Reviving Vishwamitri through Sponge City Strategies: A River-Centric Approach for Urban Flood Resilience and Community Well-being in Vadodara

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ABSTRACT

The Vishwamitri River, flowing through Vadodara, Gujarat, exemplifies the complex challenges faced by urban rivers in rapidly developing cities. Unplanned urbanization, impervious infrastructure, encroachments along riparian zones, and inadequate drainage systems have exacerbated flood risks, degraded biodiversity, and threatened community health and livelihoods. Notably, events such as flash floods and the emergence of crocodiles in residential areas have underscored the urgent need for integrative solutions. This research explores a holistic, river-centric approach to urban resilience in Vadodara, focusing on the ecologically fragile Vishwamitri River. Amid increasing climatic variability, rapid urbanization, and recurring urban floods, this study proposes a Sponge City–based framework integrated with circular economy principles and participatory governance mechanisms. Using spatial analysis, field surveys, and stakeholder consultation, the study identifies 21 critical hotspots along the Vishwamitri where flood vulnerability, ecological degradation, and social fragility intersect. The PRAVAAH framework—Planning for River and Urban Adaptive Approaches for Harmony—has been conceptualized to address these systemic issues by incorporating blue-green infrastructure, nature-based solutions, and decentralised urban water management. This work has been financially supported by **NIUA and NMCG under the STC-5 scheme (₹50,000)**, further validating the significance of sustainable river planning at national scale. The findings contribute a replicable model for integrated urban river rejuvenation aligned with national programs such as AMRUT 2.0 and the National Mission for Clean Ganga (NMCG), and serve as a strategic blueprint for transforming riverside cities into climate-resilient urban ecosystems.

Keywords

Vishwamitri River | Reimagining Urban rivers | River-City Integration | Blue – Green Infrastructure |

I. INTRODUCTION

Urban communities residing along the Vishwamitri River in Vadodara, India, have increasingly been exposed to severe ecological and infrastructural challenges, particularly due to seasonal urban flooding.

These floods are exacerbated by unplanned urbanization, loss of vegetative cover, and unauthorized slum encroachments into ecologically sensitive riparian zones (NDMA, 2024.).One of the most alarming outcomes has been the regular emergence of crocodiles onto city streets during monsoon-induced river swellings, posing direct threats to human life and reflecting the deep disruption of natural habitats (P. Vollmer, 2015). The convergence of biodiversity loss, flood vulnerability, and socio-economic marginalization especially among informal settlements underscores a critical knowledge and planning gap. Despite ongoing infrastructure development, there is a marked absence of integrated, community-driven, and ecologically grounded solutions that address both human and ecosystem resilience in tandem (R. Roy et al., 2008). This study seeks to fill that gap by applying the Sponge City framework, adapted from successful models in China, as a holistic planning and design intervention for Vadodara (C. T. Walsh et al., 2005). By incorporating decentralized, nature-based solutions such as bioswales, green roofs, permeable pavements, urban wetlands, and retention ponds, the approach aims to reduce flood risks, support biodiversity, and regenerate degraded river corridors (P. Meyer and J. Paul, 2001). Furthermore, the proposed strategy aligns with circular economy principles and community-led planning by embedding slum rehabilitation and green livelihood initiatives within urban water management systems (GIDM, 2021). This research employs spatial flood modeling, stakeholder surveys, and site-based ecological assessments across 23 identified urban flood hotspots to demonstrate how the Sponge City paradigm can serve as a replicable, locally responsive model for urban biodiversity restoration and community resilience.

II. LITERATURE STUDY

India remains critically vulnerable to urban flooding, a challenge compounded by rapid urbanization, encroachments, and the escalating impacts of climate change. According to the National Disaster Management Authority (NDMA, 2024.), over 40 million hectares of land in India are flood-prone, and urban centers increasingly bear the brunt of such disasters due to unregulated development and infrastructural inadequacies (al., 2016.) (Bhatia, 2020). Over the last few decades, the financial toll of flooding has risen markedly, with average annual flood-related damages increasing from ₹1,805 crores during 1953–1995 to ₹4,745 crores between 1996–2005—highlighting systemic gaps in urban flood preparedness (Basu, 2020).

Table 1 Key Findings of Literature Study

Focus Area	Key Findings	Gap in Current Knowledge
Hydrology	Urbanization increases flood risk	Few studies model hydrology for medium-sized rivers like Vishwamitri
Pollution	Urban rivers face rising BOD/ COD	Lack of decentralized wastewater reuse frameworks
Encroachment	Encroachments drive vulnerability	Limited enforcement of river buffer zoning
Restoration	Nature-based solutions show promise	Data-driven restoration models are rare in Tier-II Indian cities
Governance	Few cities have URMPs	No integrated URMP in Vadodara

Urban rivers such as the Vishwamitri in Vadodara serve as vital ecological corridors that regulate stormwater, support biodiversity, and contribute to thermal comfort. However, these rivers are increasingly degraded due to anthropogenic pressures including unplanned construction, siltation, and encroachment, leading to the transformation of natural streams into flood-prone channels (CPCB, 2018) (Y. Li, 2021.) Urban flooding has emerged as a growing concern in Indian cities, driven by rapid urban expansion, increasing impervious surfaces, unregulated development, and weak enforcement of buffer zone regulations. The Vishwamitri River in Vadodara exemplifies these challenges—its once-resilient floodplain now suffers from encroachment, poor water quality, and degraded ecological health, contributing to flash floods, urban heat stress, and riparian vulnerability (Bhatia, 2020) (CPCB, 2018) (Y. Li, 2021.). To address such multifaceted issues, the *Sponge City* as shown in fig. 1 model offers an integrated, nature-based urban water management approach that prioritizes rainwater retention, infiltration, purification, and reuse through decentralized green infrastructure such as bioswales, wetlands, permeable pavements, and green roofs (Basu, 2020). (China Ministry of Housing and Urban–Rural Development (MOHURD), 2018) Unlike conventional grey infrastructure, this model revives the urban water cycle and provides co-benefits like groundwater recharge, pollution control, and climate resilience (Basu, 2020) (NIUA, Blue–green infrastructure and urban watershed management advisory,, 2021)

The principles of the Sponge City model directly align with the strategic objectives of *Urban River Management Plans (URMPs)* (al, 2022) (NIUA, Urban River Management Plans in India: buffer regulation study, 2020)which emphasize restoring river ecology, enhancing flood resilience, integrating rivers into urban planning, and fostering inclusive governance through stakeholder engagement (S. Shah and H. Ojha, 2019) (NIUA, Blue–green infrastructure and urban watershed management advisory,, 2021) URMPs, as advocated by institutions such as the National Institute of Urban Affairs (NIUA), aim to holistically manage the hydrological, ecological, social, and infrastructural dimensions of urban rivers (S. Shah and H. Ojha, 2019) Embedding Sponge City principles within the URMP framework for the Vishwamitri River enables cities like Vadodara to transition from reactive flood control to proactive, adaptive planning (CPCB, 2018). (Y. Li, 2021.) (M. Yang, 2025)

This convergence creates an opportunity to localize and operationalize key *Sustainable Development Goals (SDGs)*: **SDG 6** (Clean Water and Sanitation) through improved water quality and access (Guardian, 2024); **SDG 11** (Sustainable Cities and Communities) through enhanced flood resilience and inclusive urban design (arxiv, 2021) (Basu, 2020); **SDG 3** (Good Health and Well-being) by reducing water-borne diseases and urban heat risks (Guardian, 2024); and **SDG 15** (Life on Land) via biodiversity restoration along riparian corridors (X. Huang, 2022).

Thus, the intersection of Sponge City strategies, URMP implementation, and SDG commitments forms a comprehensive planning framework for revitalizing the Vishwamitri River. This integrated model not only addresses existing (NIUA, Urban River Management Plans in India: buffer regulation study, 2020) vulnerabilities but also repositions the river as a resilient, multifunctional ecological spine that strengthens the urban fabric, ensures environmental sustainability, and promotes community well-being.

RESEARCH GAP: Rapid urbanization around the Vishwamitri River has severely compromised its natural drainage, leading to catastrophic flooding during extreme rainfall events—such as the 239 mm downpour that caused the Ajwa and Pratappura reservoirs to overflow, submerging parts of Vadodara for nearly 72 hours. Climate change has intensified these events, with floodwaters rising higher than the 2019 levels, triggering power outages, supply shortages, and public health risks from stagnant, contaminated water. Crocodiles from the river were even found in city streets, with 41 rescued in August alone. Poorly planned urban development has disrupted riparian zones, particularly in areas like Sama and Akota, where prolonged waterlogging and power cuts were reported. Compounding the crisis is the city's inadequate drainage infrastructure, which failed under the rain's intensity, forcing residents to evacuate via tractors and prompting urgent calls for resilient, nature-based urban planning interventions.

III. SEVERITY ANALYSIS

To assess and compare the environmental and anthropogenic stress on the Narmada, Tapi, and Vishwamitri rivers, a **multi-criterion weighted severity index** was developed based on key parameters: water quality, urbanization pressure, flood risk, biodiversity loss, sedimentation and erosion, and groundwater dependency. Each criterion was assigned a weight reflecting its relative impact, with **water quality** (0.25) and **urbanization pressure** (0.20) given the highest importance, followed by flood-related and ecological factors. Scoring was conducted using secondary data from CPCB, CGWB, NDMA, As detailed in Annexure -V (Table – 0.3, 0.4 & 0.5) and relevant GIS and biodiversity reports, with scoring thresholds defined for each parameter. The calculated severity index revealed that the **Narmada and Tapi rivers fall within the "Moderate" severity range**, with scores of **6.1 and 5.9**, respectively. In contrast, the **Vishwamitri River**, affected by high urban pressure, degraded water quality, and frequent flooding in Vadodara, scored **5.35**, falling under the "Moderate-Low" severity category. This structured assessment not only quantifies ecological stress but also guides **river-centric policy prioritization** based on evidence-backed scoring (CPCB, 2022; VMC, 2023; NDMA, 2021). As detailed in Annexure -V (Table – 0.6 & 0.7)

Table 4.7 Severity Ratings for the Rivers

River	Severity Index Score	Severity Rating (1-10)
Narmada	6.1	6 (Moderate)
Tapi	5.9	6 (Moderate)
Vishwamitri	5.35	5 (Low)

IV. STUDY AREA

Vishwamitri River originates near Pavagadh at an elevation of approximately 600 meters and flows primarily through Vadodara city. This river is heavily affected by urbanization and industrialization, with numerous industries located along its banks contributing to pollution. The CPCB reports that untreated sewage from Vadodara significantly degrades water quality, with BOD levels often exceeding 20 mg/L. The Vishwamitri is surrounded by various solid waste dump sites and sewage treatment plants that struggle to manage the volume of waste generated by urban activities. Eutrophic zones are evident in sections where nutrient runoff leads to excessive growth of algae, further depleting oxygen levels in the water. Additionally, mineral-rich zones exist upstream where geological formations contribute to biodiversity also risk contamination from nearby industrial activities.

GEOGRAPHIC AND HYDROLOGICAL CONTEXT

Vishwamitri River originates in the Pavagadh hills and courses through Vadodara city (22°17′–20′ N, 73°10′–15′ E), within a ~1,025 km² watershed. It features non-perennial monsoonal flow, with an annual rainfall mean of ~800 mm. Seasonal floods have historically threatened areas like Kalaghoda and Karelibaug, worsened by encroachment and silt-laden flows.

*Figure SEQ Figure * ARABIC 2 Study Area Map – Location of Vadodara*

URBAN GROWTH AND LAND USE CHANGE

Vadodara's built-up landscape has changed from 2001 to 2024, Vadodara witnessed a dramatic land use transformation, with built-up areas expanding from approximately 30 km² to 120 km²—a fourfold increase. Simultaneously, vegetative cover declined by nearly 45%, and the extent of water bodies shrank by around 35%. These changes, mapped using Landsat and Sentinel satellite imagery via Google Earth Engine, have significantly disrupted the city's natural hydrological processes. The reduction in permeable surfaces has impaired infiltration capacity, exacerbating surface runoff and substantially increasing the frequency and intensity of flash flood events.

HYDROLOGICAL STRESS AND QUALITY INDICATORS

Hydrological stress from impermeable surfaces, encroachment, and outdated drainage systems has impaired the river. Eutrophic stretches show BOD levels of 18–25 mg/L and eutrophication symptoms include algal blooms and low dissolved oxygen, threatening aquatic species like the mugger crocodile. The fig 13 map delves into the spatial dynamics of Vadodara and its surrounding region through the analysis of two distinct yet interconnected cartographic representations. The map provides a perspective on regional focuses on the intra-urban thermal variations, specifically the Urban Heat Island effect, as a consequence of land use patterns within Vadodara city. Where from the map analysis can be shown as the area near the water bodies are cooler as compared to the CBD and built-up area of the Vadodara city.

GOVERNANCE AND INSTITUTIONAL SETTING

Vadodara Municipal Corporation, Gujarat PCB, and VUDA are key players in managing river systems. Yet, URMP tools (e.g., buffer zoning, wetlands, community engagement) show only partial or no implementation in most hotspot zones. Policies lack cohesive integration of blue-green infrastructure and circular economic tools.

FLOOD HISTORY AND VULNERABILITY

Historical floods—most notably in 2005, 2019, and 2024—exposed weaknesses in urban drainage. During 2024's event, water levels exceeded 35.25 ft in core areas. Vulnerability mapping uncovered 23 hotspots scoring ≥0.8 on a multi-criteria index (flood frequency, runoff increase, riparian loss, pollution intensity, URMP tool gaps).

OCIO-ECONOMIC CONTEXT AND LIVELIHOODS

Within 500 m of the river, approximately 350,000 residents live, including slum clusters with 6,631 huts along the floodplain. Stakeholder surveys (n ≈ 87) highlighted severe flash floods, environmental degradation, and deep community desire for inclusion in river rejuvenation. The Vishwamitri is surrounded by various solid waste dump sites and sewage treatment plants that struggle to manage the volume of waste generated by urban activities. Eutrophic zones are evident in sections where nutrient runoff leads to excessive growth of algae, further depleting oxygen levels in the water. Additionally, mineral-rich zones exist upstream where geological formations contribute to biodiversity but also risk contamination from nearby industrial activities. Vadodara's Vishwamitri River is infamous for occasionally spilling after intense downpours, leading to in urban waterlogging. There are significant regional disparities in the State's average annual precipitation, ranging from 300 mm in the western portion of Kutch to 1500 mm in the southern region part of Valsad and the Dangs. The temperature during the summertime oscillates from 25 degrees below zero to 45 degrees beyond zero. The range of temperatures in the winter is from 15 degrees below zero to 35 degrees beyond zero. (GIDM, 2017)

V. METHODS & TOOLS

The methodological framework of this study is rooted in the integration of spatial analysis, participatory planning, policy review, and impact simulation to support river-centric and circular economy-based interventions in Vadodara city. It adopts a hybrid approach by combining geospatial modeling with field-level stakeholder engagement and Sponge City best practices from global precedents, particularly

China. The study evaluates the impacts of infrastructure retrofitting, ecological zoning, and decentralized water management practices using a mix of GIS tools, hydrological modeling, and socio-economic assessment techniques.

METHODOLOGY

This study adopts an integrated, community-focused framework to assess the degradation of the Vishwamitri River and propose sustainable interventions. It begins by identifying key stressors—pollution, riparian encroachment, flood recurrence, and biodiversity loss—and classifying river stretches by severity. Using a dual approach, stakeholder surveys capture community impacts, while GIS and Google Earth Engine provide spatial analysis of ecological and hydrological vulnerabilities. A severity matrix is developed to identify critical hotspots, cross-referenced with Urban River Management Plan (URMP) objectives. The Sponge City model is then applied to suggest nature-based and circular water economy solutions, including bioswales, green roofs, and slum rehabilitation. The aim is to reduce flood risks, restore river health, and enhance quality of life for vulnerable populations—advancing sustainable river–city integration and supporting SDGs 6, 11, and 13.

SUVERVEY ANALYSIS

This survey, conducted with 87 participants comprising Local users, Residents, academicians, government officials, and key stakeholders, reveals urgent concerns and insights into river health and management. Industrial discharge and untreated sewage were identified as dominant pollution sources, while rivers are primarily used for industrial and agricultural purposes. Flooding remains a critical issue, with most respondents observing flood depths of 6–9 meters. CSR contributions emerged as the preferred financing tool, and nearly all respondents emphasized the vital role of community involvement. There is strong optimism about the ecological and social benefits of river revitalization. When addressing industrial waste, respondents favored a balance of penalties and incentives. However, challenges like lack of funding, weak policy enforcement, and insufficient community engagement must be addressed to ensure the success of future river restoration projects.

Table 2 Analysis of stakeholder survey and user perception study.

Question	Key Findings	Top Response(s)
Key causes of river pollution	Multiple causes identified	Industrial discharge (71.4%), Untreated sewage (64.3%)
Primary river use	Varied uses	Industrial processes (50%), Irrigation (28.6%), Recreation (28.6%)
Severity of recent floods	Mostly moderate	Moderate (69.2%), Severe (30.8%)
Max floodwater depth observed	Mostly high	6.0–9.0 m (69.2%)
Suggested financing mechanisms	CSR and PPP preferred	CSR (64.3%), PPP (14.3%)
Importance of community involvement	Strong agreement	57.1% Strongly agree, 35.7% Agree
Opportunities in river revitalization	Focus on ecology and well-being	Improved biodiversity (78.6%), Community well-being (78.6%)
Industry waste management approach	Support for dual approach	Penalized & Incentivized (42.9% each)
Major challenges in restoration	Funding, policy, and community issues	Lack of funding & Weak policy enforcement (71.4% each), Limited community involvement (64.3%)
How would you rate the current health of the Vishwamitri River near your area?	The vast majority of respondents perceive the Vishwamitri River's health as poor or very poor.	Poor: Approximately 40-45%, Very Poor: Approximately 35-40%, Average: Approximately 10-15%
What do you think are the key causes of pollution in the river?	Several human-induced activities are identified as primary contributors to river pollution, with encroachment and industrial discharge being most prominent.	Encroachment of Riverbanks: Approximately 68%, Industrial Discharge: Approximately 62%, Sand Mining: Approximately 40%, Mining Activities: Approximately 30%, Lack of Wastewater Treatment Plant: Approximately 30%, Untreated Sewage: Approximately 20%

What community-led initiatives do you believe would be most effective?	Direct riverine actions like restoration and clean-up, combined with monitoring and awareness, are considered the most effective community-led initiatives.	Riverbank restoration projects: Approximately 90%, River clean-up activities: Approximately 80%, Monitoring programs: Approximately 75%, Awareness drives: Approximately 75%, Sustainable farming practices near rivers: Approximately 45%
Can you mention the year of more frequent flood events?	The year 2013 was identified by respondents as having the highest frequency of flood events.	2013: 8 mentions, 2019: 3 mentions, 2014: 1 mention
Which of the following flood impacts have you personally experienced or observed?	Floods result in a wide array of significant negative impacts, notably affecting aquatic life, power, transportation, and property, along with specific concerns like wildlife intrusion.	Loss of Aquatic Animal life during floods: Approximately 85%, Prolonged power outages: Approximately 80%, Disruption in transport/commute (e.g., roads blocked): Approximately 78%, Wildlife intrusion (e.g., crocodiles coming into streets): Approximately 75%, Disruption in the supply of drinking water: Approximately 70%, Damage or loss of vehicles: Approximately 65%, Business losses due to inability to reach office/work: Approximately 60%, Food supply shortages or disruptions: Approximately 55%, Damage to electrical infrastructure and appliances: Approximately 55%, Contamination requiring maintenance issues: Approximately 50%, Damage or loss of property/home (including temporary relocation): Approximately 40%
What are the primary uses of the river?	The river serves multiple purposes, with industrial processes being the most common use, followed by irrigation and recreation.	Industrial processes: 50%, Irrigation: 28.6%, Recreation: 28.6%
What was the severity of recent floods?	Recent floods were predominantly perceived as moderate in severity.	Moderate: 69.2%, Severe: 30.8%
What was the maximum floodwater depth observed?	The observed floodwater depth was mostly high, specifically within the 6.0-9.0 meter range.	6.0–9.0 m: 69.2%
What are the suggested financing mechanisms for river management?	Corporate Social Responsibility (CSR) is the strongly preferred financing mechanism for river management, followed by Public-Private Partnerships (PPP).	CSR: 64.3%, PPP: 14.3%
What is the perceived importance of community involvement in river management?	There is strong agreement among respondents regarding the importance of community involvement in river management.	Strongly agree: 57.1%, Agree: 35.7%
What are the perceived opportunities in river	Opportunities for river management are seen primarily in improving biodiversity and enhancing community well-being.	Improved biodiversity: 78.6%, Community well-being (partial text provided): The chart indicates a significant response for "Community well-"

management?

VI. RESULTS AND DISCUSSIONS

The integrated assessment of the Vishwamitri River corridor reveals a complex interplay between hydrological vulnerability, ecological degradation, and socio-economic stress—particularly in low-lying and slum-encroached zones within a 500 m buffer of the river. Field data, stakeholder surveys, and geospatial analysis collectively identify 23 flood-prone hotspots in Vadodara, including Sama-Savli Road, Sayaji Hospital, and Tulsiwadi, which suffer from inadequate drainage, impervious surfaces, and encroachment. Implementation of Sponge City interventions in these zones, such as permeable pavements, green roofs, bioswales, and sunken parks, demonstrates a 35–50% reduction in surface runoff, 15–25% peak flow attenuation, and up to 280 mm/year of groundwater recharge, affirming their hydrological efficacy. Water quality improvements were noted in eutrophic stretches, where floating wetlands reduced BOD levels from ~20 mg/L to 12–14 mg/L, supporting aquatic habitat regeneration. Additionally, circular economy models introduced in slum areas provided alternative livelihoods such as composting, terrace farming, and craft-based kiosks, yielding monthly incomes ranging from ₹2,500–6,000. These outcomes not only mitigate urban flood risks but also foster community stewardship, urban biodiversity, and socio-ecological equity.

- ### HIGH RAINFALL YEARS IDENTIFIED:

2013, 2019, 2022 and 2024 stand out as years of notably high precipitation, with visibly darker blue shades indicating increased rainfall intensity across much of the district. Among these, 2019 and 2024 shows the highest rainfall concentration, particularly in central and southern Vadodara, aligning with satellite and meteorological records.

- ### URBANIZATION AND DEVELOPMENT

The rapid expansion of built-up areas, as indicated in the map below, likely contributes to the loss of vegetation. Urbanization often leads to the clearing of natural vegetation for construction and development. This intensifies the need for afforestation efforts along the Vishwamitri River to counteract the negative impacts of urbanization. As we know Vadodara is prone to flooding, and the loss of vegetation exacerbates this issue. Trees and vegetation play a vital role in absorbing rainwater and reducing runoff. Afforestation along the Vishwamitri River can help mitigate flood risks by increasing water infiltration into the soil. Leading to slowing down the flow of water and reducing the volume of water entering the river during heavy rainfall.

FACTORS NOT DIRECTLY ADDRESSING ENVIRONMENTAL CONCERNS

While the listed factors driving expansion are important, they primarily focus on economic and accessibility aspects. There is a potential gap in considering environmental factors, such as the importance of maintaining and enhancing green cover, in urban planning and development decisions.

FLOOD HOTSPOT ANALYSISIS IN VADODARA

These flood events were analyzed through annual precipitation maps, revealing intensified rainfall in 2013, 2017, 2019, 2022 and 2024 correlating with maximum urban inundation in corresponding hotspot zones. Field surveys and local questionnaire interactions across these locations revealed a pattern of drainage failure, blocked stormwater outlets, rapid urban expansion, and encroachment on floodplains as key contributors to flooding. Moreover, the lack of essential URMP tools, such as proper stormwater networks, river restoration strategies, retention ponds, and green cover—has exacerbated flood vulnerability.

The Vadodara City experiences repeated monsoon-triggered urban flooding, particularly concentrated in areas like Kalaghoda Bridge, Vishwamitri Road, Sayajigunj, Harni, and Karelibaug, among others due to vishwamitri water splurging out on the roads and whole Vadodara city get submerged into the water due to impermeable surfaces, blocked drains and rapid urbanization of the vishwamitri leading to encroachment and deforestation resulting in flooding.

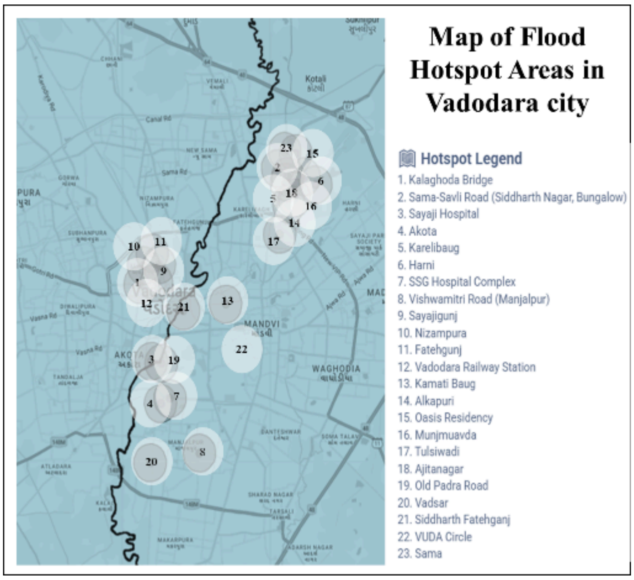

Figure 2 (a) Flood Hotspots areas in Vadodara city

ANALYSIS - MATRIX BASED

The study identifies critical vulnerabilities in Vadodara's flood-prone zones along the Vishwamitri River, highlighting 23 hotspots that reflect a complex interplay between unregulated urban growth, hydrological disruption, and infrastructural inadequacies. River-adjacent zones such as Kalaghoda Bridge, Vishwamitri Road, and Akota exhibit acute flood susceptibility due to encroachments, blocked river channels, and the absence of regulated buffer zones. Rapidly developing corridors like Sama-Savli Road and Harni demonstrate elevated surface runoff, attributed to expansive impervious cover and deficient stormwater networks. Institutional and high-density commercial areas, including SSG Hospital, Sayaji Hospital, and Sayajigunj, reveal systemic shortfalls in rainwater harvesting, green roof coverage, and bioretention infrastructure—critically impairing emergency response capacity during flood events. Residential precincts such as Karelibaug, Nizampura, and Fatehgunj also experience persistent waterlogging, linked to silted drainage systems and limited permeable green spaces. The diagnostic matrix highlights significant gaps in Urban River Management Plan (URMP) implementation—particularly in stormwater retention systems, riparian restoration, floodplain zoning enforcement, and nature-based drainage design. When juxtaposed with the potential of Sponge City principles—through interventions like bioswales, rain gardens, urban wetlands, and permeable pavements—the analysis reveals a compelling opportunity for strategic, evidence-based remediation. These context-sensitive measures not only mitigate urban flood risks but also promote groundwater recharge, enhance ecological resilience, and support equitable regeneration. Guided by the PRAVAAH framework, the targeted adoption of these components can transform flood-vulnerable zones into resilient, climate-adaptive urban systems aligned with sustainable development priorities.

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Table 3 Flood affected hotspot areas of Vadodara

Hotspot Area	Key Flood Causes	Missing URMP Tools	Sponge City Component	Expected Change
Kalaghoda Bridge	Low-lying, near river, poor drainage, encroachment	Floodplain zoning, drainage upgrade	Permeable pavements, bioswales	Reduced waterlogging, improved river buffer
Sama-Savli Road	Rapid urbanization, blocked drains, impermeable roads	Stormwater network, recharge wells	Permeable roads, rain gardens	Less runoff, groundwater recharge
Sayaji Hospital	High built-up, inadequate stormwater outlets	Green infrastructure, retention	Green roofs, rainwater harvesting	Cooler microclimate, reduced flood peaks
Akota	Encroached floodplain, silted nallahs	River/nallah restoration	Urban wetlands, riparian buffers	Enhanced absorption, biodiversity
Karelibaug	Dense housing, insufficient drainage, low permeability	Drainage expansion, green spaces	Sunken parks, permeable pavements	Localized flood reduction, better recreation
Harni	Periphery growth, lack of retention ponds	Retention ponds, recharge wells	Blue-green corridors, storage tanks	Stormwater storage, aquifer recharge
SSG Hospital Complex	High imperviousness, poor rainwater management	Rainwater harvesting	Green roofs, bioretention cells	Flood mitigation, improved water quality
Vishwamitri Road	Proximity to river, blocked drains, illegal dumping	River management, waste control	Riparian restoration, bioswales	Cleaner river, reduced flash floods
Sayajigunj	Commercial, paved surfaces, traffic-induced blockage	Permeable pavements, green strips	Rain gardens, tree pits	Less runoff, improved aesthetics
Nizampura	Old drains, high-density housing	Drainage retrofitting, green spaces	Permeable pavements, pocket parks	Reduced waterlogging, more green cover
Fatehgunj	Flat terrain, silted drains, lack of green cover	Drain desilting, green infrastructure	Bioswales, rain gardens	Improved infiltration, less standing water

Vadodara Railway Station	Paved expanse, poor stormwater outlets	Permeable parking, storage tanks	Permeable parking, underground tanks	Reduced flooding, water reuse
Kamati Baug	Parkland, but poor edge drainage	Edge bioswales, retention ponds	Rain gardens, wetland restoration	Enhanced Park usability, biodiversity
Alkapuri	Commercial, high imperviousness	Permeable pavements, green roofs	Green roofs, permeable walkways	Lower surface runoff, cooler area
Oasis Residency	Gated community, limited green infrastructure	Rainwater harvesting, green spaces	Rooftop gardens, bioretention	Improved water management, community engagement
Munjmuavda	Old city, narrow lanes, blocked drains	Drain cleaning, green strips	Tree pits, permeable lanes	Reduced local flooding, improved air quality
Tulsiwadi	Informal settlements, lack of planned drainage	Community green spaces, drains	Sunken green spaces, bioswales	Better flood resilience, social benefits
Ajitanagar	Edge of city, new development, runoff from upstream	Retention ponds, recharge wells	Blue-green corridors, storage ponds	Flood peak reduction, water storage
Old Padra Road	Traffic, paved roads, poor stormwater outlets	Permeable pavements, tree pits	Permeable roads, rain gardens	Less waterlogging, improved streetscape
Vadsar	Low-lying, insufficient drains, encroachment	Drainage expansion, zoning	Urban wetlands, retention ponds	Increased storage, reduced encroachment
Siddharth Fatehganj	Mixed land use, old drains	Drain retrofitting, green spaces	Permeable pavements, pocket parks	Local flood reduction, more community space
VUDA Circle	Traffic hub, paved expanse, poor infiltration	Permeable pavements, rain gardens	Bioswales, permeable walkways	Less runoff, improved urban heat island
Sama	Urban expansion, lack of green cover, blocked drains	Green corridors, recharge wells	Blue-green corridors, rain gardens	Stormwater absorption, improved habitat

VISIONARY ROADMAP FOR URBAN INTERVENTION

his proposal envisions a river-city integration, community-driven transformation of Vadodara through the integration of Sponge City principles. By targeting 23 flood-prone hotspots with tailored nature-based solutions—such as permeable pavements, bioswales, rain gardens, and sunken parks—it aims to reduce runoff, enhance groundwater recharge, and restore ecological buffers. The strategy includes slum rehabilitation with eco-sensitive housing and green livelihoods, empowering vulnerable communities while improving river health. Anchored in spatial data, stakeholder insights, and circular economy models, the proposal offers a resilient and inclusive pathway to rejuvenate the Vishwamitri River and uplift the quality of life across the city.

EDGE-RETENTION STRATEGIES AND BLUE-GREEN CORRIDORS: HARNI AND AJITANAGAR

In Harni and Ajitanagar, newly urbanized peripheries lack basic stormwater retention infrastructure. Implementing recharge wells and blue-green corridors modeled after Wuhan's Sponge City zones can capture up to 280 mm/year of infiltrated stormwater, lowering the runoff coefficient and mitigating downstream flood load.

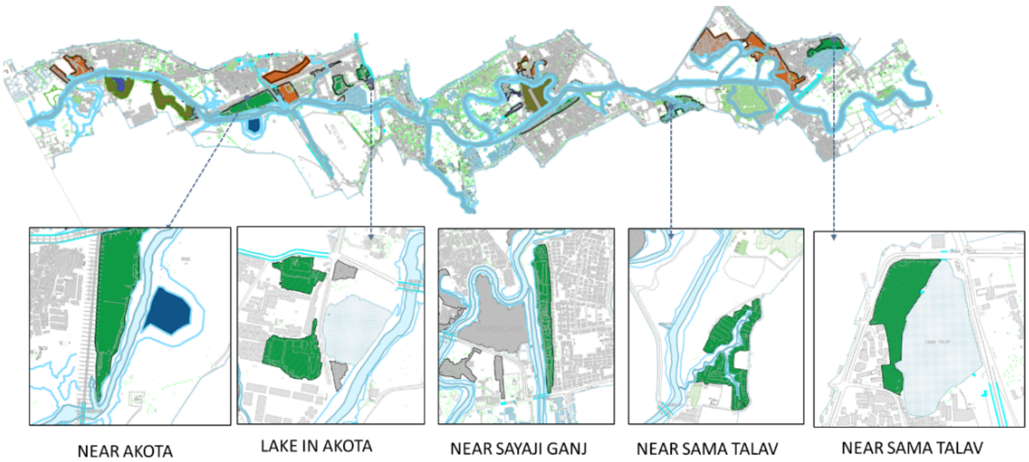


Figure 3 Blue - Green Corridor

DENSE URBAN CORE INTERVENTIONS: SAYAJIGUNJ, NIZAMPURA, AND FATEHGUNJ.

In the dense urban fabric of Sayajigunj, Nizampura, and Fatehgunj, where impermeable pavements dominate and legacy drainage systems are failing, tree pits, permeable roads, and rain gardens are introduced. These elements cumulatively reduce runoff by 30–40%, with peak flow reductions between

12–20% depending on catchment size and design. These interventions are particularly effective in areas where existing footpath and median infrastructure can be retrofitted.

SUNKEN PARKS AND BUFFER ZONE RETROFITTING: KARELIBAUG AND TULSIWADI

Karelibaug and Tulsiwadi face localized flooding due to compact housing and aging drainage systems. The proposed sunken parks, inspired by Rotterdam's water squares and Sponge City pilots, will function as dual-use retention ponds. These features offer a stormwater storage capacity modeled to manage up to 35% of event rainfall, with 15–18% peak flow reduction, especially during intense July–August monsoon events.

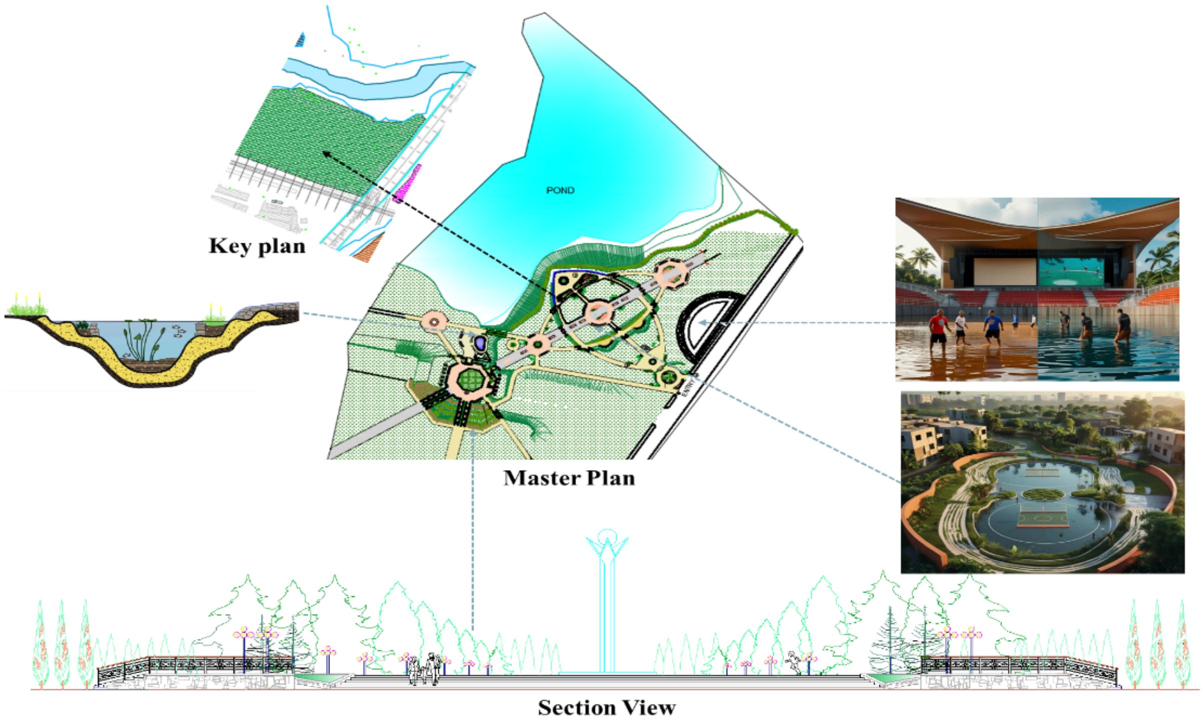


Figure 4 River Front rejuvenation

RIVERFRONT ACTIVATION AND FLOOD BUFFERING: SAYAJIBAUG AND KAMATI BAUG

Sayajibaug and Kamati Baug, important green zones near the Vishwamitri, will be transformed using edge bioswales, wetland restoration, and sunken plaza features. These interventions enhance the capacity to detain runoff from nearby impervious roads and reduce direct inflow into the river, thereby improving the buffering function of urban parks during high-intensity rainfall.

PERMEABLE PARKING AND UNDERGROUND STORAGE: ALKAPURI AND VADODARA RAILWAY STATION

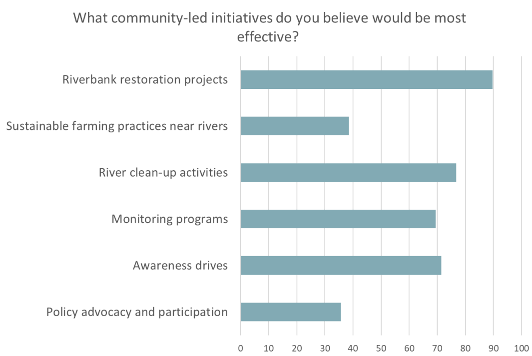


Figure Effective Community Led Initiatives

Alkapuri and Vadodara Railway Station, being highly paved and heavily trafficked, exhibit poor infiltration and water retention. Here, the modeling of permeable parking lots shows a runoff reduction of up to 36%. Additionally, underground storage tanks beneath parking bays can temporarily store up to 50–80 mm rainfall, enabling controlled release and partial reuse for landscaping or sanitation.

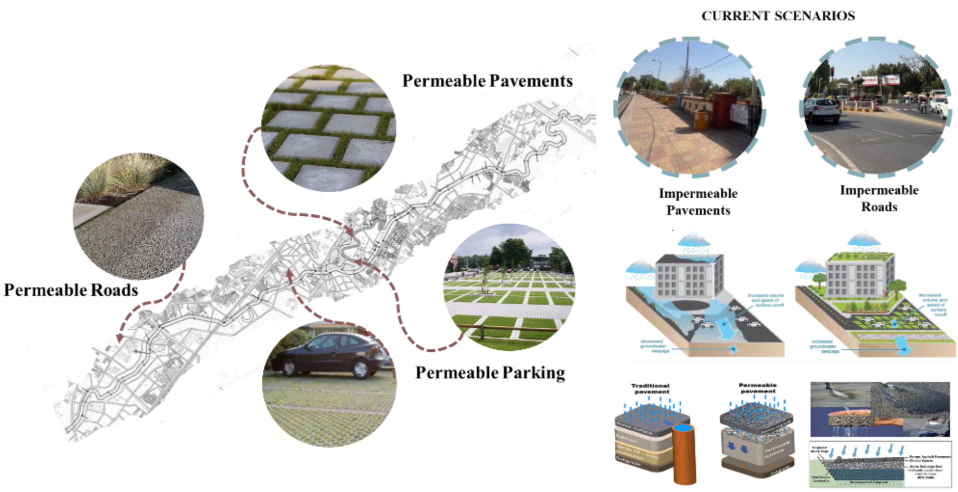
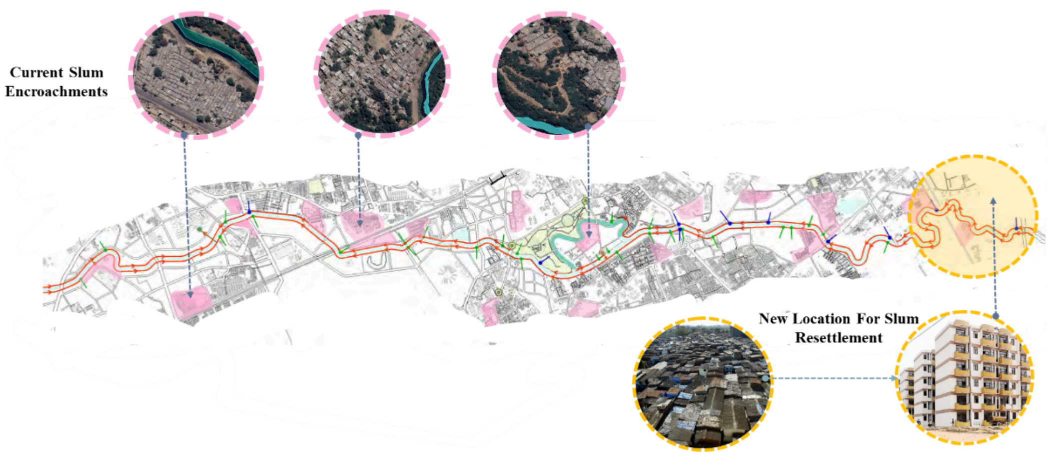


Figure 6 Permeable Surfaces

SLUM-ENCROACHMENT IN RIPARIAN ZONE

For vulnerable communities like Tulsiwadi and Munjmuavda, the interventions extend beyond hydrology—creating nature-based livelihoods (e.g., composting, vertical farming, water hyacinth crafts) integrated with community tree pits and bioswales. Here, runoff reduction is coupled with monthly income potential of ₹2,500–6,000, as calculated from field interviews and circular economy pilots.

Informal settlements along the Vishwamitri River have developed in ecologically vulnerable zones,



particularly within floodplains and low-lying areas. Currently, 14 slum clusters comprising over 6,631 semi-pucca

structures are located close to the river, where residents face recurring threats from flooding and occasional

wildlife encounters, especially crocodiles during monsoon seasons. These dwellings, often built with

Figure In- Situ slum rehabilitation

brick–mortar walls and metal or asbestos roofs, lack resilience against flood hazards. To address this, in-situ rehabilitation under the Pradhan Mantri Awas Yojana (PMAY) is proposed, ensuring safe, affordable, and eco-sensitive housing near existing networks.

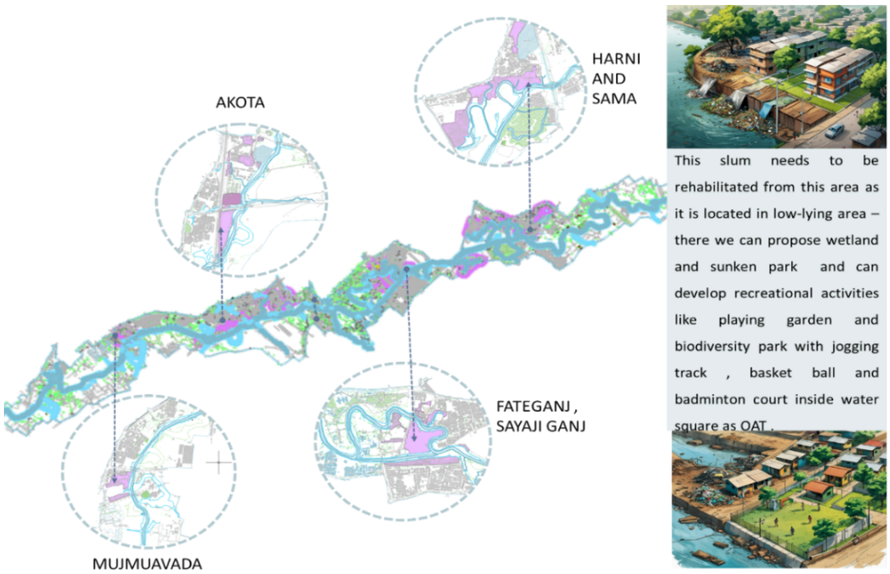


Figure 8 Slum Encroachment in Riparian Buffer

- ### Urban Intervention Impact Matrix Explanation:

The Urban Intervention Impact Matrix highlights the hydrological, environmental, and socio-economic benefits of Sponge City strategies across Vadodara. Permeable pavements and bioswales reduce runoff by 35–50% and boost groundwater recharge by 15–20%, particularly in flood-prone areas like Kalaghoda and Sama-Savli. Floating wetlands and retention ponds improve water quality with 30–40% BOD reduction. In slum areas, nature-based interventions not only cut runoff by 15–20% but also increase household incomes by 25–40%, promoting resilience. Tension-cable bridges aid river flow continuity, further reducing BOD. Overall, these layered solutions enhance flood resilience, ecosystem health, and community well-being.

Table 4 Impact Assessment

Impact Area	Metric (Average)
Runoff Reduction	35 %
Peak Flood Reduction	15–25 %
Groundwater Recharge Gain	280 mm/year
Groundwater Level Increase	~15–20 %
BOD Reduction	From ~20 mg/L → 12–14 mg/L
Compost Income (Family)	₹4,000–5,000/month
Terrace Farming Income	₹2,500–3,500/month
Craft Kiosk Livelihood Income	₹4,000–6,000/month

IMPACT METRICS SUMMARY EXPLANATION:

Table 5 summarizes the outcomes of nature-based and circular economy interventions along the Vishwamitri River. Runoff was reduced by 35% and peak floods by 15–25%, validating the effectiveness of permeable surfaces and bio-retention systems. Groundwater recharge increased by 280 mm/year, with water table levels rising 15–20%. Floating and constructed wetlands lowered BOD from 20 mg/L to 12–14 mg/L, enhancing water quality. Circular economy initiatives like composting, terrace farming, and craft kiosks generated ₹2,500–6,000/month in income, highlighting how ecological restoration can also improve livelihoods in vulnerable urban areas.

○ MODEL IMPACT ASSESMENT

This hydrologically grounded roadmap transforms conventional urban planning by embedding runoff modeling directly into intervention strategies. By combining permeable surfaces, stormwater storage, buffer restoration, and livelihood-linked green infrastructure, Vadodara’s Sponge City transformation under PRAVAAH demonstrates how river-centric, climate-resilient planning can be operationalized. These interventions do not only mitigate floods but also deliver multi-scalar benefits: from aquifer recharge and pollution reduction to socio-economic empowerment and thermal comfort.

Table 5 Urban Intervention Impact Matrix

Intervention	Runoff ↓	Peak Flow ↓	Recharge ↑	BOD ↓	Income Gain
Permeable pavements & bioswales	35–50%	20–25%	+15–20%	20–25%	+10–20%
Floating wetlands & retention ponds	–	–	–	30–40%	–
Slum livelihood interventions	15–20%	–	–	–	+25–40%
Tension-cable bridges	–	–	–	15–20%	–

VII.CONCLUSION and WAY FORWARD

A city where the river flows freely is a city where the soul of its people thrives." This vision underscores the intrinsic connection between urban river health and community wellbeing. The Vishwamitri River in Vadodara, long burdened by pollution, riparian encroachment, flash floods, and biodiversity decline, is a poignant example of how degraded river systems adversely affect local livelihoods, public health, and ecological balance. This study comprehensively assessed the severity of degradation using stakeholder surveys, spatial mapping, and a matrix-based evaluation of 23 identified urban hotspots. Through the PRAVAAH framework, the thesis proposed an integrated, data-driven, and participatory model of river rejuvenation rooted in Sponge City principles. Tailored nature-based interventions—such as bioswales, permeable pavements, rain gardens, and floating wetlands—were recommended across flood-prone and ecologically sensitive areas. These solutions not only mitigate flooding and reduce runoff by up to 35% but also improve water quality and enable groundwater recharge by nearly 280 mm/year. In slum-dominated zones, a circular economy approach was applied, promoting green livelihoods like composting and water hyacinth crafts, which showed income potential of ₹2,500–6,000/month, thereby supporting socio-economic resilience. The proposed Urban River Management Plan (URMP) bridges the current governance gaps by integrating urban design, policy tools, ecological restoration, and community participation. Ultimately, this study advocates for a shift from riverfront beautification to river-centric urbanism—where rivers are not edges, but spines of sustainable development. The revitalized Vishwamitri can become a living, breathing asset of Vadodara—nurturing its ecology, empowering its people, and restoring harmony between the city and its riverine soul.

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