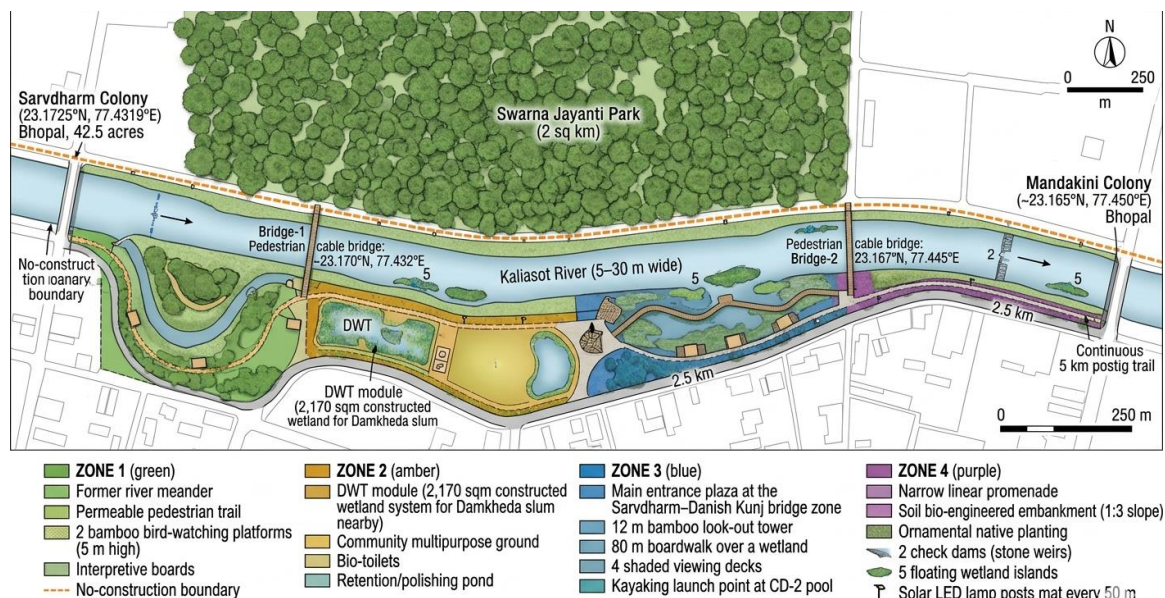


Figure 10 — Riverfront Development Master Plan: 2.5 km Study Stretch.

Fig. 5.7: Zone 02 Socio-Economic Space — Ghat and Livelihood Infrastructure Design
(Source: Author; Field Survey Documentation; UN-Habitat 2015)

5.5.4 Zone 03 — Recreational Zone (60–100 m from Riverbank)

The Recreational Zone extends from 60 to 100 metres from the riverbank and constitutes the primary public amenity dimension of the riverfront. This is the zone that becomes visible to, and used by, the broadest urban population — including residents who have no traditional relationship with the river but who will use a restored and accessible riverfront as a park, a cycling route, and a community gathering space.

The activation of Zone 03 is explicitly conditional on Phase 2 progress targets: a minimum DO of 5 mg/L at Stations S1 through S3, a WQI below 100 at Station S1, and a riparian cover above 25 percent. These conditions ensure that Zone 03 infrastructure is built alongside a visibly recovering river — one with flowing water, emerging vegetation, and the sensory experience of ecological improvement — rather than alongside a dead channel whose continuing degradation would undermine the public investment.

The Zone 03 infrastructure programme comprises: a continuous 3-metre-wide riverside walkway of permeable paving (interlocking rubble stone or compacted gravel with geotextile membrane) extending for the full Zone 2 midstream length (6 to 22 kilometres), where population density and demand are highest; a parallel 2-metre-wide cycle track separated from the walkway by a 1-metre planting strip; seating nodes at 200-metre intervals incorporating naturally shaped stone benches and shaded pergola structures with native climbers; viewing platforms at river bend locations where topographic advantage creates elevated vistas; pocket park nodes at 500-metre intervals with children's nature play equipment, fitness stations, and native meadow planting; and interpretation panels at 1-kilometre intervals providing ecological monitoring data (current DO, BOD, and NDWI values) in visual format accessible to the general public.

The CPTED (Crime Prevention Through Environmental Design) framework governs all Zone 03 infrastructure design decisions. The principles applied are: natural surveillance (designing spaces so that users can observe each other and the surrounding area — achieved through open sightlines, limiting shrub height to 0.8 metres within 5 metres of the walkway, and positioning seating at elevated points); natural access control (defining clear routes of access and limiting access points to reduce the opportunity for concealment — achieved through clear pathway design and strategic planting); territorial reinforcement (creating a sense of ownership and active use through programming, vendor presence, and community garden plots that generate consistent human activity throughout the day); and maintenance (ensuring that the zone is consistently well-maintained to signal active management and community ownership).

Lighting design for Zone 03 is a critical safety specification. The minimum illuminance of 50 lux at the walking surface — consistent with BIS IS 1944 Part 2 for pedestrian ways and the Smart Cities Mission riverfront lighting guidelines — is achieved through solar-powered LED columns at 25-metre intervals, designed with a mounting height of 4 metres to provide the diffuse, shadow-free illuminance that characterises effective CPTED lighting. A secondary emergency lighting system, powered by a separate battery backup circuit with 8-hour autonomy, ensures that the walkway remains illuminated during power failures. Emergency

call points — containing a direct connection to the nearest police station and Bhopal Municipal emergency services — are installed at 500-metre intervals, mounted at a height accessible to wheelchair users.

Fig. 5.8: Zone 03 Recreational — CPTED Walkway Design and Lighting Layout (Source: Author; CPTED Guidelines BIS; Smart Cities Mission Riverfront Guidelines)

5.5.5 Zone 04 — Green Edge Zone (100–115 m from Riverbank)

The Green Edge Zone is the 10 to 15-metre transition band between the urban built fabric and the recreational riverfront. Its design function is simultaneously structural (as a physical and visual boundary between the river environment and the city), ecological (as a bioswale network intercepting urban runoff before it reaches the river), and thermal (as a tree-lined green corridor that reduces ambient temperatures and improves air quality in the immediately adjacent urban area).

The primary planting of Zone 04 is a double row of native shade trees — Neem (*Azadirachta indica*), Peepal (*Ficus religiosa*), and Banyan (*Ficus benghalensis*) — at 8-metre intervals, providing a canopy that intercepts rainfall, reduces impervious surface runoff temperatures, and creates the shaded, human-scaled pedestrian environment that makes the transition from the urban street to the riverfront an experiential journey rather than an abrupt boundary crossing.

The bioswale network occupies the surface between the tree rows, planted with sedge species and grass mixtures selected for their phytoremediation capacity — their ability to absorb and metabolise the heavy metals, petroleum hydrocarbons, and nutrients concentrated in urban road runoff. The bioswale channels are designed with a 1 to 2 percent longitudinal gradient and a cross-section depth of 300 to 400 millimetres, providing the retention volume required to treat the first 25 millimetres of rainfall — the 'first flush' event that concentrates 80 percent of the annual pollutant load from urban impervious surfaces into its initial runoff pulse. By intercepting and treating this first-flush load, the Zone 04 bioswale network is estimated to reduce the annual pollutant load reaching the river channel by 40 to 60 percent — a significant contribution to water quality improvement that complements the STP-based treatments of Proposals 1 and 3.

The Zone 04 boundary wall is a significant design element that has received insufficient attention in comparable riverfront projects. A poorly designed boundary — too high, opaque, or formally demarcated — can signal exclusion and deter casual use by residents who might otherwise treat the riverfront as an extension of their daily movement patterns. The Zone 04 boundary is therefore designed not as a wall but as a planted berm — a 0.6 to 0.8-metre raised earthwork planted with the Vetiver-Bamboo combination that serves simultaneously as a visual marker of the boundary, a physical deterrent to vehicular intrusion, a root barrier against pedestrian erosion, and a habitat element for small ground-nesting birds. Gaps in the berm at 200-metre intervals, aligned with adjacent street intersections, provide clear entry points that are welcoming rather than gatekeeping in character.

Zone	Width	Distance from Bank	Primary Function	Permitted Uses	Excluded Uses	Performance Indicator
Zone 01 — Ecological	33 m	0–33 m	NGT buffer; ecological function; E-Flow bank	Native planting; wetland cells; monitoring paths	All permanent structures; paving; lighting; commercial	Riparian cover > 33% (NDVI); bank erosion < baseline
Zone 02 — Socio-Economic	27 m	33–60 m	Livelihood; cultural; community social infrastructure	Ghats; fish yards; market structures; composting	Exclusive private development; eviction without rehabilitation	30% livelihood space maintained; community satisfaction score
Zone 03 — Recreational	40 m	60–100 m	Public amenity; active and passive recreation	Walkway; cycle track; seating; pocket parks; lighting	Concrete embankments; non-native landscaping; exclusionary design	Daily visitor count; gender safety score; CPTED compliance

Zone	Width	Distance from Bank	Primary Function	Permitted Uses	Excluded Uses	Performance Indicator
Zone 04 — Green Edge	15 m	100–115 m	Encroachment barrier; bioswale; thermal amelioration	Tree planting; bioswale channels; pedestrian paths	Commercial buildings; hard paving; parking	First-flush pollutant reduction 40–60%; ambient temperature - 2°C

Table 5.6: Four-Zone Riverfront Development — Summary of Controls and Performance Indicators Source: Author; NGT Order 2022; MoHUA URMP 2019; Smart Cities Mission Guidelines; CPTED BIS

5.6 Phasing Strategy

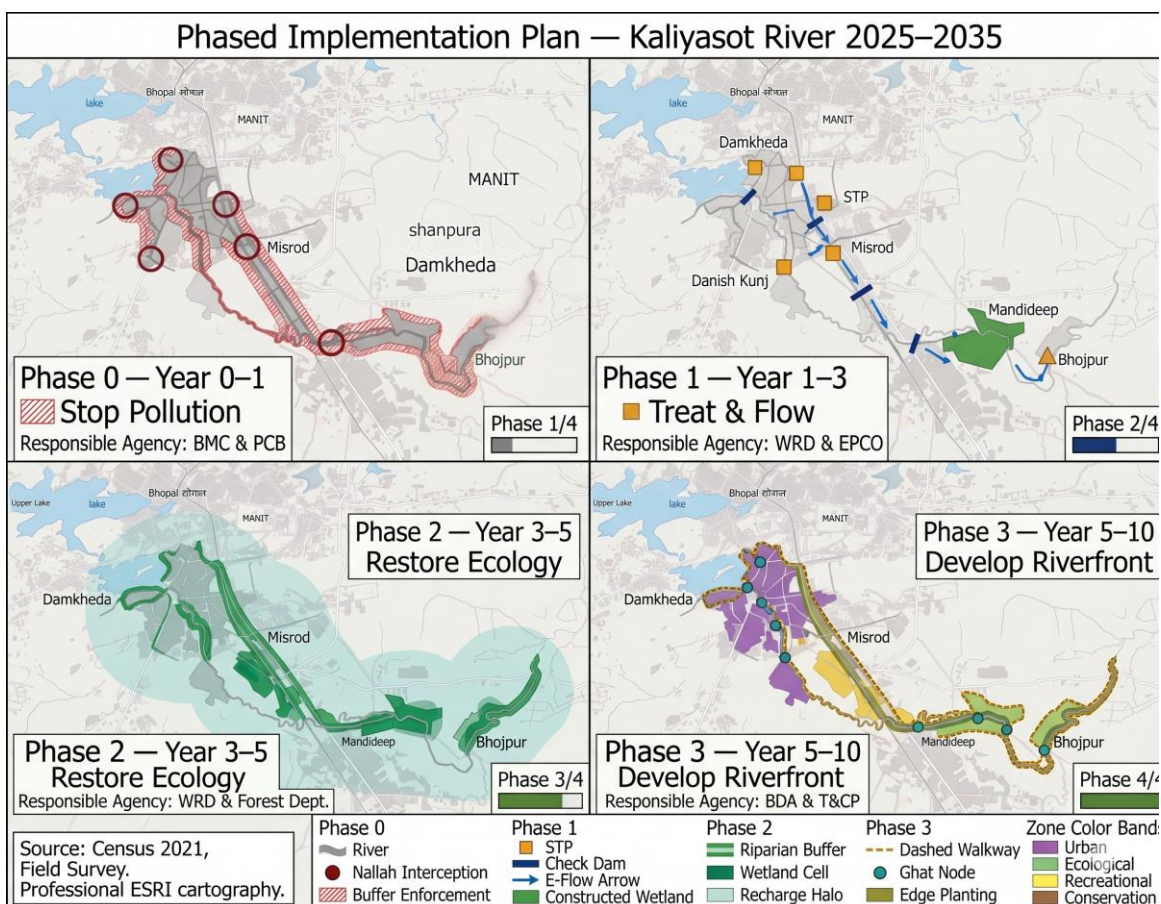


Fig. 5.9: Phased Implementation Map — Kaliyasot River Corridor 2025 to 2035 (Source: Author; BDA 2031; NRCP MoEF; CWC River Restoration Framework)

5.6.1 Phasing Philosophy and Rationale

The phasing strategy of this study represents the practical operationalisation of the ecology-first principle. It does not proceed from the assumption that all interventions must be implemented simultaneously or that the public realm development component must wait indefinitely until ecological perfection is achieved. Rather, it establishes a conditional sequence: each phase has specific, measurable performance thresholds that trigger the commencement of the next phase, ensuring that resource investment in later phases is protected by the ecological foundations laid by earlier phases.

The four-phase structure follows the logic articulated by the National River Conservation Plan: Phase 0 stops the active destruction of the river; Phase 1 restores the basic ecological conditions (flow and treatment) that enable recovery; Phase 2 deepens the ecological recovery; and Phase 3 — and only Phase 3 — builds the public amenity that makes the restored river a visible urban asset. This sequence is not bureaucratic rigidity; it is the lesson learned from every riverfront project that skipped phases and produced disappointing or harmful results.

The governance structure — specifically the establishment of the Kaliyasot River Corridor Authority — is identified as a pre-condition for Phase 0, not as a parallel workstream. Without unified governance, the inter-jurisdictional pollution that characterises the corridor will continue regardless of restoration investment, and the phasing strategy will be undermined before it begins.

5.6.2 Phase 0 — Stop Pollution (Year 0–1)

Phase 0 is the crisis management phase. Its purpose is not to restore the river — that takes years — but to stop making it worse. Every day that 125 MLD of untreated sewage continues to enter the Kaliyasot is a day that undoes the potential of all subsequent restoration investment. Phase 0 creates the stable baseline from which ecological recovery can begin.

Phase 0 actions: (i) Legal — Issue construction stop orders for all 321 structures in the NGT buffer; commence joint verification by MPPCB, BDA, and Jal Nigam of all nallah outfall locations and flow rates; establish the Kaliyasot River Corridor Authority through state government notification. (ii) Infrastructure —

Install temporary nallah interception works at all five major outfall points, diverting raw sewage to the existing Shahpura STP inlet; commence emergency rehabilitation of Misrod STP to restore design capacity and effluent quality; audit and repair all Shahpura STP inlet distribution structures to optimise 25 MLD treatment utilisation. (iii) Monitoring — Establish monthly water quality monitoring at all five MPPCB stations, with results reported publicly to the River Corridor Authority; install six NDWI satellite monitoring transects for quarterly hydrological condition tracking. (iv) Planning — Commission Detailed Project Reports for Zone 1 STP (40 MLD) and Zone 3 STP (50 MLD); complete socio-economic survey of Zone 01 buffer-zone households for in-situ rehabilitation design.

Budget estimate: INR 15 to 25 crore (Phase 0 — primarily enforcement, monitoring, and emergency STP works). Lead agencies: MPPCB (enforcement and monitoring); Bhopal Jal Nigam (STP works); BDA (encroachment documentation and stop orders).

5.6.3 Phase 1 — Treat and Flow (Year 1–3)

Phase 1 introduces the two transformative infrastructure investments that will, within three years, convert the Kaliyasot from a dry sewage drain into a river with continuous, treated-quality flow and a functioning check dam retention system. This is the most capital-intensive phase and the one that generates the ecological transformation upon which all subsequent investment depends.

Phase 1 actions: (i) Construct Zone 1 STP (40 MLD, SBR technology) with Eco-STP polishing cells; commission E-Flow release structure with controlled 5 to 10 MLD discharge mechanism. (ii) Construct Zone 3 STP (50 MLD, industrial-grade SBR) with nallah interception trunk sewer from Zone 3 outfall points. (iii) Complete Misrod STP rehabilitation and expand capacity from 20 to 55 MLD. (iv) Install 8 check dams along the corridor in rubble masonry as per IS 14451; survey and design the two additional optional structures. (v) Establish constructed wetland system (3 hectares, Phase 1; expand to 4 hectares in Phase 2) at Zone 3 terminus. (vi) Begin nallah interception at all remaining outfall points with connection to respective STP catchments.

Budget estimate: INR 180 to 240 crore (Phase 1 — primarily STP construction, check dams, and wetland). Lead agencies: Bhopal Jal Nigam (STP construction); PWD (check dam construction); CGWB (groundwater monitoring); MPPCB (monitoring and compliance).

Phase transition trigger: Phase 2 may commence when all three STPs are operational at above 80 percent design capacity, when E-Flow has been established for a minimum of six continuous months, when DO at Stations S1 and S2 exceeds 3.0 mg/L on three consecutive monthly measurements, and when BOD at all five stations is below 30 mg/L.

5.6.4 Phase 2 — Restore Ecology (Year 3–5)

Phase 2 builds on the improved water quality conditions established by Phase 1 to develop the biological dimension of ecological recovery — the riparian vegetation, aquatic biodiversity, and groundwater recharge functions that transform the river from a treated wastewater channel into a functioning ecosystem.

Phase 2 actions: (i) Full riparian planting programme — 190 hectares of Zone 01 buffer zone on both banks, full 29-kilometre corridor, using the species mix in Table 5.5. (ii) In-situ rehabilitation of Zone 01 encroachment households — design and construction of replacement housing within 300 metres of original location, with community liaison team managing transition. (iii) Wetland biodiversity enhancement — introduce fish and invertebrate populations to check dam ponded sections; expand constructed wetland cell area to 4 hectares. (iv) Quarterly monitoring — WQI, DO, and NDWI (satellite) at all five stations; annual NDVI analysis of riparian corridor to track planting establishment. (v) Stormwater management — install Zone 04 bioswale network along approach roads within the BDA-designated corridor zone.

Budget estimate: INR 20 to 35 crore (Phase 2 — primarily planting, rehabilitation, and monitoring). Lead agencies: Forest Department (planting programme and maintenance); MNRE (groundwater monitoring programme); NIUA (community liaison and rehabilitation); BDA (bioswale network).

Phase transition trigger: Phase 3 may commence when DO exceeds 5.0 mg/L at Stations S1 through S3 on six consecutive monthly measurements; when WQI is below 100 at Station S1; when riparian vegetation cover exceeds 25 percent as measured by NDVI analysis; and when in-situ rehabilitation of Zone 01 affected households is complete.

5.6.5 Phase 3 — Develop Riverfront (Year 5–10)

Phase 3 is the public realm development phase — the phase in which the restored ecological corridor becomes a visible, accessible, and valued urban amenity. By the time Phase 3 commences, the Kaliyasot River should have: visible, flowing, oxygenated water year-round; established riparian vegetation providing shade, ecological character, and bank stability; measurably improving water quality that meets Class B standards at upstream stations; and an active groundwater recharge programme that is measurably benefiting Zone 1 well users. The riverfront developed in Phase 3 is not a cosmetic treatment of a dead river — it is an enhancement of a visibly recovering one.

Phase 3 actions: (i) Zone 03 Recreational Zone — Construct 16-kilometre riverside walkway (both banks, Zone 2 midstream); cycle track; seating nodes; viewing platforms; pocket park nodes; CPTED lighting at 50 lux to BIS standard; emergency call points. Complete women's safety audit before finalising layout. (ii) Zone 02 Socio-Economic Zone — Construct six ghats in terraced sandstone; establish 30% livelihood allocation through formal community land tenure agreements; develop market structure and fish processing area; complete cultural heritage documentation. (iii) Zone 04 Green Edge Zone — Install tree planting along all Zone 2 and Zone 3 approach roads; complete bioswale network. (iv) Monitoring and governance — Establish annual I-SEER performance assessment cycle; WQI-linked maintenance trigger system; public reporting dashboard.

Budget estimate: INR 80 to 120 crore (Phase 3 — primarily public realm construction). Lead agencies: BDA and Smart Cities Mission (overall development); ULB (operations and maintenance); Community organisations (30% livelihood zone management).

*Integrated Riverfront Development and Conservation of Kaliyasot
River, Bhopal*

Phase	Period	Focus	Primary Actions	Budget Estimate (INR crore)	Lead Agency	Phase-to-Phase Trigger
Phase 0	Year 0–1	Stop Pollution	NGT enforcement; nallah interception; STP audit; Corridor Authority established; monitoring baseline	15–25	MPPCB; BDA; Jal Nigam	Pollution inputs reduced by >50%; monitoring baseline established
Phase 1	Year 1–3	Treat and Flow	Zone 1 STP 40 MLD; Zone 3 STP 50 MLD; Misrod STP 55 MLD; E-Flow 5–10 MLD; 8 check dams; 3 ha wetlands	180–240	Jal Nigam; PWD; CGWB	DO >3.0 mg/L at S1 and S2; BOD <30 mg/L all stations; E-Flow sustained 6 months
Phase 2	Year 3–5	Restore Ecology	190 ha riparian planting; in-situ rehabilitation; biodiversity enhancement; bioswale network; monitoring	20–35	Forest Dept; NIUA; BDA	DO >5.0 mg/L at S1–S3; WQI <100 at S1; riparian cover >25%
Phase 3	Year 5–10	Develop Riverfront	Zone 03 walkway/cycle track; Zone 02 ghats and livelihoods; Zone 04 green edge; annual I-SEER review	80–120	BDA; Smart Cities; ULB	Annual WQI + I-SEER social + community satisfaction review

Phase	Period	Focus	Primary Actions	Budget Estimate (INR crore)	Lead Agency	Phase-to-Phase Trigger
TOTAL	10 years	Integrated	Full ecological + social + physical transformation of 29 km corridor	295–420	Corridor Authority	I-SEER targets: Env 78; Social 72; Economic 65

Table 5.7: Phased Implementation Plan — Summary Source: Author; NRCP MoEF; CWC River Restoration Framework; MoHUA URMP 2019; Dravyavati DPR JDA 2015

5.7 Governance Recommendations

The single most significant risk to the implementation of these proposals is not technical or financial — it is institutional. The Kaliyasot River corridor is currently governed by three separate administrative jurisdictions with no mechanism for integrated management, no shared monitoring data, no unified enforcement capacity, and no single point of accountability for the corridor's overall ecological condition. This fragmentation will undermine any restoration investment unless it is structurally addressed before Phase 0 begins.

The NIUA River Governance Framework (2021) recommends the establishment of River Corridor Authorities as statutory inter-jurisdictional bodies for river corridors that pass through multiple administrative boundaries. For the Kaliyasot, this would take the form of a Kaliyasot River Corridor Authority (KRCA), constituted by the following members: BDA (Chair, as largest jurisdiction); Misrod ULB; Mandideep Industrial Area Authority; MPPCB; CGWB; Forest Department; Bhopal Jal Nigam; and two civil society representatives from the Zone 1 and Zone 2 corridor communities.

The KRCA's mandate would include: integrated water quality monitoring and public reporting; unified enforcement of NGT buffer orders; corridor-wide STP commissioning and operational oversight; coordination of Phase 0 through Phase 3 implementation; annual I-SEER performance assessment; and conflict resolution

between jurisdictional interests. Funding for KRCA operations would be drawn from a dedicated River Corridor Fund constituted from contributions by all member jurisdictions, supplemented by central government grants under the NRCP and Smart Cities Mission frameworks.

5.7.1 Community Participation Framework

The governance architecture proposed for the Kaliyasot River corridor includes a formal community participation framework that goes beyond the two civil society seats on the KRCA board. River restoration in an inhabited corridor of the density and social complexity of the Kaliyasot cannot be effectively implemented without the understanding, cooperation, and ultimately the active participation of the communities who live adjacent to it. Experience from the Kham River restoration in Aurangabad and the Dravyavati River in Jaipur consistently demonstrates that community participation is not merely a procedural obligation but a practical necessity: communities who understand the purpose and expected benefits of restoration are more likely to prevent encroachment, report pollution incidents, maintain plantings, and engage constructively with the rehabilitation processes that are inevitably disruptive.

The community participation framework proposed for the Kaliyasot restoration operates at three levels. The first level is information and transparency: the KRCA will maintain a public-facing monitoring dashboard displaying real-time water quality data, NDWI values, and restoration progress against phase targets, accessible through a web platform and a printed monthly bulletin distributed to community organisations in all three zones. This transparency is the minimum necessary to build the trust between communities and institutions that sustained multi-phase restoration programmes require.

The second level is consultation and co-design: all elements of the Zone 02 Socio-Economic Zone infrastructure will be designed through participatory workshops with the documented livelihood communities — fishers, washermen, farmers, vendors — ensuring that the ghat structures, livelihood spaces, and access arrangements reflect their actual needs and practices rather than a planner's assumptions about them. The women's safety audit proposed for Zone 03 will be

conducted with women residents from the corridor localities rather than by external consultants, using structured walking methodology (the 'women's safety audit' approach developed by UN-Habitat) to directly incorporate the place-specific knowledge of the women who will use the riverfront.

The third level is stewardship and employment: Phase 2 and Phase 3 implementation will include a minimum 30 percent local employment target for unskilled and semi-skilled work — planting, maintenance, ghat construction, bioswale installation — providing direct economic benefit to corridor communities and creating the sense of investment and ownership that sustains long-term stewardship. The Zone 02 livelihood space is managed through a Community Riverfront Management Committee — a formally constituted body of elected representatives from all corridor community groups — which holds a renewable 5-year management licence for the zone's commercial activities, providing institutional continuity for the livelihood provisions.

The in-situ rehabilitation programme for the 321 households currently within the NGT buffer — the most sensitive component of the entire restoration programme from both a social justice and an implementation risk perspective — is managed through a dedicated Community Liaison Team operating under the KRCA's social development mandate. This team is responsible for: conducting the household-level socio-economic assessment that determines rehabilitation options for each affected household; facilitating the design of replacement housing within 300 metres of the original location; managing the phased transition process to avoid displacement without provision; and monitoring the outcomes of rehabilitation against the anti-displacement targets of the I-SEER Social Benefit pillar.

5.8 Ecosystem Services and Co-Benefits Assessment

5.8.1 Ecosystem Services Framework

The four integrated proposals generate ecological, social, and economic benefits that extend substantially beyond the direct indicators tracked by the I-SEER framework. These benefits are most systematically understood through the ecosystem services framework — the categorisation of the goods and services that functioning ecosystems provide to human societies — which provides a more

comprehensive basis for understanding the full value of the proposed restoration and for communicating that value to decision-makers and funders.

The Millennium Ecosystem Assessment (2005) and the TEEB (The Economics of Ecosystems and Biodiversity) framework identify four categories of ecosystem services: provisioning services (food, water, raw materials); regulating services (climate regulation, water purification, flood mitigation, air quality); cultural services (recreation, aesthetics, spiritual values, educational uses); and supporting services (nutrient cycling, soil formation, habitat provision). A restored Kaliyasot River corridor would contribute to all four categories, though the nature and magnitude of each contribution varies by zone and phase.

5.8.2 Regulating Services

The most economically significant ecosystem services generated by the proposed restoration are in the regulating category. Water quality regulation — the capacity of the restored riparian system to filter and process pollution inputs before they reach the river channel — is estimated to provide an avoided treatment cost benefit of INR 12 to 18 crore per year, representing the cost of achieving equivalent water quality improvement through additional STP capacity rather than through natural filtration. This estimate is based on CPHEEO treatment cost benchmarks of INR 8 to 12 per kilolitre of sewage treated, applied to the estimated volume of runoff filtered by the restored 190-hectare riparian planting.

Flood regulation is the second major regulating service. The combination of check dam retention, riparian planting, and bioswale infrastructure proposed in Phases 1 and 2 is estimated to reduce peak monsoon discharge by 20 to 30 percent at the Zone 1 channel constriction points — the locations where flash flooding has historically caused the most damage. Based on the documented flood damage costs from the 2022 and 2024 monsoon events (estimated INR 15 to 25 crore per event, two to three events per year), the avoided flood damage from the restoration programme is estimated at INR 30 to 75 crore per year once the riparian and check dam system is fully established. This represents a benefit stream that, discounted at 8 percent over 25 years, has a net present value of approximately INR 320 to 800

crore — substantially exceeding the estimated Phase 0 through Phase 2 restoration cost of INR 215 to 300 crore.

Groundwater recharge regulation is the third major regulating service. The check dam network, operating over the 29-kilometre corridor, is estimated to recharge 2.0 to 3.5 MCM (Million Cubic Metres) of groundwater per year — reversing the documented decline rate and potentially stabilising or slightly improving groundwater table levels within the Zone 1 and Zone 2 aquifer by the end of Phase 2. For the approximately 45,000 household well users in the corridor zone who currently report declining water table levels, this groundwater stabilisation represents a tangible economic benefit estimated at INR 3 to 5 crore per year in avoided water trucking and deepening costs.

Urban heat island mitigation is a fourth regulating service of growing significance given Bhopal's documented trend of increasing mean temperatures. The 190-hectare riparian planting proposed in Phase 2, combined with the open water surfaces created by the check dam network, is estimated to reduce ambient temperatures within 200 metres of the river by 2.5 to 3.5 degrees Celsius — consistent with the data from the Bishan-Ang Mo Kio restoration in Singapore. For the 55,000 residents within 500 metres of the corridor, this temperature reduction translates to measurable reductions in heat stress, particularly during the March to June pre-monsoon period when Bhopal's ambient temperatures regularly exceed 40 degrees Celsius.

5.8.3 Cultural Services

The cultural ecosystem services generated by the restored Kaliyasot River corridor are among the most difficult to quantify but are among the most significant for the social licence and community support required to sustain the restoration programme. The Kaliyasot River has historical and cultural significance for Bhopal's Hindu and tribal communities — as a site of ritual bathing, festival celebration, agricultural practice, and ancestral connection that has persisted through the river's degradation and will be renewed by its restoration.

The recreational value of the restored corridor is estimated from the Kham River and Dravyavati precedents: the Kham River walking trail attracts

approximately 8,000 to 12,000 daily users following restoration (PCMC, 2023), generating an estimated INR 5 to 8 crore per year in economic activity through food vendors, recreational services, and tourism. The Dravyavati river attraction in Jaipur generates significantly higher economic activity — estimated at INR 80 to 120 crore per year in tourism and recreational spending (JDA DPR 2015) — though this is partly a function of Jaipur's higher tourism base. A conservative estimate for the Kaliyasot, based on Bhopal's lower tourism volumes, suggests recreational economic activity of INR 15 to 30 crore per year by Phase 3.

The educational value of the restored corridor is not easily quantified but is of particular significance given MANIT Bhopal's location in the corridor catchment: the river can serve as a living laboratory for environmental sciences, urban planning, ecology, and civil engineering students — generating research output and technical capacity that will contribute to the long-term monitoring and management of the corridor.

5.8.4 Climate Co-Benefits

The restoration proposals also generate climate co-benefits that align with Madhya Pradesh's commitments under the State Action Plan on Climate Change and India's Nationally Determined Contributions under the Paris Agreement. The 190-hectare riparian planting programme, using native tree species with an average carbon sequestration rate of 2 to 4 tonnes of CO₂ equivalent per hectare per year, is estimated to sequester approximately 380 to 760 tonnes of CO₂ equivalent annually by the time the planting reaches maturity in Phase 3 — equivalent to offsetting the annual emissions of approximately 80 to 160 passenger vehicles.

The constructed wetlands provide a more complex climate co-benefit picture: horizontal subsurface flow wetlands are net carbon sinks under aerobic conditions but can become net methane emitters under anaerobic conditions. The design specification for the Kaliyasot constructed wetlands — maintaining aerobic conditions through controlled inlet loading rates and recirculation — is therefore important not only for treatment performance but for the climate co-benefit calculation. Under the aerobic design conditions specified in Section 5.3, the

wetland system is estimated to be a net carbon sink of approximately 50 to 80 tonnes CO₂ equivalent per year.

The groundwater recharge co-benefit also has a climate dimension: the avoided pumping energy for the approximately 45,000 household well users in the corridor zone represents an electricity saving of approximately 2 to 4 million kilowatt-hours per year — equivalent to a greenhouse gas saving of approximately 1,600 to 3,200 tonnes of CO₂ equivalent per year at Madhya Pradesh's current grid emission factor of 0.82 kg CO₂ per kWh.

5.9 Expected Outcomes and I-SEER Evaluation

I-SEER Indicator	Baseline (2025)	Phase 1 Target (Year 3)	Phase 2 Target (Year 5)	Full Target (2030)
WQI at S1 (Damkheda)	82 (Very Poor)	60 (Poor)	45 (Approaching Good)	< 50 (Good)
WQI at S3 (Sarvdharm)	153 (Toxic)	100 (Threshold)	70 (Poor)	< 60 (Poor-Good)
DO at S1 (mg/L)	3.1	4.0	5.0	5.5 (Class B)
DO at S3 (mg/L)	1.2 (dead zone)	2.5	4.5	5.0 (Class B)
Riparian Cover (NDVI)	15%	18%	27%	33% (NGT target)
Coliform at S1 (MPN)	2,800	1,500	800	< 500 (Class B)
I-SEER Environmental Score	18/100	42/100	62/100	78/100
I-SEER Social Score	32/100	45/100	60/100	72/100
I-SEER Economic Score	25/100	40/100	55/100	65/100

Table 5.8: Expected Outcomes against I-SEER Indicators (Baseline 2025 vs Targets 2028 and 2030) Source: Author; I-SEER Framework (Journal of Cleaner Production, 2025); Dravyavati and Kham River Outcome Data

Fig. 5.10: Expected WQI Improvement Trajectory at All Stations (2025–2030) (Source: Author; based on Dravyavati and Kham River post-restoration monitoring data; I-SEER Framework)

The full implementation of the four proposals across the three active phases is expected to produce measurable and verifiable improvements across all three I-SEER pillars by 2030. The Environmental Quality score improvement from 18 to 78 reflects: BOD reduction to below 10 mg/L at upstream and midstream stations; DO recovery to Class B standards at Stations S1 through S3; riparian cover increase from 15 to 33 percent; and year-round visible flow through the full corridor. The Social Benefit score improvement from 32 to 72 reflects: 30 percent livelihood space provision; in-situ rehabilitation of all Zone 01 households; gender safety score improvement through CPTED implementation; and community access to six ghats and 16 kilometres of walkway. The Economic Viability score improvement from 25 to 65 reflects: land value increment in the 1-kilometre corridor zone (estimated INR 2,000 to 4,000 crore based on Dravyavati precedent); avoided flood damage in Zone 1 (estimated INR 15 to 25 crore per year based on recent flood event damage records); and avoided healthcare costs from reduced Coliform exposure (estimated INR 8 to 12 crore per year).

Beyond the quantifiable I-SEER indicators, the expected outcomes include: the protection of the Betwa River from toxic downstream transfer through the Zone 3 constructed wetland; the reversal of the CGWB semi-critical groundwater decline trend in the Zone 1 urban area; the creation of a 29-kilometre continuous ecological corridor that connects the Upper Lake ecosystem to the Betwa River system for the first time in decades; and the transformation of the Kaliyasot River from a planning problem into a planning asset — a visible demonstration that ecology-first riverfront planning is viable, just, and replicable in the secondary cities of central India.

CHAPTER 6 — CONCLUSIONS AND FUTURE SCOPE

6.1 Summary of Research

This thesis has presented a comprehensive, evidence-based analysis of the Kaliyasot River corridor in Bhopal, Madhya Pradesh, and has formulated a set of integrated proposals for its ecological restoration and sustainable riverfront development. The research was structured around five analytical dimensions — environmental change, water quality, buffer violation, sewage infrastructure, and socio-economic vulnerability — and four proposal categories — environmental flow and STP network, check dam network, constructed wetlands and riparian buffer, and a four-zone eco-sensitive riverfront model — evaluated collectively against the I-SEER framework.

The analytical findings establish, with statistical rigour, the depth and urgency of the Kaliyasot's ecological crisis. The Water Quality Index of 225-plus at Station S5 (Industrial outfall) represents ecological collapse under every established classification system. The WQI of 82 at Station S1 — the least degraded monitoring point, located immediately downstream of Bhopal's Upper Lake — indicates that even the best-quality reach of the river fails to meet any established standard for human contact, recreational use, or aquatic life support. The 34 percent decline in surface water presence documented by the NDWI analysis between 2015 and 2025 confirms that the hydrological crisis is not merely one of pollution but of flow elimination — the river is disappearing as a physical entity in addition to failing as an ecological one.

The socio-economic analysis has produced findings of particular significance for planning practice. The statistical disproof of the assumption that informal riverside communities are the primary drivers of river degradation — expressed through the non-significant correlation coefficient of $r = +0.12$ between informal settlement density and BOD loading — transforms the ethical and methodological basis for riverfront planning in the corridor. It establishes that displacement-led development is not merely unjust but is analytically unsound: it would not address the primary causes of the river's degradation, which are

infrastructure failures of the formal sewage system, not the domestic activities of the zone's poorest residents.

The four proposals formulated in Chapter 5 are responsive to these findings in both their technical content and their ethical orientation. The STP network addresses the infrastructure failure that is the primary cause of degradation. The check dam network addresses the hydrological failure that has eliminated base flow. The constructed wetland and riparian buffer restoration address the ecological structure failure that has removed the river's natural resilience. And the four-zone development model translates the ecology-first principle into a spatial planning framework that sequences ecological restoration ahead of public amenity provision, reserves 30 percent of commercial space for existing livelihood uses, and embeds CPTED safety design as a non-negotiable provision — not an optional enhancement.

6.2 Key Contributions of the Study

6.2.1 Methodological Contributions

This thesis makes several methodological contributions to the study of urban river restoration in Indian secondary cities. First, it demonstrates the viability of multi-sensor remote sensing analysis for longitudinal hydrological change assessment in rivers for which ground-based hydrological monitoring data is limited or absent. The NDWI approach, combined with LULC classification, provides a rigorous and reproducible basis for characterising decadal change in river corridor conditions that is independent of the often incomplete or inconsistent institutional monitoring record.

Second, it advances a structured approach to socio-economic vulnerability analysis for riverfront planning that disaggregates the population by income, livelihood type, gender, and distance from the river, enabling a differentiated understanding of exposure and dependency that single-indicator analyses miss. The survey instrument developed for this study, and the correlation analysis framework applied to its outputs, provides a replicable model for socio-economic analysis in comparable river corridor contexts.

Third, it applies the I-SEER framework to a non-perennial, semi-arid urban river context for which it was not specifically developed, demonstrating its adaptability and identifying the specific indicator modifications — particularly the treatment of E-Flow-derived base flow as a proxy for natural base flow — required for valid application in seasonal river systems.

6.2.2 Substantive Contributions

The substantive contribution of this thesis to the planning literature on urban river restoration is the demonstration, in a specific and documented Indian secondary city context, that the dominant assumptions of displacement-led riverfront development are empirically unfounded. The three cities most commonly cited as models for Indian riverfront development — Ahmedabad (Sabarmati), Jaipur (Dravyavati), and Pune (Kham River) — represent a spectrum from high displacement (Sabarmati) to low displacement (Kham River), and the evidence base consistently favours the lower-displacement, ecology-first approaches in terms of long-term social benefit. This thesis adds a quantitative socio-economic analysis to this debate, making the case for equity-centred planning on evidentiary grounds rather than normative ones.

The four-zone riverfront development model proposed in Chapter 5 is a substantive contribution to urban design practice for seasonal rivers. It resolves the apparent contradiction between conservation and development by establishing a spatial sequence — from the river's edge outward — that recognises ecological protection, socio-economic integration, public recreation, and urban edge management as complementary, sequential demands rather than competing alternatives. This model, and the design principles embedded in it, is directly transferable to comparable river corridors in Madhya Pradesh and across the semi-arid belt of central India.

6.3 Validation against Objectives

The study's four objectives, as stated in Section 1.4, have been addressed as follows:

Objective 1 — Assess the ecological and hydrological status: Fully addressed through the NDWI, LULC, water quality, and buffer zone analyses of Chapter 4, which provide a comprehensive quantitative characterisation of the corridor's current condition against all relevant standards and benchmarks.

Objective 2 — Analyse socio-economic vulnerability: Fully addressed through the household survey analysis, livelihood dependency classification, equity and risk analysis, and statistical correlation analysis of Section 4.6, which provide a disaggregated and statistically validated characterisation of social vulnerability in the corridor.

Objective 3 — Formulate integrated proposals: Fully addressed through the four proposals of Chapter 5, which collectively address all primary dimensions of degradation identified in Chapter 4 and are responsive to the social equity findings of Section 4.6.

Objective 4 — Evaluate proposals against I-SEER: Fully addressed through the I-SEER baseline scoring derived from Chapter 4 data and the target scoring presented in Table 5.8, which provide a quantitative basis for assessing expected outcomes and for monitoring actual outcomes against targets during implementation.

6.4 Limitations Revisited

The limitations identified in Section 1.7 of the Introduction have been consistently acknowledged in the analytical chapters. The reliance on 2019 MPPCB water quality data, rather than contemporaneous monitoring, is the most significant of these, as it is possible that conditions have changed in the intervening period — in either direction. The two-station gap between the MPPCB monitoring programme and the study's five-station analysis partially addresses this gap but does not eliminate the fundamental uncertainty introduced by the data vintage.

The household survey sample of 120 respondents, while adequate for the statistical analyses presented, is not sufficient for full sub-group analysis at the zone level. Zone 3, in particular, is under-represented in the survey sample due to the lower residential density and the industrial rather than riverfront orientation of the dominant economic activity. Future surveys targeting Zone 3 industrial workers and agricultural labourers would strengthen the socio-economic evidence base.

The budget estimates provided in the phasing strategy are indicative rather than detailed cost estimates. They are derived from comparable project data (Dravyavati DPR, Kham River monitoring reports) and adjusted for Bhopal's construction cost indices, but they have not been validated against detailed engineering quantities. Detailed Project Reports for each phase component would be required before any financing decisions.

6.5 Recommendations for Future Research

6.5.1 Priority Research Gaps

The following research directions are identified as priorities for future study of the Kaliyasot River corridor and comparable non-perennial urban rivers in central India:

First, updated water quality monitoring at the five stations characterised in this thesis, using contemporaneous sampling (ideally monthly over at least one full hydrological year including both monsoon and dry-season measurements), would substantially strengthen the analytical foundation. The MPPCB should be encouraged to expand its Kaliyasot monitoring to a monthly frequency and to add a sixth monitoring station between S3 and S4 to better characterise the midstream-to-downstream transition.

Second, a detailed hydrogeological study of the Kaliyasot catchment — including aquifer characterisation, recharge rate estimation, and groundwater table monitoring across a representative network of observation wells — is required to validate the check dam recharge estimates presented in Table 5.3 and to design the optimal check dam spacing for groundwater recharge maximisation.

Third, a comparative study of non-perennial urban river restoration in the Deccan Plateau and Vindhyan Range semi-arid zone — encompassing rivers with similar seasonal flow characteristics, comparable catchment urbanisation, and comparable industrial pressure — would contribute to a generalisable framework for the ecological planning of this river type, which is significantly under-represented in the global river restoration literature relative to its Indian geographic prevalence.

Fourth, a post-implementation monitoring framework designed around the I-SEER indicators identified in Table 5.8, with pre-agreed monitoring protocols, data collection responsibilities, and reporting formats, would enable the systematic evaluation of this study's proposals against their expected outcomes. The institutional home for this monitoring programme — the Kaliyasot River Corridor Authority — has been identified in Section 5.7.

6.5.2 Extensions to Study Area

The analytical and proposal framework developed in this thesis is, in the judgement of the researcher, directly applicable — with appropriate local calibration — to several comparable river corridors in Madhya Pradesh and neighbouring states. The Betwa River tributaries within the Bhopal Metropolitan Region, several of which share the Kaliyasot's characteristics of seasonal flow, urban pressure, and sewage treatment deficit, are the most immediate candidates. Beyond Madhya Pradesh, the rivers of the Chhattisgarh urban fringe — particularly those draining rapidly urbanising secondary cities such as Durg-Bhilai and Korba — present comparable analytical challenges and could benefit from the application of the NDWI-LULC-WQI-socioeconomic framework developed here.

6.6 Final Statement

The Kaliyasot River is not a problem to be managed. It is an opportunity to be realised. A 29-kilometre ecological corridor running through the heart of Bhopal, connecting one of India's most historic water bodies to the Betwa River system, traversed daily by tens of thousands of residents whose wellbeing is directly

connected to its ecological health — this is a planning resource of extraordinary value, temporarily obscured by institutional failure and infrastructure deficit.

The findings of this thesis establish that the institutional failure and infrastructure deficit are addressable, within a decade, for an investment that is modest relative to the economic and social value that a restored Kaliyasot would generate. The path from a WQI of 225 to a WQI of 50 — from ecological collapse to functional recovery — is technically well-understood, financially within reach, and substantiated by the evidence of comparable restoration projects in India and internationally. What has been lacking is not technical knowledge but integrated analysis, institutional will, and an equity-centred planning framework that ensures the communities most harmed by the river's degradation are the primary beneficiaries of its restoration.

This thesis has attempted to provide the integrated analysis and equity-centred framework. The institutional will and the investment decision remain the work of the institutions responsible for the Kaliyasot River — the BDA, the MPPCB, the Bhopal Jal Nigam, and ultimately the Government of Madhya Pradesh. It is the researcher's hope that this document provides them with the evidence base, the planning rationale, and the actionable proposals they need to begin.

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