

# Climate-Change Adaptation through Blended Finance Models for Urban Flood Resilience in India: Assessing Viability Gap Funding and Performance-Linked Guarantees in Smart Drainage Systems

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**Abstract:** *Urban flooding is an increasing climate adaptation challenge in Indian cities due to extreme rainfall, rapid urbanization, and degraded drainage systems. This study examines how blended Public-Private Partnership models can improve urban flood resilience through smart drainage infrastructure. It focuses on Viability Gap Funding and performance-linked operation and maintenance guarantees as key financial instruments. Using policy analysis and case studies from Kolkata, Chennai, Nagpur, and Bengaluru, the study evaluates financial feasibility and resilience outcomes. Results show that VGF support reduces capital burden and improves project viability, while performance-linked guarantees lower operational risks and promote technology adoption. The findings suggest that blended PPP models can enable scalable climate-resilient infrastructure if supported by clear risk allocation, institutional capacity, and outcome-based contracting.*

**Keywords:** Urban flood resilience, smart drainage systems, blended finance, Public-Private Partnerships, Viability Gap Funding, performance-based contracting, climate-resilient infrastructure”.

## 1. Introduction

### The Escalating Urban Flooding Crisis

The hydro-climatic and land-use conditions of Indian cities have undergone significant transformation over the past few decades. Rising global temperatures, localized micro-climatic changes, and shifting monsoon dynamics have increased the frequency and intensity of short-duration, high-intensity rainfall episodes. When these climatic shocks interact with the dense, highly impervious built environment of Indian megacities, they translate into recurrent episodes of severe urban flooding with wide-ranging impacts on infrastructure, livelihoods, and public services (NIDM, 2009; MoHUA, 2022).

Between 2018 and 2024, major economic hubs such as Mumbai, Bengaluru, Chennai, and Kolkata witnessed repeated and disruptive waterlogging events, leading to the temporary collapse of transport networks, commercial activity, and daily civic life. These episodes are no longer isolated incidents but part of an emerging pattern of urban hydrological stress. Aggregate assessments indicate that annual flood-related damages in India consistently exceed ₹1,800 crore, affecting more than 7.5 million hectares of land and resulting in an estimated 1,600 fatalities each year (NIDM, 2009; World Bank, 2025). The underlying vulnerability of these cities stems from a combination of historical infrastructure gaps and rapid, often unplanned, land-use change.

Mumbai exemplifies the consequences of aging infrastructure operating under modern climatic loads. A substantial portion of the city’s drainage network dates back to the late nineteenth and early twentieth centuries, when systems were designed to

handle rainfall intensities of around 25 millimetres per hour. Contemporary monsoon events, by contrast, frequently exceed 100 millimetres per hour in localized pockets, overwhelming the existing “grey” drainage infrastructure and triggering prolonged inundation (ADB, 2025; World Bank, 2025). Projections suggest that, without substantial flood-resilience interventions, riverine and pluvial flooding in Indian cities could impose economic costs on the order of USD 770 billion annually by 2050 (World Bank, 2025).

Beyond structural deficits, the degradation of natural hydrological buffers has further amplified urban flood risk. Bengaluru, once renowned for its network of over 1,000 lakes and wetlands that functioned as natural detention basins, has lost approximately 80 percent of these blue-green assets to encroachment and land-conversion. This process of concretization has drastically reduced infiltration capacity, so that most rainfall now converts directly into surface runoff. The implications became evident during a 2024 event in Yelahanka, where an accumulation of 157 millimetres of rainfall within six hours submerged more than 1,030 households in a matter of hours. Coastal cities such as Chennai and Kolkata face an additional layer of complexity, as they must contend with pluvial flooding, riverine overflows, and coastal storm surges exacerbated by tidal backwater and projected sea-level rise (NIUA, 2022; ADB, 2025).

Tackling these compound vulnerabilities demands a significant and sustained mobilisation of capital. Global analyses estimate that achieving adequate climate adaptation for water, sanitation, and hygiene (WASH)-related infrastructure requires an annual investment of approximately USD 114 billion worldwide (CWAS, 2023). Within India, a

conservative projection suggests that enabling essential flood-resilience measures in about 60 percent of the country's high-risk urban centres over the next fifteen years would require roughly USD 150 billion in cumulative investment (World Bank, 2025). Moving from reactive disaster-response approaches to anticipatory, technology-enabled urban infrastructure requires a shift toward predictive planning, integrated drainage systems, and, crucially, innovative financing mechanisms that blend public and private capital.

## 2. Review of Literature and Conceptual Framework

The academic and policy discourse on urban flood management has shifted from isolated civil-engineering measures to broader socio-ecological resilience approaches. This evolution is critical for assessing how contemporary financial instruments can support urban flood-resilience infrastructure (NIDM, 2009; World Bank, 2025).

### 2.1 The Evolution of Urban Flood Resilience and Smart Drainage

Urban flood resilience is now understood as a city's capacity to anticipate, absorb, adapt to, and recover from flood-related shocks while maintaining essential services and livelihoods (UN-Habitat, 2020). This definition moves beyond static infrastructure to a systemic, adaptive perspective. Conventional drainage systems are largely reactive. They rely on gravity and fixed physical capacities. Once these thresholds are exceeded, they cannot respond dynamically to increased flows.

Smart drainage systems, in contrast, embed predictive and adaptive control into the urban water network. Sensor-based monitoring, AI-driven runoff forecasting, and automated sluice-gate or pump control turn passive pipes into responsive infrastructure (ADB, 2025). Digital twins—virtual, real-time models of physical drainage networks—allow municipal technicians to simulate storm events and optimise pump and detention-basin operations before rainfall begins. Empirical studies show that when smart drainage is combined with Nature-Based Solutions such as bioswales and permeable pavements, stormwater runoff volumes can fall by up to 50 percent (CWAS, 2023).

### 2.2 The Public Goods Dilemma in Urban Drainage

Urban drainage exhibits characteristics of a public good: it is non-excludable and non-rivalrous. Once a city's flood-protection system is in place, residents cannot be excluded from its benefits, and one person's safety does not reduce another's. Because these benefits are diffused and hard to price, private markets tend to underinvest in drainage infrastructure (Acemoglu & Robinson, 2012).

Nevertheless, the social return on investment is substantial. Flood mitigation reduces property damage, sustains commercial activity, lowers health-related risks, and improves public welfare. Private developers, however, face high capital costs, long and politically sensitive construction periods, and uncertain regulatory conditions. Directly charging users for "avoided flooding" is practically

infeasible. As a result, commercial returns often appear low or negative under conventional financing models (World Bank, 2025).

### 2.3 Blended Finance and Public–Private Partnerships

This market failure calls for blended finance approaches. Blended finance combines developmental or philanthropic public funds with private capital to crowd-in investment in high-impact but financially constrained sectors (OECD, 2020). In the context of urban flood resilience, blended PPP models integrate public grants, private operational efficiency, and de-risking instruments such as guarantees and performance-linked annuities (CWAS, 2023).

These mechanisms aim to reshape the risk-reward trade-off. Public funding lowers the initial capital burden on private partners. Sovereign or municipal guarantees secure stable revenue streams during operation. Viability Gap Funding and similar instruments help transform otherwise unviable projects into bankable propositions for institutional investors and infrastructure-focused equity funds (Government of India, 2020). Scholarly work emphasises that, without structured risk-sharing arrangements, private capital flows to climate-adaptation infrastructure in developing economies will remain limited (World Bank, 2025; CEEW, 2025).

## 3. Research Methodology and Analytical Framework

This study adopts a mixed-methods approach to assess the effectiveness of blended PPP models for urban flood resilience in Indian cities. The design combines qualitative policy analysis with quantitative financial and infrastructural assessments drawn from national pilot projects (Yin, 2018).

### 3.1 Policy and Desk-Based Review

The research starts with a comprehensive desk-based review of national-level PPP frameworks. It focuses on statutory provisions under the Department of Economic Affairs' Viability Gap Funding (VGF) scheme and related guidelines on PPP structuring in urban infrastructure (Government of India, 2020). These are read alongside national guidance documents from the National Disaster Management Authority (NDMA) and climate-resilience studies by independent research institutes. The aim is to understand how existing policy instruments support—or constrain—blended PPPs for flood-resilience projects.

### 3.2 Case-oriented Analysis

After the policy review, the study shifts to a case-oriented analysis of detailed project reports (DPRs) for emerging smart-drainage pilots. The primary focus is the advanced smart-drainage initiative proposed for the Kolkata–Howrah metropolitan region. Engineering designs, cost estimates, and operational assumptions from the DPR are mapped against alternative PPP structures. By overlaying real-world technical and financial parameters onto theoretical blended PPP models, the analysis tests the practical feasibility of VGF, guarantees, and performance-linked annuities (ADB, 2025).

### 3.3 Four-Dimensional Analytical Framework

The analysis is organised around four interlinked dimensions.

**Project typology** : The study classifies each flood-resilience scheme as either a “pure” infrastructure project—focused mainly on hard assets such as concrete drains, culverts, and retaining walls—or a “soft-hard” hybrid package. Hybrid projects integrate cyber-physical systems (sensors, SCADA, AI-driven control), long-term operation and maintenance (O&M), and community-based monitoring or early-warning mechanisms. This distinction affects risk allocation, financing structure, and monitoring requirements (CWAS, 2023).

**Funding architecture**: The framework examines the composition of project finance, including the share of VGF grants, O&M-support subsidies, and other sovereign guarantees as a percentage of Total Project Cost (TPC). It also considers timing and sequencing: how much capital is injected during construction versus how much is paid as operational annuities after commissioning. The study explores whether front-loaded grants or back-loaded performance-linked payments yield better fiscal and resilience outcomes (World Bank, 2025).

**Risk-sharing matrix**: A key concern is the distribution of project risks across public, private, and financial actors. The analysis identifies responsibilities for construction delays, design shortfalls, technology obsolescence, regulatory changes, and extreme climate events. It evaluates whether current PPP templates clearly assign these risks or leave them ambiguously shared. The study also tests whether guarantees and insurance mechanisms are adequate to absorb climate-related shocks without undermining fiscal discipline (OECD, 2020).

**Resilience-performance indicators**: The final dimension links financial design to resilience outcomes. The framework assesses how changes in flood duration, waterlogging depth, inundated area, and socio-economic losses are quantified and monitored. It examines whether these indicators are embedded in concession agreements as performance-linked payment triggers. The study explores whether “pay-for-resilience” or “pay-for-O&M” logics dominate, and how this affects private partners’ incentives to maintain high-quality drainage performance over the long term (UN-Habitat, 2020).

Together, these dimensions provide a structured basis for evaluating how blended PPP models can- or cannot- support scalable, bankable, and resilient urban flood-management systems in Indian cities.

## 4. Financial Architecture: Viability Gap Funding and Performance Guarantees

Smart, multi-layered cyber-physical drainage systems require large upfront capital. Installing a smart-drainage corridor—complete with subterranean detention cells, intelligent outfall nodes, and SCADA integration—can incur capital expenditure (CAPEX) of ₹100–₹150 crore per multi-kilometre stretch. A city-wide rollout in a major Indian metropolitan area often demands investments in the range of

₹3,000–₹4,000 crore, spread over ten to fifteen years. Given the weak direct revenue base from end-users, strong fiscal support is essential to attract private capital into such projects (Government of India, 2020).

### 4.1 The Evolution and Application of Viability Gap Funding

The Government of India, through the Department of Economic Affairs (DEA), has institutionalised the Viability Gap Funding (VGF) scheme to address market failures in infrastructure. Originally aimed at economically productive assets such as toll highways, airports, and ports, the scheme has been expanded to include social and environmental sectors (Government of India, 2020).

VGF operates as a one-time or deferred capital grant, disbursed during the construction phase of a PPP project. By covering a substantial share of initial CAPEX, the public sector reduces the private partner’s equity requirement and lowers the volume of commercial debt. This grant lowers the project’s weighted average cost of capital (WACC) and enables the private consortium to achieve a reasonable internal rate of return (IRR), even where user revenues are limited (World Bank, 2025).

Revised DEA guidelines create a favourable environment for climate-resilient urban infrastructure. Under standard parameters, VGF is capped at 40 percent of Total Project Cost (TPC), split equally (20 percent each) between the Central and sponsoring State Governments. For social sectors—including wastewater treatment, solid waste management, water supply, and, by extension, urban drainage—the ceiling is raised to 60 percent of TPC. Within this category, the Central and State or municipal authorities may each contribute up to 30 percent of capital costs (Government of India, 2020).

For experimental pilot projects in health and education, guidelines allow capital support of up to 80 percent. Although smart-drainage projects fall under the 60 percent social-infrastructure cap, the willingness of the state to absorb the majority of capital risk highlights a mature policy recognition of blended finance needs (OECD, 2020).

### 4.2 Operation and Maintenance (O&M) Support Guarantees

VGF reduces CAPEX barriers, but private operators still face operational risks over the life of a concession. Smart drainage requires continuous software updates, regular maintenance of submerged sensors, uninterrupted power for pumps, and specialised technical oversight. To ensure bankability, the financial architecture must include robust O&M-phase guarantees.

Recent PPP reforms formalise Operation and Maintenance (O&M) support for eligible projects. The government may subsidise up to 50 percent of O&M costs for the first five years after the Commercial Operation Date (COD), with the national and State Governments each contributing 25 percent (Government of India, 2020).

This subsidy is critical for smart-drainage deployment. The first five years serve as a calibration phase: digital-twin

models are tuned against real-time storm data, AI algorithms are refined to reduce false alerts, and hardware reliability is tested under field conditions. By guaranteeing O&M funding during this learning period, the state shields private operators from early-phase financial volatility and reduces the risk of project abandonment due to technical teething problems (ADB, 2025).

#### 4.3 The Hybrid Annuity Model (HAM) Integration

Beyond direct O&M support, the Hybrid Annuity Model (HAM) has reshaped water-sector PPPs in India and offers a template for smart-drainage schemes. Piloted under large-scale river-rejuvenation programmes such as Namami

Gange, HAM limits the private developer's capital exposure to about 40 percent of CAPEX. The remainder, supported by VGF and a defined O&M margin, is paid through fixed semi-annual annuities over a typical fifteen-year concession (Government of India, 2020).

These annuity payments are conditional. They depend on strict performance benchmarks. If system uptime falls below threshold levels or if flood-reduction targets are not met, annuities are reduced or withheld. This design links the private operator's financial returns to long-term resilience outcomes, shifting the focus from asset construction to guaranteed, sustained service delivery (World Bank, 2025).

Financial parameter	Traditional public procurement	Blended PPP (VGF + HAM)
Capital funding burden	100% borne by constrained municipal budgets	40–60% public grant (VGF); 40–60% private equity/debt (Government of India, 2020)
Operational risk	Fully retained by the public sector	Transferred to private operator; incentivises efficiency (OECD, 2020)
O&M financing	Subject to volatile annual municipal budgets	Guaranteed via 15-year annuities + up to 50% O&M support (Government of India, 2020)
Technology lifecycle	Risk of obsolescence and poor maintenance	Continuous private upgrades mandated by performance metrics (ADB, 2025)

### 5. Empirical Case Studies and Pilot Evaluations

To ground the theoretical discussion of blended finance and smart hydrology, this study examines real-world applications across Indian cities. A comparative analysis of ongoing pilot projects, basin-scale programmes, and municipal wastewater models reveals the evolving trajectory of urban flood resilience (NIDM, 2009; World Bank, 2025).

#### 5.1 The Kolkata–Howrah Smart Drainage Paradigm

The Kolkata–Howrah metropolitan region faces one of India's most complex hydrological settings. The area lies in a low-lying deltaic plain, with average elevations of only six to eight metres above mean sea-level. It is exposed to intense cyclonic rainfall and tidal backflow from the Hooghly River (ADB, 2025). The existing drainage system, largely inherited from colonial engineering, is silted, clogged with solid waste, and dependent on manually operated pumps that often fail during peak storms. Rapid urbanisation has increased surface runoff by 30–40 percent, worsening flood frequency and duration (MoHUA, 2022).

The local authorities have prepared a Detailed Project Report (DPR) for a Smart Drainage system, initially targeting the Behala–Taratala corridor. The strategy proposes four to six intelligent outfall nodes. Each node integrates ultrasonic water-level sensors, high-precision tipping-bucket rain gauges, and motorised, fail-safe sluice gates controlled by programmable logic controllers (PLCs). The system continuously monitors tidal levels and rainfall forecasts. When a severe storm coincides with high tide– the main trigger for catastrophic waterlogging in Kolkata– the system autonomously closes outfall gates to block tidal ingress and activates high-capacity variable-frequency-drive pumps to discharge urban runoff against tidal pressure (Singha et al., 2025).

An AI-linked SCADA centre further enhances performance. Using LiDAR-based hydro-topographic data and digital-twin

simulations, the system predicts localized inundation patterns hours in advance. It routes excess flow into newly constructed modular underground detention cells, each with a capacity of 2,000–10,000 cubic metres of stormwater storage (Singha et al., 2025).

The financial design of the pilot illustrates the need for blended financing. Capital expenditure for the corridor is estimated at ₹100–₹150 crore, a level beyond the scope of pure municipal funding. The proposed structure uses the national Viability Gap Funding (VGF) scheme, targeting a 40 percent capital grant– about ₹48 crore for a ₹120 crore project—to de-risk construction and sensor deployment (Government of India, 2020).

Socio-economic modelling shows that the system could reduce the duration of severe waterlogging by up to 80 percent, cutting episodes from 24–48 hours to under 12 hours. The pilot corridor alone may generate annual savings of ₹50–₹80 crore in avoided property damage, reduced health costs, and preserved commercial activity. A city-wide rollout over fifteen years, projected at ₹3,000–₹4,000 crore, could yield annual savings of ₹200–₹300 crore, making the upfront public subsidy an economically justifiable lever to attract private operators (Singha et al., 2025).

#### 5.2 Integrated Resilience in the Chennai Metropolitan Area

Chennai offers a complementary case of urban vulnerability and adaptive finance. After the 2015 floods, which caused economic losses exceeding ₹15,000 crore, the city re-evaluated its water-management strategy (MoHUA, 2017). Flat coastal topography and widespread encroachment on wetlands and estuaries had eroded the city's natural drainage capacity (ADB, 2025).

The Integrated Urban Flood Management project for the Kosasthalaiyar basin aims to protect nearly 1.9 million residents. The programme combines “grey” infrastructure

upgrades—rehabilitation and construction of over 175 kilometres of primary stormwater drainage system and installation of high-capacity pumping stations- with non-structural measures. The design explicitly accounts for climate projections, targeting resilience to rainfall intensities of 79 mm per hour alongside a sea-level rise of 21.7 cm under the RCP 8.5 scenario by 2050 (ADB, 2025).

Chennai has also embedded advanced digital systems into its resilience planning. The Chennai Smart City initiative has deployed IoT-based flood-level sensors across the city. These sensors feed data into the India Urban Data Exchange (IUDX) platform, enabling predictive analytics that integrate rainfall, soil saturation, tides, and local drain-blockage information (IUDX, 2022). This approach moves beyond simple rainfall monitoring to a multi-variable risk-assessment framework.

The project further incorporates Nature-Based Solutions (NBS). It mandates the construction of 23,000 groundwater-recharge pits along road networks, addressing both flood risk and dry-season water scarcity. The financing mix relies on blended international capital. The Asian Development Bank (ADB) and other multilateral institutions provide substantial loans and technical guarantees, demonstrating how sovereign and multilateral support can de-risk large-scale urban adaptation programmes (ADB, 2025).

### 5.3 Pluvial and Ecological Challenges in Bengaluru and Mumbai

Bengaluru and Mumbai exemplify how ecological degradation and infrastructure deficits interact differently within and across cities. Bengaluru, at an elevation of about 900 metres, does not face tidal flooding. Its flood crisis is entirely pluvial and largely human-induced. The city once relied on a cascading network of lakes and stormwater channels to manage monsoon rains. Encroachment and land-conversion have eliminated nearly 80 percent of these blue-green assets (ATREE, 2025). The loss of natural detention capacity means that short-duration downpours now trigger flash floods across multiple wards.

Strategic studies by the Ashoka Trust for Research in Ecology and the Environment (ATREE) argue that Bengaluru's resilience requires both hard infrastructure and large-scale ecological restoration. Proposed measures include permeable pavements, decentralised recharge wells, and systematic clearing of traditional stormwater channels. Hydrological simulations suggest that equipping 25 percent of the city with recharge wells and 25 percent with green roofs could reduce total runoff volume by 45 percent and cut the area under very high flood risk by about 77 percent (ATREE, 2025). Monetising these indirect benefits- such as improved groundwater recharge, lower urban-heat-island effects, and reduced river-pollution loading- requires innovative PPP structures that go beyond conventional user-tariff models.

Mumbai faces a different risk profile. As a dense island metropolis, it contends with intense monsoons, outdated colonial drainage networks, and rising sea levels. The 2005 floods, which caused over 1,000 deaths and economic losses of about ₹2,250 crore (equivalent to roughly ₹20,000 crore in

today's terms), exposed these systemic vulnerabilities (NIDM, 2009). The city's emerging resilience strategies combine engineered responses- floodgates, pumping stations, and improved drainage- with ecological protection. A key priority is the restoration and conservation of coastal mangrove forests. These ecosystems absorb storm-surge energy, reduce coastal inundation, and provide habitat for marine biodiversity (NIUA, 2022).

Financing such hybrid infrastructure-ecosystem packages calls for broadening PPP definitions. New models must incorporate valuation of biodiversity, carbon sequestration, and coastal-protection services alongside traditional flood-damage-avoidance metrics.

### 5.4 Validating the Financial Model: The Nagpur Wastewater Paradigm

While city-wide smart-drainage PPPs are still evolving, parallel sectors offer robust evidence of blended-finance effectiveness. The Nagpur wastewater-reuse project is a representative case. Facing acute regional water stress, the Nagpur Municipal Corporation adopted a Design, Build, Finance, and Operate (DBFO) model for sewage treatment and reuse (CWAS, 2023).

Under this arrangement, a private concessionaire funded 54 percent of the capital expenditure required to construct advanced sewage-treatment facilities. The financial viability did not depend on fluctuating user tariffs but on a guaranteed off-take. The regional thermal power utility Mahagenco committed to purchase treated wastewater for cooling, paying about ₹2.25 million annually (CWAS, 2023).

This closed-loop structure delivered multiple benefits. It treated millions of litres of urban sewage daily, reducing pollution of local rivers. It supplied a reliable, drought-resistant water source for industrial use and reduced freshwater extraction from reservoirs, thereby supporting climate-mitigation goals through improved watershed-health and carbon-sequestration co-benefits (CWAS, 2023). The Nagpur DBFO experience shows that, when risks are clearly allocated and revenue streams are creatively structured- even indirectly- private capital and technical expertise can be effectively mobilised for complex urban-hydrological projects.

## 6. Policy Implications and Institutional Governance

Recent national policy and institutional reforms provide a strong enabling environment for climate-resilient urban infrastructure. Municipal bodies cannot bear the full cost of climate adaptation alone. The Government of India has therefore created large-scale, structured funding instruments that channel capital from the central level to targeted urban-resilience projects (Government of India, 2020; World Bank, 2025).

### 6.1 National Funding Integration and Sovereign Capital

The Fifteenth Finance Commission's recommendations have reshaped how India finances disasters. Earlier allocations

focused mainly on post-event relief and reconstruction. The current framework emphasises ex-ante mitigation and resilience (Fifteenth Finance Commission, 2020). The National Disaster Mitigation Fund (NDMF) has been set up with an allocation of ₹13,693 crore, much of which is earmarked for urban-flood-risk reduction in major metropolitan areas (Government of India, 2020).

The fund operates through the Urban Flood Risk Management Programme (UFRMP). This multi-phase initiative strengthens both structural and non-structural measures in Indian cities. Phase 1 channelled over ₹3,075 crore to primary metros such as Chennai, Mumbai, and Kolkata. Phase 2 expands coverage to eleven additional vulnerable cities, including Guwahati, Bhopal, and Patna, with an outlay of more than ₹2,444 crore. The financing model follows a 90:10 cost-sharing arrangement between the Central and State Governments (PIB, 2024).

These sovereign-backed pools complement blended PPP models. NDMF grants can function as the public-equity component within a Viability Gap Funding (VGF) structure. By aligning disaster-mitigation capital with smart-drainage programmes, the state can crowd-in long-term private investment in high-risk urban corridors (World Bank, 2025).

## 6.2 Transitioning to Outcome-Based Contracting

The integration of smart technologies and blended finance demands a shift from conventional procurement. Traditional municipal contracts reward contractors for physical outputs only—concrete laid, pipelines installed, or embankments constructed. This approach encourages short-term construction activity but often neglects long-term maintenance, resilience, and technological performance (OECD, 2020).

Hybrid Annuity-type structures now enable outcome-based contracting. In this model, private operators receive payments only if they meet predefined performance indicators over time. Long-term annuities and O&M subsidies are tied to measurable outcomes rather than box-ticking milestones (Government of India, 2020).

For smart drainage, indicators must be precise and digitally verifiable. Key performance indicators (KPIs) can include:

- Reduction in the duration of street-level waterlogging after a defined rainfall threshold;
- Uptime and calibration accuracy of the IoT-based sensor network;
- Speed and reliability of automated sluice-gate responses to tidal fluctuations;
- Pre-emptive lowering of detention-basin levels ahead of forecasted storms (Singha et al., 2025).

Financial rewards rise when the system avoids flooding. Penalties apply if failures occur due to poor maintenance, software errors, or inaccurate forecasts. This design aligns private-sector incentives with long-term urban resilience, not just asset delivery.

## 6.3 Establishing Municipal Smart Drainage Cells

Outcome-based PPPs redefine the role of the private consortium. It becomes a long-term risk-bearer and performance-holder, not just a construction vendor. This shift, however, requires cities to strengthen internal technical capacity. Many urban-local-body (ULB) engineering departments lack expertise in data-driven hydrology, AI-based forecasting, cybersecurity for municipal telemetry, and complex annuity-based finance (NIUA, 2022).

To bridge this gap, many cities are beginning to institutionalise dedicated “Smart Drainage Cells” within ULBs. These multidisciplinary units typically combine hydrologists, data scientists, civil engineers, and infrastructure-finance specialists. They act as the central interface between:

- Slow-moving municipal administrations;
- Agile private-technology providers; and
- Risk-averse institutional lenders.

These cells negotiate contracts, oversee digital-twin platforms, monitor performance data, and enforce contractual obligations. By embedding technical and financial expertise within the city administration, they reduce information asymmetries and improve the quality of blended-PPP contracts for smart-drainage and other climate-resilience infrastructure (World Bank, 2025).

## 7. Conclusion

Climate-driven urban flooding in India requires a shift from traditional drainage systems to adaptive, technology-enabled infrastructure. This study shows that blended PPP models, supported by Viability Gap Funding and performance-linked annuities, can improve financial viability and long-term resilience of smart drainage systems. Case evidence suggests that such models reduce capital constraints and align private incentives with public outcomes. Future implementation should focus on strengthening municipal capacity, integrating ecological solutions, and adopting outcome-based contracting. These measures can support scalable and sustainable urban flood resilience across Indian cities.

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