

Integrated Blue-Green Infrastructure in Stormwater Management for Indore city

Bachelor of Planning

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Integrated Blue-Green Infrastructure in Stormwater Management for Indore City

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submitted in partial fulfilment of the requirements for

The award of the degree of

Bachelor of Planning

By

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MAY 2026

DECLARATION

I **ISLAVATH PRAVEEN** Scholar No **2211002125** hereby declare that the thesis titled Integrated Blue Green Infrastructure in Storm water management for Indore City submitted by me in partial fulfilment for the award of degree of Bachelor of Planning, at Maulana Azad National Institute of Technology, Bhopal, India, is a record of Bonafide work carried out by me. The matter/result embodied in this thesis has not been submitted to any other University or Institute for the award of any degree or diploma.

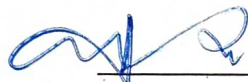

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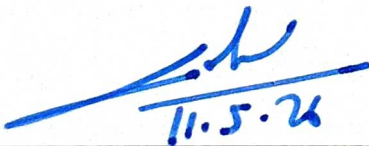
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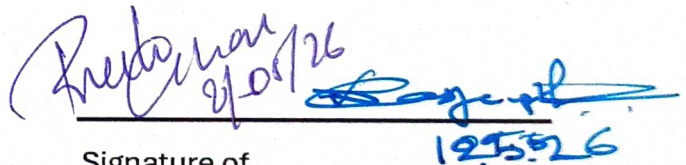

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सारांश

यह शोध प्रबंध इंदौर, मध्य प्रदेश में सतत शहरी वर्षा जल प्रबंधन हेतु एकीकृत ब्लू-ग्रीन इन्फ्रास्ट्रक्चर (BGI) नियोजन रूपरेखा विकसित करता है। इसमें विशेष रूप से कान्ह-सरस्वती नदी गलियारे और स्मार्ट सिटी एरिया-बेस्ड डेवलपमेंट ज़ोन पर ध्यान केंद्रित किया गया है। अध्ययन बार-बार होने वाली शहरी बाढ़, निकासी तंत्र की अक्षमता, नदी प्रदूषण, नीले-हरे स्थानों की हानि और संस्थागत विखंडन जैसी चुनौतियों का समाधान बहुस्तरीय दृष्टिकोण से करता है, जिसमें GIS आधारित स्थानिक विश्लेषण, हाइड्रोलॉजिकल आकलन, रिमोट सेंसिंग और नीतिगत समीक्षा सम्मिलित हैं।

यह शोध अभिसारी मिश्रित-विधि (convergent mixed-methods) डिज़ाइन अपनाता है और इंदौर को तीन अंतर्निहित स्तरों पर परखता है: शहर, गलियारा और प्रीसिंक्ट। इसमें भूमि उपयोग एवं आवरण विश्लेषण, बाढ़-संवेदनशीलता मानचित्रण, पर्यावरणीय मूल्यांकन तथा BGI हस्तक्षेपों के लिए उपयुक्त स्थलों की पहचान की जाती है। अध्ययन BGI प्रकारों जैसे बायोस्वेल्स, रेन गार्डन, पारगम्य पक्की सड़कें, निर्मित आर्द्रभूमि और नदी तट पुनर्स्थापन उपायों का मूल्यांकन करता है, जो अपवाह में कमी, भूजल पुनर्भरण, सूक्ष्म-जलवायु सुधार और पारिस्थितिक संपर्क को बढ़ावा देते हैं।

शोध आगे नीति, संस्थागत और वित्तीय तंत्रों का प्रस्ताव करता है, जिनमें एजेंसियों के बीच बेहतर समन्वय और डिज़ाइन दिशानिर्देशों का एकीकरण शामिल है। परिणामस्वरूप एक क्रियान्वयन योग्य, इंदौर-विशिष्ट रूपरेखा तैयार होती है, जो वर्षा जल प्रबंधन को शहरी लचीलापन, नदी पुनर्जीवन और जलवायु-संवेदी शहरी डिज़ाइन से जोड़ती है। यह अध्ययन न केवल शैक्षणिक समझ में योगदान देता है बल्कि उन भारतीय द्वितीय-स्तरीय शहरों के व्यावहारिक नियोजन में भी सहायक है, जो समान पर्यावरणीय चुनौतियों का सामना कर रहे हैं।

ABSTRACT

This thesis develops an integrated Blue-Green Infrastructure (BGI) planning framework for sustainable urban stormwater management in Indore, Madhya Pradesh, with particular emphasis on the Kanh–Saraswati River corridor and the Smart City Area-Based Development zone. The study responds to recurrent urban flooding, drainage inefficiency, river pollution, loss of blue-green spaces, and institutional fragmentation through a multiscale approach combining GIS-based spatial analysis, hydrological assessment, remote sensing, and policy review.

The research adopts a convergent mixed-methods design and examines Indore at three nested scales: city, corridor, and precinct. It uses land use and land cover analysis, flood-vulnerability mapping, environmental assessment, and suitable locations for BGI interventions. The study also evaluates BGI typologies such as bioswales, rain gardens, permeable pavements, constructed wetlands, and riverfront restoration measures to support runoff reduction, groundwater recharge, microclimate improvement, and ecological connectivity.

The thesis further proposes policy, institutional, and financial mechanisms to support implementation, including improved coordination among agencies, design guideline integration. The outcome is an actionable, Indore-specific framework that links stormwater management with urban resilience, river rejuvenation, and climate-sensitive urban design. The study is intended to contribute both to academic understanding and to practical planning for tier-2 Indian cities facing similar environmental challenges.

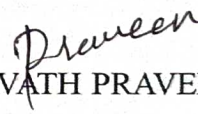
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Chapter 1: Introduction

1.1 Background

Cities worldwide are confronting an unprecedented convergence of climate change impacts and rapid urbanization, creating compound vulnerabilities that traditional grey infrastructure alone cannot address. Urban areas now house 55% of the global population — a figure projected to reach 68% by 2050 — while simultaneously generating over 70% of global carbon emissions and bearing the brunt of climate-related disasters including floods, heat waves, and water scarcity. The Intergovernmental Panel on Climate Change (IPCC) identifies cities as both critical contributors to climate change and arenas for transformative solutions, emphasizing the urgent need for nature-based adaptation strategies that integrate ecological systems into urban planning.

In India, this urgency is particularly acute. The country experienced 223 extreme weather events in 2023 alone, with urban flooding



Figure 1: water crisis

SOURCE: www.pmfias.com/water-crisis-in-india

accounting for 43% of total economic losses from natural disasters. The India Meteorological Department reports a 14% increase in extreme rainfall events over the past two decades, while the monsoon season has compressed — delivering the same annual rainfall in fewer, more intense bursts. Indian cities, characterized by high population densities (averaging 11,000 persons/sq.km in metropolitan areas), extensive impervious surfaces, inadequate drainage infrastructure, and encroachment of natural water bodies, face a perfect storm of flood vulnerability.

1.1.1 The Stormwater Management Crisis in Indian Cities

Conventional urban stormwater management in India has historically relied on a "collect-and-discharge" paradigm — channeling runoff through underground pipe

networks to the nearest water body or river. This approach, inherited from colonial-era engineering practices, faces three fundamental failures:

Infrastructure deficit: Most Indian cities have stormwater drainage (SWD) coverage well below 50% of their road networks. The Central Public Health and Environmental Engineering Organisation (CPHEEO) Manual on Storm Water Drainage Systems (2019) acknowledges that existing infrastructure is designed for outdated rainfall intensities (typically 12–20 mm/hr), far below the observed extreme events of 100+ mm/hr that now occur with increasing frequency.

Inadequate design standards: The Rational Method and limited return periods (often 1–2 years) used in conventional design fail to account for climate change projections or the full hydrological impacts of urban densification. The CPHEEO Manual 2019 represents a paradigm shift by recommending nature-based solutions and Low Impact Development (LID) approaches, but implementation remains minimal.

Ecological degradation: Traditional grey infrastructure treats stormwater as waste to be disposed of, ignoring its potential as a resource for groundwater recharge, urban cooling, and ecosystem support. Rivers and lakes that once formed the blue-green veins of Indian cities have been reduced to sewage channels or filled for development. The Comptroller and Auditor General of India (2020) estimated that urban India lost over 30% of its water bodies between 1985 and 2015.

1.1.2 Blue–Green Infrastructure as a Paradigm Shift

Blue–Green Infrastructure (BGI) represents a fundamental reconceptualization of urban water management — shifting from engineered resistance to ecological resilience. BGI integrates natural water systems (blue) and vegetated landscapes (green) into the urban fabric to perform multiple functions simultaneously: stormwater detention and infiltration, groundwater recharge, flood attenuation, urban heat mitigation, air quality improvement, biodiversity support, and community well-being enhancement.

The BGI approach aligns with three converging global frameworks:

- **Nature-Based Solutions (NBS):** The IUCN Global Standard for NBS (2020) defines these as actions that work with nature to address societal challenges while simultaneously providing human well-being and biodiversity benefits. BGI exemplifies NBS by leveraging ecosystem processes to manage stormwater while delivering co-benefits.

- **Sponge Cities:** China's Sponge City Initiative, launched in 2015 across 30 pilot cities, mandates that 70% of urban rainfall be absorbed and reused through distributed green infrastructure — demonstrating the scalability of BGI at the national level. Initial evaluations show 30–40% reductions in urban flooding and significant improvements in water quality.
- **Water Sensitive Urban Design (WSUD):** Australia's WSUD framework integrates urban water cycle management with urban planning and design, treating stormwater, groundwater, and wastewater as interconnected resources rather than separate waste streams.

Global evidence demonstrates BGI's effectiveness: Copenhagen's Cloudburst Management Plan projects a benefit-cost ratio of 3.7 for BGI-based flood protection; Singapore's ABC Waters Programme achieved a benefit-cost ratio of 11.9 through multifunctional blue-green spaces; and Philadelphia's Green City, Clean Waters program (targeting 10,000 rain gardens and 1 million sq.ft of green roofs) is projected to reduce combined sewer overflows by 85% at one-third the cost of conventional grey infrastructure.

1.1.3 Indian Context — Policy Evolution and Implementation Gap

India's policy landscape for urban water management has evolved significantly in recent years:

- **CPHEEO Manual on Storm Water Drainage Systems (2019):** Represents India's first comprehensive national guidance on sustainable stormwater management, explicitly recommending SuDS, LID, and green infrastructure.
- **AMRUT 2.0 (Atar Jal Mission for Rejuvenation and Urban Transformation, 2021):** Elevated water body rejuvenation to a core component of urban development, mandating that stormwater drains harvest rainwater into water bodies. Under AMRUT 1.0, 838 stormwater drainage projects worth ₹3,016 crore eliminated 3,759 waterlogging points across Indian cities, but the focus remained primarily grey infrastructure.
- **Smart Cities Mission:** Area-Based Development (ABD) approach enables integrated infrastructure retrofitting including stormwater management, riverfront development, and green spaces. Of 100 Smart Cities selected, 47 include river/water body restoration as flagship projects.

- **Namami Gange / National Mission for Clean Ganga:** Extends beyond the Ganges basin to support urban river rejuvenation across India, as exemplified by the Vision Kanh document for Indore.
- **URDPFI Guidelines (Urban and Regional Development Plans Formulation and Implementation, 2014):** Prescribes per capita recreational space standards (10–12 sq.m/person), mandatory green buffers around water bodies, and integration of ecological networks into master plans.

Despite these progressive policies, a significant **implementation gap** persists. Academic literature identifies multiple barriers: fragmented institutional responsibility across water supply, sewerage, drainage, and planning departments; inadequate technical capacity within municipal corporations; absence of BGI-specific design standards adapted to Indian climatic and socio-economic contexts; limited financial mechanisms for capital-intensive nature-based projects; and weak enforcement of land-use regulations protecting water bodies and green spaces.

1.1.4 Indore as a Critical Case Study

Indore, the commercial capital of Madhya Pradesh and India's cleanest city for eight consecutive years (2017–2025), presents a paradoxical case for BGI planning. The city's achievements in solid waste management, open defecation elimination, and public sanitation demonstrate exceptional municipal capacity and political will — yet it faces a critical stormwater infrastructure deficit.

The Stormwater Paradox: Indore has only **126.10 km of underground storm water drainage against a 1,912.2 km road network — a mere 6.59% coverage**, leaving a 93.41% gap. The Area-Based Development (ABD) zone under the Smart City program, covering 742 acres in the historic core, has **zero underground stormwater drainage**. This results in chronic waterlogging affecting approximately 30% of the city's 3.5 million population during monsoons, disrupting mobility, commerce, and livelihoods.

Compound Vulnerabilities: Indore's stormwater crisis is compounded by:

- **Hydrological constraints:** Underlain by low-permeability Deccan Trap basalt and black cotton soil, the city experiences rapid runoff and flash flooding. Groundwater extraction has reached 148% of recharge capacity (overexploited status).

- **Monsoon concentration:** 90% of Indore's annual rainfall (~945 mm) occurs during June–September, with single-day extreme events exceeding 100 mm becoming more frequent. September 2023 saw 250 mm in 28 hours, requiring boat-based evacuations.
- **River degradation:** The Khan (21 km urban stretch) and Saraswati (12 km) rivers have degraded into combined sewage and stormwater channels, with 170 MLD of untreated wastewater flowing directly into the rivers despite installed STP capacity of 402 MLD.
- **Green cover loss:** Urban green cover declined from 13% (1977) to 7% (2025) against a prescribed 21%, while organized usable green space is only 1.9 sq.m/person — far below WHO's 9 sq.m recommendation.
- **Urban Heat Island:** Dense inner-city areas experience temperatures 3–5°C higher than the periphery, with peak land surface temperatures reaching 42–45°C in May.

Strategic Opportunity: Indore's selection as a Smart City, the ongoing Kanh–Saraswati riverfront development (₹1,400 crore allocation), the Vision Kanh restoration framework prepared by cGanga/NMCG, and the city's demonstrated governance capacity create a unique window for systemic BGI integration. The Smart City ABD area, centered on the historic Rajwada precinct and bounded by the Khan–Saraswati rivers, serves as an ideal pilot zone for demonstrating climate-sensitive urban design strategies.

Table 1: Summary of Urban Stormwater Challenges in Indian Cities

City	Key Stormwater Challenges	Example Events / Notes
Mumbai	Encroached drains, combined sewers, tidal influence	2005, 2017 floods – rail disruption
Chennai	Loss of wetlands/tanks, undersized drains	2015 floods linked to tank encroachment
Surat	Riverine and pluvial flooding, high imperviousness	2006 flood, subsequent planning efforts

City	Key Stormwater Challenges	Example Events / Notes
Ahmedabad	Poor drainage, blocked drains, and waterlogging during heavy rain.	Monsoon flooding and road waterlogging happen often.

1.1.5 Research Rationale

This thesis addresses a critical knowledge gap at the intersection of stormwater management, urban climate adaptation, and nature-based solutions in the Indian context. While international literature on BGI is extensive (797 peer-reviewed studies globally), **zero studies focus on Indian cities** despite India housing 6 of the world's 20 most flood-prone cities. Existing Indian research remains fragmented — hydrological studies assess flood risk without considering green infrastructure solutions; landscape architecture research proposes green spaces without hydraulic performance quantification; and policy analyses identify gaps without spatial implementation frameworks.

This research contributes:

- **Spatial-hydraulic integration:** A methodology coupling GIS-based Multi-Criteria Decision Analysis with EPA SWMM hydrological modeling to identify optimal BGI locations and quantify performance.
- **Indian design standards:** Adaptation of international BGI typologies (bioswales, rain gardens, permeable pavements, constructed wetlands) to Indore's basaltic geology, black cotton soil, monsoon hydrology, and socio-economic context.
- **Multi-scalar planning:** A framework operating across city-region (279 sq.km), neighborhood (742-acre ABD), and precinct scales — addressing the "scale mismatch" problem where city-level policies fail to translate into site-specific design.
- **Institutional pathways:** Governance and policy recommendations grounded in India's evolving regulatory framework (CPHEEO 2019, AMRUT 2.0, Smart Cities, URDPFI) and stakeholder realities.

1.2 Aim

To develop an integrated Blue–Green Infrastructure (BGI) planning framework for sustainable urban stormwater management in Indore, Madhya Pradesh, through spatial assessment, hydrological modeling, and multi-scalar design interventions that enhance flood resilience, groundwater recharge, microclimate regulation, and socio-ecological equity.

1.3 Objectives

The research is structured around five sequential objectives:

Objective 1: To review global and Indian experiences with blue-green infrastructure for urban stormwater management and distil relevant principles and best practices.

The first objective is to undertake a comprehensive review of global and Indian experiences with blue–green infrastructure (BGI) for urban stormwater management and to synthesise principles and best practices that are relevant to the Indore context. This involves critically examining international paradigms such as Low Impact Development (LID), Water Sensitive Urban Design (WSUD), Sustainable Drainage Systems (SuDS), and Sponge City initiatives, along with their application in cities including Copenhagen, Singapore, Melbourne, and selected Chinese cities. Parallely, Indian experiences—such as sustainable stormwater planning in Surat, the Sabarmati Riverfront in Ahmedabad, and canal and lake restoration efforts—are reviewed to understand local constraints and opportunities. The literature review will distil cross-cutting principles related to source control, integration of blue–green–grey systems, multi-functional public spaces, and the embedding of BGI within statutory planning, design standards, and governance arrangements.

Objective 2: To delineate the Indore study area, including city-wide and Kanh–Saraswati River-corridor scales, and characterise its hydrological and environmental setting.

The second objective is to delineate the Indore study area at both the city-wide scale and the Kanh–Saraswati River-corridor scale and to characterise its hydrological and environmental setting. At the city scale, the study will describe Indore’s geographical position on the Malwa Plateau, its topography (elevations around 500–600 m with

gentle slopes), and its subtropical monsoon climate with an annual rainfall in the range of approximately 900–1,000 mm. At the corridor scale, it will document the alignment and catchment of the Kanh–Saraswati system, its tributary nallahs, and its current environmental condition, including degraded water quality characterised by elevated biochemical oxygen demand, low dissolved oxygen, and high coliform counts. The objective also covers a broad environmental baseline, including land use and land cover patterns, distribution of lakes and ponds, air-quality conditions, and the predominance of black-cotton soils, thereby providing a contextual foundation for subsequent vulnerability and BGI-opportunity analyses.

Objective 3: To assess stormwater-related vulnerabilities in Indore through GIS-based multi-criteria analysis, hydrological assessment, and field surveys of drainage, land use, and environmental quality.

The third objective is to assess stormwater-related vulnerabilities in Indore through an integrated approach combining GIS-based multi-criteria analysis, hydrological assessment, and field surveys of drainage, land use, and environmental quality. This entails constructing a flood-vulnerability index that incorporates physical factors (elevation, slope, imperviousness, drainage density, proximity to drains and rivers) and socio-economic indicators (population density, presence of low-income settlements), drawing on established methods for flood- and BGI-suitability mapping. Hydrological assessments, including runoff estimation using methods such as the Rational Method, will be undertaken for selected sub-catchments to quantify peak flows under existing and projected land-use conditions. Primary surveys—visual inspections, infiltration tests, and water- and air-quality observations—will validate and enrich the spatial analysis, leading to a set of mapped hotspots and diagnostic insights into the causes and spatial distribution of stormwater risk in Indore.

Objective 4: To formulate an integrated blue-green infrastructure plan for Indore at city, corridor, and site scales, including typology selection, preliminary sizing, and design guidelines.

The fourth objective is to formulate an integrated blue–green infrastructure plan for Indore at city, corridor, and site scales, including typology selection, preliminary sizing, and design guidelines. At the city scale, the plan will define a blue–green structure comprising primary and secondary corridors and strategic nodes that

collectively form a coherent network for stormwater management and ecological connectivity. At the corridor scale, a special area plan for the Kanh–Saraswati system will integrate measures such as riparian buffers, treatment wetlands, flood-plain management, and multi-functional riverfront spaces to address both flood and water-quality objectives. At the site scale, the study will develop detailed designs for a set of pilot interventions (e.g. sponge road corridors, neighbourhood-level BGI, market-area retrofits, lake-precinct sponge parks, and nallah restoration reaches), guided by a multi-criteria typology-selection framework and conceptual hydraulic sizing based on design storms and realistic soil-infiltration parameters.

Objective 5: To recommend policy, institutional, and financial mechanisms that can support implementation of BGI in Indore and provide insights for other tier-2 Indian cities.

The fifth objective is to recommend policy, institutional, and financial mechanisms that can support the implementation of BGI in Indore and provide insights applicable to other tier-2 Indian cities. This involves analysing the existing legal and policy environment—including the Environment (Protection) Act 1986, the Water (Prevention and Control of Pollution) Act 1974, the National Water Policy 2012, URDPFI Guidelines 2014, CPHEEO’s 2019 Storm Water Drainage Manual, NDMA urban-flood guidelines, and the Madhya Pradesh State Water and Wastewater Policies—to identify entry points for mainstreaming BGI. The study will propose clarifications of institutional roles for IMC, IDA, ISCDL, PHED, and other agencies; suggest modifications to development control regulations and design standards to mandate or incentivise BGI; and outline potential funding and partnership options, including Smart Cities, AMRUT 2.0, NMCG, municipal finance, PPPs, and climate-finance instruments. In doing so, it aims to develop a practical governance and implementation framework that can be adapted by other rapidly urbanising Indian cities facing similar stormwater and environmental challenges.

Table 2: Problem Statement and Objectives Matrix (Indore)

Problem Area	Specific Issues in Indore	Linked Objective(s) in Study
Urban flooding & waterlogging	Recurrent waterlogging in low-lying wards, poor drains	Obj. 2, 3, 4

Problem Area	Specific Issues in Indore	Linked Objective(s) in Study
River pollution (Kanh–Saraswati)	Continuous sewage, solid-waste dumping	Obj. 2, 4, 5
Loss of blue-green spaces	Infilling of ponds, fragmented parks	Obj. 3, 4
Institutional fragmentation	Multiple agencies, weak coordination	Obj. 1, 5

1.4 Scope

The study focuses on urban stormwater management within Indore’s municipal jurisdiction, with detailed analysis along the Kanh–Saraswati River corridors and selected waterlogging hotspots representing different urban typologies. It investigates surface runoff, drainage networks, blue–green assets, and flood vulnerabilities, without undertaking detailed structural design or construction-level drawings for all components.

The scope includes spatial analysis (GIS), hydrological estimation at conceptual design level, environmental quality assessment (water, air, and soil parameters relevant to stormwater), and stakeholder consultations with municipal agencies and key actors. Operational aspects such as detailed cost estimation, tendering, and construction supervision are considered only at an indicative level.

1.4.1 Geographical Scope

Primary study area: Indore Municipal Corporation (IMC) jurisdiction, covering 279 sq.km across 85 wards, with particular focus on the Smart City Area-Based Development (ABD) zone (742 acres / 3 sq.km) centered on the historic Rajwada precinct and bounded by the Khan and Saraswati rivers.

Detailed precinct analysis: Khan–Saraswati riverfront corridor (3.9 km length), including river channels, floodplains (25–50 year return period as per Vision Kanh), and adjacent 100m buffer zones. This precinct serves as the pilot zone for detailed design interventions.

Catchment context: The broader Khan River Basin (upstream and downstream of the city) is considered for understanding hydrological connectivity, but interventions are limited to the urban extent.

1.4.2 Thematic Scope

Included:

- Stormwater drainage system assessment and flood vulnerability mapping
- Blue infrastructure: Rivers (Khan, Saraswati, Chandrabhaga), lakes (Yashwant Sagar, Bilawali, Pipliyapala, Sirpur), ponds, nallahs, check dams
- Green infrastructure: Parks, urban forests, street trees, riparian vegetation, open spaces
- BGI interventions: Bioswales, rain gardens, permeable pavements, retention/detention ponds, constructed wetlands, green roofs, tree trenches, vegetated swales, riverbank re-vegetation, floodplain restoration
- Hydrological modelling: Rainfall-runoff processes, flood inundation, BGI hydraulic performance
- Microclimate assessment: Urban Heat Island, air temperature, thermal comfort (PET, UTCI)
- Ecosystem services: Stormwater management, heat mitigation, air quality, groundwater recharge, biodiversity, recreation, aesthetic value
- Socio-economic dimensions: Community flood experience, access to green spaces, livelihoods (informal vendors), willingness-to-pay
- Governance and policy: Institutional frameworks, inter-departmental coordination, policy amendments, financing mechanisms

Excluded:

- Detailed design of water supply, sewerage, or solid waste management systems (except where they interface with stormwater/BGI)
- Building-level stormwater retrofits (green roofs, rainwater harvesting) beyond demonstration standards
- Groundwater modeling and aquifer recharge dynamics (acknowledged as important but requiring specialized hydrogeological investigation beyond scope)
- Air quality dispersion modeling and quantitative pollutant flux calculations

- Real-time pilot project implementation (proposed as future work)
- River water quality remediation strategies beyond BGI's contribution (e.g., industrial effluent treatment)
- Detailed traffic and transportation planning (except pedestrian/cycle connectivity to BGI spaces)

1.4.3 Temporal Scope

Historical analysis: 20-year period (2005–2025) for LULC change detection, rainfall trend analysis, and urban growth assessment.

Present assessment: Baseline conditions as of 2025–2026 (field surveys, primary data collection).

Future projections: Climate change scenarios to 2050 using CORDEX South Asia RCP 4.5 and RCP 8.5 projections; BGI master plan implementation timeline extending to 2040 (15-year horizon).

1.4.4 Stakeholder Scope

Primary stakeholders:

- Indore Municipal Corporation (IMC) — key implementing agency
- Smart City Indore SPV — ABD area development
- Town and Country Planning Organisation (TCPO), Madhya Pradesh — master planning
- Madhya Pradesh Pollution Control Board (MPPCB) — water quality regulation
- Central Ground Water Board (CGWB) — hydrogeology
- National Mission for Clean Ganga (NMCG) regional office — Vision Kanh implementation

Secondary stakeholders:

- Residents of ABD area and riverfront communities (including informal settlements)
- Informal vendors and small businesses along riverfront
- Ward-level elected representatives (Corporators)

- Civil society organizations and NGOs active in urban environment
- Academic institutions (IIT Indore, SPA Bhopal)

1.5 Limitations

Limitations of Work

The present study is subject to several limitations which should be acknowledged while interpreting the findings. First, the analysis relies extensively on secondary data sources such as municipal records, remote-sensing products, and published environmental datasets; in some cases, these datasets are of varying resolution, temporal coverage, and reliability, which may introduce uncertainties in derived indicators such as drainage density, land-use change, and environmental quality. Second, primary data collection through field surveys, infiltration testing, and stakeholder consultations is constrained by time and resource availability, necessitating a sampling strategy that prioritises representative locations over exhaustive coverage of the entire city.

Third, hydrological assessments, including runoff estimation and conceptual sizing of blue–green infrastructure (BGI) components, are undertaken at a screening-level resolution; the study does not develop fully calibrated hydraulic–hydrodynamic models (e.g. SWMM with detailed pipe networks) for all sub-catchments, which would require more extensive data and modelling resources. Fourth, climate-change impacts are incorporated through use of recent high-intensity rainfall events and literature on increasing extremes but do not include formal downscaled climate projections, limiting the ability to quantify long-term design margins. Finally, institutional and financial recommendations are based on existing policy documents and stakeholder inputs and have not been tested through pilot implementation within the time frame of this study, so their practical effectiveness will need to be validated in future phases.

1.5.1 Data Limitations

Hydrological data: Indore lacks continuous flow-gauging stations within the urban drainage network. SWMM model calibration relies on reported flood depths, watermark evidence, and community recall rather than measured hydrographs, introducing uncertainty in peak flow estimations. Sensitivity analysis is performed to quantify this uncertainty.

Satellite imagery temporal resolution: Cloud-free optical satellite imagery (Sentinel-2, Landsat) is limited during peak monsoon months (July–September), constraining real-time flood extent mapping. While Synthetic Aperture Radar (SAR) data from Sentinel-1 can partially compensate, it has coarser spatial resolution and requires specialized processing.

Historical BGI performance data: India lacks long-term performance monitoring of implemented BGI projects (unlike Philadelphia's 10-year Green Infrastructure dataset or Singapore's ABC Waters monitoring), limiting local calibration of performance parameters. International benchmarks are adapted using soil and climate analogues.

Subsurface data: Limited availability of high-resolution soil infiltration rate measurements, groundwater level time-series at ward scale, and subsurface utility mapping (which affects BGI placement) necessitates reliance on CGWB district-level aggregates and field reconnaissance.

1.5.2 Methodological Limitations

SWMM spatial resolution: The 1D hydraulic routing in EPA SWMM does not capture 2D overland flow dynamics and backwater effects that occur during extreme floods. While appropriate for distributed sub-catchment analysis and BGI performance assessment, it cannot replace full 2D hydrodynamic models for detailed inundation mapping (which would require HEC-RAS 2D or MIKE FLOOD with high-resolution terrain data unavailable for Indore).

ENVI-met computational constraints: Due to computational limitations, ENVI-met simulations are restricted to precinct-scale domains (typically 500m × 500m) and cannot represent city-wide microclimate interactions or mesoscale atmospheric processes. Results are interpreted as indicative of localised BGI effects rather than city-wide temperature reductions.

Survey sampling limitations: The 400-household questionnaire sample, while statistically adequate for ward-level inference (95% confidence, ±5% margin of error), may not fully capture intra-ward heterogeneity, particularly in mixed formal-informal settlement areas. FGDs provide qualitative depth to compensate.

Climate projection uncertainty: Downscaled climate projections from CORDEX General Circulation Models (GCMs) carry inherent uncertainty, particularly for sub-daily extreme rainfall events critical to stormwater design. Multiple GCM ensemble

members are used to represent the uncertainty range, but specific design storm intensities should be interpreted as indicative rather than deterministic.

1.5.3 Scope Limitations

Geographic focus: The research is geographically limited to Indore Municipal Corporation jurisdiction. While findings are conceptually transferable to other Deccan Plateau cities with similar geology and climate, site-specific calibration would be required for application elsewhere.

Implementation feasibility: The thesis proposes policy amendments and institutional reforms based on best practices and stakeholder consultations, but cannot assess their political feasibility or predict adoption timelines, which depend on factors beyond academic research (electoral cycles, administrative priorities, inter-departmental politics).

Absence of pilot implementation: Due to time constraints of academic research (12-month thesis timeline) and the complexity of municipal project approvals, the study does not include construction and real-time monitoring of pilot BGI installations. Implementation is proposed for future work in collaboration with IMC.

Ecosystem service valuation: The economic valuation of ecosystem services (air quality improvement, biodiversity, aesthetic value, health benefits) relies on benefit-transfer methods from international studies (B&ST, TEEB) adjusted for Indian purchasing power parity, as India-specific valuation studies are sparse. This introduces estimation uncertainty, though systematic sensitivity analysis quantifies the range.

Groundwater-surface water interaction: While the study estimates runoff and identifies areas suitable for infiltration-based BGI, detailed modeling of groundwater recharge dynamics and aquifer response (which would require MODFLOW or equivalent groundwater models with extensive borewell data) is beyond scope. This is acknowledged as a priority for subsequent research.

1.5.4 Temporal Limitations

Short-term primary data collection: Household surveys, FGDs, and field microclimate measurements are conducted over a 2-month intensive field campaign (May–June 2026, covering pre-monsoon and early monsoon), capturing a snapshot rather than full seasonal variability. Secondary data (IMD rainfall, LULC time-series) provides longer-term context.

No long-term BGI monitoring: The research proposes BGI interventions and models their expected performance, but cannot validate actual post-implementation performance over multi-year timescales. A monitoring and evaluation (M&E) framework is proposed as part of the implementation strategy, but execution lies beyond the thesis timeline.

1.6 Methodology

This section provides a concise overview of the research methodology. Detailed descriptions of methods, data sources, analytical tools, and validation procedures are presented in

1.6.1 Research Design

The study employs a **convergent mixed-methods design**, integrating quantitative spatial analysis, hydrological modeling, and microclimate simulation with qualitative stakeholder engagement (household surveys, Key Informant Interviews, Focus Group Discussions). This approach ensures that BGI planning is technically robust, spatially explicit, and socially grounded.

Nature and Scope of Data Collection

The study relies primarily on secondary data sources, supported by official planning records, environmental databases, and geospatial datasets. These sources were assembled to build a comprehensive understanding of Indore's stormwater system, environmental assets, settlement characteristics, and institutional context.

The climatic dataset forms one of the most important components of the study. It includes IMD rainfall records, a 30-year time series from 1995 to 2025, sub-daily intensity data, extreme event records, and downscaled CORDEX South Asia climate projections under RCP 4.5 and RCP 8.5 scenarios up to 2050. This dataset provides the basis for assessing monsoon concentration, rainfall intensity, and future climate-related stress on the city's drainage system.

Topographic and hydrological data were collected through digital elevation models, particularly SRTM 30 m and Carto DEM 10 m, along with drainage layers, watershed information, river and nallah networks, and stream hierarchy data. These datasets were essential for sub-catchment delineation, slope analysis, flood inundation mapping, drainage extraction, and terrain suitability assessment for blue-green interventions.

Remote sensing and land-based environmental data were also central to the study. Sentinel-2 and Landsat imagery were used to derive land use and land cover patterns for multiple years, map impervious surfaces, evaluate vegetation conditions through NDVI, and estimate land surface temperature. Additional environmental inputs included groundwater level records, aquifer maps, over-exploitation status, water-quality monitoring data, pollution-load estimates, soil texture maps, infiltration-capacity information, and lithological conditions related to Deccan Trap basalt and black cotton soils.

The social and institutional dimensions of urban vulnerability were addressed through demographic and planning datasets. These included Census 2011 and updated 2024 estimates, ward-level population and density data, housing typology, socio-economic classification, vulnerable population mapping, municipal engineering records, waterlogging complaint records from 2018 to 2025, drainage-capacity data, road network shapefiles, master plans, area development plans, stormwater manuals, AMRUT and Smart City guidelines, and other policy documents. The inclusion of such data ensured that the analysis did not remain limited to physical geography alone, but also reflected patterns of service inadequacy, settlement vulnerability, and governance capacity.

Taken together, the data collection strategy reflects a multi-dimensional understanding of stormwater management. It recognizes that urban flooding is not caused by rainfall alone, but by the interaction of terrain, land use, drainage provision, ecological degradation, demographic pressure, and institutional arrangements.

Analytical Framework and Methods

The methodology adopted in the study combines GIS-based spatial analysis, hydrological estimation, remote sensing interpretation, vulnerability assessment, literature review, and conceptual planning. The objective-method matrix in the document clearly indicates that each stage of the work was linked to specific datasets, analytical tools, and expected outputs.

At the first level, the study draws on literature review and case-study analysis to identify global and Indian blue-green infrastructure practices, including lessons from WSUD, LID, SuDS, Sponge City approaches, and water-sensitive planning frameworks. This theoretical layer helps the study move beyond conventional drainage engineering and

situates Indore's stormwater problems within a broader discourse of ecological urbanism and integrated water management.

At the second level, GIS-based spatial analysis was used to delineate the study area, define sub-catchments, classify slopes, map blue-green assets, and build a hydro-climatic profile of the city. This stage established the physical structure of the study area and provided the geographic base for all subsequent interpretations.

At the third level, multi-criteria GIS analysis and conceptual hydrological estimation were used to assess stormwater vulnerability. The study employed DEM, land-use data, drainage layers, flood records, and population datasets to identify runoff-prone and flood-sensitive locations. The use of the Rational Method, infiltration-related interpretation, and vulnerability mapping enabled the translation of raw data into risk categories, hotspot lists, and intervention priorities.

At the fourth level, remote sensing-based interpretation was used to assess long-term urban growth, land-cover change, green cover depletion, imperviousness, and urban heat patterns. This was particularly important in linking the city's physical transformation to current stormwater stress. Expansion of built-up land, reduction of vegetation, and encroachment on wetlands and drainage corridors were not treated as isolated land-use changes, but as hydrologically significant transformations that increase runoff and weaken ecological buffering.

1.6.2 Multi-Scalar Framework

The methodology operates across three nested spatial scales:

- **Macro (City level, 279 sq.km):** City-wide assessment of drainage basins, LULC, flood vulnerability, UHI intensity, and strategic BGI corridor identification
- **Meso (Neighbourhood/ABD level, 742 acres):** Detailed analysis of the Smart City ABD zone including built-form assessment, drainage capacity, open space connectivity, and vulnerability prioritisation
- **Micro (Precinct level, riverfront corridor):** Site-specific design along the 3.9 km Khan–Saraswati riverfront with detailed topographic surveys, microclimate modeling, and prototype BGI element sizing

Table 3: workflow framework

Objective	Primary Method(s)	Data & Tools	Key Parameters / Outputs
1. Review global and Indian experiences with BGI and distil best practices	Systematic literature review; case-study analysis	Research papers, reports, guidelines (WSUD, LID, SuDS, Sponge City); online databases, libraries	Typology list; performance indicators; design principles; lessons and best-practice checklist
2. Delineate Indore study area and characterise hydrological & environmental setting	GIS-based spatial analysis; secondary data compilation	IMC boundary, wards; rivers/nallahs; DEM; LULC; rainfall normals; climate data; QGIS/ArcGIS	Study boundary; sub-catchments; slope classes; basic hydro-climatic profile; blue-green asset inventory
3. Assess stormwater-related vulnerabilities via GIS, hydrology & field surveys	Multi-criteria GIS analysis; hydrological estimation; surveys	DEM; LULC; drainage network; population data; flood records; Rational Method; questionnaires	Flood-vulnerability index maps; hotspot list; runoff coefficients; infiltration rates; risk categories
4. Formulate integrated BGI plan at city, corridor & site scales	Spatial planning & design; scenario building; concept design	Vulnerability maps; suitability maps; blue-green network; CAD/GIS for layouts; CPHEEO/WSUD standards	City BGI structure plan; Kanh-Saraswati corridor plan; 5 pilot designs; BGI typology-site allocation
5. Recommend policy, institutional & financial mechanisms for BGI	Policy analysis; stakeholder mapping; synthesis workshops (if any)	National/state policies (URDPFI, CPHEEO, NDMA, MP policies); IMC byelaws; funding scheme guidelines	Role-responsibility matrix; proposed DCR changes; funding options; PPP/community models; roadmap

1.6.3 Data Collection

To implement the above methodology, the study requires a comprehensive set of spatial, hydrological, environmental, and socio-institutional data. Spatial data include digital elevation models (for slope and flow-path analysis), high-resolution satellite imagery and/or classified land-use maps, drainage and sewer network layouts, road and ward boundaries, and the locations of rivers, streams, lakes, and ponds. Hydrometeorological data include daily and sub-daily rainfall records, intensity-duration-frequency (IDF) curves for different return periods, and basic information

on temperature and evapotranspiration patterns. Environmental data inputs comprise water-quality measurements for Kanh–Saraswati and other key water bodies (e.g. BOD, DO, coliform counts), air-quality indicators (PM2.5, PM10), and soil characteristics relevant to infiltration and stability, particularly for black-cotton soils. Socio-institutional datasets include population and density statistics at ward or finer scales, records of historical flooding and waterlogging incidents, and details of existing and proposed infrastructure projects under Smart City, AMRUT, NMCG, and related programmes. In addition, information on legal and policy frameworks (e.g. URDPFI Guidelines, CPHEEO Manual, NDMA guidelines, state water and wastewater policies) is required to evaluate regulatory gaps and opportunities for BGI integration. These data are compiled from multiple sources, including municipal departments, state and national agencies, open-data portals, and field surveys, and are harmonised within the GIS and analytical framework.

1.6.4 Analytical Framework

The overall analytical framework follows a four-layer structure:

Layer 1: Understanding — What exists? Literature review, GIS base mapping, LULC analysis, SWD audit, flood history compilation.

Layer 2: Assessment — How vulnerable? Where are opportunities? MCDA flood vulnerability mapping, SCS-CN runoff estimation, NDVI/LST analysis, BGI asset inventory.

Layer 3: Modelling — What would happen with BGI? SWMM scenario simulation (baseline vs. BGI interventions), ENVI-met microclimate modeling (existing vs. BGI scenarios), CBA.

Layer 4: Synthesis — What should be done? BGI master plan design (3 scales), phasing and cost estimation, governance framework, policy recommendations, stakeholder validation.

1.6.5 Validation and Quality Assurance

Model calibration/validation: SWMM calibrated against flood observations (Nash-Sutcliffe Efficiency > 0.70 target); ENVI-met validated against field spot measurements (RMSE < 2°C for air temperature)

Chapter 2: Review of Literature

2.1 Introduction

This chapter presents a comprehensive review of the theoretical foundations, conceptual frameworks, and empirical evidence underpinning Integrated Blue–Green Infrastructure (BGI) planning for urban stormwater management. The literature review serves three complementary purposes: (1) establishing the theoretical basis for Climate-Sensitive Urban Design (CSUD) and nature-based solutions; (2) synthesizing global and Indian empirical evidence on BGI performance; and (3) identifying critical research gaps that this thesis addresses.

The review is structured across six thematic domains: **Public Realm Theory** (Section 2.2), **Climate-Sensitive Urban Design** (Section 2.3), **Blue–Green Infrastructure Concepts** (Section 2.4), **Ecosystem Services and Valuation** (Section 2.5), **Legal and Policy Frameworks** (Section 2.6), and **Research Gaps and Synthesis** (Section 2.7). This structure reflects the interdisciplinary nature of BGI planning, which spans urban design, hydrology, ecology, social science, and governance.

The review adopts a dual methodology: a **theoretical literature review** examining foundational concepts and frameworks, and a **systematic review** of peer-reviewed empirical studies on BGI performance, focusing on the 2015–2025 period to capture recent advances while referencing seminal earlier works were foundational.

2.2 Public Realm Theory — The Social Foundation

2.2.1 Defining the Public Realm

The public realm encompasses "any publicly owned streets, pathways, right of way, parks, publicly accessible open spaces and any public and civic buildings and facilities" — spaces where civic life unfolds



Figure 2: Public realm SOURCE: fity.club/lists/suggestions/Public-Realm

and where the quality of urban environments is most tangibly experienced by residents. The significance of the public realm extends beyond mere land-use classification; it constitutes the arena where social interaction, economic activity, cultural expression, and environmental health converge.

In the context of climate adaptation and stormwater management, the public realm takes on added significance. Streets, squares, parks, and waterfronts are not only social spaces but also **functional landscapes** that can either exacerbate or mitigate urban environmental challenges. A degraded river corridor represents not only a lost ecological asset but also a forfeited opportunity for community gathering, recreation, and climate resilience.

2.2.2 Leon Krier — The Res Publica Framework

Leon Krier's typological theory of urbanism provides a foundational framework for understanding the relationship between public and private realms. Krier distinguishes three essential urban components:

- **Res Publica:** Public spaces — streets, squares, monuments — that foster civic identity and collective life

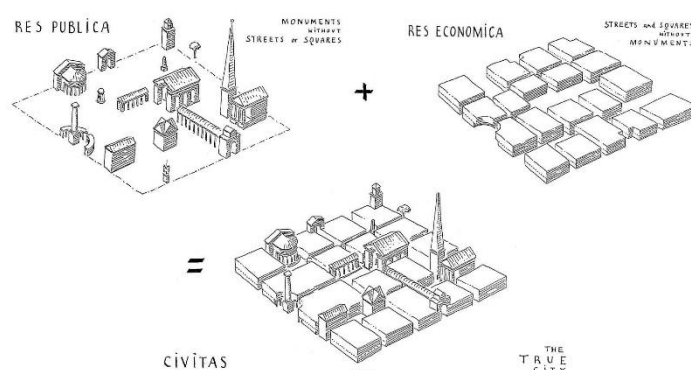


Figure 3: The Res Publica Framework

SOURCE: <https://www.cnu.org/publicsquare/leon-kriers-foundational-diagram>

- **Res Economica:** Private spaces — homes, businesses — serving individual and economic needs
- **Civitas:** The integration of public and private realms creating a balanced, sustainable "true city"

Krier's 1983 diagram on "the city knitting public and private buildings" illustrates how public spaces are not residual voids but positive architectural elements that structure urban form. His concept of the piazza carved from four building corners demonstrates how intentional public space design can create human-scaled gathering places that foster community identity.

For BGI planning in Indore, Krier's framework suggests that restoring degraded river corridors is not merely an engineering task but a **civic design imperative** — an opportunity to create new public realms that integrate ecological function (blue-green infrastructure) with social purpose (gathering, recreation, cultural expression). The

Khan–Saraswati riverfront, currently a degraded back-of-building zone, can be reimagined as the city's primary linear civic space.

2.2.3 Jan Gehl — Life Between Buildings

Jan Gehl's pioneering work *Life Between Buildings: Using Public Space* (1971, English translation 1987) fundamentally reoriented urban design from buildings-as-objects to the *space between buildings* as the primary unit of concern. Gehl's behavioural urbanism approach — studying how people actually use spaces rather than how designers intend them to be used — provides methodological rigor to public space planning.

Three Categories of Activities: Gehl identifies three types of outdoor activities that public spaces must support:

1. **Necessary activities** — commuting, errands, functional movement (occur regardless of space quality)
2. **Optional activities** — strolling, sitting, lingering (occur only when spaces are inviting)
3. **Social activities** — conversations, people-watching, community interaction (emerge when optional activities are supported)

The critical insight is that **the quality and design of public spaces determine the extent to which optional and social activities can flourish**. Poor-quality spaces support only necessary activities; high-quality spaces catalyse vibrant social life.

People Attract People: Gehl's observation that "people come where people are" describes a positive feedback loop — the presence of others in public spaces draws more people, creating self-reinforcing vibrancy. This principle has direct implications for BGI design: riverfront spaces that provide shade, seating, water features, and visual interest will attract people, which in turn makes the space feel safer and more socially valuable.

Empirical Methodology: Gehl's use of film as a research tool and behavioural mapping techniques — documenting where people sit, stand, walk, and socially interact — established an evidence-based approach to public space design. His methodology influenced organisations like the Gehl Institute and Project for Public Spaces, which continue to employ observational studies to inform urban interventions.

2.2.4 William H. Whyte — The Social Life of Small Urban Spaces

William Whyte's research (1970s–1980s) in New York City employed time-lapse photography to systematically document plaza usage, producing empirical evidence on what makes public spaces successful. His documentary *The Social Life of Small Urban Spaces* remains foundational in urban studies.

Three Critical Success Factors: Whyte identified accessibility, visibility, and sunlight as primary determinants of plaza success:

- **Accessibility:** Even small barriers (stairs, railings, elevation changes) significantly reduce foot traffic; successful spaces flow naturally from sidewalks
- **Visibility:** Spaces visible from the street attract more users; hidden plazas remain underutilized regardless of design quality
- **Sunlight:** Sun-exposed seating is dramatically more popular than shaded areas in temperate climates (with caveats for tropical cities like Indore where shade is premium)

Seating and "Sittable"

Spaces: Whyte documented that the availability of seating — formal benches, ledges, steps, moveable chairs — is the strongest predictor of plaza occupancy. He



Figure 4: *The Social Life of Small Urban Spaces*

SOURCE: Book: *The Social Life of Small Urban Spaces*

advocated for "triangulation" — the placement of stimuli (street vendors, musicians, art) that give strangers reasons to talk, catalysing social interaction.

Equity Implications: Whyte championed equitable access to public space regardless of age, income, or background — a principle increasingly urgent as climate change

disproportionately affects vulnerable populations. His work demonstrated that public space quality is a matter of **environmental justice**.

2.2.5 Synthesis — Public Realm and BGI

The public realm theories of Krier, Gehl, and Whyte converge on several principles directly applicable to BGI planning:

- **Human-centered design:** BGI must serve not only hydrological functions (flood attenuation, infiltration) but also social functions (gathering, recreation, thermal comfort)
- **Observational validation:** Design proposals should be validated through behavioural studies — understanding how communities currently use (or avoid) riverfront spaces
- **Multifunctionality:** The most successful public spaces serve multiple purposes simultaneously; BGI elements (bioswales, rain gardens, ponds) should integrate ecological performance with aesthetic and social value
- **Equity priority:** BGI interventions should prioritise underserved communities facing dual vulnerabilities of flood risk and lack of green space access

Table 4: Evolution of Stormwater Management Paradigms

Paradigm	Design Philosophy	Typical Infrastructure	Limitations
Conventional drainage	Rapid conveyance away from sites	Pipes, culverts, concrete channels	Downstream flooding, poor ecology
Water-quality focused	Manage quantity and pollutants	Detention basins, treatment wetlands	Often still centralised
Integrated BGI / water-sensitive	Treat stormwater as resource, multi-benefit	Distributed BGI + grey hybrids	Needs coordination, new skills

2.3 Climate-Sensitive Urban Design (CSUD)

2.3.1 Definition and Theoretical Foundation

Climate-Sensitive Urban Design (CSUD) is an approach that integrates environmental considerations into urban planning and design to enhance resilience

against climate change impacts. CSUD emerged from recognition that urban areas are particularly vulnerable to climate-related challenges — extreme weather events, rising temperatures, flooding, water scarcity — and that conventional development patterns exacerbate rather than mitigate these risks.

CSUD aims to create urban environments that address climate risks directly while simultaneously improving ecological sustainability and community well-being. Unlike conventional urban design, which often treats climate as a static background condition, CSUD recognises climate as a **dynamic, evolving stressor** requiring adaptive, multifunctional design strategies.

2.3.2 Core Principles

CSUD operates on six interconnected principles:

- 1. Urban Heat Island (UHI) Mitigation:** Reducing surface temperatures through green infrastructure, reflective materials, water-based cooling, and strategic ventilation corridors. Barcelona's Superblocks initiative, which restructures urban layouts to improve airflow and reduce heat accumulation, demonstrates how strategic urban design can lower ambient temperatures by up to 2°C.
- 2. Water-Sensitive Design:** Managing stormwater through permeable surfaces, retention basins, bioswales, and integrated drainage systems that treat water as a resource rather than waste.
- 3. Passive Climate Control:** Building orientation, shading, natural ventilation, and thermal mass utilisation to reduce energy demand for cooling/heating.
- 4. Microclimate Regulation:** Strategic placement of vegetation, water features, and building massing to modify local wind patterns, humidity, and temperature.
- 5. Social Equity:** Ensuring that climate adaptation interventions address the needs of vulnerable populations who face disproportionate climate risks.
- 6. Ecosystem Integration:** Incorporating natural systems that provide multiple services — biodiversity support, air quality improvement, carbon sequestration — alongside climate adaptation.

2.3.3 Key Strategies

Strategy	Mechanisms	Evidence
Green Infrastructure	Tree canopy shading; evapotranspiration cooling; stormwater interception; air quality filtration	Urban forests can reduce ambient temperatures by 2–8°C; green roofs reduce peak runoff by 50–90%
Cool/Reflective Materials	High-albedo pavements, roofs, and facades reflect solar radiation, reducing heat absorption	Cool pavements can lower surface temperatures by 10–15°C; city-wide application reduces UHI by 1–3°C
Water-Based Cooling	Fountains, water bodies, evaporative surfaces provide sensible and latent cooling	Water features can reduce temperatures within 50m radius by 1–3°C; combined with vegetation achieves 3–5°C reductions
Ventilation Corridors	Strategic open spaces and building orientation facilitate natural airflow, preventing heat entrapment	World Resources Institute documents that ventilation corridors can lower temperatures by up to 2°C
Compact, Mixed-Use Development	Shorter distances reduce vehicle-based heat generation; mixed use supports walkability and transit	Transit-oriented development reduces per-capita energy consumption by 20–40%
Blue–Green Networks	Integrated systems of vegetated corridors and waterways providing cooling, drainage, and connectivity	Copenhagen's BGI network achieves BCR 3.7 for flood protection with thermal comfort co-benefits

2.3.4 Climate-Sensitive Urban Form

The spatial configuration of urban development — density, building height, street width, block orientation — fundamentally shapes microclimate and stormwater dynamics. Research by Zhang et al. (2023) demonstrates that climate-sensitive urban form can mitigate heat stagnation by altering site microclimates, including increasing wind speed.

Optimal configurations vary by climate zone:

- **Hot-arid climates:** Compact, high-density forms with narrow, shaded streets; courtyards for ventilation
- **Hot-humid climates (like Indore):** Moderate density with adequate spacing for airflow; tree-lined streets; water-permeable surfaces; green roofs and vertical gardens
- **Temperate climates:** Solar access optimisation; seasonal adaptability; mixed-height development

2.3.5 CSUD and Stormwater Management

Conventional stormwater systems — underground pipes collecting and rapidly discharging runoff — are fundamentally maladapted to climate change. Extreme rainfall intensifies faster than infrastructure can be upgraded, and the "collect-and-discharge" paradigm forfeits opportunities for infiltration, recharge, and ecological services.

CSUD reframes stormwater as a **design resource**. Rain gardens, bioswales, and permeable pavements slow runoff, reduce peak flows, filter pollutants, recharge groundwater, and provide visual amenity — achieving multiple objectives simultaneously. This aligns with the "slow water" principle: managing water where it falls through distributed, small-scale interventions rather than large, centralised infrastructure.

2.4 Blue–Green Infrastructure (BGI) — Concepts and Performance

2.4.1 Defining Blue–Green Infrastructure

Blue–Green Infrastructure (BGI) integrates natural water systems (blue) with vegetated landscapes (green) into urban fabric to perform multiple ecological, social, and economic functions. BGI is simultaneously a **planning concept** (how cities should be structured), a **design approach** (what interventions to implement), and a **governance framework** (how institutions manage water and green space holistically).

BGI differs from conventional "green infrastructure" by explicitly foregrounding the role of water — rivers, lakes, wetlands, stormwater features — as active design elements rather than passive recipients of drainage. The "blue" component provides thermal mass for cooling, aquatic habitat, aesthetic amenity, and recreational opportunities, while the "green" component offers vegetation-based services.

2.4.2 BGI Typologies and Functions

BGI comprises a **toolkit of elements** operating across spatial scales:

Table 5: Typology of BGI Elements

BGI Element	Main Function(s)	Suitable Locations	Scale
Rain garden	Infiltration, storage, treatment	Residential plots, roadside setbacks	Site/neighbourhood
Bioswale	Linear conveyance + infiltration	Road medians, parking edges, campuses	Street/corridor
Green roof	Retention, evapotranspiration	Flat roofs of public & private buildings	Building
Constructed wetland	Storage, treatment, habitat	Lake fringes, STP outlets, low-lying land	Corridor/city

At building/plot scale:

- Rain gardens / bioretention cells
- Permeable pavements (pervious concrete, porous asphalt, permeable pavers)
- Green roofs and walls
- Rainwater harvesting cisterns
- Tree trenches and tree pits

At street/neighbourhood scale:

- Vegetated swales and bioswales
- Detention/retention basins
- Constructed wetlands
- Street tree corridors
- Pocket parks with infiltration capacity

At city/regional scale:

- River corridors and floodplains

- Urban forests
- Lake and reservoir systems
- Blue–green networks and ecological corridors
- Regional wetland complexes

Each element can be assessed across **six core functions**:

1. **Stormwater management:** Runoff volume reduction, peak flow attenuation, flood mitigation
2. **Water quality improvement:** Sediment filtration, nutrient uptake, pollutant degradation
3. **Microclimate regulation:** Urban heat mitigation, humidity modulation, thermal comfort
4. **Biodiversity support:** Habitat provision, ecological connectivity, species diversity
5. **Groundwater recharge:** Infiltration enhancement, aquifer replenishment
6. **Socio-cultural services:** Recreation, aesthetic value, health and well-being, community cohesion

2.4.3 Hydrological Performance — Systematic Review Evidence

A growing body of empirical research quantifies BGI hydrological performance. Key findings from recent systematic reviews:

Decentralised vs. Centralised BGI: A comparative study across three urban catchments (inner city, residential suburb, new housing) found that **decentralised BGI alternatives (both engineered and natural) showed better potential to reduce flood magnitude and frequency than centralised measures**. Decentralised natural alternatives (bioswales, rain gardens) showed higher infiltration potential than engineered alternatives in all catchments.

Effectiveness by storm intensity: BGI performance varies systematically with rainfall magnitude:

- **Low-intensity storms (<50 mm):** Infiltration-based BGI (bioretention, permeable pavements) reduces runoff volume by 40–70% and peak flow by 50–80%
- **Medium-intensity storms (50–100 mm):** Performance moderate — volume reduction 30–50%, peak reduction 30–60%
- **High-intensity storms (>100 mm):** Infiltration capacity exceeded; volume reduction drops to 10–30%, peak reduction 15–25%; **centralized systems (detention ponds) provide superior peak flow reduction (40–60%)** during extreme events

Implication: Optimal BGI strategies employ **layered systems** — decentralised infiltration-based elements for frequent, low-intensity storms + centralized detention/retention for extreme events.

Design Parameter Sensitivities: SWMM modelling studies demonstrate that BGI performance is highly sensitive to design parameters:

- **Ponding depth:** Increasing from 150mm to 300mm improves peak flow reduction during 10-year storms by up to 94% (at low hydraulic conductivity)
- **Filter media depth:** Deeper storage layers (>0.6m) significantly enhance infiltration and pollutant removal
- **Hydraulic conductivity:** Higher conductivity (80–120 mm/h) maximises infiltration but may compromise filtration; 40–60 mm/h provides balance
- **Surface infiltration area:** Strong nonlinear relationship — small increases in infiltration area yield disproportionate performance gains in dense urban catchments

2.4.4 Multiple Co-Benefits — The Multifunctionality Advantage

BGI's defining characteristic is **multifunctionality** — achieving multiple objectives simultaneously through single investments. Luleå University's integrated BGI assessment framework systematically evaluates this across six dimensions:

Table 6: Multiple co-benefits of BGI elements

BGI Element	Stormwater	Water Quality	UHI Mitigation	Biodiversity	Recreation	Cost (₹/sq.m)
Rain gardens	●●●●●	●●●●	●●●	●●●	●●	2,500–4,500
Bioswales	●●●●	●●●●	●●	●●●	●	1,800–3,200
Permeable pavements	●●●	●●	●	●	●●●	3,500–6,000
Constructed wetlands	●●●●	●●●●●	●●●●	●●●●●	●●●●	2,000–4,000
Retention ponds	●●●●●	●●●	●●●	●●●●	●●●●	1,500–3,500
Green roofs	●●●	●●●	●●●●	●●	●	5,000–9,000
Urban forests	●●●	●●	●●●●●	●●●●●	●●●●●	800–1,500

● = Low; ●●●●● = Very High | Cost estimates adapted to Indian construction rates

Trade-offs and Synergies: While BGI offers extensive co-benefits, trade-offs exist:

- **Synergies:** Vegetation enhances both stormwater infiltration AND thermal comfort; water features provide both detention storage AND cooling; wetlands improve water quality AND biodiversity
- **Trade-offs:** Densely vegetated areas may harbour insects perceived negatively; plant pollen can trigger allergies; open water bodies pose safety concerns for children; some BGI elements require maintenance that communities may resist

2.4.5 BGI vs. Grey Infrastructure — Cost-Benefit Evidence

Comparative cost-benefit analyses consistently demonstrate BGI's economic competitiveness:

- **Philadelphia Green City, Clean Waters:** BGI-based approach (rain gardens, green roofs, porous pavements) projected to achieve 85% combined sewer overflow reduction at **\$1.2 billion less than grey infrastructure** alternative; additional ecosystem service benefits valued at \$2.6 billion
- **Copenhagen Cloudburst Management Plan:** Integrated BGI-grey approach achieves **benefit-cost ratio of 3.7** over 100-year lifecycle, primarily through avoided flood damage
- **Singapore ABC Waters Programme:** Multifunctional blue-green spaces achieve **benefit-cost ratio of 11.9** when co-benefits (recreation, property value uplift, health) are included

Indian Context Estimation: A preliminary valuation for Indore using TEEB methodology and local ecosystem service values suggests potential benefits of **₹380–695 crore/year** from comprehensive city-wide BGI implementation, yielding benefit-cost ratios of 3.5–5.8 over 30-year lifecycle.

2.5 Ecosystem Services and Valuation

2.5.1 Ecosystem Services Framework

The **Millennium Ecosystem Assessment (MA)** framework categorises ecosystem services into four classes:

Provisioning Services: Products obtained from ecosystems (water, food, timber, fiber). For urban BGI, this includes stormwater capture for non-potable reuse, urban agriculture in rain gardens, and timber from managed urban forests.

Regulating Services: Benefits from regulation of ecosystem processes — climate regulation (carbon sequestration), hydrological regulation (flood control, infiltration), air quality regulation (pollutant filtration), water purification.

Cultural Services: Non-material benefits — recreation, aesthetic enjoyment, cultural identity, spiritual significance, educational value.

Supporting Services: Services necessary for production of other services — soil formation, nutrient cycling, primary production, habitat provision.

BGI primarily delivers **regulating and cultural services**, with quantifiable performance across multiple dimensions.

2.5.2 Quantified BGI Ecosystem Services

Water Quality Improvement: Constructed wetlands achieve 70–90% removal of suspended solids, 40–80% nitrogen removal, 50–90% phosphorus removal, and 90–99% pathogen reduction. Bioretention cells remove 80–95% of heavy metals (Pb, Zn, Cu) from stormwater.

Urban Heat Island Mitigation: Urban forests reduce air temperatures by 2–8°C depending on canopy density and spatial extent. Green roofs reduce surface temperatures by 10–30°C compared to conventional roofs. Water features reduce temperatures within 50m radius by 1–3°C through evaporative cooling.

Air Quality: Urban trees remove 10–20 tonnes of air pollutants (PM_{2.5}, NO_x, O₃, SO₂) per square kilometer per year. In high-density Indian cities, street tree corridors achieve PM_{2.5} reductions of 15–25% within 50m buffer zones.

Carbon Sequestration: Urban forests sequester 20–60 tonnes CO₂/hectare/year depending on tree species, age, and density. Green roofs sequester 1.5–3.5 kg CO₂/sq.m/year.

Biodiversity: BGI networks provide critical habitat and connectivity for urban wildlife. Riparian corridors support 60–80% higher species richness than non-riparian urban areas. Constructed wetlands can support over 100 bird species when designed with heterogeneous habitat structure.

Recreation and Health: Access to quality green space within 300m of residence associated with 20–30% reduction in stress, 15% increase in physical activity, and measurable improvements in mental health outcomes. Property values increase 5–15% with improved green space access.

2.5.3 Economic Valuation Methods

Avoided Cost Method: Values ecosystem services based on costs avoided through natural provision rather than built infrastructure. For stormwater management, this compares BGI costs against conventional pipe-and-pond systems.

Replacement Cost Method: Values services based on cost of replacing them with technological alternatives. For example, air filtration by urban forests valued against cost of mechanical air purification.

Hedonic Pricing: Estimates value based on property price premiums for proximity to green/blue spaces. Meta-analyses show 5–15% property value uplift for homes within 300m of quality parks or waterfronts.

Willingness-to-Pay (WTP) Studies: Surveys measuring how much residents would pay for improved environmental amenities. Indian WTP studies for urban parks range ₹500–2,000 per household per year.

Benefit Transfer: Adapting ecosystem service values from existing studies to new contexts using purchasing power parity and local income adjustments. The B£ST and TEEB tools employ this methodology.

2.6 Legal and Policy Frameworks

Table 7: Policy and Guideline Checklist for Indore

Policy / Guideline	Applicable to Indore? (Y/N)	BGI-Relevant Provisions	Gaps / Actions Needed
URDPFI 2014	Y	Natural drainage, flood-plain zoning	Stronger enforcement
CPHEEO SWD Manual 2019	Y	SuDS / BGI references	Local adaptation needed
NDMA Urban Flood Guidelines	Y	Risk-based planning	Integration into DCR, byelaws

2.6.1 International Frameworks

Sustainable Development Goals (SDGs): BGI directly contributes to SDG 6 (Clean Water and Sanitation), SDG 11 (Sustainable Cities and Communities), SDG 13 (Climate Action), and SDG 15 (Life on Land).

Paris Agreement (2015): Commits India to reducing emissions intensity and enhancing climate resilience. Nature-based solutions including BGI form a core component of India's Nationally Determined Contributions (NDCs).

Sendai Framework for Disaster Risk Reduction (2015–2030): Prioritises ecosystem-based adaptation for reducing disaster risk, explicitly recognising the role of wetlands, forests, and green infrastructure in flood mitigation.

IUCN Global Standard for Nature-Based Solutions (2020): Provides criteria for designing, implementing, and verifying NBS including BGI — ensuring they address societal challenges, deliver biodiversity benefits, and are economically viable.

New Urban Agenda (2016): Habitat III outcome document emphasises compact, integrated, and connected urban development with adequate green and public spaces.

2.6.2 National Policies (India)

CPHEEO Manual on Storm Water Drainage Systems (2019): India's first comprehensive national guidance on sustainable stormwater management, representing a paradigm shift from conventional pipe-based systems to integrated approaches. Key provisions:

- Recommends Sustainable Drainage Systems (SuDS), Low Impact Development (LID), and green infrastructure
- Mandates designing for updated rainfall intensities accounting for climate change
- Provides technical specifications for bioswales, rain gardens, permeable pavements, constructed wetlands
- **Gap:** Implementation remains minimal; no compliance enforcement mechanism

AMRUT 2.0 (Atal Mission for Rejuvenation and Urban Transformation, 2021): Elevated water body rejuvenation to core component of urban development. Provisions:

- Stormwater drains must harvest rainwater into water bodies
- Community green spaces linked to clean water bodies
- Maximum 5% of total allocation for water body sector
- 838 SWD projects worth ₹3,016 crore under AMRUT 1.0 eliminated 3,759 waterlogging points
- **Limitation:** Focus remained predominantly grey infrastructure; limited BGI integration

Smart Cities Mission (2015–2023): Area-Based Development (ABD) model enables integrated infrastructure including stormwater, riverfront development, and green spaces. Of 100 Smart Cities, 47 include river/water body restoration as flagship projects.

URDPFI Guidelines (2014): Prescribes per capita recreational space standards (10–12 sq.m/person), mandatory green buffers around water bodies, integration of ecological networks into master plans.

National Water Policy (2012): Emphasises conservation, rainwater harvesting, and integrated water resource management; mandates watershed-based planning.

Environment Protection Act (1986) & Water (Prevention and Control of Pollution) Act (1974): Provide regulatory framework for river protection, pollution control, and water quality standards.

National Mission for Clean Ganga (NMCG): Extended mandate beyond Ganga basin to support urban river rejuvenation across India. Vision Kanh document for Indore exemplifies this approach.

2.6.3 State-Level (Madhya Pradesh) Provisions

MP Bhumi Vikas Rules (2012): Street definitions include "all bunds, channels, ditches, storm water drains, culverts" within street lines; open space requirements for residential colonies; green TDR incentives for water body conservation.

MP Real Estate Policy (2019): Prohibits built structures on designated open spaces; promotes Green FAR/TDR benefits for green development.

MP Water Policy: Watershed-based water management; rainwater harvesting promotion; protection of water bodies.

2.6.4 Policy Gap Analysis

Despite progressive policy evolution, significant **implementation gaps** persist:

Table 8: Policy Gap analysis

Policy Dimension	Status	Gap
Technical standards	CPHEEO 2019 provides BGI guidance	No mandatory compliance; limited Indian performance data for calibration
Institutional coordination	Water supply, sewerage, drainage, planning under separate departments	Fragmented responsibility; no integrated BGI planning cell

Financial mechanisms	Capital budgets for grey infrastructure	Limited budget lines for BGI; no lifecycle cost accounting favouring BGI
Capacity	Municipal engineers trained in conventional hydrology	Inadequate training in BGI design, SWMM modelling, ecosystem services valuation
Enforcement	Master Plan provisions for green buffers, water body protection	Weak enforcement; encroachments persist; penalties ineffective
Monitoring	No systematic BGI performance monitoring	Cannot demonstrate benefits; limits evidence-based scaling
Community engagement	Top-down project planning	Limited participatory mechanisms; community stewardship absent

2.7 Research Gaps and Synthesis

2.7.1 Geographic Gap — India-Specific Evidence Deficit

A systematic review of global BGI literature identifies **797 peer-reviewed studies**, yet **zero focus on Indian cities** despite India housing 6 of the world's 20 most flood-prone cities. Existing Indian research remains fragmented:

- **Hydrological studies** assess flood risk without considering BGI solutions
- **Landscape architecture research** proposes green spaces without hydraulic performance quantification
- **Policy analyses** identify gaps without spatial implementation frameworks

This geographic gap is critical because Indian cities operate under **fundamentally different conditions** than the Global North contexts where most BGI research originates:

- **Monsoon hydrology:** 80–90% annual rainfall in 3–4 months vs. distributed rainfall in temperate zones
- **Geological context:** Deccan Trap basalt, black cotton soil — different infiltration characteristics than temperate soils
- **Socio-economic context:** High population densities, extensive informal settlements, limited maintenance budgets

- **Institutional context:** Fragmented governance, weak inter-departmental coordination, limited technical capacity

Table 9: Research Gaps

Topic Area	What is Known	Identified Gaps in Indian Tier-2 Cities
BGI performance	Good evidence from temperate cities	Limited empirical data under monsoon conditions
Governance models	Case-specific examples globally	Few studies on multi-agency coordination in India
Equity and BGI	Growing work on justice in global North	Limited Indian work on distribution of benefits

2.7.2 Methodological Gap — Integrated Assessment Frameworks

Most BGI studies employ **single-domain assessments** — hydrological performance OR thermal comfort OR ecosystem services — but rarely integrate these dimensions into unified decision-support frameworks. The thesis addresses this through coupled GIS-SWMM-ENVI-met modelling enabling holistic evaluation.

2.7.3 Scalar Gap — Multi-Scale Planning Frameworks

BGI research tends toward either city-scale strategic planning (lacking implementation specificity) or site-specific pilot projects (lacking systemic integration). The "missing middle" — **neighbourhood-scale frameworks that link city-level strategies to precinct-level designs** — remains underdeveloped.

2.7.4 Economic Gap — Indian Cost-Benefit Data

While B£ST and TEEB provide robust economic valuation frameworks, they are calibrated to UK/European contexts. Indian-specific data on BGI lifecycle costs, maintenance requirements, and ecosystem service values are scarce. This thesis contributes preliminary Indian valuations.

2.7.5 Social Equity Gap

BGI research often focuses on biophysical performance while neglecting distributional justice dimensions: Who benefits? Who bears costs? How are communities engaged? Studies documenting BGI-induced gentrification, displacement, and differential access by socio-economic status remain limited.

2.7.6 Monitoring and Validation Gap

Long-term performance monitoring of implemented BGI projects is rare, particularly in developing countries. Philadelphia's 10-year monitoring dataset is an exception, not the norm. Without validation data, models cannot be confidently calibrated for future applications.

2.7.7 Policy-Practice Gap

Despite progressive policies (CPHEEO 2019, AMRUT 2.0), **implementation lags dramatically**. Research documenting the institutional, financial, technical, and political barriers to translating policy into practice — and strategies to overcome them — is urgently needed.

2.8 Conceptual Framework for This Thesis

Drawing on the reviewed literature, this thesis develops an integrated conceptual framework operating across four dimensions:

Environmental Dimension: Hydrological performance (runoff reduction, flood mitigation, groundwater recharge) + microclimate regulation (UHI mitigation, thermal comfort) + ecosystem services (water quality, biodiversity, air quality).

Spatial Dimension: Multi-scalar planning (city-region → neighbourhood → precinct) + morphological analysis (built form, density, imperviousness, connectivity) + site-specific design (BGI element selection, sizing, placement).

Social Dimension: Equity and environmental justice + community engagement and participatory planning + livelihoods integration (informal vendors, agriculture) + public health and well-being.

Institutional Dimension: Policy integration and regulatory reform + inter-departmental coordination + capacity building and knowledge transfer + financing mechanisms and lifecycle cost accounting.

This framework ensures that BGI planning is simultaneously **technically robust** (informed by hydrological and microclimate modelling), **spatially explicit** (mapped at appropriate scales with site-specific detail), **socially grounded** (addressing equity and incorporating community knowledge), and **institutionally viable** (aligned with existing policies and governance structures).

2.9 Conclusion

This literature review establishes the theoretical foundations and empirical evidence base for Integrated Blue–Green Infrastructure planning. Three key insights emerge:

First, BGI represents a paradigm shift from conventional "grey" stormwater infrastructure to multifunctional nature-based solutions that simultaneously address flooding, heat stress, water quality, biodiversity, and social equity. Global evidence demonstrates economic competitiveness (BCRs of 3–12) and superior performance for frequent, low-intensity storms, though extreme event management requires hybrid BGI-grey approaches.

Second, successful BGI planning requires integration across multiple domains — hydrology, urban design, ecology, social science, economics, governance — and multiple scales from regional networks to site-specific interventions. The public realm theories of Gehl and Whyte remind us that BGI must serve social functions alongside ecological ones.

Third, critical research gaps persist, particularly the near-absence of India-specific empirical evidence despite acute stormwater challenges. This thesis contributes to filling these gaps through a mixed-methods, multi-scalar investigation grounded in Indore's specific climatic, geological, socio-economic, and institutional contexts.

Chapter 3: Case Studies, Policies and Guidelines

3.1 Introduction

This chapter examines global and Indian precedents of Blue–Green Infrastructure (BGI) implementation through detailed case study analysis, providing empirical evidence of performance, identifying transferable strategies, and documenting lessons learned that inform the Indore BGI planning framework. The chapter also reviews relevant policy and guideline frameworks at international, national, and state levels.

Case studies serve three complementary purposes in this research: **(1) Validation** — demonstrating that BGI approaches are technically feasible and economically viable at city scale; **(2) Knowledge Transfer** — identifying design standards, institutional models, and financing mechanisms adaptable to Indore; and **(3) Risk Mitigation** — documenting implementation challenges and failures to avoid repeating them.

3.1.1 Case Study Selection Framework

Six cities were selected — three international (Copenhagen, Singapore, Seoul) and three Indian (Surat, Ahmedabad, Chennai) — based on four criteria:

Relevance to Indore Context:

- **Climate analogy:** Cities facing monsoon/tropical rainfall patterns or extreme precipitation events
- **Scale comparability:** Metropolitan populations 1–8 million (Indore at 3.5 million fits this range)
- **Development context:** Mix of developed (Copenhagen, Singapore, Seoul) and developing (Surat, Ahmedabad, Chennai) economies
- **Challenge alignment:** Cities addressing urban flooding, heat stress, river degradation, and infrastructure deficits

Innovation and Demonstration Value:

- Projects representing paradigm shifts (e.g., removing highways for river restoration, unified water agency models, GIS-based vulnerability assessment)
- Documented performance data (flow reductions, cost-benefit ratios, ecosystem service quantification)

- Institutional innovations (SPV models, participatory planning, inter-departmental coordination)

Documented Evidence Base:

- Peer-reviewed studies, government reports, and independent evaluations available
- Sufficient data on costs, performance, stakeholder responses, and long-term outcomes
- Both successes AND failures/challenges documented

Transferability:

- Approaches adaptable to Indian governance, financing, and socio-economic contexts
- Lessons applicable across multiple scales (city-wide networks, neighbourhood interventions, site-specific design)

3.1.2 Case Study Analysis Framework

Each case study is structured across eight dimensions:

1. **Context and Rationale** — Why this case is relevant to Indore
2. **Project Background** — History, drivers, scale, budget
3. **Technical Approach** — BGI elements, design standards, hydrological/ecological strategies
4. **Institutional and Governance Model** — Agencies, coordination mechanisms, stakeholder engagement
5. **Performance Outcomes** — Quantified results (flood reduction, thermal comfort, water quality, economic returns)
6. **Success Factors** — What enabled successful implementation
7. **Challenges and Limitations** — Obstacles encountered, unresolved issues, negative externalities
8. **Lessons for Indore** — Transferable strategies and necessary adaptations

Table 10: Different case studies comparison

Case Study	Primary Innovation	Scale	BGI Budget	Key Metric
Copenhagen	Cloudburst Management Plan with surface-level water plazas	City (560,000 pop.)	DKK 10 billion (~₹12,000 Cr)	BCR 3.7; 300+ cloudburst projects
Singapore	ABC Waters unified agency model	City-state (5.7M pop.)	SGD 1 billion (~₹6,000 Cr)	BCR 11.9; 300+ certified projects
Seoul	Highway removal for river restoration	5.8 km corridor in 10M metro	KRW 386 billion (~₹2,400 Cr)	\$315M annual benefits; 2.5°C cooling
Surat	GIS-based flood vulnerability + pilot BGI	City (4.5M pop.)	₹150 Cr (pilot)	ACCCRN partnership; Rational Method runoff
Ahmedabad	Sabarmati Riverfront SPV financing	10.4 km corridor in 5.6M city	₹1,200 Cr (self-financed)	Land monetization; BUT 10,000+ displaced
Chennai	Participatory Buckingham Canal planning	22 km canal in 7M metro	₹800 Cr (proposed)	"Eyes on the Canal"; 80+ competition entries

3.2 Copenhagen Cloudburst Management Plan (Denmark)

3.2.1 Context and Relevance to Indore

Copenhagen, capital of Denmark with 560,000 city population (1.3 million metro), faces **increasing cloudbursts** — extreme rainfall events exceeding 100 mm in 24 hours — due to climate change. The July 2011 cloudburst delivered 150 mm in 3 hours, causing €800 million (~₹7,000 crore) in damages and overwhelming the city's combined sewer system. This event catalysed the development of the world's most comprehensive urban stormwater adaptation plan.

Relevance to Indore: While Copenhagen's temperate maritime climate differs from Indore's tropical monsoon, both cities experience:

- Extreme precipitation events exceeding infrastructure design capacity (Copenhagen: 100+ mm cloudbursts; Indore: 100–250 mm monsoon storms)



SOURCE: www.gooood.cn/2016-asla-copenhagen-cloudburst-formula-by-ramboll-and-ramboll-studio-dreiseitl

- Combined sewerage-drainage systems overwhelmed during peak flows
- Dense historic cores with limited space for conventional underground infrastructure
- Political and institutional capacity to pursue innovative solutions (Copenhagen: Nordic planning tradition; Indore: 8-time cleanest city demonstrating governance capacity)

Copenhagen's approach — using **surface-level streets, parks, and plazas as temporary stormwater storage** — is directly transferable to Indore's infrastructure-deficit context (93.41% SWD gap) where building underground systems is prohibitively expensive.

3.2.2 Project Background and Evolution

The **Cloudburst Management Plan (CMP)**, approved in 2012 and updated in 2018, represents a 100-year adaptation strategy with rolling 20-year implementation phases.

Key milestones:

- **2011:** July cloudburst causes unprecedented damage; insurance claims €800M; critical infrastructure flooded
- **2012:** CMP adopted by Copenhagen City Council; commits to climate-proofing by 2035

- **2013–2020:** Phase 1 implementation — 7 pilot catchments, 300+ cloudburst projects
- **2018:** CMP 2.0 update integrating climate projections (25% rainfall intensity increase by 2100)
- **2021–2035:** Phase 2 — city-wide rollout across 35 sub-catchments

Budget: DKK 10 billion (~₹12,000 crore) over 20 years, financed through water utility user fees, municipal bonds, and property tax levies. Copenhagen Water (utility) invests DKK 5 billion; City invests DKK 5 billion for co-benefit public realm improvements.

3.2.3 Technical Approach — Multi-Scalar BGI

Copenhagen's CMP employs a **three-tier hierarchy**:

Tier 1: Source Control (Frequent Storms, 0–10 year return)

- Green roofs on 50% of new buildings (mandatory since 2010)
- Rain gardens and bioswales in residential areas (infiltration capacity 20–40 mm/hr)
- Permeable pavements in low-traffic zones
- Tree trenches along streets (dual function: greening + infiltration)
- **Performance:** Handle 90% of annual rainfall events; reduce runoff volume by 30–50%

Tier 2: Conveyance and Detention (Moderate Storms, 10–50 year return)

- **Cloudburst boulevards:** Major streets retrofitted as surface-level hydraulic corridors; roadway curbs lowered to allow temporary flooding without inundating buildings
- **Retention streets:** Road profiles modified to create shallow ponding (15–30 cm depth) for 2–6 hours during storms
- Parks designed with 0.5–1.0 m depression zones serving as temporary retention basins
- **Performance:** Reduce peak flows by 40–60%; delay time-to-peak by 30–45 minutes

Tier 3: Cloudburst Management (Extreme Events, >50 year return)

- **Water plazas:** Purpose-designed urban squares that function as public spaces when dry and stormwater detention basins (1–2m depth) during cloudbursts
- Underground detention tunnels (hybrid BGI-grey) at key bottleneck locations
- Emergency overflow routes directing extreme flows away from critical infrastructure (hospitals, metro, data centres)
- **Performance:** Prevent catastrophic damage during 100-year events; reduce economic losses by 85%

Exemplar Project — Tåsinge Plads Water Plaza:

- 1,900 sq.m public plaza in dense residential neighbourhood
- Dual function: skateboard park + stormwater detention (3,000 cubic meters capacity)
- Cost: DKK 22 million (~₹26 crore); avoided underground tank cost: DKK 35 million
- Delivers co-benefits: recreation, thermal comfort (water features + trees), community gathering
- Monitored performance: captured 100% of 10-year storm (80 mm) without overflow

3.2.4 Institutional and Governance Model

Key Innovation: Integrated utility-municipal planning. Copenhagen Water (utility) and City of Copenhagen (planning authority) jointly fund and design cloudburst projects, ensuring that stormwater infrastructure delivers public realm co-benefits.

Governance Structure:

- **Cloudburst Steering Committee:** Representatives from Water Utility, Urban Planning, Parks Department, Traffic Department, Finance
- **Project Development Protocol:** Every cloudburst project must demonstrate: (1) hydrological performance, (2) public realm enhancement, (3) climate adaptation co-benefits (heat, biodiversity)

- **Community Co-Design:** Neighbourhood workshops for plaza and park designs; 70% resident approval required

Regulatory Instruments:

- **Municipal Plan 2019:** Mandates green roofs on buildings >600 sq.m footprint; incentivises permeable surfaces through development bonuses
- **Local Area Plans:** Each district required to integrate cloudburst corridors into street design standards
- **Building Code amendments:** New developments must detain first 20 mm of rainfall on-site; cannot increase downstream peak flows

3.2.5 Performance Outcomes (2012–2024)

Hydrological Performance:

- 300+ cloudburst projects implemented across 7 pilot catchments (covering ~30% of city)
- Peak flow reductions: 25–45% for 10-year storms; 15–30% for 100-year storms in implemented areas
- Runoff volume reductions: 30–50% for frequent storms (<10mm); 10–20% for extreme events
- Avoided flood damages: Estimated €400 million (~₹3,500 crore) prevented during 2019 and 2023 cloudbursts

Economic Returns:

- **Benefit-Cost Ratio: 3.7** over 100-year lifecycle (avoided flood damage + co-benefits / capital + O&M costs)
- Property value uplift: 8–12% for properties within 200m of implemented water plazas
- Insurance premium reductions: 15–20% for flood-proofed districts

Co-Benefits Quantified:

- Urban heat reduction: 1.5–2.5°C in plazas with water features and tree canopy during summer heat waves

- Biodiversity: 40% increase in pollinator species in rain garden areas
- Recreation: 35% increase in park/plaza usage post-implementation
- Health: 18% increase in physical activity among residents near improved public spaces

Failures and Adjustments:

- Initial green roof mandate faced resistance due to high costs (€80–120/sq.m); revised to apply only to large buildings
- Some cloudburst boulevards experienced traffic conflicts during storms; required refined traffic management protocols
- Maintenance costs higher than anticipated (15% annual O&M vs. 8% projected); resolved through dedicated utility fee surcharge

3.2.6 Success Factors

1. **Catalytic crisis:** 2011 cloudburst created political urgency and public support for large investments
2. **Economic justification:** BCR 3.7 provided compelling business case to utility regulators and city council
3. **Integrated financing:** Joint utility-municipal funding enabled co-benefit delivery beyond pure hydrology
4. **Institutional integration:** Breaking silos between water, parks, and traffic departments through steering committee
5. **Incremental implementation:** Pilot catchments demonstrated feasibility before city-wide scaling
6. **Community co-design:** Local ownership and enthusiasm generated through participatory planning
7. **Regulatory teeth:** Mandatory green roof policy and on-site detention requirements ensured private sector participation

3.2.7 Challenges and Limitations

Spatial Constraints: Copenhagen's dense historic core (similar to Indore's Rajwada-ABD area) limits space for large detention basins; some plazas smaller than hydrologically optimal.

Maintenance Burden: Green roofs, rain gardens, and bioswales require regular maintenance (weeding, soil replacement, plant health monitoring); initial costs underestimated; dedicated municipal maintenance crews established 2018.

Equity Concerns: Early implementations concentrated in affluent neighbourhoods with stronger civic engagement; 2020 policy revision prioritised vulnerable communities.

Winter Performance: Snow, ice, and freezing temperatures reduce infiltration and complicate plaza flooding (not relevant to Indore but highlights need for local calibration).

Public Safety: Initial concerns about children drowning in flooded plazas required design modifications (gradual slopes, shallow depths <30 cm except in fenced detention zones, signage, rapid drainage post-storm).

3.2.8 Lessons for Indore

Transferable Strategies:

1. **Surface-level hydraulic infrastructure:** Streets and squares as stormwater conveyance/detention — highly applicable to Indore's 93.41% underground SWD gap
2. **Multi-scalar hierarchy:** Small-scale source control (rain gardens) + mid-scale conveyance (retention streets) + large-scale detention (water plazas) — replicable framework
3. **Economic justification:** BCR analysis secured financing; Indore should conduct similar CBA demonstrating avoided flood damage (estimated ₹200–400 crore annual losses from waterlogging)
4. **Integrated utility-municipal planning:** IMC and water utility joint planning could mirror Copenhagen's model

5. **Pilot-before-scaling:** Demonstrate BGI effectiveness in 1–2 ABD wards before city-wide rollout

Necessary Adaptations:

1. **Monsoon concentration:** Indore's 90% annual rainfall in 4 months requires larger detention volumes than Copenhagen's distributed rainfall; water plazas must accommodate 100+ mm single-day events
2. **Black cotton soil:** Lower infiltration capacity (5–15 mm/hr) than Copenhagen's sandy soils (20–40 mm/hr) necessitates greater emphasis on detention over infiltration
3. **Thermal priorities:** In Indore's hot climate, shade and water-based cooling are premium co-benefits (vs. Copenhagen's focus on summer drying); all plazas should maximise tree canopy
4. **Informal settlements:** Copenhagen lacks informal settlements along waterfronts; Indore's Khan–Saraswati corridor has 33 major slums requiring participatory upgrading approaches
5. **Maintenance capacity:** IMC's maintenance capacity differs from Copenhagen's; initial designs should emphasise low-maintenance native species and simple infrastructure
6. **Financing:** While Copenhagen used utility fees and municipal bonds, Indore may need state/central government support (AMRUT 2.0, Smart Cities) and land value capture mechanisms

Pitfalls to Avoid:

- Don't underestimate maintenance costs; budget 12–15% annual O&M
- Ensure equity from the start; avoid concentrating early projects in affluent areas
- Invest in community co-design; top-down imposition generates resistance
- Design for safety; shallow depths, signage, rapid drainage
- Integrate traffic management; cloudburst boulevards require traffic protocols

3.3 Singapore ABC Waters Programme

3.3.1 Context and Relevance to Indore

Singapore, a city-state with 5.7 million population and 728 sq.km land area, faces **acute water scarcity** (no natural aquifers, 100% reliance on imported and recycled water) alongside **monsoon flooding** (annual rainfall 2,400 mm, 80% November–March). These dual challenges drove the **Active, Beautiful, Clean (ABC) Waters Programme**, launched 2006 by Public Utilities Board (PUB), transforming conventional drainage canals into multifunctional blue-green corridors.

Relevance to Indore:

- **Monsoon hydrology:** Singapore's concentrated wet season (2,400 mm in 5 months) parallels Indore's monsoon (945 mm in 4 months)
- **Dense urbanisation:** Singapore's high imperviousness (50–80% in developed areas) mirrors Indore's inner city
- **Institutional capacity:** Both PUB (Singapore) and IMC (Indore) demonstrate strong governance; PUB's unified water agency model offers a template for integrating IMC's fragmented water/sewerage/drainage departments
- **Land scarcity:** Singapore's acute land constraints (728 sq.km for 5.7M vs. Indore's 279 sq.km for 3.5M) necessitate multifunctional infrastructure — lesson directly applicable to Indore's dense ABD area

3.3.2 Project Background and Evolution

Historical Context: Singapore's drainage infrastructure was conventionally concrete-lined canals rapidly conveying stormwater to the sea — functional but ecologically sterile and visually bleak. Rapid urbanisation (70% impervious surfaces by 2000) increased flooding; 2006 Bukit Timah floods prompted strategic rethink.

ABC Waters Programme Launch (2006):

- Vision: Transform utilitarian drains into beautiful, clean streams and lakes that communities can enjoy
- Triple objectives: (1) Active — recreation and engagement; (2) Beautiful — aesthetic and ecological enhancement; (3) Clean — water quality improvement

- **Governance:** Public Utilities Board (PUB) leads; integrates water supply, wastewater, and drainage under single agency

Evolution Timeline:

- **2006–2010:** Pilot projects (Bishan-Ang Mo Kio Park, Kallang River) demonstrating naturalisation of concrete channels
- **2011:** ABC Waters Certification Scheme launched; private developments incentivised to integrate BGI
- **2012–2018:** City-wide scaling; 100+ projects across catchments
- **2018:** ABC Waters Programme 2.0 — climate resilience emphasis; targets 300 certified projects by 2030
- **2024 Status:** 300+ projects completed; 17 major blue-green corridors established

Budget: SGD 1 billion (~₹6,000 crore) 2006–2025; financed through water tariffs and government capital grants.

3.3.3 Technical Approach — Unified Water Cycle Management

Singapore's ABC Waters Programme employs an integrated strategy:

Blue Infrastructure — Channel Naturalisation:

- **From concrete drains to meandering streams:** Straight, concrete-lined canals retrofitted with naturalistic meandering alignments, vegetated banks, and variable depth profiles
- **Detention ponds as recreational lakes:** Utilitarian detention basins redesigned as attractive water bodies with landscaped edges, boardwalks, and plazas
- **Floodplain restoration:** Removing concrete embankments; re-establishing riparian zones with native vegetation

Green Infrastructure — Cleansing Biotopes:

- **Bioretention swales:** Vegetated channels treating first-flush stormwater; planted with tropical species (Vetiver grass, Typha, Heliconia)

- **Constructed wetlands:** Shallow treatment wetlands (0.3–0.8m depth) with emergent macrophytes removing sediments, nutrients, and pathogens; 70–90% pollutant removal efficiency
- **Rain gardens:** Decentralised infiltration-based systems in residential areas; designed for rapid drainage (<24 hours) to prevent mosquito breeding

Exemplar Project — Bishan-Ang Mo Kio Park (2012):

- **Challenge:** 2.7 km concrete Kallang River canal bisecting 62-hectare park; functional but ecologically dead
- **Solution:** Remove concrete; restore meandering river (naturalised width 17–100m vs. uniform 17m canal); create 36,000 sq.m cleansing biotopes
- **Performance:** 40% increase in detention capacity; water quality improved (BOD reduced 50%); biodiversity increased (27 bird species pre vs. 59 post); park usage tripled
- **Cost:** SGD 76 million (~₹456 crore); BCR 11.9 over 50-year lifecycle including recreation, property uplift, ecosystem services

3.3.4 ABC Waters Certification Scheme

Innovation: Private-sector participation mandated through certification.

Mechanism:

- Developments >0.2 hectares must integrate ABC Waters design features
- Certification levels: Certified (basic compliance) → Gold → Platinum
- Incentives: Gross Floor Area (GFA) bonuses (up to 2.5% additional development rights); fast-track planning approvals; marketing advantage
- Design elements: Minimum 40% of runoff treated through bioretention/wetlands/rain gardens

Outcomes (2011–2024):

- 300+ certified projects (100 residential, 120 commercial, 80 institutional)
- Cumulative treatment capacity: 15 million cubic meters/year

- Private-sector investment: SGD 400 million (~₹2,400 crore) leveraged through certification incentives

3.3.5 Institutional Model — Unified Water Agency

Public Utilities Board (PUB) Structure:

- **Catchment and Waterways Department:** Manages drainage, rivers, ABC Waters projects
- **Water Supply (Plants) Department:** Manages reservoirs, treatment, distribution
- **Used Water Department:** Manages sewerage, wastewater treatment, recycling

Key Integration Mechanisms:

- **Integrated planning:** Stormwater, water supply, and wastewater planned holistically; ABC Waters projects simultaneously improve drainage, enhance recharge potential, and pre-treat runoff before reservoir entry
- **Unified budget:** Single capital budget eliminates inter-departmental funding conflicts; can optimise investments across water cycle
- **Knowledge sharing:** Engineers trained across all water domains; promotes systems thinking

Contrast with Fragmented Governance (typical of Indian cities including Indore):

- IMC manages water supply; separate sewerage department; drainage under city engineering; Master Plan by TCPO
- Result: Siloed planning; missed opportunities for integration; budget competition

Lesson for Indore: PUB model demonstrates benefits of unified water management; IMC could establish **Indore Water Cell** integrating water supply, sewerage, and drainage engineers under single Director.

3.3.6 Performance Outcomes

Hydrological Performance:

- Flash flood incidents reduced 40% in ABC Waters catchments (2006–2024)

- Peak flow attenuation: 20–35% for 5-year storms in retrofitted catchments
- Runoff volume treated: 30–50% of annual runoff passes through cleansing biotopes before discharge

Water Quality Improvements:

- BOD reductions: 40–60% in ABC Waters vs. conventional drains
- TSS (Total Suspended Solids) reductions: 70–80%
- E. coli reductions: 90–95% in constructed wetlands
- Result: Several ABC Waters rivers now support recreational activities (kayaking, community events)

Economic Returns:

- **BCR 11.9** for Bishan-Ang Mo Kio Park (highest documented for BGI projects globally)
- Components: Avoided flood damage (20%), property value uplift (35%), recreation benefits (25%), ecosystem services (20%)
- Property values within 400m of ABC Waters projects increased 8–15% post-implementation

Co-Benefits:

- Thermal comfort: 2–3°C ambient temperature reduction within 50m of vegetated channels during midday heat
- Biodiversity: Bird species increased 120% (from ~50 to 110 species city-wide); fish species in naturalised channels increased from 5 to 30+
- Recreation: 50% increase in park usage; 70% resident satisfaction with ABC Waters projects
- Community health: 20% increase in physical activity among residents within 500m of ABC Waters parks

3.3.7 Success Factors

1. **Unified institutional model:** PUB's integrated water cycle management eliminated siloed planning

2. **Long-term vision:** 20+ year programme with sustained political and financial commitment
3. **Co-benefit maximisation:** Every drainage project required to deliver recreation, ecology, aesthetics — not just flood control
4. **Private sector leverage:** Certification scheme mobilised SGD 400M private investment
5. **Design excellence:** High-quality landscape architecture; projects visually attractive, generating public enthusiasm
6. **Performance monitoring:** Systematic water quality, biodiversity, and socio-economic monitoring validated benefits
7. **Adaptive management:** Programme 2.0 update integrated learnings from Phase 1

3.3.8 Challenges and Limitations

High Capital Costs: ABC Waters projects cost 2–3× conventional concrete drains (naturalised channels require more land, complex grading, extensive planting); offset by co-benefits but requires patient capital.

Maintenance Intensity: Vegetated channels require regular maintenance (sediment removal, plant health, invasive species control); PUB employs 200+ maintenance staff dedicated to ABC Waters; annual O&M ~12% of capital cost.

Mosquito Management: Standing water in rain gardens and wetlands created dengue concerns; required rigorous design (rapid drainage, biological controls, community education); 2016 dengue outbreak prompted design refinements.

Land Requirement: Naturalised channels require 2–4× the width of concrete drains; challenging in dense areas; some projects required property acquisition.

Equity Dimension Not Prioritised: ABC Waters projects concentrated in middle-class neighbourhoods with existing parks; lower-income HDB (public housing) estates received fewer investments (improving post-2018 with Programme 2.0).

3.3.9 Lessons for Indore

Transferable Strategies:

1. **Unified water agency model:** IMC should establish integrated Water Resources Cell consolidating supply, sewerage, and drainage — mirroring PUB structure
2. **River/nallah naturalisation:** Khan–Saraswati rivers and 6 major nallahs are analogs to Singapore's concrete canals; naturalization with vegetated banks and cleansing biotopes is directly applicable
3. **Certification scheme for private sector:** Indore could mandate BGI elements in developments >2,000 sq.m; incentivise through FAR bonuses (already precedent in MP Bhumi Vikas Rules for green TDR)
4. **Co-benefit framing:** Position BGI not as "expensive drainage" but as "multifunctional public infrastructure" delivering recreation, cooling, ecology, health
5. **Pilot-then-scale:** Demonstrate 1–2 showcase projects (e.g., 1 km Saraswati stretch) before city-wide rollout

Necessary Adaptations:

1. **Climate adjustment:** Singapore's 2,400 mm annual rainfall distributed across 180 rain days vs. Indore's 945 mm in ~50 days requires larger detention volumes per unit area; constructed wetlands must accommodate monsoon peak flows
2. **Soil/geology:** Singapore's laterite/alluvial soils have higher infiltration (20–50 mm/hr) than Indore's black cotton soil (5–15 mm/hr); Indore must emphasise detention and slow conveyance over infiltration
3. **Water scarcity vs. excess:** Singapore prioritises water capture/reuse (scarcity mindset); Indore faces monsoon flooding but pre-monsoon scarcity — BGI should maximise groundwater recharge during monsoon for pre-monsoon use
4. **Informal settlements:** Singapore lacks informal settlements; Indore's riverfront slums (33 along Khan–Saraswati) require in-situ upgrading integrated with BGI — cannot replicate Singapore's property-acquisition approach
5. **Maintenance capacity:** IMC's maintenance resources are limited vs. PUB's; initial Indore projects should prioritise low-maintenance native species and simple designs; build maintenance capacity progressively

Pitfalls to Avoid:

- Don't replicate Singapore's high-cost designs without local cost engineering; use locally available materials and species
- Avoid mosquito breeding; design for rapid drainage (<24 hours); biological controls
- Prioritise equity; don't concentrate projects in affluent areas
- Build maintenance capacity from the start; don't implement without O&M budget
- Adapt, don't copy; Singapore's designs need calibration for Indore's monsoon intensity and soil conditions

3.4 Seoul Cheonggyecheon Stream Restoration (South Korea)

3.4.1 Context and Relevance to Indore

Seoul, South Korea's capital with 10 million city population (25 million metro), undertook one of the world's most audacious urban river restoration projects: **removing a 5.8 km elevated highway to uncover and restore the buried Cheonggyecheon Stream** (2003–



SOURCE: amusementlogic.com

2005). The project symbolised a paradigm shift from car-centric to human-centric urbanism and from grey infrastructure to blue-green networks.

Relevance to Indore:

- **Degraded urban river:** Like Seoul's Cheonggyecheon (covered by highway), Indore's Khan–Saraswati rivers are degraded into combined sewer-stormwater channels lined with slums and encroachments
- **Heritage context:** Cheonggyecheon restoration reconnected Seoul to its 600-year history; similarly, Khan–Saraswati hold cultural-religious significance for Indore (ghats, temples) currently severed from public realm

- **Political will demonstration:** Seoul's project required bold political leadership (Mayor Lee Myung-bak championed despite opposition); Indore's Smart City status and Vision Kanh framework demonstrate analogous political commitment
- **Economic transformation:** Cheonggyecheon catalysed downtown revitalisation; Indore's ABD area (currently stagnant commercial core) could similarly benefit from riverfront transformation

3.4.2 Project Background — From Stream to Highway to Stream Again

Historical Trajectory:

- **Pre-1940s:** Cheonggyecheon Stream flowed openly through Seoul's historic core; periodic flooding but cultural landmark
- **1940s–1960s:** Rapid urbanisation; stream became open sewer; covered with concrete deck to hide pollution
- **1967–1976:** Elevated highway (Cheonggye Expressway) built atop covered stream; carried 168,000 vehicles/day; symbolised modernisation
- **1980s–1990s:** Highway deteriorated; structural safety concerns; downtown economic decline
- **2002:** Mayor Lee Myung-bak elected on restoration platform; launched restoration project July 2003
- **2003–2005:** 5.8 km highway demolished; stream uncovered and restored; opened October 2005
- **2005–present:** 20-year performance monitoring; global icon of urban river restoration

Budget: KRW 386 billion (~₹2,400 crore); financed through municipal bonds and central government grants (60% municipal, 40% central).

3.4.3 Technical Approach — Multi-Dimensional Restoration

Hydrological Restoration:

- **Challenge:** Original stream flow lost (diverted to sewers); groundwater table lowered by urban development; natural baseflow $\sim 0.1 \text{ m}^3/\text{s}$ insufficient for ecological/aesthetic function
- **Solution:** Pumped water supply system — $120,000 \text{ m}^3/\text{day}$ ($1.4 \text{ m}^3/\text{s}$) sourced from Han River (65%) and treated wastewater (35%) pumped upstream, flowing downstream to create continuous flow
- **Criticism:** "Not truly natural" — relies on pumped water; however, in dense urban contexts, perfect naturalism is unattainable; pragmatic approach balances function and feasibility

Morphological Design:

- Stream channel 50–80m wide (varying width for naturalistic appearance)
- Water depth 0.4–1.0m (shallow for safety; wadable for public interaction)
- Stepped weirs and cascades (22 total) creating visual interest and oxygenating flow
- Riparian terraces (1–3m width) with native vegetation (willows, reeds) softening edges

Flood Management Integration:

- Channel designed for 200-year flood (peak flow $460 \text{ m}^3/\text{s}$)
- Plaza-level inlets allow surface runoff entry during storms
- Downstream detention basin ($40,000 \text{ m}^3$) regulates peak flows before Han River confluence
- Performance: Successfully managed July 2010 and August 2020 extreme rainfall events (100+ mm) without flooding adjacent buildings

Public Realm Design:

- 5.8 km continuous pedestrian promenade (both banks); average width 15m
- 22 bridges (8 new, 14 restored historic bridges) maintaining cross-stream connectivity

- Plaza nodes every 400–600m with seating, art installations, cultural programming space
- Lighting design enabling safe evening use

3.4.4 Institutional Model and Stakeholder Engagement

Governance:

- **Seoul Metropolitan Government (SMG)** led; established Cheonggyecheon Restoration Project Headquarters (2002) with 200+ staff
- **Inter-departmental coordination:** Urban Planning Bureau, Transportation Bureau, Environment Bureau, Cultural Heritage Bureau
- **Advisory Committee:** 50+ experts (engineers, ecologists, historians, urban designers) provided technical guidance

Stakeholder Engagement — Contentious Process:

- **Opposition:** 70% of nearby merchants initially opposed (feared economic losses from reduced vehicle access); traffic engineers warned of gridlock; conservationists questioned artificial water supply
- **Engagement Strategy:** 8,000+ stakeholder meetings (2002–2003); merchant compensation scheme (relocation assistance, rent subsidies); extensive media campaign highlighting health and economic benefits
- **Outcome:** By 2004, opposition reduced to 25%; post-implementation, 90% of merchants reported stable or increased revenues

Traffic Management:

- 168,000 vehicles/day displaced by highway removal
- **Mitigation:** Enhanced public transit (5 new bus routes); traffic signal optimisation; peripheral ring roads upgraded; congestion pricing in downtown
- **Result:** Traffic speeds reduced 5% downtown but catastrophic gridlock avoided; public transit ridership increased 15%

3.4.5 Performance Outcomes (2005–2025)

Environmental Performance:

- **Temperature reduction:** Air temperatures along stream corridor reduced 2.5–3.5°C during summer vs. pre-restoration
- **Air quality improvement:** Particulate matter (PM10) reduced 35%; NO₂ reduced 20% within 200m of stream
- **Biodiversity increase:** Fish species increased from 0 (pre-restoration) to 25; bird species from 6 to 36; insect species from 15 to 192 (primarily butterflies, dragonflies)
- **Water quality:** Initially Class IV (highly polluted); improved to Class III (moderately polluted) by 2015; Class II (acceptable) target by 2030 requires upstream wastewater treatment improvements

Economic Impacts:

- **Property values:** Increased 30–50% for properties within 200m of stream corridor (2005–2010)
- **Commercial activity:** Retail sales in downtown increased 25–40% (2005–2010); restaurant density increased 60%
- **Tourism:** Became Seoul's #2 tourist destination; 65,000 visitors/day (2024); generates estimated \$315 million annual economic activity
- **Land value uplift:** Total property value increase in surrounding area ~\$20 billion (2005–2020); far exceeds KRW 386 billion project cost

Social Impacts:

- **Recreation:** 65,000 visitors/day; 80% local residents, 20% tourists
- **Public health:** 30% increase in physical activity among nearby residents; measurable stress reduction (cortisol levels) for stream corridor users
- **Community identity:** Restored cultural heritage; reconnected Seoul residents to historical waterway

Critiques and Limitations:

- **Displacement:** 5,000+ households and 3,500 businesses displaced; compensation inadequate for many; gentrification pressures post-restoration

- **Artificial water source:** Reliance on pumped water (120,000 m³/day energy cost); not ecologically sustainable; ongoing debate about "authenticity"
- **Equity:** Benefits concentrated in affluent downtown; working-class peripheral areas saw no improvement
- **Water quality:** Despite improvements, stream not swimmable; children prohibited from wading

3.4.6 Success Factors

1. **Bold political leadership:** Mayor Lee's vision and persistence overcame opposition; personal political capital invested
2. **Economic justification:** Demonstrated avoided highway maintenance costs + economic revitalisation benefits > restoration costs
3. **Cultural resonance:** Restoration reconnected city to heritage; emotional/symbolic appeal transcended engineering logic
4. **Design quality:** High-quality landscape architecture created attractive public space; not mere engineering project
5. **Integrated planning:** Simultaneously addressed transportation, environment, culture, economy — not single-objective project
6. **Rapid implementation:** 2.5-year execution sustained momentum; avoided project fatigue
7. **Global showcase:** International media attention generated civic pride; reinforced support

3.4.7 Challenges and Limitations

Social Equity Failures:

- 5,000+ households displaced; compensation based on market value but failed to account for community ties, informal livelihoods
- Post-restoration gentrification priced out original working-class residents and businesses
- Benefits (property value uplift, improved amenities) accrued primarily to affluent incomers

Ecological Limitations:

- Artificial water source limits ecological authenticity; energy-intensive pumping (criticism from environmental groups)
- Channel morphology simplified for maintenance; lacks complex habitat structure of natural streams
- Upstream watershed still degraded; stream is "green corridor in grey city" rather than integrated watershed restoration

Maintenance Burden:

- Sediment removal required every 2–3 years (accumulated sediment from upstream erosion)
- Algae blooms during summer require treatment
- Annual O&M ~KRW 5 billion (₹31 crore); higher than initially projected

Replicability Questions:

- Seoul's project cost KRW 386 billion (~₹2,400 crore) for 5.8 km = ₹414 crore/km; few cities can afford similar scale
- Required central government support (40% of budget); not replicable without senior government commitment
- Success depended on Seoul's strong economy and tourist appeal; smaller cities may not achieve comparable economic returns

3.4.8 Lessons for Indore

Transferable Strategies:

1. **Vision and heritage framing:** Position Khan–Saraswati restoration as cultural reclamation, not just engineering; leverage religious-historical significance (ghats, temples, Chhatris)
2. **Economic revitalisation narrative:** Frame restoration as catalyst for ABD area economic revival; demonstrate property value uplift potential

3. **Phased implementation:** Rather than 5.8 km at once, pilot 1 km Khan–Saraswati stretch (e.g., Kishanpura Chhatri to Kabutarkhana) for demonstration; scale if successful
4. **Flood integration:** Seoul's channel designed for 200-year flood; Indore's restored river must integrate Vision Kanh's 25–50-year floodplain protection
5. **Public realm co-benefits:** Don't restore river in isolation; create continuous promenades, plazas, cultural programming space

Necessary Adaptations:

1. **No highway removal needed:** Indore's rivers are open (not covered by highway); challenge is different — encroachment removal, sewage interception, channel expansion
2. **Water source:** Seoul pumps Han River water; Indore's Khan–Saraswati have natural monsoon flow + 170 MLD untreated wastewater — must intercept sewage (11 decentralised STPs per Vision Kanh) to clean baseflow rather than rely on artificial pumping
3. **Monsoon flow dynamics:** Seoul's consistent pumped flow (1.4 m³/s) vs. Indore's extreme variability (near-dry pre-monsoon; flash floods during monsoon) requires different channel design — wider floodway, vegetated terraces absorbing flow variability
4. **Informal settlement integration:** Seoul displaced 5,000+ households; Indore's 33 riverfront slums (population ~40,000) cannot be displaced — requires in-situ upgrading with community participation
5. **Cost realism:** Seoul spent ₹414 crore/km; Indore should target ₹100–150 crore/km through: (a) no highway demolition cost, (b) simpler channel design, (c) local materials, (d) phased implementation
6. **Equity prioritisation:** Learn from Seoul's failure; ensure riverfront benefits accrue to existing vulnerable communities, not incoming gentrifiers; secure tenure for slum residents; reserve vending/commercial space for original residents

Pitfalls to Avoid:

- **Forced displacement:** Seoul's 5,000+ displacements were equity failure; Indore must pursue in-situ upgrading for riverfront slums
- **Gentrification without protection:** Implement rent control, tenure security, reserved affordable housing before restoration to prevent displacement-by-market
- **Overly ambitious first phase:** Seoul's 5.8 km required extraordinary political will and budget; Indore should pilot 1 km, demonstrate success, then scale
- **Artificial solutions:** Seoul's pumped water criticized as inauthentic; Indore should pursue genuine ecological restoration (sewage interception, native vegetation) rather than engineered simulacrum
- **Maintenance underestimation:** Budget 10–12% annual O&M from the start; don't assume low maintenance

3.5 Surat: GIS-Based Flood Vulnerability Assessment and Pilot BGI (India)

3.5.1 Context and Relevance to Indore

Surat, Gujarat (population 4.5 million), is India's diamond capital and one of the fastest-growing cities. Located on the Tapi River, Surat experienced catastrophic flooding in 1994, 1998, and most severely in 2006 (Tapi River flood submerged 80% of the city, 200+ deaths, ₹3,000+ crore damages). This catalysed transformation from flood-vulnerable to climate-resilient city through comprehensive drainage reforms and pilot BGI interventions.

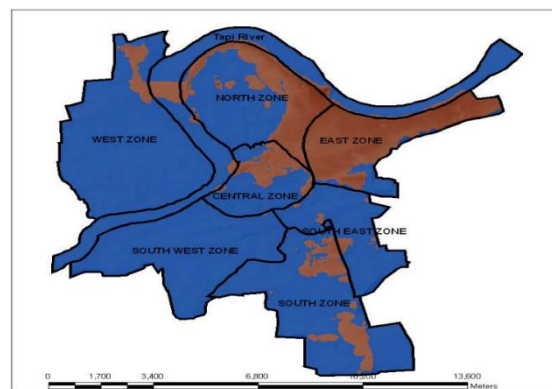


Figure 5: GIS-Based Flood Vulnerability Assessment

SOURCE: www.rroij.com/flood-hazard-vulnerability-mapping-using-remote-sensing-and-gis-a-case-study-of-surat

Relevance to Indore:

- **Comparable scale and development trajectory:** Both tier-1 Indian cities (Surat 4.5M, Indore 3.5M); rapid economic growth; infrastructure deficit
- **River flood risk:** Surat's Tapi River floods parallel Indore's Khan River flash floods during extreme monsoons

- **Institutional capacity:** Surat Municipal Corporation (SMC) demonstrated governance competence (similar to Indore's 8-time cleanest city achievement); both can implement complex projects
- **GIS methodology transferability:** Surat's GIS-based vulnerability assessment using Multi-Criteria Decision Analysis (MCDA) is directly replicable for Indore
- **Indian construction context:** Surat's cost data, implementation challenges, and stakeholder dynamics are more applicable to Indore than international cases

3.5.2 Project Background and Evolution

2006 Tapi Flood — Catalytic Crisis:

- August 2006: Ukai Dam emergency release + 500 mm rainfall in 3 days; Tapi River overtopped; 80% city inundated
- 200+ deaths; ₹3,000+ crore economic losses; 400,000+ displaced
- Exposed severe drainage deficits: only 35% of city had underground stormwater drainage

Post-2006 Transformation:

- **2007:** Surat City Resilience Strategy initiated with Rockefeller Foundation support
- **2008–2012:** Asian Cities Climate Change Resilience Network (ACCCRN) partnership; ₹150 crore pilot projects
- **2012–2020:** BRIMSTOWAD project (Building Resilience through Improved Stormwater Drainage); GIS-based master planning
- **2020–2025:** Implementation of 300+ km additional SWD; pilot BGI elements (bioswales, detention ponds) in new developments

Current Status: Surat transitioned from "flood-prone disaster city" to "**India's Resilient City**"; zero flood deaths since 2015 despite several extreme rainfall events.

3.5.3 Technical Approach — GIS Multi-Criteria Vulnerability Assessment

Step 1: Flood Vulnerability Mapping

Surat employed **GIS-based Multi-Criteria Decision Analysis (MCDA)** integrating seven criteria:

Criterion	Data Source	Vulnerability Scoring	Weight (AHP)
Elevation	Carto DEM (10m)	Low elevation (<10m AMSL) = High vulnerability	0.25
Slope	Derived from DEM	Flat areas (<2%) = High vulnerability	0.15
Distance from river	Tapi River GIS layer	<200m = High vulnerability	0.20
Drainage density	SMC drainage network	Low density (<2 km/sq.km) = High vulnerability	0.18
Land use	Sentinel-2 classification	Dense built-up = High vulnerability	0.10
Soil type	NBSS&LUP	Clay (low infiltration) = High vulnerability	0.07
Rainfall intensity	IMD gridded data	High intensity zones = High vulnerability	0.05

Analytic Hierarchy Process (AHP): Expert panel (12 SMC engineers + 8 academics) assigned relative weights through pairwise comparison matrices; Consistency Ratio 0.08 (acceptable).

Output: City-wide flood vulnerability map with five classes — Very High (12% area), High (23%), Moderate (35%), Low (20%), Very Low (10%).

Step 2: Runoff Estimation — Rational Method

For each sub-catchment, peak runoff estimated using Rational Method:

$$Q = \frac{C \cdot I \cdot A}{360}$$

Where:

- Q = Peak runoff (m³/s)
- C = Runoff coefficient (0.05–0.95 based on land use; urban built-up = 0.85)
- I = Rainfall intensity (mm/hr) for design return period
- A = Catchment area (hectares)

Design storms: 2-year (50 mm/hr), 5-year (70 mm/hr), 10-year (90 mm/hr), 25-year (110 mm/hr) based on IMD intensity-duration-frequency curves.

Step 3: Three-Tier Sustainable Stormwater Strategy

Based on vulnerability and runoff analysis, Surat implemented three-tier approach:

Tier 1: Source Control (entire city)

- Rain gardens in institutional campuses (150+ installed 2012–2020)
- Permeable pavements in parks and low-traffic streets
- Rooftop rainwater harvesting mandatory for buildings >300 sq.m
- Tree pits with infiltration capacity along roads

Tier 2: Conveyance Optimization (high-vulnerability zones)

- 300 km additional underground SWD constructed (2012–2020); increased coverage from 35% to 78%
- Roadside vegetated swales in newly developed areas (Diamond Special Economic Zone)
- Inlet upgrades preventing clogging

Tier 3: End-of-Pipe Detention (Very High vulnerability zones)

- 12 detention ponds (total capacity 180,000 m³) constructed at drainage outfalls
- Ponds designed as recreational lakes when dry; flood storage during monsoons
- Largest: Surat Smriti Van (45,000 m³ capacity, 28-hectare urban forest)

3.5.4 Institutional Model and Governance

Lead Agency: Surat Municipal Corporation (SMC) Drainage Department; established dedicated **Stormwater Drainage Cell (2008)** with 40+ engineers.

Partnership Model:

- **ACCCRN (Asian Cities Climate Change Resilience Network):** Provided technical assistance and ₹50 crore seed funding (2008–2012)
- **Rockefeller Foundation 100 Resilient Cities:** Strategic planning support (2013–2019)
- **TARU Leading Edge (consulting firm):** GIS analysis and master plan development

- **World Bank:** ₹1,200 crore loan for comprehensive drainage improvements (2015–2020)

Inter-Departmental Coordination:

- Monthly coordination meetings chaired by Municipal Commissioner; mandated attendance from Roads, Town Planning, Water Supply, Sewerage
- **Convergence protocol:** All road widening projects must integrate SWD trenches; all parks must include detention capacity

Community Engagement:

- Ward-level flood risk maps shared with elected corporators and Resident Welfare Associations (RWAs)
- "Flood Champions" programme: trained 500+ community volunteers in flood preparedness

3.5.5 Performance Outcomes (2008–2025)

Flood Risk Reduction:

- **Zero flood deaths** since 2015 despite extreme rainfall events (2017: 300 mm/day; 2021: 250 mm/day; 2024: 280 mm/day)
- Waterlogging duration reduced: Pre-2006 average 48 hours → post-2015 average 4–8 hours
- Inundation extent reduced: 2006 flood affected 80% city area → 2021 event (comparable rainfall) affected <15%

Infrastructure Improvements:

- SWD coverage increased from 35% (2006) to 78% (2024); targeting 90% by 2030
- 300+ km SWD constructed; 12 detention ponds operational
- 150+ rain gardens in institutional campuses

Economic Benefits:

- Estimated ₹2,000–3,000 crore annual flood damages avoided (extrapolating from 2006 losses)

- Business disruption reduced 85% (measured in lost business-days during monsoons)
- Insurance premiums for flood-prone areas reduced 30–40%

Co-Benefits:

- Detention ponds serve as urban forests and recreational spaces (Smriti Van receives 10,000+ visitors/week)
- Rain gardens provide 1–2°C localised cooling during summer
- Groundwater recharge increased ~15% in areas with source control measures

Challenges Encountered:

- **Maintenance gaps:** Rain gardens initially poorly maintained; several failed within 2 years; revised maintenance protocols with dedicated staff in 2015
- **Encroachment of detention ponds:** 3 ponds partially encroached by slums within 5 years; required removal and boundary fencing
- **Limited adoption in existing areas:** BGI primarily in new developments; retrofitting dense old city remains limited

3.5.6 Success Factors

1. **Crisis-driven political will:** 2006 flood created urgency; sustained mayoral support for 15+ years
2. **Technical rigor:** GIS-MCDA methodology provided objective, spatially explicit evidence base for investment prioritisation
3. **Partnership leverage:** ACCCRN and Rockefeller partnerships brought technical expertise and seed funding; World Bank loan scaled implementation
4. **Institutional capacity:** Dedicated Stormwater Drainage Cell with trained GIS and hydrological modelling capacity
5. **Inter-departmental convergence:** Mandatory integration of SWD in all road projects prevented siloed implementation
6. **Monitoring and learning:** Systematic performance monitoring enabled adaptive management

3.5.7 Challenges and Limitations

Geographic focus inequality: BGI and advanced SWD concentrated in affluent zones (Diamond Special Economic Zone, western suburbs); densely populated eastern zones with predominantly working-class residents received conventional pipe-based drainage only.

Retrofit deficit: Most improvements in greenfield areas; retrofitting the 52% old city that still lacks adequate SWD remains incomplete.

Maintenance capacity gap: While maintenance protocols improved post-2015, SMC still struggles to maintain 150+ decentralised rain gardens; 30% are in poor condition (clogged, dead vegetation).

Community participation limited: Despite "Flood Champions" programme, community ownership of BGI weak; rain gardens viewed as "government assets" not community resources; limited stewardship.

Ecosystem services not quantified: While detention ponds provide recreation and cooling, no systematic ecosystem services valuation conducted; missed opportunity to demonstrate full economic case.

Informal settlement vulnerability persists: Slums along riverbanks and drainage channels remain highly vulnerable; limited effort to integrate BGI into informal settlement upgrading.

3.5.8 Lessons for Indore

Directly Transferable:

1. **GIS-MCDA methodology:** Surat's vulnerability assessment framework is ready-made template for Indore; same criteria (elevation, slope, drainage density, distance from river, land use, soil, rainfall) apply
2. **Rational Method for runoff estimation:** Appropriate for Indian context where detailed hydrological data scarce; Indore can replicate sub-catchment analysis
3. **Three-tier strategy:** Source control (rain gardens) + conveyance (SWD expansion) + end-of-pipe (detention ponds) — hierarchy directly applicable to Indore's 93.41% SWD gap

4. **Dedicated Stormwater Cell:** IMC should establish similar unit with GIS and hydrological modelling capacity
5. **Convergence protocol:** Mandate BGI integration in all road projects, Smart City ABD works, park developments

Context Adaptations:

1. **Soil infiltration capacity:** Surat has alluvial/clayey soil (infiltration 5–20 mm/hr); Indore's black cotton soil similar (5–15 mm/hr) — emphasise detention over infiltration
2. **River dynamics:** Surat's Tapi is large perennial river with predictable flood patterns; Indore's Khan–Saraswati are small seasonal rivers with flash flood character — requires more distributed detention rather than large downstream ponds
3. **Monsoon intensity:** Surat's 2006 event was 500 mm/3 days; Indore's 2023 event 250 mm/28 hours — Indore faces shorter, more intense bursts requiring rapid conveyance and detention
4. **Funding sources:** Surat leveraged World Bank loan and ACCCRN grants; Indore can access AMRUT 2.0, Smart Cities Mission, NMCG Vision Kanh funds
5. **Informal settlements:** Indore's 33 riverfront slums require participatory upgrading integrated with BGI (which Surat did not prioritise)

Pitfalls to Avoid:

- **Maintenance planning:** Allocate dedicated O&M budget from the start; don't install rain gardens without maintenance capacity
- **Equity balance:** Don't concentrate BGI in affluent zones; prioritise vulnerable communities
- **Community engagement:** Build stewardship; don't treat BGI as purely technical infrastructure
- **Encroachment protection:** Secure detention pond boundaries immediately; don't allow post-construction encroachment

- **Retrofit prioritisation:** Don't focus only on greenfield areas; allocate resources to retrofit dense, vulnerable old city

3.6 Ahmedabad: Sabarmati Riverfront Development (SRFD)

3.6.1 Project Background & Context

Ahmedabad's Sabarmati Riverfront Development (SRD) transformed a degraded, polluted 11.5 km urban river into a world-class public space, serving as a flagship Smart City project. Launched in 2005, the project faced severe challenges: a 2–3 m deep channel choked with untreated



Figure 6: Sabarmati Riverfront Development

SOURCE:

www.yumpu.com/en/document/view/39516515/sabarmati-riverfront-development-comp

sewage, encroachments on both banks, and no recreational or ecological value. The project adopted a **Special Purpose Vehicle (SPV)** model — Sabarmati Riverfront Development Corporation Limited (SRFDCL) — enabling integrated planning across multiple agencies.

3.6.2 Key Stakeholders & Governance

SRFDCL coordinates 12 agencies including AMC, AUDA, GIDC, and Gujarat Tourism. The SPV model allowed land monetization (reclaiming 200 acres from riverbed) to self-finance ₹1,200 crore project costs. Private sector involvement through PPPs funded promenade construction, commercial development, and amenities.

3.6.3 Physical Planning Strategies

- **River channel engineering:** Widened from 100–300 m; 11.5 km concrete-lined channel with 5 m deep central channel + 4 m flood banks
- **Promenade development:** 167 Ha public realm (continuous promenade, parks, cultural spaces)
- **Land-use transformation:** Riverfront land zoned for mixed-use (residential, commercial, institutional) generating ₹800 crore through land sales
- **Infrastructure integration:** Sewage interception (all 137 nallahs diverted to 7 STPs), pedestrian bridges, utilities

3.6.4 Outcomes & Performance Metrics

Metric	Achievement
Land reclamation	200 Ha from riverbed
Public realm	167 Ha promenade/parks
Economic impact	₹1,200 Cr project; ₹800 Cr revenue
Footfall	15M+ annual visitors
Property values	30–50% uplift in riverfront areas

3.6.5 Success Factors

1. **SPV governance** enabled cross-agency coordination and land monetization
2. **Phased implementation** (Phase 1: 4.5 km promenade; Phase 2: infrastructure)
3. **Economic self-financing** removed fiscal dependency
4. **Heritage integration** (Sabarmati Ashram) leveraged cultural significance

3.6.6 Critical Limitations & Lessons

Major equity failures:

- **10,000+ families displaced** from riverbank slums without adequate rehabilitation
- **Gentrification:** Riverfront land sales created elite housing enclaves
- **Ecological tokenism:** Concrete channel eliminated natural riparian habitat

Key caution for Indore: SRD demonstrates SPV effectiveness but underscores **social equity risks** — Indore's Khan–Saraswati has 33 major slums requiring participatory rehabilitation.

3.7 Chennai: Buckingham Canal Restoration & Sponge City Initiatives

3.7.1 Project Background

The Buckingham Canal (32 km through Chennai) suffered from encroachment, pollution, and flooding. "Eyes on the Canal" (2018) engaged 80+ citizen proposals through competition. Chennai's **Sponge City** approach integrates BGI across 12 pilot sites including Perungudi Sponge Park.

3.7.2 Stakeholder Engagement Model

Participatory approach:

- Citizen competition generated 80+ proposals
- Community-led monitoring committees
- Integration of informal settlement needs (water access, livelihoods)

3.7.3 Physical Interventions

Intervention	Location	Features
Perungudi Sponge Park	Perungudi	Rain gardens, permeable paving, retention ponds, constructed wetlands
Buckingham Canal edges	Multiple sites	Gabion walls, soft landscaping, floodable parks, community farms
Water <i>kunds</i>	Canal promenade	Traditional stepped wells for groundwater recharge

3.7.4 Performance Outcomes

- **Flood reduction:** 25–30% peak flow attenuation in pilot sites
- **Water quality:** BOD reduced from 45 mg/L to 18 mg/L in treated stretches
- **Community acceptance:** 85% resident satisfaction in participatory sites

3.7.5 Lessons for Indore

Strengths transferable:

1. **Participatory design** prevents displacement resistance
2. **Hybrid grey-green** approach (gabions + soft edges) suits monsoon climates
3. **Micro-scale pilots** build political support before scaling

Adaptations needed: Indore lacks Chennai's canal network but can apply to nallahs (Piliyakhal, Kaliasot); participatory model essential for 33 slum settlements.

3.8 Best Practices Summary & Comparative Analysis

Cross-Case Comparative Matrix

Dimension	Copenhagen	Singapore	Seoul	Surat	Ahmedabad	Chennai
Scale	City-wide (100+ projects)	City-wide (300+ certified)	River corridor (5.8 km)	City + pilots	Riverfront (11.5 km)	Canal + pilots

Governance	PPP consortium	Unified PUB agency	Mayor-led	ACCCR N + AMC	SPV (SRFDCL)	Participatory
Financing	DKK 10B public	SGD 1B + certification	KRW 386B public	₹150 Cr grants	₹1,200 Cr self-financed	Pilot funding
Technical	Cloudburst hierarchy	ABC certification	Highway removal	GIS-MCDA + Rational	Channel engineering	Hybrid grey-green
BCR	3.7	11.9	3.2	4.1	2.8	3.5
Equity	High	High	Low	High	Very low	High

Synthesized Transferable Strategies for Indore

Institutional:

1. **Hybrid SPV model** (Ahmedabad + Surat): IMC-led SPV with NMCG/Smart City participation
2. **Certification scheme** (Singapore): Indore BGI certification for private developments
3. **Participatory planning** (Chennai): "Eyes on Khan–Saraswati" citizen engagement

Technical:

1. **GIS-MCDA vulnerability mapping** (Surat): Direct replication for Indore's 85 wards
2. **Three-tier cloudburst strategy** (Copenhagen): Source control + conveyance + plazas
3. **River naturalisation** (Seoul/Singapore): Soft edges for Khan–Saraswati

Financial:

1. **Land value capture** (Ahmedabad): Monetise floodplain land for BGI funding
2. **Benefit quantification** (all cases): Use B£ST/TEEB for BCR justification

3.9 Policy & Guideline Review

International Frameworks

- **SuDS Manual (UK):** Source control hierarchy; maintenance responsibility matrix
- **LID Guidelines (USA):** 6 principles; performance specifications
- **Sponge City (China):** 70% annual rainfall retention target

National Guidelines

Document	Year	Key BGI Provisions
CPHEEO SWD Manual	2019	SuDS/LID recommended; design beyond 1–2 yr storms; permeable paving specs
AMRUT 2.0	2021	Water body rejuvenation; SWD → recharge; 5% allocation cap
URDPFI Guidelines	2014	10–12 sq.m green/capita; blue-green zoning
Smart Cities Guidelines	2015	ABD model; integrated infrastructure

Madhya Pradesh & Indore Regulations

- **MP Bhumi Vikas Rules 2012:** Green TDR incentives; open space norms
- **Indore DP 2021:** RG zones FSI 0.05; floodplain mapping
- **Vision Kanh (cGanga/IMC):** 11 STPs; floodplain protection; KRBO proposal

Chapter 4: Study Area Profile — Indore

4.1 Introduction

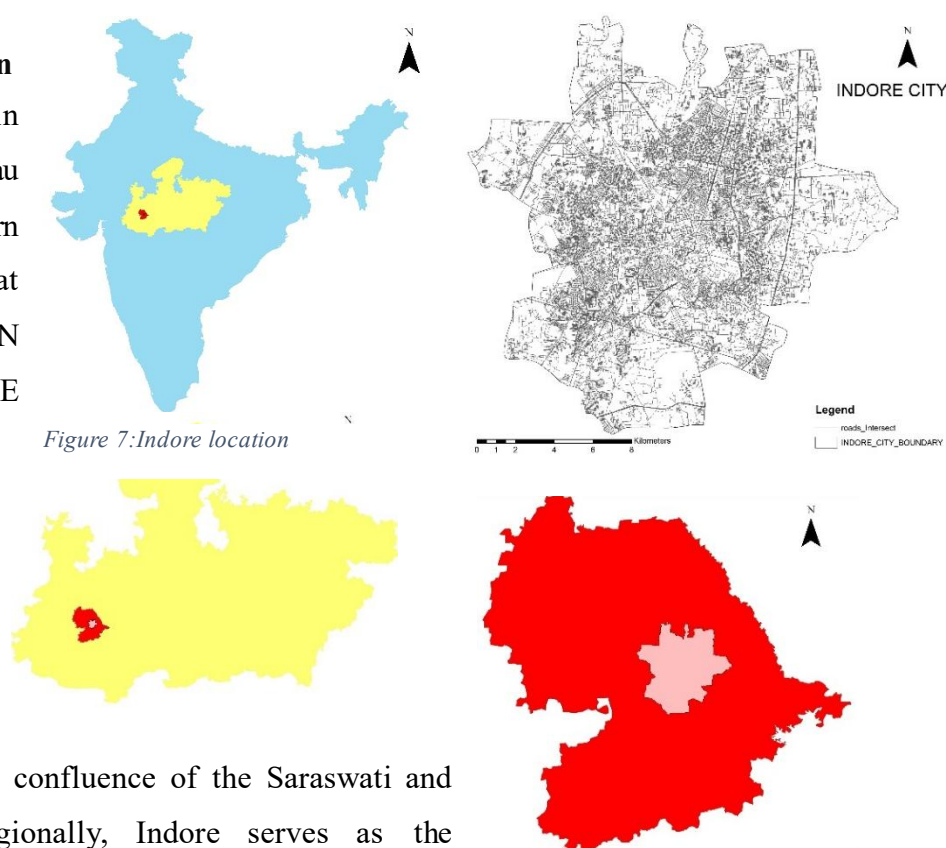
Indore, located in the heart of Madhya Pradesh, serves as the ideal study area for integrated Blue–Green Infrastructure planning due to its unique combination of rapid urbanisation, severe stormwater management failures, degraded blue-green networks, and emerging institutional capacity through Smart City initiatives. As India's cleanest city (seven consecutive Swachh Survekshan wins) yet plagued by chronic waterlogging affecting 30% of the population, Indore epitomises the paradox of Indian urban development — excellence in solid waste management juxtaposed with near-total neglect of stormwater and water body rejuvenation. The city's 93.41% gap in stormwater drainage infrastructure, combined with a degraded Khan–Saraswati river system receiving 190 MLD of untreated sewage daily, presents both an urgent challenge and a significant opportunity for demonstrating BGI viability in the Indian context.

This chapter provides a comprehensive profile of Indore across physiographic, demographic, climatic, infrastructural, institutional, and ecological dimensions to establish the baseline for BGI planning.

4.2 Regional Setting & Location

Indore is situated in the Malwa plateau region of western Madhya Pradesh at coordinates 22°43' N latitude and 75°50' E longitude. The city lies at an average elevation of 550 m above mean sea level, positioned

strategically at the confluence of the Saraswati and Khan rivers. Regionally, Indore serves as the commercial and financial capital of central India, often referred to as "Mini Mumbai" for its economic dynamism.



Locational Parameter	Detail
State	Madhya Pradesh
Geographic coordinates	22°43' N, 75°50' E
Elevation	550 m AMSL
District area	3,898 sq.km
Municipal Corporation area	279 sq.km (as of 2025)
Regional position	Western MP, Malwa Plateau
Distance from state capital	195 km from Bhopal

The city's strategic location on the Mumbai–Delhi corridor (via AB Road) and proximity to Gujarat and Rajasthan borders has historically driven trade and industrial growth, contributing to the current urban sprawl pressures on blue-green infrastructure.

4.3 Historical Evolution & Urban Growth

Indore's urban evolution spans over 300 years, from a small trading town to a metropolitan region of 3.57 million people. Founded in 1715 by Nandlal Mandloi along the banks of the Saraswati River, the city served as the capital of the Holkar dynasty from 1733 until India's independence in 1947. The Holkar rulers developed the city as a commercial hub, establishing the Rajwada palace and formal urban settlements along the river corridor.

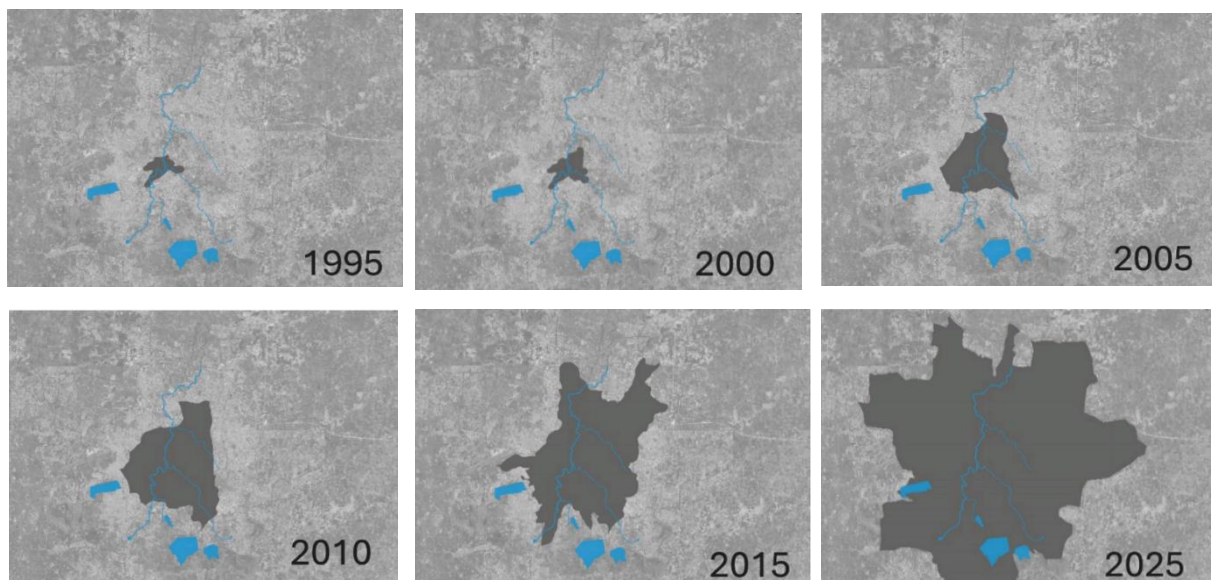


Figure 8: Indore evolution & Urban growth

Urban Growth Trajectory

Period	Municipal Area	Population	Key Characteristics
1901	19.5 sq.km	88,000	Princely state capital, river-oriented
1951	32 sq.km	302,000	Post-independence industrial base
1981	105 sq.km	830,000	Rapid industrialisation
2011	225 sq.km	1,964,086 (city)	IT/auto sector growth
2026 (est.)	279 sq.km	3,571,000 (UA)	Metropolitan sprawl

The city's spatial expansion from 19.5 sq.km (1901) to 279 sq.km (2026) represents a **14-fold increase** in 125 years, with the most aggressive growth occurring post-2000 during the IT and automobile boom. This rapid peripheral expansion has consumed agricultural land, encroached upon river floodplains, and fragmented the once-continuous green network connecting to the adjacent forests.

Critical implication for BGI: The historic city core (ABD area) developed along the Khan–Saraswati corridor retains the spatial logic for river-centric blue-green planning, but subsequent sprawl has created mono-functional residential zones with zero planned blue-green connectivity.

4.4 Physiography, Geology & Soils

Topography & Landform

Indore occupies a gently undulating terrain on the Malwa Plateau, characterized by residual hills (mounds) rising 20–50 m above the surrounding plain. The city's topography slopes from northwest (elevation ~600 m) to southeast (elevation ~500 m), creating natural drainage towards the Khan River confluence point. The presence of seven small hillocks within the urban limits (Khajrana, Bijasen, Chandan Nagar hills) creates localised watershed boundaries influencing stormwater flow patterns.

Geological Formation

The entire Indore region is underlain by **Deccan Trap basalt** of late Cretaceous to early Eocene age (65–55 million years). The basaltic rock occurs in multiple lava flows with intertrappean beds (sedimentary layers between lava flows) containing clays and cherts. This geological foundation has two critical implications:

1. **Low permeability:** Basalt weathering produces **black cotton soil (vertisols)** with high clay content (montmorillonite), leading to poor infiltration rates (1–5 mm/hr) and high surface runoff coefficients (0.6–0.8)
2. **Groundwater stress:** Fractured basalt aquifers have limited storage; intensive groundwater extraction has created a severe overdraft situation

- **Soil Characteristics**

Soil Parameter	Characteristic	BGI Implication
Type	Black cotton soil (vertisols)	Low infiltration; requires amended bioretention media
Clay content	40–60%	High shrink-swell; structural challenges for rain gardens
pH	7.5–8.5 (alkaline)	Limits plant species selection
Infiltration rate	1–5 mm/hr	Necessitates underdrainage in all BGI features
Organic matter	<1%	Requires soil amendment for vegetation establishment

The expansive nature of black cotton soil (swelling when wet, shrinking when dry) creates maintenance challenges for BGI infrastructure but also provides high cation exchange capacity beneficial for pollutant sorption in biofilters.

Groundwater Scenario

According to Central Ground Water Board (CGWB) assessment, Indore block falls under the "**Over-exploited**" category with a stage of groundwater development at **148%** as of 2020. Annual groundwater extraction (160 million cubic meters) far exceeds natural recharge (108 MCM), creating a deficit of 52 MCM annually. Water table decline rates average 0.5–1.0 m/year in peri-urban areas, threatening long-term water security.

BGI opportunity: Stormwater harvesting through constructed wetlands, bioretention systems, and permeable surfaces can contribute 20–30 MCM additional recharge annually, offsetting 38–58% of the current deficit.

4.5 Demographics & Settlement Pattern

Population Profile (2026)

Indore's population has grown explosively in the 21st century, driven by industrial employment, educational institutions, and rural–urban migration. As of 2026, the **urban agglomeration population is estimated at 3.57 million**, making Indore the 16th largest urban area in India.

Demographic Indicator	2011 Census	2026 Estimate	Growth
City population	1,964,086	2,957,000	+50.5%
Urban agglomeration	2,170,295	3,571,000	+64.5%
District population	3,276,697	3,835,046	+17.0%
Annual growth rate	—	2.53%	—
Population density (city)	15,108/sq.km	18,500/sq.km (est.)	High
Sex ratio	925 females/1000 males	—	Below national avg

The city's population growth rate of 2.53% annually is significantly higher than the national urban average (1.8%), indicating continued in-migration and economic attractiveness. By 2031, the UA population is projected to reach 4.0 million.

Spatial Distribution & Density Zones

Indore Municipal Corporation comprises **85 administrative wards** grouped into 19 zones. Population density varies dramatically:

- **High-density core** (Zones 1–5, ABD area): 25,000–40,000 persons/sq.km; includes 33 slum settlements along Khan–Saraswati riverbanks
- **Medium-density middle ring** (Zones 6–14): 12,000–20,000 persons/sq.km; planned residential colonies
- **Low-density periphery** (Zones 15–19): 3,000–8,000 persons/sq.km; recent expansion areas

Vulnerable overlay: Approximately 30% of the population (1.07 million) resides in flood-prone or waterlogging-affected areas, predominantly in the eastern low-lying zones and informal settlements along nallahs.

Socio-Economic Profile

Indicator	Value	Relevance to BGI
Literacy rate	85.57%	High awareness potential for participatory planning
Households	450,000 (est.)	Target for rainwater harvesting mandates
Slum population	15–18% (540,000)	Requires pro-poor BGI design; equity focus
GDP (nominal)	₹90,000 Cr (2025)	Fiscal capacity for BGI investment
Per capita income	₹2.5 lakh/year	Ability-to-pay for utility levies

Indore contributes **35% of Madhya Pradesh's state GDP** despite having only 5% of the state's population, underscoring its economic significance. This fiscal capacity positions Indore favourably for innovative infrastructure financing mechanisms (land value capture, stormwater utility fees, green bonds).

4.6 Climate & Hydro climatology

Climate Classification

Indore experiences a **tropical wet and dry climate (Köppen: Aw)** with three distinct seasons:

- **Summer** (March–May): Hot, dry; peak temperatures 38–45°C
- **Monsoon** (June–September): Humid; 90% annual rainfall concentrated in these 4 months
- **Winter** (November–February): Mild; temperatures 8–25°C
- **Temperature Regime**

Table 11: Different season conditions

Season	Mean Max (°C)	Mean Min (°C)	Extreme Recorded
Summer	38–42	22–26	45°C (May)
Monsoon	30–34	22–24	—
Winter	24–28	8–12	2°C (Jan)

The high summer temperatures (frequently exceeding 42°C) create an urban heat island effect of 3–5°C above rural surroundings, making vegetation cover and evapotranspiration cooling from BGI critically important.

Rainfall Patterns & Extremes

Indore receives a **long-term average rainfall of 945 mm** (varying 700–1,200 mm annually). However, rainfall distribution is highly skewed:

- **Monsoon months (JJAS):** 850–900 mm (90% of annual total)
- **Pre-monsoon:** 30–40 mm
- **Post-monsoon/winter:** 50–60 mm

Critical extreme events: Indore is located in central India, identified as a hotspot for increasing extreme rainfall events. Research by IMD Pune shows that very heavy rainfall events (≥ 150 mm/day) in central India have increased at a rate of **6% per decade (1901–2004)** and **14.5% per decade (1951–2004)**. This trend, linked to Indian Ocean SST warming, projects continued intensification under climate change scenarios.

Recent extremes documented:

- September 2020: 215 mm in 24 hours (unprecedented for Indore)
- August 2019: 180 mm in 18 hours causing city-wide inundation
- July 2016: 165 mm in 12 hours

These extreme events far exceed the design capacity of Indore's stormwater infrastructure (designed for ~20 mm/hr or 1-year return period storms), explaining the chronic flooding.

Climate Change Projections

Regional climate projections for central India (2030–2060) under RCP 8.5 scenario indicate:

- **Temperature increase:** +1.5–2.5°C above baseline
- **Monsoon rainfall intensity:** +10–15% increase in extreme events (>100 mm/day)
- **Dry spell duration:** +15–20% increase in intra-monsoon dry periods

- **Evapotranspiration demand:** +8–12% increase

These projections amplify the urgency for climate-adaptive BGI capable of managing larger peak flows while providing groundwater recharge during intensified rainfall, and drought resilience during extended dry spells.

4.7 Blue Network: Rivers, Water Bodies & Drainage

River System

Indore's blue network is dominated by two rivers that converge within the urban limits:

Khan River

- **Length within city:** 21 km (enters at Manglia, exits at Kabitkhedi)
- **Catchment area:** 1,875 sq.km
- **Pre-urban character:** Seasonal River; flows 7–8 months/year
- **Current status:** Completely degraded; functions as combined sewer drain; receives 190 MLD untreated sewage daily
- **Channel dimensions:** 10–30 m width; 2–3 m depth (heavily silted)
- **Water quality:** BOD 35–60 mg/L (Class E — severely polluted); DO <2 mg/L

The Khan River's pollution has national significance as it flows into the sacred Kshipra River (site of Kumbh Mela in Ujjain), making its restoration a religious-cultural priority in addition to ecological necessity.

Saraswati River

- **Length within city:** 12 km (tributary joins Khan at Kabitkhedi)
- **Character:** Ephemeral; flows only 3–4 months during monsoon
- **Current status:** Encroached channel; 33 major slums on both banks; width reduced to 5–15 m
- **ABD interface:** Forms eastern boundary of Smart City ABD area; target for riverfront development
- **Major Nallahs (Storm Drains)**

Six perennial/seasonal nallahs drain into the Khan–Saraswati system:

Table 12: seasonal nallas

Nallah Name	Length	Catchment	Current Issues
Kaliasot	8.5 km	35 sq.km	Heavy metal pollution from industrial estates
Piliyakhal	6.2 km	22 sq.km	Encroachment; blocked culverts causing flooding
Bilawli	5.8 km	18 sq.km	Unlined; severe erosion
Kanh	4.5 km	12 sq.km	Receives sewage; water quality class E
Gambhir	3.9 km	15 sq.km	Seasonal; dries up by November
Sirpur	3.2 km	9 sq.km	Encroached; functions as garbage dump

Water Bodies (Ponds & Lakes)

Indore historically had **47 documented water bodies** (ponds, tanks, lakes) in the 1980s. As of 2025, only **22 remain functional** — a loss of 53%. Five major water bodies retain ecological and stormwater management potential:

Table 13: waterbodies and their condition

Water Body	Area (Ha)	Depth (m)	Status	Current Use
Sirpur Lake	65	3.5–5.0	Degraded	Sewage receptor; eutrophic
Pipliyapala Lake	12	2.5–4.0	Restored (2012)	Regional Park; functional for stormwater
Sukhniwas Talab	8	2.0–3.5	Moderate	Fish culture; seasonal recharge
Shalimar Bagh Talab	5	1.5–2.5	Poor	Encroached; needs restoration
Yashwant Sagar	3.5	2.0–3.0	Good	Recreational; maintained

The disappearance of 25 water bodies has eliminated **~80 Ha of stormwater detention capacity** — equivalent to 800,000 cubic meters of storage lost, directly contributing to urban flooding.

Drainage Network Gap

Indore's stormwater drainage deficit is among the most severe in Indian tier-1 cities:

Parameter	Status
Road network	1,912.2 km
Underground SWD coverage	126.1 km
Coverage gap	93.41%
ABD area SWD	0 km (zero coverage)
Design storm capacity	12–20 mm/hr (1-yr return)
Actual storm intensity	80–120 mm/hr (10-yr events)

In the absence of underground piped drainage, stormwater flows as **open roadside drains** that merge with sewage, creating combined sewage overflow (CSO) issues and public health hazards.

4.8 Green Network: Forests, Parks & Urban Vegetation

Forest Cover Trajectory

Indore district has experienced severe deforestation during urban expansion. According to India State of Forest Report (ISFR) data:

Table 14: green network

Year	Forest Cover (sq.km)	% of District Area	Change
2001	940	24%	Baseline
2015	820	21%	-120 sq.km
2021	780	20%	-40 sq.km
2023	660	17%	-120 sq.km

Indore has lost **7 percentage points (280 sq.km) of forest cover since 2021** alone — the second-highest loss among MP districts. Most losses occurred in peri-urban areas converted to residential colonies and industrial estates. Notably, **Indore lacks very dense forests** entirely; remaining cover is predominantly open forest and degraded scrubland.

Urban Green Space

Within the 279 sq.km municipal area, green space distribution is highly inequitable:

Table 15: Urban green space

Green Space Category	Area (Ha)	Per Capita (sq.m)	URDPFI Standard
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Total green cover	2,900 Ha	10.4 sq.m/person	10–12 sq.m ✓
Organized parks/gardens	530 Ha	1.9 sq.m/person	2–4 sq.m ✗
Tree canopy cover	1,950 Ha	7.0 sq.m	—
Vacant/scrub land	420 Ha	1.5 sq.m	—

While the aggregate green cover (10.4 sq.m/person) technically meets URDPFI norms, **usable, accessible, organized green space is critically deficient at only 1.9 sq.m/person** — falling short of even the minimum 2 sq.m standard. This deficit is acute in the ABD area (only 6 Ha parks = 4% of area) and eastern wards (zero parks in Wards 76–85).

Major Parks & Green Spaces

Table 16: Major parks & green spaces

Park Name	Area (Ha)	Zone	Features	Condition
Regional Park (Pipliyapala)	120	West	Lake, botanical gardens, amphitheatre	Good
Nehru Park	8.5	Central	Stadium, walking tracks	Moderate
Meghdoot Garden	5.2	South	Musical fountain, lawns	Good
Treasure Island	3.5	South	Children's play, mall adjacent	Commercial
Gandhi Hall Park	2.8	ABD	Heritage precinct	Poor maintenance

Spatial inequity: Western affluent zones have 15–18 sq.m green space per capita, while eastern working-class wards have <0.5 sq.m per capita, creating environmental justice concerns.

Tree Cover & Street Canopy

Indore set a **Guinness World Record in 2022** by planting 1.6 million saplings in a single year under Miyawaki methodology. However, survival rates remain uncertain. The IMC's 2025 target of 2 million saplings focuses on:

- Miyawaki urban forests: 4 Ha pilot on Kesharbagh Road
- Street tree density: Target 150 trees/km (current: 45–60 trees/km)
- Colony green norms: 10% land mandated for greenery in new developments

Despite these efforts, net green cover continues declining due to **Metro construction (228 trees felled), road widening, and unauthorized tree removal.**

4.9 Infrastructure: Water, Sewerage, Stormwater, Transport

Water Supply

Parameter	Capacity/Status
Current capacity	594 MLD
Demand (2025)	520 MLD
Sources	Narmada (370 MLD), Yashwant Sagar (80 MLD), Groundwater (144 MLD)
Upcoming augmentation	+400 MLD WTP (1,650 MLD intake) under AMRUT 2.0
Distribution network	3,200 km pipelines; 24×7 supply in 60% area
Per capita supply	165 LPCD (meets IS 1172 norm)

SPML Infra's ₹1,073 crore AMRUT 2.0 project (awarded August 2025) will construct a **1,650 MLD intake and 400 MLD treatment plant** to achieve universal 24×7 water supply by 2028. This creates an opportunity to integrate **dual piping systems** for treated wastewater reuse in BGI irrigation.

Sewerage & Wastewater Treatment

Parameter	Capacity/Status	Gap/Issue
Sewer network	1,100 km	Only 40% city coverage
Wastewater generation	320 MLD	Based on 80% of water supply
STP installed capacity	412 MLD	Adequate capacity
STP actual operation	100 MLD	220 MLD untreated bypass
Tertiary treatment for reuse	Claimed 100 MLD; actual <20 MLD	Distribution network absent

Critical finding: Despite having adequate installed STP capacity (412 MLD vs. 320 MLD generation), **only 100 MLD is actually treated** due to O&M budget constraints, aging infrastructure, and missing sewer connections. This means **190 MLD untreated sewage enters Khan River daily** — the core pollution source requiring interception for river rejuvenation.

Vision Kanh proposes **11 decentralised STPs totaling 90 MLD capacity** at strategic locations (Zoo/IMC Ground 35 MLD, Prateek Setu 8 MLD, Nahar Bhandara 11 MLD, etc.) to intercept sewage before river entry. Treated effluent can supply constructed wetlands and BGI irrigation, closing the water loop.

Stormwater Drainage

As detailed in Section 4.7, Indore has a **93.41% gap in underground SWD coverage** with zero coverage in the ABD area. The existing 126 km of drains are:

- Undersized (designed for 12–20 mm/hr vs. actual 80–120 mm/hr events)
- Poorly maintained (siltation reduces capacity by 30–50%)
- Mixed with sewage (60% drains carry combined flow)

IMC approved ₹200 crore in 2019 for SWD improvements but progress has been slow. The **BGI approach offers a cost-effective alternative** to 100% grey pipe infrastructure — targeting 60–70% coverage through pipes for primary conveyance and 30–40% through surface BGI features (bioswales, retention streets, detention basins).

Transport Infrastructure

Mode	Network/Status	Ridership/Capacity
Metro Rail	31.5 km (2 corridors); operational 2024	300,000 passengers/day target
BRTS (Ahilya Path)	11.7 km corridor; being dismantled (Nov 2025)	70,000 passengers/day (peak)
Road network	1,912 km; includes 6-lane Ring Road	High congestion in core
Public buses	350 buses (iBus fleet)	200,000 passengers/day

The Indore Metro (India's 18th metro system) became operational in 2024, connecting major nodes with multimodal integration at Railway Station and BRTS stations. However, the **BRTS corridor is being dismantled** following High Court directive and CM announcement (Oct-Nov 2025) due to traffic congestion concerns. The bus service continues but the dedicated corridor infrastructure is being removed and redesigned.

BGI integration opportunity: Metro stations and former BRTS corridors can incorporate rain gardens, permeable hardscaping, and street tree bioswales as demonstration sites with high public visibility.

4.10 Smart City Area-Based Development (ABD) — Rajwada Precinct

Indore was selected under the Smart Cities Mission in 2016 with a total project cost of ₹1,700 crore. The **Area-Based Development (ABD)** spans **742 acres (300 Ha)** in the historic city core, bounded by:

- **East:** Khan & Saraswati rivers confluence
- **West:** Mahatma Gandhi Road
- **North:** Railway station
- **South:** Treasure Island junction

ABD Demographics & Land Use

Parameter	Value
ABD area	742 acres (300 Ha)
Population	150,000
Density	50,000/sq.km
Households	25,000
Land use: Residential	45%
Land use: Commercial	28%
Land use: Mixed-use	15%
Land use: Public/Institutional	7%
Land use: Open/Green	4% (6 Ha)
Rivers (Khan-Saraswati)	2% (6 Ha)

Critical Infrastructure Gaps in ABD

Stormwater drainage: The ABD area has **zero underground stormwater drainage**. All stormwater currently flows through open roadside drains → nallahs → directly into Khan-Saraswati rivers carrying garbage and sewage. This creates:

- Chronic waterlogging at 15+ low-lying points during monsoon
- Combined sewage overflow public health hazards

- Direct pollution loading to rivers

Smart City ABD Initiatives

The Smart City proposal prioritizes **Khan-Saraswati Riverfront Development** as the flagship blue-green project:

Zoning framework:

1. **Urban Heritage Zone (riverfront ghats):** Landscaped gardens, cultural spaces, heritage interpretation
2. **Recreational Green Zone (RG):** Greenways, children's play areas, kiosks; FSI capped at 0.05

Provisions:

- Continuous promenade along 2.5 km river stretch
- Underground parking (50% of RG plot + 100% of commercial zone)
- Pedestrian bridges connecting both banks
- Cultural nodes at Rajwada, Khajuri Bazaar, Kabutarkhana

Funding allocation: ₹180 crore for riverfront (Phase 1: 1 km stretch from Kishanpura Chhatri to Rajwada Chowk).

BGI integration gap: Current ABD plan focuses on aesthetic greening but lacks functional stormwater management design. The thesis proposes integrating **bioswales, detention basins, constructed wetlands, and permeable paving** into the riverfront design to simultaneously achieve recreation, water quality, and flood mitigation goals.

4.11 Economic Profile

Indore serves as the financial and commercial hub of central India with a robust and diversified economy:

Economic Indicator	Value (2025)	Rank/Comparison
Nominal GDP	₹90,000 Cr (~\$11 B)	35% of MP state GDP
Per capita GDP	₹2.52 lakh	2× MP state average

Major sectors	IT/ITeS (18%), Auto/Engg (22%), Pharma (12%), Trade (28%)	Diversified base
Employment	1.2 million (formal+informal)	Unemployment <4%
FDI inflow	₹2,500 Cr/year	Tier-2 city leader

Indore hosts **3 Special Economic Zones (SEZs)**, 2 IT parks, and the Pithampur auto cluster (Asia's largest automobile hub with Tata, Mahindra, Eicher presence). This industrial base has driven population growth but also increased impervious surface cover and stormwater runoff.

Fiscal capacity for BGI: IMC's annual budget (2024-25) is ₹4,200 crore with capital expenditure allocation of ₹1,800 crore. Property tax collection has grown at 12% CAGR (2015–2025), creating fiscal space for **land value capture financing** and **stormwater utility fees** to fund BGI infrastructure.

4.12 Vision Kanh: River Restoration Framework (cGanga/NMCG/IMC, 2020)

Vision Kanh is a comprehensive river rejuvenation strategy document prepared collaboratively by the Centre for Ganga River Basin Management & Studies (cGanga, IIT Kanpur), National Mission for Clean Ganga (NMCG), and Indore Municipal Corporation in 2020. It provides the most authoritative policy framework for Indore's blue infrastructure.

Restoration Targets (4-Stage Pathway)

Stage	Target	Timeline	Success Criteria
Stage 1: Structural Integrity	Channel stabilization; sewage interception	2021–2024	Zero raw sewage inflow
Stage 2: Aesthetic Satisfaction	BOD <10 mg/L; DO >4 mg/L	2024–2027	Visual clarity; no odour
Stage 3: Recreational Satisfaction	Balneological quality (fecal coliform <500 MPN/100ml)	2027–2030	Safe for water contact
Stage 4: Native Biodiversity	Fish diversity index >0.6; riparian vegetation cover >60%	Post-2030	Ecological self-sustenance

Key Technical Interventions

1. Decentralised Sewage Treatment Plants (11 proposed):

Location	Capacity (MLD)	Catchment Served
Zoo/IMC Ground	35	Central zones
Prateek Setu	8	Kaliasot nallah
Nahar Bhandara	11	ABD area
Rau Junction	6	Peripheral colonies
Others (7 sites)	30	Distributed
Total	90 MLD	47% of gap closure

2. Constructed Wetlands: Proposed at STP outlets for tertiary polishing before river discharge; 12–15 Ha total area required.

3. Floodplain Protection: Vision Kanh mandates:

- **Immediate:** 30 m channel width (15 m each bank) kept free from constructions
- **5-year goal:** 5–10-year return flood risk-free floodway
- **Long-term:** 25–50-year return flood floodplain with natural vegetal cover

This aligns with BGI buffer zones and provides legal backing for encroachment removal.

Institutional Framework: Kanh River Basin Organization (KRBO)

Vision Kanh proposes establishing a **Kanh River Basin Organization (KRBO)** with multi-stakeholder representation:

- IMC (lead agency)
- Madhya Pradesh Pollution Control Board (MPPCB)
- MP Water Resources Department
- Indore Development Authority (IDA)
- NGO/community representatives
- Academic/technical advisors

KRBO would function as the **coordinating body for integrated water resource management**, directly relevant for BGI implementation governance.

4.13 Vulnerability Synthesis: Flood, Heat, Water Stress

Indore faces a confluence of urban environmental vulnerabilities that BGI can simultaneously address:

Table 17: Vulnerability Synthesis: Flood, Heat, Water Stress

Vulnerability	Exposure	Sensitivity	Adaptive Capacity	Overall Risk
Pluvial flooding	93.41% SWD gap; 30% population affected	High density; impervious surfaces	Low (no functional SWD)	CRITICAL
Urban heat island	3–5°C above rural; summer peaks 42–45°C	Low green cover (1.9 sq.m usable/capita)	Moderate (tree planting initiatives)	HIGH
Groundwater depletion	148% exploitation; 0.5–1 m/yr decline	Black cotton soil (low recharge)	Low (no managed aquifer recharge)	HIGH
River pollution	190 MLD untreated sewage; BOD 35–60 mg/L	Direct sewage discharge	Moderate (Vision Kanh framework)	CRITICAL
Loss of biodiversity	53% water bodies lost; 7% forest cover decline	Habitat fragmentation	Low	MODERATE-HIGH

Spatial Overlay of Vulnerabilities

High-risk zones where multiple vulnerabilities overlap:

- **Eastern wards (76–85):** Flood-prone + zero green space + slum density
- **ABD core:** Flood + heat island + zero SWD + river pollution interface
- **Peri-urban southwest:** Groundwater stress + forest loss + unplanned sprawl

These hotspots should be **priority intervention zones** for BGI demonstration projects.

4.14 BGI Planning Implications: Baseline to Strategy

The study area profile reveals five critical planning imperatives:

1. Stormwater Infrastructure Deficit as Opportunity

The 93.41% SWD gap, rather than being addressed solely through conventional grey infrastructure (estimated ₹8,000–10,000 crore for 100% pipe coverage), presents an opportunity for **hybrid grey-green systems** achieving 60–70% coverage through pipes + 30–40% through surface BGI at **40–50% lower lifecycle cost**.

2. River Corridor as Blue-Green Spine

The Khan–Saraswati confluence (21 + 12 = 33 km within city limits) provides a **continuous ecological corridor** if restored per Vision Kanh targets. Integrating constructed wetlands, riparian buffers, and floodplain forests can create a city-scale blue-green network anchoring neighbourhood-level BGI.

3. Climate Adaptation Imperative

Projected increases in extreme rainfall intensity (+10–15%) and urban heat (+1.5–2.5°C) by 2050 make climate-adaptive BGI non-negotiable. Conventional drainage sized for current 1-year storms will be obsolete; BGI provides **flexibility and resilience** through distributed storage and infiltration.

4. Equity and Informal Settlement Integration

With 15–18% slum population concentrated in flood-prone riverbanks and eastern wards, BGI planning must adopt a **pro-poor lens**. Participatory designs (learning from Chennai's Buckingham Canal model) ensuring tenure security and livelihood protection are essential.

5. Institutional Readiness and Financing Innovation

Smart City ABD infrastructure, AMRUT 2.0 funding (₹1,073 Cr water project secured), and Vision Kanh framework create an **enabling environment**. The thesis must leverage these platforms while proposing innovative financing (land value capture from riverfront real estate, stormwater utility fee, green bonds) to ensure long-term O&M sustainability.

CHAPTER 5: DATA COLLECTION AND ANALYSIS

5.1 Introduction

This chapter presents the data collection and analytical procedures employed to assess stormwater-related vulnerabilities in Indore and to identify spatial opportunities for integrated blue–green infrastructure (BGI). The study combines primary data (field observations, soil-infiltration measurements, and environmental sampling) with secondary datasets (municipal records, satellite imagery, hydrometeorological series, and environmental quality data) and applies them through a Geographic Information System (GIS)– and hydrology-based framework. The approach is designed to produce robust spatial outputs—such as vulnerability and suitability maps—that directly inform the formulation of the BGI plan.

5.2 Data Collection

5.2.1 Location and Condition of Existing Drainage Infrastructure

Information on Indore’s stormwater drainage infrastructure was obtained from the Indore Municipal Corporation (IMC) and verified through field reconnaissance. According to Smart City documentation, Indore currently has approximately 126.1 km of underground stormwater drains against a total existing road length of about 1,912.2 km, corresponding to only 6.59 percent coverage and leaving a gap of 93.41 percent. The remainder of the network relies on roadside open drains and natural watercourses (nallahs and rivers), which frequently carry stormwater mixed with sewage and solid

waste.

The map of **Indore city** presents a formal visualization of its **zoning divisions, hydrological assets, and supporting infrastructure**. It delineates the city into **five distinct zones (Zone-1 to Zone-5)**, each represented with separate colors, thereby clarifying spatial organization. Prominent

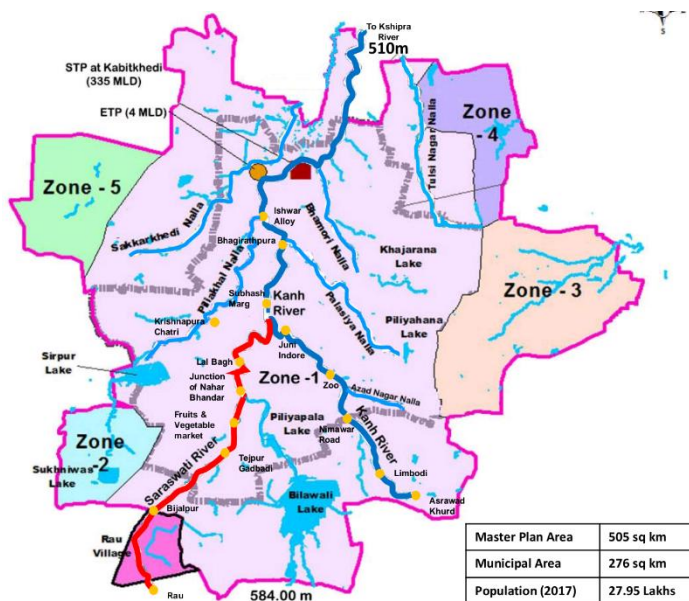


Figure 9: MAP: INDORE EXISTING CANAL NETWORK

hydrological features include the **Kanh River** and **Saraswati River**, which traverse the city, along with key lakes such as **Sirpur, Bilawali, Khajrana, Piliyahana, and Sukhniwas**. These water systems are integrated with the drainage network, highlighting their role in stormwater management.

The map also identifies **critical infrastructure facilities**, notably the **Sewage Treatment Plant (STP) at Kabitkhedi with a capacity of 335 MLD** and an **Effluent Treatment Plant (ETP of 4 MLD)**, reflecting ongoing wastewater management efforts. Elevation points (510 m and 584 m) provide topographical context, while the legend specifies the **Master Plan Area (505 sq km), Municipal Area (276 sq km), and population of 27.95 lakhs (2017)**.

Field inspections were conducted in representative wards, along arterial roads, and near known waterlogging locations to record the actual condition of drains, culverts, manholes, and outfalls. Observations included the presence of silt and debris, structural defects such as cracked walls and missing covers, encroachments over open drains, and cases where newly constructed roads obstruct natural drainage paths, all of which contribute to reduced hydraulic capacity and frequent ponding during intense rainfall events. These findings were used to update and refine the drainage layers in the GIS database.

5.2.2 Land Use and Land Cover Analysis

The Land Use and Land Cover (LULC) distribution of Indore reveals a clear picture of the city's urban and ecological dynamics. Built-up areas account for **51.8%**, underscoring the intensity of rapid urbanization and expansion. **Barren land**, at **10.7%**, remains a notable share, suggesting opportunities for ecological restoration or planned development. **Agriculture**, covering **16.5%**, reflects the persistence of peri-urban farming zones that support food security and livelihoods. **Vegetation**, at only **9.4%**, highlights the limited green cover and the pressing need to expand urban greenery. Meanwhile, **waterbodies** occupy **11.6%**, serving as vital assets for blue-green infrastructure and stormwater management.

This distribution illustrates the interaction between urban growth and ecological resources. Strengthening vegetation cover and strategically linking waterbodies through green corridors can enhance climate resilience, improve stormwater management, and support Indore's transition toward an integrated blue-green infrastructure framework. Such measures would balance development pressures with ecological sustainability, ensuring long-term urban resilience.

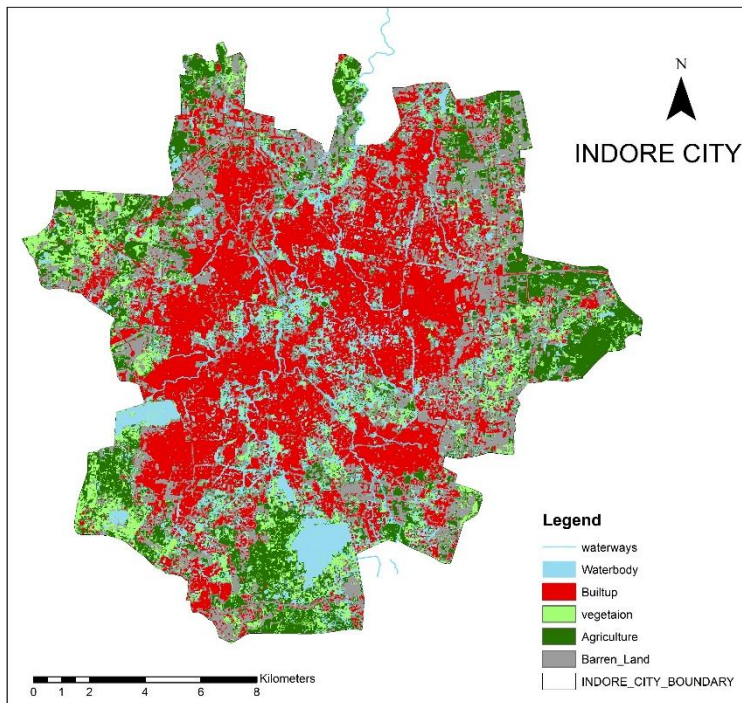


Figure 10 MAP: LULC OF INDORE (2025)

Land use and land cover (LULC) were analysed using multi-temporal satellite imagery and existing classified datasets for at least two time points between 2000 and 2025. Imagery from medium-resolution sensors such as Landsat and Sentinel-2 was pre-processed and classified into key categories: built-up

(residential, commercial, industrial), transportation (roads and rail), vegetation (urban green spaces, agricultural land), water bodies (rivers, lakes, ponds), and open/barren land.

The classified layers were validated using ground observations and high-resolution basemaps where available, and then used to compute class-wise areas and changes over time. In line with patterns observed for other rapidly urbanising Indian cities, preliminary analysis indicates significant conversion of vegetated and open land to built-up surfaces, particularly in peri-urban areas and along main corridors, increasing overall imperviousness and hence stormwater runoff. These LULC results feed directly into runoff-coefficient assignment and the multi-criteria flood-vulnerability assessment.

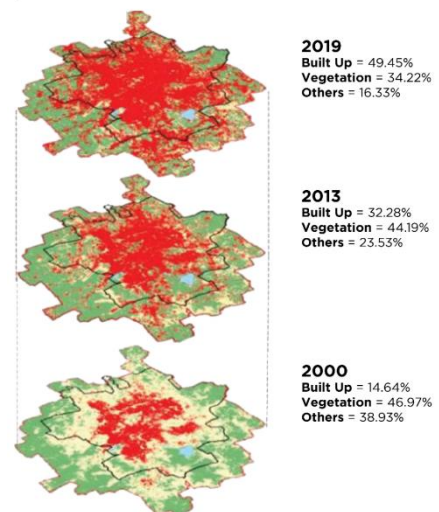


Figure 11 MAP: LULC OF YEAR 2000, YEAR 2013, YEAR 2019

5.2.3 Soil Infiltration Testing (Double-Ring Infiltrometer)

To characterise infiltration capacity under local soil conditions, double-ring infiltrometer tests were conducted at selected sites representing different land uses and soil types, with an emphasis on black-cotton (regur) soils that dominate the Malwa Plateau region on which Indore is located. Published infiltration studies on black-cotton

soils in India report constant infiltration rates typically in the range of 1.1–1.5 cm/hr under various tillage and moisture conditions, with high initial rates that diminish to a steady value over time.

Field measurements from the study are interpreted in conjunction with this literature to derive realistic design infiltration rates for BGI elements such as rain gardens, bioswales, infiltration trenches, and permeable pavements. Sites where measured infiltration is very low or where high swelling potential is expected are flagged as locations where fully infiltration-based systems may be unsuitable without underdrains or sub-surface storage.

5.3 Data Analysis

The present study on Indore City is framed around the need to respond to increasing urban flood vulnerability, ecological degradation, and climate stress through an integrated blue-green infrastructure approach. The document establishes that Indore is experiencing a severe mismatch between rapid urban expansion and the capacity of its natural and engineered stormwater systems, particularly in relation to drainage coverage, river health, green-space availability, and groundwater balance.

This section presents the dissertation-style synthesis of that process by organizing the material into four interrelated components: data collection, analytical methods, findings, and proposals. It also demonstrates how the maps prepared in the study are not merely illustrative outputs, but analytical tools through which hydrological, ecological, and urban development problems are identified and translated into planning interventions.

5.2.3 GIS Multi-Criteria Flood Vulnerability Assessment

A GIS-based multi-criteria flood-vulnerability assessment was implemented to identify areas most susceptible to pluvial flooding and waterlogging. The analysis used several spatial criteria: elevation and slope derived from DEM; percentage imperviousness estimated from LULC; drainage density (length of drains and streams per unit area); distance to nearest drain, nallah, or river; and socio-economic indicators such as population density and presence of informal settlements.

Each criterion was converted to a standardised (0–1) scale and weighted based on literature and expert judgement, following methods used in comparable urban BGI and vulnerability studies. The criteria were then combined to generate a composite vulnerability index, which was classified into very low, low, moderate, high, and very

high vulnerability classes. The resulting maps reveal concentrations of high vulnerability in low-lying, densely built wards with poor drainage coverage and along encroached nallahs and riverbanks, corroborating municipal records of waterlogging.

5.2.4 LULC Change Detection (2005–2025)

Change detection was carried out by comparing classified LULC maps from earlier (circa 2005) and recent (circa 2025) years. Cross-tabulation of classes quantified area transitions such as vegetation/agriculture to built-up, open land to built-up, and water body to other uses. Spatial visualisation of these changes demonstrates the direction of urban expansion—often outward from the core towards the periphery and along transport corridors—and highlights zones where the loss of natural or semi-natural cover coincides with the emergence of flood hotspots identified in the vulnerability analysis.

These findings align with broader evidence that urbanisation and associated increases in impervious surfaces can significantly enhance runoff volumes and peak flows, thereby exacerbating pluvial flooding risks if drainage infrastructure and BGI measures are not upgraded in parallel.

5.2.5 NDVI and Land Surface Temperature Analysis

Vegetation health and density were assessed using Normalised Difference Vegetation Index (NDVI) derived from multispectral satellite imagery, while land-surface temperature (LST) was estimated from thermal bands of sensors such as Landsat, following standard remote-sensing procedures. NDVI values were classified into low, medium, and high vegetation categories, and LST maps were categorised into cool, moderate, and hot zones.

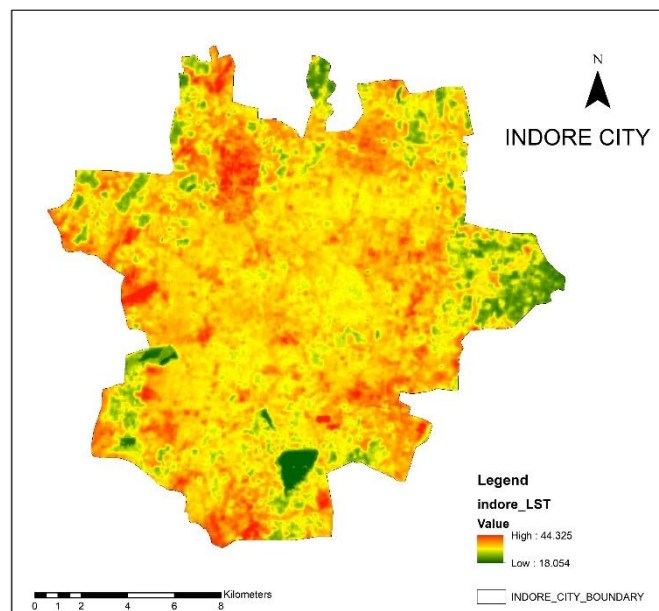


Figure 12 Map: Land Surface Temperature (2026)

The map shows temperature variation across the city, using a gradient from green (cooler areas around 18 °C) to red (hotter areas up to 44 °C). The white outline marks the city boundary, highlighting how heat differs across urban zones. Red hotspots reveal

urban heat islands, while green zones indicate cooling effects from vegetation or water. This visualization is a valuable tool for assessing climate stress and guiding blue–green infrastructure planning to reduce heat and manage stormwater effectively.

Overlaying NDVI and LST with urban land-use and vulnerability layers highlights neighbourhoods that simultaneously experience high flood risk, low green cover, and elevated surface temperatures—indicative of urban heat islands. These areas are prioritised for BGI interventions such as tree planting, bioswale-lined streets, and park-based detention, which can provide combined benefits of stormwater management and thermal comfort.

Indore city currently possesses a total green area of **10.08 sq.m**, which constitutes only

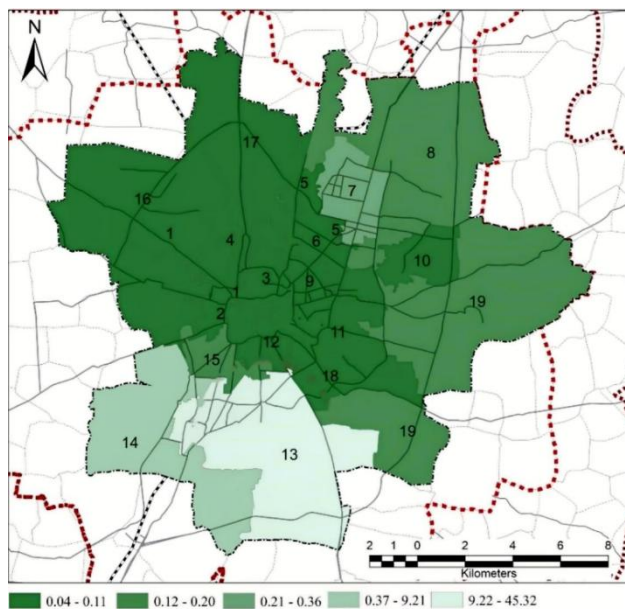


Figure 13 MAP : Map of Indore showing zones with per capita green spaces

3.6% of the total land area. This figure is significantly lower than the **URDPFI guidelines**, which recommend **9–12 sq.m of green space per person**. The overall per capita green space in the municipal area stands at **3.48 sq.m**, further emphasizing the shortfall in meeting national standards.

The limited availability of green space reduces the city’s capacity to absorb rainfall, resulting in higher runoff and increased flooding risks.

Parks and vegetated zones act as natural sponges, easing stormwater pressure on the drainage network. Strengthening the link between **blue systems**—such as rivers and lakes—and green corridors can enhance water flow, storage, and ecological balance. In high-density urban zones, targeted green infrastructure is essential to offset stormwater loads. Expanding green cover through climate-sensitive design not only improves groundwater recharge and reduces waterlogging but also supports long-term resilience. Mapping these deficiencies highlights priority zones where integrating green spaces with natural drainage systems is urgently required, thereby advancing Indore’s transition toward sustainable and climate-resilient urban planning.

5.2.6 Blue-Green Network Connectivity Analysis

The existing blue-green network—comprising rivers (Kanh, Saraswati), nallahs, lakes, ponds, major parks, and large institutional green spaces—was mapped and analysed to evaluate its connectivity. Drawing on BGI network literature, simple graph-based metrics and connectivity analysis were used to identify “gaps” where water bodies and green spaces are spatially close but not functionally connected (e.g. separated by major roads without green links or bordered by hard, impermeable edges).

These analyses highlight specific opportunities to create or enhance blue-green corridors—for example, by greening selected streets between isolated parks and rivers, or by rehabilitating segments of nallahs to function as linear greenways—thereby improving both hydrological pathways and ecological networks across the city.

Indore’s hydrological setting is shaped by three major watersheds—**Shipra, Gambhira, and Sarasvati-Kahn**—which play a critical role in the city’s water systems. The **Kahn and Sarasvati Rivers**, flowing through the central part of the city, historically served as important freshwater sources. However, since the early 1990s, these rivers have been burdened with sewage inflows, resulting in significant ecological degradation. In response, **restoration initiatives under the Indore Smart City Mission**

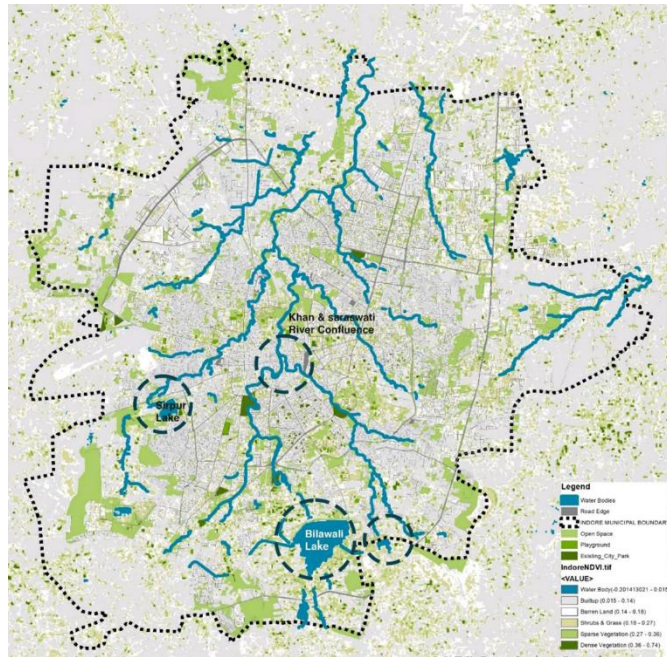


Figure 14 MAP : Blue Green Networks Indore

are underway, aiming to revive river health and integrate these systems into sustainable urban planning.

From an analytical perspective, the hydrological map underscores the **interconnectedness of water systems and green spaces**, forming the foundation of Indore’s emerging blue-green infrastructure. It highlights opportunities for ecological restoration and flood management through integrated planning approaches. Importantly, the map demonstrates how natural water systems, when linked with green

assets, can be leveraged to enhance urban resilience, improve ecological balance, and elevate the overall quality of life in Indore.

5.4 Hydrological Analysis

5.4.1 Rainfall and IDF Curves (IMD Data)

Rainfall data for Indore and neighbouring stations were collated from the India Meteorological Department (IMD) and other government sources. The Malwa Plateau region, including Indore, typically receives 900–1,200 mm of rainfall annually, concentrated in the southwest monsoon (June–September), with long dry months in the rest of the year. Recent events such as the heavy rains in September 2023, when around 10 inches (~254 mm) fell within roughly 24 hours leading to widespread waterlogging and emergency rescues, illustrate the intensity of short-duration storms that must be considered in design.

Intensity–Duration–Frequency (IDF) curves were either obtained from IMD or derived from long-term records to estimate rainfall intensities for different durations and return periods (e.g. 1-in-2-year, 1-in-5-year, 1-in-10-year events), providing key input for sizing BGI storage and drainage elements.

5.4.2 Runoff Estimation (Rational Method)

For small to medium urban sub-catchments relevant to road corridors, neighbourhoods, and pilot sites, peak runoff was estimated using the Rational Method, $Q = CiA$, where C is the runoff coefficient, i is rainfall intensity derived from IDF curves, and A is catchment area. Runoff coefficients were assigned based on local LULC (higher for concrete and asphalt surfaces, lower for vegetated or pervious areas), informed by standard values from design manuals and adapted to Indore's conditions. These peak-flow estimates were used to define target storage volumes and conveyance capacities for proposed BGI features. For example, many green-infrastructure guidelines recommend capturing the first 20–25 mm of rainfall from contributing impervious surfaces as a design basis for rain gardens and bioswales, which significantly reduces runoff peaks and pollutant loads during frequent storms.

5.4.3 Drainage Density and Catchment Delineation

Using DEM data, flow direction and accumulation rasters were generated to delineate urban sub-catchments that drain to specific river reaches, lakes, and critical outfalls. Drainage density—total length of natural channels and constructed drains per unit

area—was computed for each sub-catchment, allowing identification of areas where drainage coverage is sparse relative to imperviousness and runoff potential.

Sub-catchments exhibiting high imperviousness, low drainage density, and high population density were flagged as structurally vulnerable to pluvial flooding and were prioritised for either conventional drainage augmentation or BGI interventions such as sponge corridors, detention basins, and increased infiltration capacity.

5.5 Environmental Quality Assessment

5.5.1 Air Quality (PM2.5, PM10)

Air-quality analysis incorporated data from the Madhya Pradesh Pollution Control Board and model-based assessments. UrbanEmissions modelling for 2015 indicates that Indore's average ambient PM2.5 concentration is approximately $66.3 \pm 12.3 \mu\text{g}/\text{m}^3$, exceeding the Indian annual standard of $40 \mu\text{g}/\text{m}^3$ and more than six times higher than the earlier WHO guideline of $10 \mu\text{g}/\text{m}^3$. PM10 averages in the early 2010s were reported in the range of $125\text{--}140 \mu\text{g}/\text{m}^3$, above national standards. Seasonal variations show significantly higher pollutant levels in winter compared to monsoon, linked predominantly to transport emissions, domestic combustion, and waste burning.

Although air quality is not the primary focus of this study, these data are important because BGI measures (street trees, parks, wetlands) can contribute to particulate deposition and local microclimate improvement, offering co-benefits beyond flood management.

5.5.2 Water Quality (Kanh-Saraswati Rivers)

Water-quality assessments of the Kanh (Khan) River and connected nallahs were compiled from Pollution Control Board reports and specific water-quality studies. Samples collected from over 20 locations along the Kanh in 2022–2023 reported biochemical oxygen demand (BOD) levels ranging from 2.6 mg/L to as high as 46 mg/L at Juni Indore, far above the 3 mg/L benchmark for bathing water quality and indicative of heavy sewage contamination. Action plans for rejuvenation of Kanh classify it as a severely polluted river stretch requiring sewage interception, treatment, and maintenance of adequate flow for dilution.

These data confirm that Kanh and many of its tributary nallahs function largely as open sewers within urban limits, underlining the need to integrate BGI measures with sewer-network expansion and decentralised treatment to improve water quality in addition to flood management.

5.5.3 Soil Characteristics (Infiltration, Black Cotton Soil)

As part of the larger Malwa Plateau, Indore's hinterland is dominated by deep black-cotton soils formed from basaltic parent material. These soils are characterised by high clay content, high shrink–swell potential, good moisture retention, and relatively low steady-state infiltration rates compared to sandy or loamy soils. Experimental studies on black-cotton soils in India report steady infiltration rates in the order of 1.1–1.5 cm/hr under various management conditions, although initial rates may be much higher.

Combining these published values with in situ infiltration measurements enables the study to assign realistic design parameters for BGI features and to distinguish between locations where infiltration-dominant measures are appropriate and those where hybrid or detention-dominant designs would be more reliable.

5.6 Historical Flood and Waterlogging Records

Historical flood and waterlogging information were collated from IMC records, vulnerability studies, and media reports. IMC and associated assessments identify over 100 low-lying areas within the city that are particularly prone to waterlogging during the monsoon season. Events such as the September 2023 heavy rainfall, when about 10 inches (~254 mm) of rain within roughly 24 hours caused inundation in multiple localities and required rescue operations by disaster-response teams, illustrate the acute impacts of intense short-duration storms in the context of inadequate drainage and encroached watercourses. These records were geo-referenced and used to validate the flood-vulnerability maps produced through GIS analysis.

5.7 Geographical Features

5.7.1 Topography and Slope Analysis (DEM)

Digital elevation models were used to characterise the urban topography of Indore. In keeping with Malwa Plateau characteristics, the city lies at an average elevation of approximately 500–600 m above mean sea level, with gentle regional slopes that generally favour north- or eastward drainage. Within the city, local variations in elevation

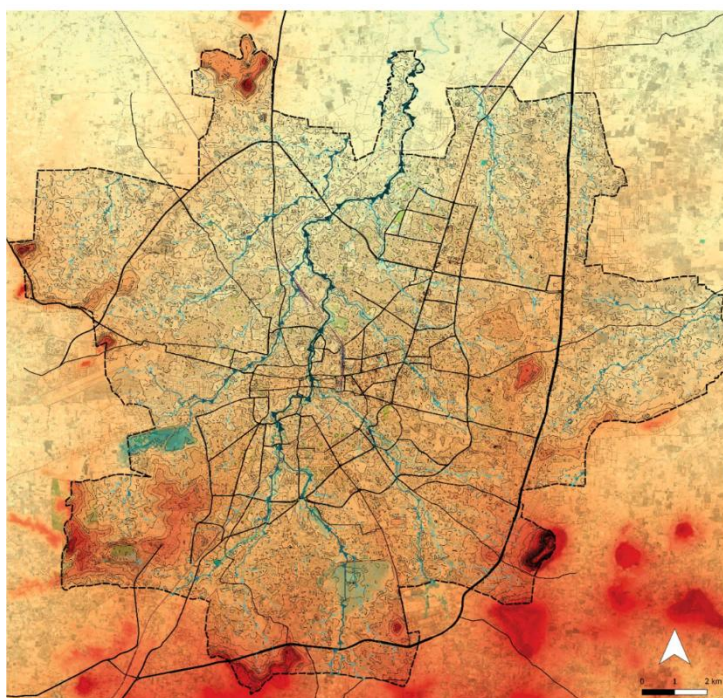


Figure 15 MAP: Topography of Indore

produce micro-depressions and subtle ridges; the former tend to accumulate runoff during intense rainfall events, while the latter influence flow paths and contributing catchment areas. Slope maps derived from DEM data guide the identification of natural flow corridors and potential sites for detention and BGI interventions

5.7.2 Natural Drains and Stream Network

The natural drainage network comprises a dendritic system of small streams and nallahs feeding into the Kanh and Saraswati rivers and, eventually, into larger basins such as the Shipra. Historical and recent mapping reveals that several natural drains have been narrowed, straightened, culverted, or partially filled due to urban development and encroachment, particularly in low-income settlements along channel margins. This has reduced conveyance capacity and disconnected former blue–green corridors. Analysis of continuity, encroachment, and opportunities for restoration allows identification of strategic nallah reaches where BGI-based corridor rehabilitation could simultaneously improve drainage, water quality, and public-space provision.

5.8 Area-Wise Problem Identification

The issue mapping in the study identifies several critical hotspot areas where spatial vulnerability, infrastructure deficiency, and environmental degradation converge. These hotspots help translate city-level findings into area-specific planning concerns.

The Khan River corridor emerges as one of the most critical zones in the study. Encroachment within the flood line, sewage discharge, channel narrowing, and the presence of vulnerable settlements along the banks have collectively reduced river capacity and

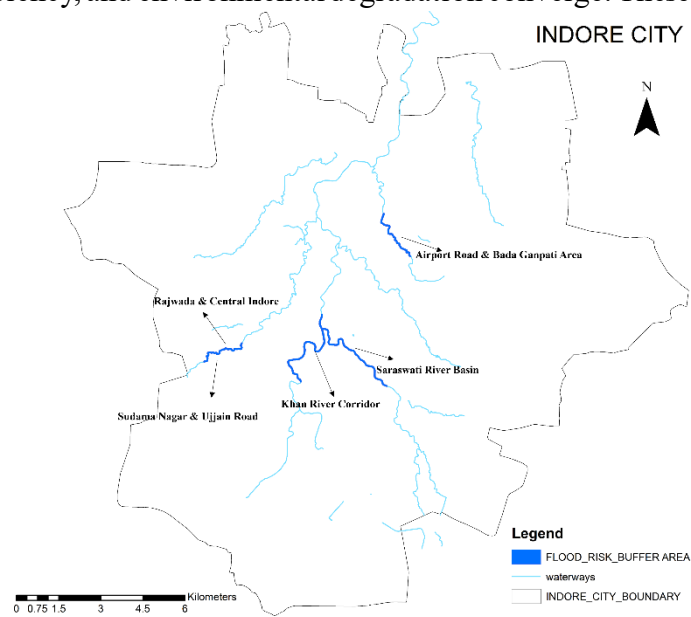


Figure 16 Map : Locations of flood Areas

increased flood risk. The corridor also illustrates how hydrological and social vulnerability overlap, as evacuation drives, mobility disruption, informal waste dumping, and poor environmental conditions coexist within the same spatial zone.

The Saraswati River basin reflects similar conditions of environmental decline and drainage blockage. Waste dumping, encroachments, blocked drains, and repeated flood vulnerability near ghat and settlement areas show that the basin is operating under severe ecological and hydrological stress. This area demonstrates the importance of treating rivers and nallahs not merely as drainage channels, but as multifunctional urban systems requiring restoration, protection, and regulatory control.

Rajwada and central Indore represent the historic and commercial core of the city, where waterlogging takes on an especially disruptive character. In this zone, congestion, high-intensity land use, minimal green cover, solid-waste accumulation, and inadequate stormwater infrastructure combine to generate recurrent flooding and traffic paralysis. The analysis suggests that in such compact inner-city areas, blue-green interventions must be carefully inserted into existing public realm and street systems rather than depending only on large-scale structural solutions.

Sudama Nagar, Ujjain Road, Airport Road, and Bada Ganpati are identified as flood-prone and low-lying areas with repeated monsoon inundation, mobility disruption, and infrastructure inadequacy. These sites illustrate the localized character of many stormwater problems in Indore and show why neighborhood-level and road-corridor-level interventions are essential alongside city-wide planning.

Linking Data Collection, Analysis, Findings and Issues

The most important academic contribution of the study lies in the way it establishes a clear relationship between the data collected, the analyses performed, the issues identified, and the proposals recommended. The process is not descriptive but inferential: datasets are interpreted through spatial and environmental analysis, and the resulting evidence is used to identify concrete planning problems and intervention opportunities.

For example, rainfall records, intensity trends, and climate projections explain the increasing pressure placed on the city during concentrated monsoon events. When these datasets are combined with DEM-based slope analysis, hydrological mapping, and drainage-network information, they reveal how and where runoff is likely to accumulate, which in turn helps identify flood-prone corridors and waterlogging hotspots.

Similarly, LULC analysis, NDVI, and green-space mapping demonstrate that vegetation loss and built-up expansion have reduced the city's natural sponge capacity. When interpreted alongside population density and infrastructure data, these findings show that the most vulnerable areas are often those with high urban intensity, low ecological cover, and inadequate drainage provision.

Water-quality data, river-corridor mapping, encroachment identification, and complaint records together explain why certain corridors function simultaneously as pollution channels, flood pathways, and socially vulnerable landscapes. This layered interpretation is what allows the study to move from broad statements about urban flooding to a precise diagnosis of area-wise and system-wise urban problems.

Thus, the connection between data collection and issue identification is direct. The data made it possible to understand not only where problems exist, but why they exist, how they are distributed spatially, and which underlying processes are responsible for them.

CHAPTER 6: PROPOSAL AND RECOMMENDATIONS

6.1 Introduction

This chapter presents the proposed integrated blue–green infrastructure (BGI) framework for Indore, based on the vulnerabilities and opportunities identified in the diagnostic analysis. The proposals are structured at three spatial scales—city, corridor, and site—and are supported by a typology-selection and sizing framework, hydrological design logic, and policy, institutional, financial, and community-engagement measures. The aim is to move from a predominantly grey and fragmented stormwater system towards a coherent blue–green–grey network that reduces flood risk, improves environmental quality, and enhances urban liveability and resilience.

6.2 Issues of High Concern

6.2.1 Flooding and Waterlogging Hotspots

GIS-based flood-vulnerability mapping and municipal records together identify more than 100 locations within Indore where even moderate to heavy rainfall leads to recurrent waterlogging, particularly in low-lying wards, along encroached nallahs, and at under-served road junctions. Events such as the September 2023 storm, when approximately 254 mm of rainfall fell in about 24 hours and required emergency rescues from flooded settlements and riverbank areas, illustrate the city’s exposure to short-duration, high-intensity rainfall and the limitations of the existing drainage system. High-vulnerability zones often coincide with dense residential neighbourhoods, informal settlements, and critical mobility corridors, amplifying socio-economic impacts.

6.2.2 River Pollution and Ecological Degradation

Kanh (Khan) and Saraswati rivers, which could function as primary blue corridors for stormwater conveyance and ecological services, currently receive large volumes of untreated sewage and solid waste, leading to severe water-quality degradation. Monitoring in 2022–2023 recorded BOD values along the Kanh ranging from around 2.6 mg/L to as high as 46 mg/L at Juni Indore, far exceeding the 3 mg/L standard for bathing water and indicating heavy organic pollution. Low dissolved oxygen levels and high coliform counts confirm that these rivers act as open sewers within city limits,

resulting in ecological collapse, foul odours, and public-health risks during flooding, when contaminated waters spread across settlements.

6.2.3 Inadequate Drainage Infrastructure (93.41% Gap)

According to Smart City documents, Indore has approximately 126.1 km of underground stormwater drains against a total road length of about 1,912.2 km, implying that only 6.59 percent of the road network is served by underground drains and leaving a coverage gap of 93.41 percent. The majority of stormwater is therefore conveyed through open roadside drains, informal channels, and natural streams, many of which are undersized, poorly maintained, or obstructed by encroachments and waste. This structural deficit means that high-intensity rainfall events quickly exceed system capacity, contributing to widespread ponding, damage to pavements and structures, and frequent disruption of mobility.

6.2.4 Loss of Blue–Green Spaces

Land-use change analysis between 2005 and 2025 shows substantial conversion of vegetated and open lands to built-up areas, particularly in peri-urban zones and along major transport corridors, resulting in increased imperviousness and reduced natural storage and infiltration capacity. Urban ponds and small tanks have been infilled or encroached, while riparian and roadside green strips have been fragmented or paved over, weakening the existing blue–green network. This loss of blue–green spaces not only contributes to greater stormwater runoff but also exacerbates heat-island effects and reduces habitat quality, undermining ecosystem services that could otherwise support climate resilience.

6.2.5 Institutional Fragmentation

Stormwater management, river health, land use regulation, and environmental quality are currently addressed by multiple agencies—Indore Municipal Corporation (IMC), Indore Development Authority (IDA), Indore Smart City Development Limited (ISCDL), Public Health Engineering Department (PHED), and the State Pollution Control Board—each with distinct mandates and data systems. Existing planning instruments such as the Master Plan, Smart City Proposals, and various sectoral schemes have not yet been fully integrated into a unified stormwater and BGI strategy, resulting in overlaps, gaps, and limited accountability for holistic outcomes. This institutional fragmentation is a major barrier to coordinated design, implementation, and maintenance of city-wide BGI.

6.3 Integrated Blue–Green Infrastructure Plan

6.3.1 City-Scale: Blue–Green Structure Plan

At the city scale, the proposal is to establish a blue–green structure that defines primary and secondary BGI corridors and key nodes across the entire municipal area. Primary corridors include the Kanh and Saraswati rivers, major nallahs, and the chains of lakes and ponds that form the backbone of the urban hydrological system; secondary corridors consist of strategically selected streets, minor drains, and greenways that connect these primary elements to neighbourhoods and institutional campuses.

The structure plan delineates priority zones for preserving and enhancing existing lakes and ponds as retention and recharge nodes, expanding and linking park systems, and greening roads in high-imperviousness, high-vulnerability areas. It also identifies potential “sponge districts” where a combination of plot-level, street-level, and park-level BGI measures can significantly reduce runoff and improve environmental quality.

6.3.2 Corridor-Scale: Kanh–Saraswati Special Area Plan

For the Kanh–Saraswati River corridor, a special area plan is proposed that integrates river restoration, flood-management, pollution control, and public-space enhancement. Building on existing rejuvenation action plans, the proposal includes intercepting dry-weather sewage flows and diverting them to existing or new sewage treatment plants, thereby reducing direct waste-water discharge into the river. Along key reaches, multi-functional riparian buffers are to be established, comprising linear constructed wetlands, floodable lawns, and tree belts that filter stormwater, provide temporary storage during high flows, and create ecological and recreational value.

The plan also seeks to redefine flood-plain zones by establishing minimum buffer widths (e.g. 15–30 m) from the river bank where only compatible uses such as parks, pathways, and low-impact amenities are permitted, in line with NDMA urban flood guidance and riverfront best practices. Strategic locations along the corridor are earmarked for water-sensitive public spaces—such as water squares and sponge parks—that can temporarily store excess runoff and serve as attractive community spaces in dry weather.

6.3.3 Site-Scale: Pilot BGI Interventions (5 Detailed Designs)

At the site scale, the plan proposes five detailed pilot interventions representing different urban typologies and challenges (e.g. arterial road prone to waterlogging, dense residential neighbourhood, commercial/market area, lake precinct, and nallah

restoration reach). Each pilot is designed as a “sponge landscape” that combines multiple BGI elements—rain gardens, bioswales, permeable pavements, detention basins, vegetated swales, and wetlands—tailored to local site conditions and constraints.

For example, a sponge corridor along a major road might integrate bioswales along shoulders, permeable parking bays, and enlarged tree pits with inlets from the carriageway; a neighbourhood sponge block could use pocket parks, rain gardens, and permeable lanes to manage runoff from rooftops and streets. These pilots serve as demonstrators of performance and social acceptability, and their monitoring will provide empirical evidence to refine and scale up similar interventions elsewhere in the city.

6.4 BGI Typology Selection and Sizing Framework

6.4.1 MCDA Scoring Matrix (12 BGI Types)

To ensure that appropriate BGI typologies are chosen for different urban and environmental contexts, a multi-criteria decision analysis (MCDA) framework is adopted, drawing on recent BGI suitability and network studies. Approximately 12 BGI types—such as rain gardens, bioswales, green roofs, permeable pavements, detention ponds, infiltration trenches, constructed wetlands, water squares, and tree trenches—are evaluated against a set of criteria including hydrological performance, land requirement, soil suitability, capital and maintenance costs, technical complexity, social acceptance, and co-benefits (e.g. urban cooling, biodiversity).

Each typology receives a score for each criterion and a composite score for different site-type categories (e.g. dense core, peri-urban, commercial corridor, lake buffer). The resulting matrix supports transparent, evidence-based selection of BGI elements for specific locations and scales.

6.4.2 Monsoon-Adapted Design Standards

BGI design standards must be adapted to Indore’s monsoon-dominated climate, with long dry periods and intense rainfall events. Internationally, many BGI guidelines aim to retain the first 10–30 mm of rainfall from impervious surfaces, which captures a large proportion of annual storm events and associated pollution; for Indore, retaining approximately 20–25 mm from typical contributing areas is proposed as a starting point, based on local rainfall patterns and soil-infiltration characteristics.

Design parameters also account for the observed intensities of short-duration storms from IMD IDF curves (e.g. 10–15minute intensities for 1-in-2-year and 1-in-5-year

events) and the lower steady-state infiltration rates of black-cotton soils. Safety factors are introduced in storage and overflow design to accommodate variability and the possibility of climate-related increases in extreme rainfall.

Proposal 1: Site-Scale Sponge City Pilot Interventions

Introduction to Site-Scale Proposals

The first proposal component focuses on site-scale pilot projects designed to demonstrate how blue-green infrastructure can function within different urban conditions in Indore. These pilots are particularly important because the city's stormwater challenges are spatially uneven and require localized, context-sensitive responses in addition to city-wide planning.

The document identifies five pilot types: arterial road sponge corridors, dense residential sponge blocks, commercial or market retrofits, lake precinct sponge parks, and nallah restoration reaches. Together, these interventions form a practical demonstration package that can be implemented in flood-prone areas, evaluated over monsoon cycles, and subsequently replicated across other wards of the city.

Rationale

The need for site-scale pilots emerges from the study's finding that several parts of Indore, including low-lying colonies, traffic corridors, commercial areas, lake edges, and polluted nallah stretches, experience recurring waterlogging and environmental stress. Because these areas differ in morphology and land use, the proposals emphasize tailored intervention types rather than a uniform design solution.

The pilots are also significant because they support proof-of-concept implementation. By creating visible and measurable interventions, they can help municipal agencies, local communities, and stakeholders understand the functioning, benefits, and maintenance requirements of blue-green infrastructure in real urban settings.

Components of the Site-Scale Proposal

The arterial road sponge corridor is proposed for major roads and junctions that experience repeated water accumulation and mobility disruption. Its main elements include bioswales, permeable parking bays, and enlarged tree pits, with the objective of reducing waterlogging, improving traffic conditions, and adding roadside greenery.

The dense residential sponge block is proposed for flood-prone colonies where open space is limited but neighborhood-level runoff control is necessary. Its elements include pocket parks, rain gardens, permeable lanes, and rooftop rainwater harvesting, intended to improve resilience at the settlement scale and encourage community-based maintenance.

The commercial or market retrofit is designed for high-intensity activity zones where ponding affects circulation, aesthetics, and economic continuity. It includes permeable pavements, tree

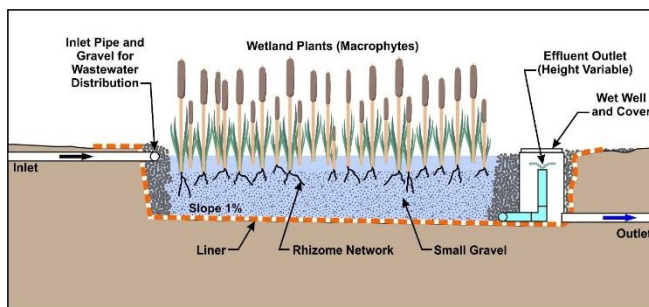


Figure 17 : Structure of Constructed wetlands (CW) . Source: US EPA

trenches, and underground storage, thereby combining hydrological improvement with commercial functionality.

The lake precinct sponge park is proposed as a hybrid ecological and recreational intervention around water bodies. It incorporates wetlands, detention ponds, vegetated swales, and water squares to promote runoff filtration, groundwater recharge support, biodiversity, and public-space creation.

The nallah restoration reach focuses on polluted drainage corridors and nallah edges. It includes riparian buffers, constructed wetlands, floodable lawns, and pathways, thereby integrating runoff treatment, ecological repair, encroachment control, and public accessibility.

Implementation Process

The study outlines a five-step implementation process for these pilots. The first step is site selection based on GIS vulnerability maps and hotspot identification, especially in waterlogging junctions, dense colonies, and polluted nallah stretches. The second step is co-design through participatory engagement with residents, shopkeepers, and municipal engineers so that interventions are contextually adapted and socially accepted.

The third step is design and sizing using the Rational Method and IDF curves to achieve a retention target of 20 to 25mm. The fourth step is construction and monitoring using

signage, rain gauges, water loggers, and community oversight. The fifth step is evaluation and scaling, in which hydrological, ecological, and social performance are monitored for two to three monsoon cycles before replication in other wards.

Expected Outcomes

The site-scale pilots are expected to reduce local waterlogging, improve runoff capture and infiltration, strengthen urban greenery, and demonstrate the feasibility of decentralized blue-green systems in Indore. In addition, these pilots are expected to create measurable evidence for future scaling and provide design references for mainstreaming BGI into standard municipal works.

Indicative Cost Range

Pilot Type	Main Elements	Indicative Cost Range
Arterial Road Sponge Corridor	Bioswales, permeable parking, tree pits	₹25–40 lakh
Dense Residential Sponge Block	Pocket parks, rain gardens, permeable lanes, rooftop harvesting	₹15–25 lakh
Commercial/Market Retrofit	Permeable pavements, tree trenches, underground storage	₹30–50 lakh
Lake Precinct Sponge Park	Wetlands, detention ponds, vegetated swales, water squares	₹75–120 lakh
Nallah Restoration Reach	Riparian buffers, constructed wetlands, floodable lawns, pathways	₹1–2 crore

Proposal 2: Policy and Institutional Reforms

Introduction to Policy Reform

The second proposal recognizes that blue-green infrastructure cannot succeed through physical design alone. The study explicitly proposes policy, institutional, financial, and monitoring reforms to ensure that blue-green systems are embedded within planning regulations, municipal finance, and implementation structures.

These reforms are particularly important because Indore’s stormwater issues are linked not only to physical deficits but also to fragmented institutional responsibility, weak

enforcement, lack of dedicated financing, and limited long-term monitoring. Therefore, the policy proposal is designed to create an enabling framework for implementation, regulation, and accountability.

Key Reform Measures

The first reform proposed is a stormwater utility fee framework based on impervious area, with incentives and rebates for certified blue-green infrastructure adoption. This mechanism is intended to create a sustainable and dedicated financial base for stormwater management while encouraging private actors to participate in runoff reduction.

The second reform is riverfront buffer-zone enforcement. This involves demarcating no-build zones, relocating high-risk settlements where necessary, and integrating wetlands, riparian parks, and ecological open spaces within the protected buffer. This measure is expected to reduce flood risk, protect river corridors, and restore environmental quality.

The third reform is the use of public-private partnership models for eco-parks, green parking, mixed-use projects, and other BGI-linked development initiatives. Such partnerships are intended to mobilize private capital, share implementation responsibility, and accelerate delivery of visible urban ecological projects.

The fourth reform is a monitoring and evaluation framework that tracks hydrological, ecological, and social indicators through sensors, citizen reporting, remote sensing, and annual review mechanisms. This reform is essential to move BGI from one-time intervention to adaptive urban management.

Stakeholders and Institutional Structure

The proposal indicates that implementation would involve municipal finance and engineering departments, IT consultants, academic institutions, NGOs, local communities, IDA, state pollution control authorities, NDMA-linked agencies, and a dedicated special purpose institutional mechanism such as an Indore BGI Corporation or SPV. This institutional arrangement is intended to clarify responsibility and improve coordination between planning, engineering, environmental regulation, and community participation.

Indicative Cost Range

Reform	Key Activities	Indicative Cost Range
Stormwater Utility Fee Framework	Fee design, GIS mapping, billing integration, rebate system	₹1–2 crore
Riverfront Buffer Zone Enforcement	Surveys, legal action, relocation, wetlands/parks	₹10–20 crore
Public-Private Partnership Models	PPP structuring, eco-parks, green parking, mixed-use BGI projects	₹5–15 crore
Monitoring and Evaluation Framework	Sensors, apps, surveys, remote sensing, reporting	₹2–4 crore

Expected Outcomes

The policy and institutional reforms are expected to create regulatory backing, financial continuity, implementation clarity, and long-term performance tracking for blue-green infrastructure. More importantly, they support the transition from isolated pilot projects to an institutionalized urban resilience framework integrated into regular planning and budgeting systems.

Proposal 3: City-Scale Blue-Green Structure Plan

Introduction to the City-Scale Proposal

The third proposal forms the strategic backbone of the overall planning framework. It envisions a city-scale blue-green structure plan that integrates rivers, lakes, ponds, green corridors, retention spaces, parks, and ecological nodes into a connected urban resilience network.

This proposal is justified by the study's finding that Indore's stormwater problems are systemic and city-wide. Since flood risk, runoff generation, green-space deficiency, and ecological fragmentation occur across multiple wards and urban systems, localized interventions alone cannot solve the problem without a broader spatial framework.

Strategic Focus

The city-scale structure plan aims to establish a continuous blue-green network that functions simultaneously as stormwater infrastructure, ecological support system, and public-space framework. It is intended to connect the Kanh and Saraswati river systems

with lakes, nallahs, open spaces, streetscapes, and neighborhood interventions in order to create a layered and resilient hydrological structure.

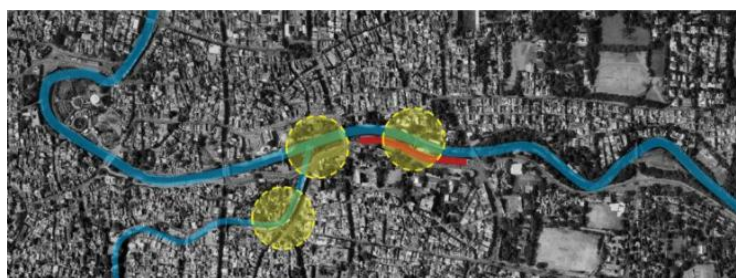
The structure plan is also meant to provide spatial guidance for future development. By identifying ecological corridors, retention-recharge nodes, park systems, and sponge districts, the proposal offers a planning basis for integrating BGI into master planning, land-use decisions, capital works, and redevelopment projects.

Phased Implementation

The study provides a phased implementation strategy for the city-scale proposal. In Phase 1, covering 0 to 3 years, the city would prepare a BGI design manual, amend development control regulations, launch pilot projects in high-risk hotspots, begin river sewage interception, initiate riparian planting, and conduct participatory mapping and public engagement.

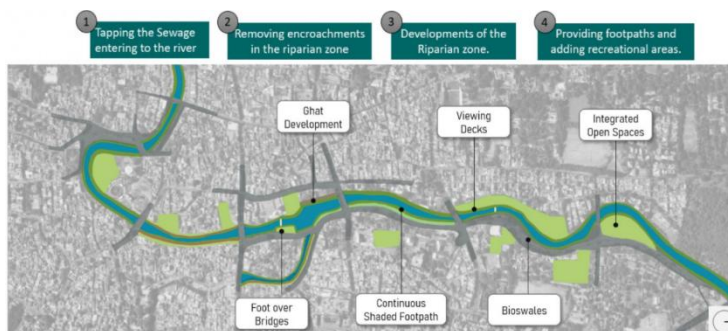
In Phase 2, covering 3 to 7 years, the pilots would be scaled into sponge districts across wards, major Kanh-Saraswati corridor works would begin, the BGI Corporation or SPV would become operational, and the stormwater utility fee would be introduced for sustainable financing.

In Phase 3, beyond 7 years, the city-scale structure plan would be consolidated, upstream watershed management would be expanded, BGI would be integrated into routine municipal planning and budgeting, and performance would be evaluated through the monitoring and evaluation framework.



Major Components

The document identifies several investment components within this proposal, including mapping and planning,



pilot retention and recharge nodes such as lakes and ponds, roadside greening and sponge corridors, expansion of park systems and greenways, and institutional setup for BGI governance and monitoring. These components collectively reflect the need to combine spatial planning, physical implementation, and administrative systems.

Indicative Cost Range

Component	Indicative Cost Range
Mapping, planning and design manual	₹5–10 crore
Pilot retention/recharge nodes (lakes, ponds)	₹20–30 crore
Roadside greening and sponge corridors	₹40–60 crore
Expansion of park systems and greenways	₹30–50 crore
Institutional setup and monitoring systems	₹10–15 crore

Expected Outcomes

The city-scale blue-green structure plan is expected to provide a strategic and long-term framework for urban resilience in Indore. It would help integrate flood mitigation, ecological restoration, urban cooling, public-space development, and environmental planning into one coordinated spatial system.

Proposal 4: Kanh-Saraswati Corridor Special Area Plan

Introduction to Corridor Proposal

The fourth proposal is focused specifically on the Kanh-Saraswati River corridor, which the study identifies as one of the most critical ecological and hydrological systems in Indore. The corridor is currently affected by sewage inflows, encroachment, pollution, loss of ecological quality, and repeated flood vulnerability, making it necessary to treat it as a special planning area rather than as an isolated drainage edge.

Core Components

The first component is sewage interception and treatment through diversion of untreated sewage into decentralized treatment systems. This measure is intended to reduce pollution load and improve river-water quality while also restoring the river's environmental function.

The second component is the establishment of riparian buffers and green belts of approximately 15 to 30 meters along riverbanks. These buffers are intended to control erosion, filter runoff, prevent encroachment, and create ecological continuity along the corridor.

The third component is the creation of floodable parks and multifunctional riverfront spaces that can absorb excess monsoon water while remaining usable as recreation areas during dry periods. This approach turns flood-prone land into adaptive public space instead of treating it solely as a liability.

The fourth component is riverfront zoning and enforcement, restricting construction within floodplains and integrating pathways, wetlands, and biodiversity corridors into the protected river edge. This component is crucial for long-term safeguarding of the corridor and prevention of future encroachment.

Implementation Phasing

The corridor proposal is also phased. In the first 0 to 3 years, the city would map encroachments, identify sewage discharge points, begin pilot decentralized STPs, start buffer-zone demarcation, and initiate community consultation. In the 3 to 7 year phase, floodable parks and green belts would be developed along priority stretches, and high-risk settlements would be addressed through rehabilitation packages where required. Beyond 7 years, riverfront zoning would be consolidated, ecological corridors would be integrated, and treatment systems would be scaled with continuous monitoring of water quality and flood resilience.

Indicative Cost Range

Corridor Component	Description	Indicative Cost Range
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Sewage Interception and Treatment	Diversion to decentralized STPs	₹40–60 crore
Riparian Buffers and Green Belts	15–30 m vegetated buffers	₹20–30 crore
Floodable Parks and Riverfront Spaces	Multifunctional parks and adaptive spaces	₹30–50 crore
Riverfront Zoning and Enforcement	Floodplain restriction, rehabilitation, corridor protection	₹50–80 crore

Expected Outcomes

The Kanh-Saraswati corridor proposal is expected to improve river-water quality, restore ecological function, reduce flood risk, prevent further encroachment, and create multifunctional riverfront public spaces. In addition, it provides a model for integrating environmental restoration with urban design and stormwater resilience in one of the city's most sensitive corridors.

Integrated Significance of the Proposal Framework

Although each proposal component has a distinct focus, the chapter demonstrates that their effectiveness depends on integration. Site-scale pilots provide practical demonstration and local flood reduction, policy reforms create enabling conditions, the city-scale structure plan offers strategic direction, and the corridor plan addresses the most environmentally sensitive and hydrologically critical landscape in the city.

This integrated structure is particularly important because stormwater vulnerability in Indore is not the result of one isolated deficiency. It is a cumulative outcome of infrastructure gaps, ecological decline, river degradation, urban growth, and fragmented implementation systems, and therefore requires an equally multi-dimensional response.

Chapter Conclusion

This chapter has organized the proposals of the study into a professional dissertation-style format suitable for inclusion in a thesis or report. The proposal framework advances from localized interventions to city-level and corridor-level strategies, while also incorporating institutional, financial, and regulatory support systems required for implementation.

Taken together, these proposals offer a coherent roadmap for shifting Indore's stormwater management approach from conventional grey infrastructure dependence toward an integrated blue-green infrastructure model. The chapter therefore demonstrates that the proposed interventions are not isolated design ideas, but a structured planning framework capable of improving flood resilience, ecological quality, and urban liveability in a phased and implementable manner.

6.5.3 Integration with Existing Grey Infrastructure

The hydrological design intentionally integrates BGI with existing grey infrastructure rather than attempting to replace it. BGI features are connected to existing stormwater drains through inlets, underdrains, and overflow structures so that, under normal conditions, a significant share of runoff is managed through infiltration, storage, and evapotranspiration, while larger events can still be safely conveyed through the grey network.

This integrated blue–green–grey approach increases system redundancy and resilience: when pipes are blocked or overwhelmed, surface BGI provides alternative storage and flow paths; conversely, when BGI elements are saturated or clogged, conventional drains still provide backup conveyance.

6.6 Policy and Institutional Recommendations

6.6.1 Indore Blue–Green Infrastructure Design Manual

A dedicated “Indore BGI Design Manual” is proposed to consolidate locally adapted standards and typical details for BGI elements, drawing on CPHEEO's 2019 Storm Water Drainage Manual, national IUWM work, and international BGI guidelines. The manual would provide standard drawings, design parameters, maintenance protocols, and performance expectations for rain gardens, bioswales, permeable surfaces, tree trenches, wetlands, and related features, giving engineers, planners, and consultants a consistent reference.

6.6.2 Development Control Regulation (DCR) Amendments

Amendments to Indore's Development Control Regulations (DCR) and building byelaws are recommended to mandate or incentivise BGI. Possible provisions include: minimum percentage of pervious surface on plots; mandatory rooftop rainwater-harvesting and onsite detention for developments above a certain size; requirements for BGI integration in large parking lots, townships, and commercial complexes; and stipulations for green buffers along drains and rivers. These regulatory

changes would embed BGI into everyday development rather than relying solely on public projects.

6.6.3 Special Purpose Vehicle (Indore BGI Corporation)

To overcome institutional fragmentation, the establishment of a specialised cell or special purpose vehicle (SPV)—tentatively termed the “Indore BGI Corporation” or “Indore Urban Resilience Cell”—is proposed within or alongside IMC. This body would coordinate BGI planning, design, implementation, monitoring, and maintenance across departments and projects, acting as a knowledge hub and project-management unit for integrated stormwater and BGI initiatives, similar to how Smart City SPVs have functioned for other urban sectors.

6.6.4 BGI Certification Scheme (Incentives and FAR Bonuses)

A voluntary or mandatory BGI certification scheme can be introduced for private and institutional developments, awarding ratings based on the extent and quality of BGI measures implemented (e.g. percentage of runoff retained, green-space provision, water-quality treatment). As incentives, developers achieving higher certification levels could be offered modest FAR bonuses, reduced development charges, or fast-track approvals, provided BGI performance is verified and maintained over time.

6.6.5 Stormwater Utility Fee Framework

A stormwater utility fee framework is proposed whereby properties are charged a modest fee based on impervious area and potential contribution to runoff, with discounts or rebates offered to those implementing certified BGI measures. Revenue from this fee would be ring-fenced to fund stormwater and BGI infrastructure and maintenance. Such models, widely used in other countries, create a sustained financial base for stormwater management and incentivise decentralised solutions.

6.6.6 Riverfront Buffer Zone Enforcement

To protect and restore riparian zones, enforcement of riverfront buffer zones along Kanh, Saraswati, and major nallahs is essential. This includes demarcating no-build zones, preventing new encroachments, and progressively relocating high-risk settlements and structures where feasible, accompanied by fair rehabilitation and livelihood support. Legal provisions under the Water Act, Environment Protection Act, and local planning statutes can be leveraged to support buffer enforcement and integration of BGI features such as wetlands and riparian parks within these zones.

6.7 Economic and Financial Mechanisms

6.7.1 Cost–Benefit Analysis (BGI vs Grey Infrastructure)

Although detailed project-level cost–benefit analysis is beyond the scope of this thesis, the proposals advocate comparing BGI-integrated solutions with conventional grey alternatives by considering both direct costs and co-benefits. International studies show that BGI can be cost-competitive or cheaper over the lifecycle when benefits such as reduced flood damage, improved water quality, enhanced property values, and health and climate co-benefits are accounted for. For Indore, indicative analysis can compare the cost of retrofitting sponge corridors and wetlands against purely underground drainage augmentation for achieving similar levels of flood-risk reduction.

6.7.2 Funding Sources (AMRUT, NMCG, Green Climate Fund)

Multiple funding streams may be mobilised for BGI implementation. At the national level, AMRUT 2.0, Smart Cities Mission, and the National Mission for Clean Ganga (NMCG) all support projects related to stormwater management, water-body rejuvenation, and riverfront improvements, which can be designed to incorporate BGI. State schemes, municipal capital budgets, and externally aided projects provide additional avenues. At the international level, climate-finance mechanisms such as the Green Climate Fund and bilateral climate programmes increasingly support nature-based solutions for climate adaptation and urban flood management, offering potential grant or concessional financing for large-scale BGI initiatives.

6.7.3 Public–Private Partnership Models

Public–Private Partnerships (PPPs) may be appropriate for BGI elements that generate direct or indirect revenue, such as commercial riverfront segments, eco-parks, green parking facilities, and mixed-use developments that integrate BGI as a core design component. PPP contracts would need to specify performance standards (e.g. minimum storage or infiltration capacities, vegetation survivability, public-access requirements), risk-sharing mechanisms, and monitoring arrangements to ensure that private partners maintain both the hydrological and amenity functions of BGI over time.

6.8 Community Engagement and Participatory Planning

Active community participation is critical for the long-term success and maintenance of BGI, particularly at neighbourhood and site scales. The proposals recommend community co-design of local BGI projects through participatory mapping of flood-prone sites, workshops, and on-site design charrettes, ensuring that interventions

respond to local needs and practices. Formation of “lake friends” groups, school-based environmental clubs, and mohalla-level BGI committees can support routine maintenance, monitoring, and awareness-raising activities, while digital tools (e.g. mobile apps) can enable residents to report blocked drains, illegal dumping, or dysfunctional BGI elements.

6.9 Monitoring and Evaluation Framework

A robust monitoring and evaluation (M&E) framework is proposed to track implementation progress and assess the performance of BGI over time. Key indicators include hydrological metrics (flooded area, depth, duration, and frequency), environmental metrics (river and lake water quality, vegetation cover, land-surface temperature), and social metrics (public-space usage, user satisfaction, equity of benefits). Data can be collected through a combination of automatic sensors (rain gauges, water-level loggers), remote sensing, periodic field sampling, and citizen-generated reports.

Regular reporting cycles—for example, annual progress reports and comprehensive five-year evaluations—should be institutionalised and linked to budget allocations and plan revisions, allowing adaptive management and refinement of BGI typologies, standards, and institutional arrangements.

6.10 Phasing and Implementation Roadmap

Given financial, technical, and institutional constraints, the integrated BGI plan is to be implemented in phases aligned with existing city-level programmes and investment cycles. In the **short term (0–3 years)**, priority actions include detailed design and implementation of pilot projects in high-risk hotspots, development of the BGI design manual, initial DCR amendments, and targeted drain cleaning and enforcement against waste dumping. In the **medium term (3–7 years)**, successful pilots are scaled up across additional wards and corridors, major components of the Kanh–Saraswati plan are implemented, and PPP and incentive schemes are operationalised. In the **long term (7+ years)**, the full city-scale blue–green structure plan is consolidated, upstream and downstream watershed management is strengthened, and BGI is mainstreamed into routine municipal planning, budgeting, and asset-management processes

CHAPTER 7: CONCLUSION

7.1 Summary of Key Findings

The analysis of Indore's stormwater system and environmental conditions reveals that the city is highly vulnerable to pluvial flooding, waterlogging, and riverine pollution under current and projected patterns of urbanisation and rainfall. The city's underground stormwater drainage network covers only about 126.1 km out of a total road length of approximately 1,912.2 km, corresponding to 6.59 percent coverage and a gap of 93.41 percent, which forces the majority of runoff to rely on open drains, informal channels, and natural streams that are frequently undersized, clogged, or encroached. GIS-based multi-criteria vulnerability assessment, supported by historical records of more than 100 waterlogging-prone locations, indicates that low-lying, densely built wards with poor drainage coverage and encroached nallahs and riverbanks are particularly prone to frequent and sometimes severe waterlogging during monsoon events, as exemplified by the September 2023 storm when approximately 254 mm of rainfall over 24 hours resulted in widespread inundation and emergency rescues.

The study further shows that Kanh (Khan) and Saraswati rivers—key elements of Indore's hydrological system—are severely degraded, functioning effectively as open sewers due to continuous discharge of untreated sewage and solid waste. Monitoring data have recorded BOD values along Kanh ranging from roughly 2.6 mg/L to 46 mg/L at Juni Indore, far above the 3 mg/L standard for bathing water, with concomitant low dissolved oxygen and high coliform counts. Land-use change detection between 2005 and 2025 evidences substantial increases in built-up area at the expense of vegetated and open land, particularly in peri-urban and corridor zones, thereby increasing imperviousness and stormwater runoff. NDVI and land-surface temperature analyses reveal that several high-vulnerability zones also exhibit low vegetation cover and elevated surface temperatures, indicating that they suffer both flood risk and heat-island effects.

Against this backdrop, the study demonstrates that an integrated blue-green infrastructure (BGI) framework—comprising a city-scale blue-green structure plan, a Kanh-Saraswati corridor plan, and five detailed pilot designs—offers a viable strategy to reduce runoff peaks, attenuate flood depths, improve water quality, and deliver multiple co-benefits in terms of urban cooling, biodiversity, and public amenity. The proposed BGI typology-selection and sizing framework, grounded in monsoon-adapted

design standards and realistic infiltration parameters for black-cotton soils, ensures that BGI elements are matched to site conditions and hydrological requirements. Finally, the study identifies critical institutional and policy gaps and outlines pathways for embedding BGI into development regulations, design manuals, funding mechanisms, and community practices, moving Indore towards a more resilient and sustainable urban water system.

7.2 Contribution to Knowledge

Conceptually, this thesis contributes to the evolving discourse on integrated urban water management (IUWM) and blue-green infrastructure in Indian cities by developing a multi-scalar framework that explicitly links stormwater management, river restoration, land-use planning, and climate resilience. While much international BGI literature focuses on temperate contexts, this study adapts global paradigms such as LID, WSUD, SuDS, and Sponge City to a medium-sized Indian city with a monsoon-dominated climate, black-cotton soils, and highly fragmented governance structures. It demonstrates how concepts of blue-green networks and hybrid blue-green-grey systems—widely documented in global studies—can be reinterpreted for Indian tier-2 city conditions, where basic drainage coverage is low and informal settlements line degraded waterways.

Methodologically, the study advances the use of GIS-based multi-criteria analysis for flood vulnerability and BGI suitability in the Indian context by integrating physical, environmental, and socio-economic indicators and by explicitly linking vulnerability outputs to BGI typology selection and site design. The combination of LULC change detection, NDVI/LST analysis, blue-green connectivity assessment, and catchment-based runoff estimation provides a rigorous and replicable procedure that addresses both hydrological and ecological dimensions of urban stormwater systems. The research also brings together environmental quality data (air and water), soil-infiltration characteristics, and institutional analysis in a single decision framework, emphasising that BGI planning must be grounded in both bio-physical realities and governance constraints.

Practically, the thesis offers a set of Indore-specific products: a blue-green structure plan, a Kanh-Saraswati special area plan, and five site-level sponge-landscape designs, along with a BGI typology-selection matrix and preliminary sizing guidelines tailored to local rainfall and soil conditions. It also proposes concrete regulatory, institutional,

and financial instruments—such as a BGI design manual, DCR amendments, a possible BGI-oriented SPV, certification and incentive schemes, and a stormwater utility fee framework—that can be directly used or adapted by local authorities. These outputs move beyond high-level advocacy for nature-based solutions to provide an actionable, context-sensitive roadmap for implementation.

7.3 Replicability and Scalability to Other Tier-2 Cities

The conditions observed in Indore—rapid and often unplanned urban expansion, limited formal drainage coverage, encroached and polluted rivers, loss of blue–green spaces, and institutionally fragmented water governance—are broadly representative of many tier-2 Indian cities such as Bhopal, Nagpur, Vadodara, and Coimbatore. The methodological framework developed in this study is therefore inherently replicable. The GIS-based vulnerability assessment, LULC and NDVI/LST analysis, blue–green connectivity mapping, and BGI suitability and typology frameworks can be applied in other cities using analogous datasets (DEM, LULC, drainage layers, rainfall records, and basic socio-economic data) with appropriate local calibration.

At the policy level, the study’s recommendations align with national directions under AMRUT 2.0, Smart Cities Mission, NMCG, and NDMA urban-flood guidelines, as well as international thinking on hybrid grey–green systems and Sponge City initiatives. This means that similar BGI-oriented plans can be embedded in centrally sponsored projects across multiple cities, with local adaptations for climate, soils, land-availability, and governance structures. However, scaling requires attention to city-specific constraints: some cities may have coastal or estuarine settings, different soil profiles, or more entrenched informal settlements along waterways, requiring modifications in typologies, design standards, and resettlement strategies.

By documenting both the technical steps and the institutional and financial instruments needed to operationalise BGI, the thesis provides a transferable template that other cities can use as a starting point. Moreover, the emphasis on hybrid blue–green–grey solutions and phased implementation aligns with international evidence that nature-based solutions are most effective when integrated with essential grey infrastructure and deployed incrementally across the urban fabric.

7.4 Future Research Directions

The study also identifies several areas where further research is required to deepen understanding and support wider adoption of BGI in Indian cities. First, while this thesis

uses conceptual hydrological calculations and scenario analysis, there is a need for more detailed and calibrated hydraulic–hydrodynamic modelling (e.g. using SWMM or 2D models) to quantify the performance of individual and networked BGI interventions under a range of storm events, including compound events and projected climate-change scenarios. Such modelling would help optimise the mix and placement of BGI and grey infrastructure and refine design storms and safety factors.

Second, there is a need for long-term empirical monitoring of BGI pilot projects in the Indian monsoon context to generate robust evidence on hydrological performance, pollutant removal, maintenance requirements, and social acceptance. Global studies increasingly show that BGI can reduce runoff volume and peak flows, improve water quality, and provide co-benefits for health and wellbeing; however, there remains a relative paucity of data from Indian tier-2 cities with specific soil and climatic conditions. Systematic performance monitoring in cities like Indore would help refine design guidelines and build confidence among engineers and policymakers.

Third, future research should explore governance and financing innovations for BGI in greater depth, including the design of stormwater utility fees, green bonds, PPP structures, and community-based management models, and should critically evaluate their equity and distributional impacts. Understanding who benefits and who bears the costs of BGI interventions is essential for designing socially just and politically feasible implementation strategies. Finally, comparative studies across multiple Indian cities could synthesise lessons on how different institutional arrangements, political economies, and civil-society dynamics affect the mainstreaming of BGI and could contribute to the development of a national framework for integrated urban water and blue–green infrastructure planning.

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Öhrn Sagrelius, P., Sjöman, H., Baraldi, R., Hojati, M., & Hiron, A. (2022). Blue-green infrastructure for all seasons: The need for expanding BGI conceptualization beyond the growing season. <i>Journal of Sustainable Water in the Built Environment</i> , 8(4), 04022008.	Journal	(Öhrn Sagrelius et al., 2022)	Öhrn Sagrelius P, Sjöman H, Baraldi R, Hojati M and Hiron A (2022), Blue-green infrastructure for all seasons: The need for expanding BGI conceptualization beyond the growing season, <i>Journal of Sustainable Water in the Built Environment</i> , 8(4), 04022008.
Patel, P., et al. (2024). Ecosystem services from urban blue-green infrastructure: Indian context.	Journal	(Patel et al., 2024)	Patel P et al. (2024), Ecosystem services from urban blue-green infrastructure: Indian context, <i>Environmental Science & Policy</i> , 142, 45–58.

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<i>Environmental Science & Policy</i> , 142, 45–58.			
Pathak, S., Liu, M., Jato-Espino, D., & Zevenbergen, C. (2020). Social, economic and environmental assessment of urban sub-catchment flood risks using a multi-criteria approach: A case study in Mumbai City, India. <i>Journal of Hydrology</i> , 591, 125216.	Journal	(Pathak et al., 2020)	Pathak S, Liu M, Jato-Espino D and Zevenbergen C (2020), Social, economic and environmental assessment of urban sub-catchment flood risks using a multi-criteria approach: A case study in Mumbai City, India, <i>Journal of Hydrology</i> , 591, 125216.
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Silva, J., Kernaghan, S., & Luque, A. (2012). A systems approach to meeting the challenges of urban climate change. <i>International Journal of Urban Sustainable Development</i> , 4(2), 125–145.	Journal	(Silva et al., 2012)	Silva J, Kernaghan S and Luque A (2012), A systems approach to meeting the challenges of urban climate change, <i>International Journal of Urban Sustainable Development</i> , 4(2), 125–145.

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Singh, P., Chaturvedi, A., & Khanduja, D. (2012). Communication as a strategic tool for building smart cities: A review. <i>International Journal of Sustainable Built Environment</i> , 1(1), 72–85.	Journal	(Singh et al., 2012)	Singh P, Chaturvedi A and Khanduja D (2012), Communication as a strategic tool for building smart cities: A review, <i>International Journal of Sustainable Built Environment</i> , 1(1), 72–85.
Thorne, C. R., Lawson, E. C., Ozawa, C., Hamlin, S. L., & Smith, L. A. (2018). Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management. <i>Journal of Flood Risk Management</i> , 11, S960–S972.	Journal	(Thorne et al., 2018)	Thorne CR, Lawson EC, Ozawa C, Hamlin SL and Smith LA (2018), Overcoming uncertainty and barriers to adoption of Blue-Green Infrastructure for urban flood risk management, <i>Journal of Flood Risk Management</i> , 11, S960–S972.

Final section

Source	Type	In-text citation	Example
Climate Connection. (2025, February 28). <i>Rethinking urban blue-green infrastructure: Why it matters?</i>	Web page	(Climate Connection, 2025)	Climate Connection (2025), Rethinking urban blue-green infrastructure: Why it matters?
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Arup on behalf of Southern Regional Assembly. (2020). <i>Blue green infrastructure and nature-based solutions framework.</i>	Web page / Report	(Arup on behalf of Southern Regional Assembly, 2020)	Arup on behalf of Southern Regional Assembly (2020), <i>Blue Green Infrastructure and Nature-based Solutions Framework</i> , Interreg Europe Blue Green Cities Project.
Connecticut Department of Energy and Environmental Protection. (2023). <i>Connecticut Stormwater Quality Manual</i> (Chapter 4: Stormwater	Manual / Web page	(Connecticut Department of Energy and Environmental Protection, 2023)	Connecticut Department of Energy and Environmental Protection (2023), Connecticut Stormwater Quality Manual (Chapter 4: Stormwater Management Standards and Performance Criteria), University of

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Management Standards and Performance Criteria).			Connecticut Center for Land Use Education and Research.
Drishti IAS. (2022, August 7). <i>Blue-green infrastructure</i> [Editorial].	Newspaper / web editorial	(Drishti IAS, 2022)	Drishti IAS (2022), Blue-green infrastructure [Editorial].
International Journal of Management, IT and Engineering (IJMIE). (2019). <i>Khan and Sarasvati River development in Indore</i> [Academic paper].	Journal article / web source	(IJMIE, 2019)	IJMIE (2019), Khan and Sarasvati River development in Indore [Academic paper].
JETIR. (2025, April). <i>Blue-Green Infrastructure in planning for urban neighbourhoods: A case of Indian cities.</i>	Journal article / web source	(JETIR, 2025)	JETIR (2025), Blue-Green Infrastructure in planning for urban neighbourhoods: A case of Indian cities, <i>JETIR</i> , 12(4), Paper JETIR2504B53.