International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2024
https://www.theaspd.com/ijes.php

Securing Urban Futures: The Critical Importance of River Health Evidence from the Najafgarh Sub-Basin, NCT of Delhi

[1*]Akhil Das, [2]Dr. Rabidyuti Biswas, [3]Dr. Shuvojit Sarkar
[1]University School of Architecture & Planning, New Delhi-110078, India, Email: akhildass@gmail.com
[2]Department of Physical Planning School of Planning & Architecture, New Delhi-110002, India
Email: r.biswas@spa.ac.in
[3]Department of Architecture School of Planning & Architecture, New Delhi-110005, India
Email: s.sarkar@spa.ac.in

ABSTRACT
Half the planet now lives in cities, and the rivers running through those cities are paying for that growth in measurable ways. He and colleagues (2021) place the urban population already facing water scarcity at roughly 933 million as of 2016, with projections climbing to anywhere between 1.69 and 2.37 billion by mid-century. India bears the heaviest share of that projected rise. In Delhi, the case has tipped well past warning. A 22-kilometre stretch of the Yamuna inside the city limits—barely two per cent of the river's full length—now carries between 76 and 80 per cent of its pollution burden (Central Pollution Control Board [CPCB], 2022), with two drains, Najafgarh and Shahdara, accounting for about 84 per cent of what the city contributes (Delhi Pollution Control Committee [DPCC], 2020). This paper builds on a thematic review of 252 peer-reviewed studies, the Delphi-validated parameter set developed for the Najafgarh sub-basin, and supplementary online evidence to argue that securing urban futures depends on one specific kind of planning instrument: an instrument capable of turning measurable land-use pressure into a binding regulatory outcome at the planning-cell scale. To operationalise that argument, I propose a framework anchored to the Driver–Pressure–State–Impact–Response logic (Lalande et al., 2014), consisting of a hydrological-pressure index keyed to land-use composition, a five-domain river-health index calibrated to CPCB norms, and a composite index that translates the two together into one of four binding action classes. Each class is mapped to a defined bundle of levers under the Master Plan of Delhi and the Unified Building Bye-Laws. Three obstacles to delivery stand out from the analysis: institutional fragmentation across overlapping agencies, the absence of a basin-scale unit in the planning regime, and the continued dominance of static zoning over adaptive regulation. Without addressing these, India's commitments under Sustainable Development Goal 6 (specifically Targets 6.3, 6.5, and 6.6) will remain out of reach, and its urban futures structurally exposed.
Keywords: *urban river health; land-use planning; Yamuna; Najafgarh sub-basin; responsive planning; DPSIR; Delhi; SDG 6*

1. INTRODUCTION

Cities have absorbed most of humanity in the space of three generations. From around 0.8 billion in 1950 (less than thirty per cent of the global total) the urban headcount climbed to 4.4 billion by 2020 (over fifty-six per cent), and on the trajectory used by the United Nations is set to reach 6.7 billion (about 68 per cent) by 2050 (He et al., 2021). India accounts for roughly 510 million of today's urban residents and continues to add more every year, at a pace its infrastructure has not been able to absorb.

The bill is being paid in water. Roughly half of all people on earth now experience severe water scarcity for at least part of any given year, and one quarter live with what the UN classes as extremely high water stress (United Nations, 2024). According to the 2024 World Water Development Report, municipal demand has overtaken every other sectoral demand for the first time in measurable history, growing faster than industrial or agricultural use, and the cause is unambiguous: cities (UNESCO, 2024).

These pressures land hardest on the rivers passing through urban centres. A river inside a dense settlement plays two roles at once. It is the receiving water for stormwater, sewage, and industrial effluent. It is also the floodplain, the drinking-water source, and the ecological corridor on which the same city depends. Paul and Meyer (2001), in what remains the foundational synthesis on the topic, capture this duality clearly: cities turn streams into pollution sinks and infrastructural conduits, and the resulting hydrological, chemical, and biological damage now shows up consistently across continents. The point has only been reinforced since.

McGrane (2016), reviewing the post-2000 evidence base, identifies impervious-surface growth and simplified drainage networks as the two mechanisms that do most of the work in destabilising urban hydrology and water quality. Lundy and Wade (2011) take the argument into the ecosystem-services frame, observing that ground-impermeability changes alone are sufficient to reduce groundwater recharge and evapotranspiration to the point of basin-level dysfunction.

Delhi's Yamuna is, by most measures, one of the worst-documented examples of where this leads. After thirty years of clean-up campaigns, beginning with the Yamuna Action Plan in 1993 and running through three successor phases of central and bilateral funding, the section of the river inside the National Capital Territory remains, in CPCB's own language, effectively dead at the point of exit. Dissolved oxygen sits at zero, faecal coliform at over 1.5 million MPN per 100 millilitres against a safe standard of 500, and dry-season flow runs at less than sixteen per cent of the river's natural non-monsoon discharge (CPCB, 2022; Sharma & Singh, 2009). About eighty-five per cent of that pollution traces to domestic rather than industrial sources (CPCB, 2006). Most of it enters through two drains. The Najafgarh carries roughly 65 per cent of Delhi's sewage on its own. Combined with the Shahdara, the two account for about 84 per cent of the pollution that reaches the Yamuna inside the city (DPCC, 2020). Delhi has thirty-seven sewage treatment plants on paper sufficient to handle 84 per cent of its wastewater output. In practice, only a fraction of those plants meet the revised effluent norms in any given audit year (CPCB, 2022).

If three decades of treatment-plant construction has not visibly improved the river, the problem is not infrastructural. It is structural. Biswas and Gangwar (2021), looking at the relationship between Delhi's urbanisation trajectory and its water crisis, locate the cause one step upstream of the treatment plant: in the land-use system itself. Built-up area expansion, together with the conversion of green and blue land to impervious surface, generates pollution loads at rates downstream treatment cannot absorb. The Yamuna, on their reading, is failing because Delhi's land-use plan never internalised the river as a receiving water that needs planning around. Comparable conclusions emerge from work on other urbanising basins. Wang and colleagues (2011) document tight statistical links between sub-basin land-use composition and downstream river health metrics in the Yanggong watershed at Lijiang. Xu and colleagues (2013) report similar correlations for Guangdong's Xizhi River.

Against this evidence, I argue that what cities now need is the one planning instrument current Indian master-planning does not provide: an instrument that turns the land-use pressure each cell imposes into a measurable consequence for the receiving river, and from there into a regulatory action class with statutory weight. The argument develops over seven sections. Section 2 reviews the empirical evidence connecting urban land use to river health. Section 3 sets out the case context (the Yamuna and the Najafgarh sub-basin). Section 4 introduces the methodology. Section 5 presents the proposed integrated index family. Section 6 considers governance and statutory anchoring. Section 7 concludes.

2. URBANISATION AND THE HEALTH OF URBAN RIVERS: EVIDENCE FROM THE LITERATURE

2.1 Hydrological alterations

Two decades of empirical work have settled the basic story. When pervious land becomes roads, roofs, and pavements, peak runoff goes up and infiltration goes down, with downstream consequences for flow regime, channel form, and base-flow availability (McGrane, 2016). Chen and colleagues (2017), tracing runoff patterns across the continental United States, find that even modest increases in urban share generate non-linear runoff responses once a catchment crosses what tends to settle around the 10–15 per cent imperviousness threshold. That threshold appears repeatedly in the urban-stream literature. Brandes, Cavallo, and Nilson (2005) document measurable declines in base flow across urbanising watersheds of the Delaware River basin as residential and commercial cover expanded, with the steepest declines visible during late-summer low-flow periods. Claessens and colleagues (2006) confirm the same pattern over a multi-decade reconstruction of an urbanising New England watershed, attributing the low-flow losses to forest cover converted into residential land.

These findings need careful translation when applied to Indian basins. Monsoon hydrology dominates the Indian annual cycle, and dry-season base flow is already a small fraction of the annual budget before any

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2024
https://www.theaspd.com/ijes.php

urbanisation pressure is added. Sharma and Singh (2009), modelling dissolved oxygen and biochemical oxygen demand in the Yamuna using the STREAM-II two-dimensional water quality model, find that during the non-monsoon months the river's dilution capacity collapses to roughly one-sixth of its natural state. That reduction has a structural cause. Upstream abstraction at the Wazirabad barrage combines with effluent loads generated within Delhi's built-up catchments to leave very little water for dilution downstream. The planning implication follows directly. In monsoonal urban basins, dry-season hydrology is the binding condition, and any land-use control must address the months when the river is at its most exposed, not the annual average.

2.2 Water-quality degradation

Water-quality impacts of urban land use are equally well-supported by the evidence. Sharma and colleagues (2020), reviewing chemical and biological monitoring studies on urban rivers, identify four dominant pathways: industrial discharge, sewage that is either untreated or partially treated, agricultural runoff entering the urban-rural fringe, and leachate from solid waste. The recurring indicators across these pathways are dissolved oxygen, biochemical and chemical oxygen demand, faecal coliform, nitrate, and phosphate. Zhu, Graney, and Salvage (2008) frame the same evidence at the watershed scale: under intensifying land use, pollutant inputs rise while pollutant retention through soil and vegetation declines, and the watershed approach offers the most coherent regulatory response to diffuse-source pollution. He and colleagues (2020), studying Xi'an's groundwater quality across a decade of land-use change, show that the same hydrochemical signature shows up in shallow aquifers connected to the urban surface.

Liu, Zhang, and Zhang (2019), using Environmental Kuznets Curve modelling to study industrial and domestic water pollution management in Shandong, find that industrial pollution responds to economic-development pressure differently from domestic pollution. They argue, on that basis, that policy instruments must be calibrated separately for the two source categories. The argument applies directly to Delhi, where Najafgarh's contributing catchment includes both heavy-industrial clusters and dense residential settlements. The single most important observation in this strand of literature for an Indian basin, however, is the relative dominance of the domestic share. CPCB (2006) reports that around 85 per cent of the Yamuna's pollution is from domestic rather than industrial sources. The implication for policy is direct: the lever that matters most is sewage capture and treatment combined with land-use control over peri-urban informal settlements, not industrial-emission regulation taken in isolation.

2.3 Thermal and microclimatic effects

Urban land use also alters river thermal regimes. Wang and colleagues (2022), in a mobile-measurement study of the cooling effect of an urban river and its interaction with the surrounding built form, show that building morphology has a measurable impact on night-time cooling and humidification, with lower Floor Area Ratios more beneficial on both counts. Gohain and colleagues (2023), modelling the relationship between land-use change, land-surface temperature, and the urban heat island in Indore, find that land-use composition is a stronger predictor of channel-segment thermal anomaly than distance to the central business district considered on its own. The finding implies that development-intensity and impervious-share variables at the segment scale carry their own explanatory weight even after position within the city is controlled for. Pathirana and colleagues (2014) take the argument one step further, showing how urban-growth-driven land-use change feeds back into local microclimate in ways that intensify the rainfall events the same drainage system is then required to absorb. Thermal effects, in short, are not separable from chemical and morphological effects. They are co-symptoms of the same underlying transformation, and any integrated index of river health has to capture all three together.

2.4 Sediment, morphology, and riparian integrity

Sediment regime is the third dimension along which urban land use damages rivers. McCallum and colleagues (2023), reviewing sedimentation rates across freshwater reservoirs, point to urban land use as a significant driver of elevated soil erosion and sediment fluxes, with road and drainage networks specifically intensifying the carrying capacity of urban runoff. Odhiambo, Rihl, and Hood-Recant (2021), looking at the historic relationship between land use and sedimentation in two urban reservoirs in Virginia, document a near-linear

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 10 No. 4, 2024
https://www.theaspd.com/ijes.php

relationship between cumulative impervious-surface area in the contributing catchment and sediment-deposition rate downstream. Okeke and colleagues (2022), in an integrated assessment of land-use impact on streambank stability for a peri-urban watershed in Nigeria, find that urban encroachment into riparian buffers raises bank-erosion rates while simultaneously stripping out the lithologic and vegetative buffering that would have absorbed that erosion. Annayat, Ashwini, and Sil (2022) report similar patterns of channel-migration driven by land-use and land-cover change in a comparable Indian basin over multi-decade time series. The cumulative point holds. Riparian morphology is itself a state variable, not a constant, and any planning framework needs to treat morphological change as data on the same footing as chemistry and thermal regime.

2.5 The integrating concept: urban stream syndrome

Across these four dimensions, hydrology, water quality, thermal regime, and morphology, the literature has converged on a single label for the joint condition: urban stream syndrome. The term originates in Paul and Meyer's (2001) framing and has been progressively reinforced by Lundy and Wade (2011), Wang et al. (2011), McGrane (2016), and the post-2020 work reviewed in the preceding sections. The signature is consistent across geography. Increased peak flows and reduced base flows. Rising biochemical and chemical oxygen demand alongside falling dissolved oxygen. Higher pathogen loading and nutrient enrichment. Thermal anomalies along channel segments. Channel-form simplification accompanied by loss of pool–riffle sequences and rising bank-erosion rates. Progressive contraction of riparian vegetation. Recognising the syndrome as a single condition matters because it forces an integrated response. A water-quality intervention by itself, without simultaneous attention to impervious-surface growth and riparian vegetation loss, cannot solve a multi-symptom problem one symptom at a time.

3. CASE CONTEXT: THE YAMUNA AND THE NAJAFGARH SUB-BASIN

3.1 The Yamuna at Delhi

The Yamuna travels approximately 1,376 kilometres from its source at the Yamunotri glacier to its confluence with the Ganga at Prayagraj. It enters the National Capital Territory of Delhi near Palla and exits south of Okhla after a 48-kilometre passage through the city. The 22-kilometre stretch from Wazirabad to Okhla is roughly two per cent of the river's total length and has produced essentially the entire body of contemporary literature on Yamuna pollution (CPCB, 2006). Within that stretch, the river takes on discharge from approximately 22 major and minor drains. Two of these dominate the load: the Najafgarh and the Shahdara. Together they account for about 84 per cent of the city's contribution to Yamuna pollution. The Najafgarh alone carries an estimated 65 per cent of the city's sewage flow (DPCC, 2020). Biochemical oxygen demand at the terminal point reaches the Yamuna at roughly 83 tonnes per day, after partial in-channel attenuation from an entry load of about 136 tonnes per day at the upstream drain confluences (CPCB, 2006).

The infrastructure response has been substantial. Delhi has installed thirty-seven sewage treatment plants, with cumulative capacity sufficient on paper to handle around 84 per cent of the city's wastewater generation. Translating that capacity into compliant outflow has been the harder part. A 2024 review found only 14 of the 37 plants meeting the revised effluent BOD standard of 10 mg/L. The remainder discharged at higher concentrations into already-polluted drains, where treated and untreated streams merge before reaching the river (CPCB, 2022). The Yamuna Action Plan, across three successive phases since 1993, has spent close to Rs. 8,000 crore on this infrastructure. Yet measured river quality at Okhla has not moved. The conclusion of recent reviews is straightforward: the binding constraint is no longer infrastructural. It is governance and land-use control upstream of the treatment system itself.

3.2 The Najafgarh sub-basin

The Najafgarh sub-basin is the largest of Delhi's drainage units. It covers approximately 977 square kilometres, or about 66 per cent of the National Capital Territory. The basin includes a natural depression, the Najafgarh Jheel, that historically served as a wetland buffer between the upper catchment and the main outfall. The contemporary basin holds an estimated 87.8 lakh (8.78 million) people as of the 2021 enumeration, drained by approximately 123 contributing channels classified by CPCB into priority classes I through V. Land-use composition is dominated by urban built-up land at roughly 60 per cent, agricultural land at about 18 per

cent, and water bodies (including the Jheel itself) at about 8 per cent. Industrial clusters at Bawana, Mongolpuri, and Wazirpur, in combination with the high-density residential agglomerations of Dwarka, Pappankalan, and Najafgarh town, generate the bulk of the basin's pollution load.

Why use Najafgarh as the empirical test ground for an integrated land-use–river-health framework? The case is straightforward. The basin contains the full range of urban-river conditions in close proximity. The Najafgarh Jheel edge functions as a relatively healthy reference segment, with dry-season river-health scores in the healthy range. The main Najafgarh drain at the other end of the basin is one of the most degraded urban drains anywhere in India. Dry-season dissolved oxygen there sits routinely below 1.5 mg/L. Biochemical oxygen demand routinely runs above 40 mg/L. Between these endpoints lie residential segments at intermediate degradation states, supplying the within-basin variation an empirical relationship needs to be defensible. The basin also lies entirely within a single statutory jurisdiction, the National Capital Territory of Delhi, which removes the cross-state administrative complications that otherwise arise in basin work.

4. METHODOLOGY: A DPSIR-ANCHORED APPROACH

4.1 The DPSIR framework and its adaptation to land-use–river relationships

The Drivers–Pressures–State–Impact–Response framework was developed in the early 1990s as a way of organising environmental information into a coherent decision-support structure (Organisation for Economic Co-operation and Development [OECD], 2003). Since 1995, it has been the principal organising logic of European Environmental Agency reporting. In 2003, it was incorporated into the Water Framework Directive's Common Implementation Strategy as the basis for river-basin management planning under Article 11 (European Commission and European Environment Agency, 2003). Lalande, Cernesson, and Decherf (2014) propose a specific adaptation, which they call DPSIR-LURE, for linking the water quality of rivers to land use. In their version, pressure indicators are constructed from three elements: the nature of the land-use parcel, its distance from the channel, and its position within the watershed. The indicators are computed at three nested spatial scales. Their field application to the Ognon basin in France shows that the framework can produce land-use-disaggregated pressure estimates that correlate measurably with bioindicator-based water-quality metrics. That methodological precedent informs the framework proposed here.

The adaptation I propose for the Najafgarh sub-basin retains DPSIR's five-stage structure but redistributes its operational content into a sequence designed for Indian master-planning workflows. The Driver stage is treated as exogenous and historical (urbanisation, demographic change, economic development). Operational attention focuses on the Pressure, State, Vulnerability, Capacity, and Response components. Each component maps to a measurable index. The Pressure component becomes a Land-Use Hydrological Pressure Index (LUHPI), constructed from land-use composition, development intensity, imperviousness, drain priority, and distance decay. The State component becomes an Urban River Health Index, Delhi-calibrated (URHI-D), constructed from chemical, thermal, morphological, sediment, and ecological-riparian indicator domains. The Vulnerability and Capacity components, concerning riparian-corridor exposure and statutory-institutional readiness respectively, are designed but flagged for post-thesis publication in subsequent work. The Response component becomes a Land-Water Responsiveness Index (LWRI), which integrates the upstream components into a binding action class through a three-layer logic: composite scoring, override rules, and statutory action bundles.

4.2 Methodological precedents

Three distinct strands of work supply the methodological precedents the framework draws on. The first is the urban-stream-syndrome literature reviewed in Section 2 (Paul & Meyer, 2001; McGrane, 2016), which makes the substantive case for an integrated multi-domain river-health metric rather than a single chemical-quality index. The second is the DPSIR-LURE work of Lalande and colleagues (2014), which supplies both the structural precedent for a pressure index keyed to land-use composition and disaggregated by spatial scale, and the European Water Framework Directive precedent for a binding link between basin-state assessment and downstream regulatory action. The third is the responsive-planning literature discussed in the next subsection, which provides the procedural template for connecting measurement to statutory consequence. The novelty of the framework I propose lies not in any single index or formula but in the integration. The

proposal is for one planning instrument that scores every cell in the basin, every river segment, and every cell-to-segment relationship; classifies cells into one of four binding action classes; and anchors each class to a defined bundle of statutory levers under the Master Plan of Delhi, the Unified Building Bye-Laws, and the Drainage Master Plan.

4.3 Responsive planning as the procedural premise

Responsive planning, as the term is used here, is an adaptive, iterative, and basin-aligned approach that continuously adjusts to changing environmental, social, and economic conditions through monitoring, feedback, stakeholder participation, and statutory enforcement. The concept has been applied across river basins of widely varying institutional and informational capacity. Foran and colleagues (2019), describing the Ayeyarwady Basin in Myanmar, document a co-production approach to participatory and deliberative planning under data and capacity constraints, with iterative knowledge-building among public agencies. Comparable adaptive co-management approaches have been reported for the Murray–Darling basin in Australia, the Kamala basin in Nepal, the Ganga basin in India under the Namami Gange programme, and the Mekong basin under the Mekong River Commission. What unites these otherwise dissimilar cases is one recognition. Static, top-down zoning cannot adapt fast enough to the conditions of basin degradation under contemporary urbanisation. The procedural premise of the framework I propose follows from that recognition. Responsiveness has to be operationalised in measurable form. A static framework cannot be made responsive simply by relabelling. The measurability requires precisely the kind of indexed, threshold-anchored architecture set out in Section 5.

5. THE INTEGRATED INDEX FAMILY

5.1 Land-Use Hydrological Pressure Index (LUHPI)

LUHPI is a planning-cell-scale composite that scores the hydrological pressure each 250-metre by 250-metre planning cell imposes on the river. Its multiplicative form combines five dimensionless factors. The first is land-use composition, expressed as a weighted sum of MPD land-use shares with weights ranging from 0.95 for heavy industry down to 0.05 for water bodies. The second is development intensity, defined as the ratio of actual to permitted floor-area ratio and capped at 1.5. The third is imperviousness, computed as the percentage of impervious cover raised to a 0.7 exponent. The fourth is drain priority, a multiplier between 1.0 and 1.4 lookup-keyed to the CPCB I–V drain class of the receiving channel. The fifth is a distance-decay factor: an exponential decay with a half-distance of 500 metres from the cell centroid to the nearest drain. The product, scaled by 100, yields a pressure score classified into four ranges. Low (0–25), Moderate (26–50), High (51–75), Critical (76–100). The architecture is consistent with the multi-scale pressure-indicator design of Lalande and colleagues (2014). The 250-metre cell was selected because it aligns with the smallest planning units used in Indian master-plan revisions and with the resolution of available Sentinel-2-derived imperviousness layers.

5.2 Urban River Health Index, Delhi-calibrated (URHI-D)

URHI-D is a segment-scale state index that scores the integrated health of a river or major drain segment on a 0–100 scale. The score combines fifteen indicators arranged across five domains. The chemical-biological domain holds six indicators: dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, faecal coliform on a log-10 scale, nitrate, and phosphate. The thermal domain holds two: channel-segment land-surface-temperature anomaly relative to the basin mean, and water temperature at summer maximum. The morphological domain holds three: channel-width loss, encroachment percentage, and sinuosity loss measured against a 2005 baseline. The sediment domain holds two: total suspended solids and turbidity. The ecological-riparian domain holds two: riparian Normalised Difference Vegetation Index within a 100-metre buffer, and wetland-area retention measured against the 2005 baseline. Each indicator is normalised against CPCB norms or Delhi-calibrated reference values to produce a 0–1 sub-score. Sub-scores within a domain are averaged arithmetically to produce a domain score. The five domain scores are then aggregated through a weighted geometric mean (chemical-biological at 0.35, ecological-riparian at 0.25, morphological at 0.20, thermal at 0.10, sediment at 0.10) to produce a final score scaled by 100. The choice of geometric over

arithmetic mean across domains is deliberate. A geometric mean refuses to mask a single failing domain in the way an arithmetic mean does. That is the same logic underlying the Canadian Council of Ministers of the Environment Water Quality Index. The score is computed for two seasons separately, a dry season covering March to June and a post-monsoon season covering October to November, with the worse of the two used as the State input to the composite index. This dual-season design is calibrated to the structural condition that monsoon dilution alters Indian urban-river quality dramatically between months, a finding documented quantitatively by Sharma and Singh (2009) for the Yamuna and consistent with the broader literature reviewed earlier.

5.3 Land-Water Responsiveness Index (LWRI)

LWRI is the composite index that converts the upstream measurements into a binding action class. It operates through three layers. The first layer is composite scoring. A weighted Need-for-Action term combines LUHPI, the inverse of URHI-D, and the riparian-vulnerability sub-index, modified by a Capacity factor derived from the planning-and-statutory-readiness sub-index. The second layer is override rules. Three explicit threshold-based rules force a minimum action class regardless of the composite score. Override Rule A: if URHI-D falls below 20, the minimum class is Protect. Override Rule B: if LUHPI exceeds 80, the minimum class is Retrofit. Override Rule C: if all three of pressure, state, and vulnerability are critical, the minimum class is Restructure. The final action class is the maximum of the score-derived rank and the override rank. This implements the principle that the strictest applicable rule governs. The third layer is the statutory bundle. Each of the four action classes (Conserve, Protect, Retrofit, Restructure) is anchored to a defined four-lever bundle drawing on Master Plan of Delhi sections 13 and 17, Unified Building Bye-Laws sections 3.4 and 6.5, and the Drainage Master Plan section 5. This three-layer architecture is what gives the framework its responsive character. The override rules ensure that single-dimension crises are not smoothed away by composite averaging. The statutory bundle ensures that the action class is not advisory but instrumental.

6. GOVERNANCE, STATUTORY ANCHORING, AND THE SUSTAINABLE DEVELOPMENT GOALS

6.1 The implementation environment

Three structural conditions define the implementation environment for any urban river framework in India. First, water is a state subject under the Constitution of India, and the Central Government's role is constitutionally limited to coordination and standard-setting (Saha & Bhattacharya, 2021). Second, urban water and sanitation policy is operationalised through Central Government missions (Jal Jeevan Mission, Atal Mission for Rejuvenation and Urban Transformation, Swachh Bharat Mission) implemented in coordination with state and local bodies. Third, river-basin governance is fragmented across multiple agencies whose jurisdictions overlap in space but rarely align in mandate. In the Najafgarh case alone, the Delhi Jal Board, the Delhi Pollution Control Committee, the Public Works Department, the Delhi Development Authority, the Irrigation and Flood Control Department, and three municipal corporations all hold partial authority over different aspects of the same river segments. This fragmentation has been identified across the empirical literature as one of the principal barriers to effective river-basin management (Biswas & Gangwar, 2021; Sharan, 2016).

6.2 Sustainable Development Goal 6 in the Indian context

Sustainable Development Goal 6, on clean water and sanitation for all, supplies the normative framework within which any river-health planning instrument now operates. India has shown measurable progress on its specific drinking-water and sanitation indicators. The Swachh Bharat Mission, launched in 2014, raised rural toilet coverage from approximately 40 per cent in 2014 to near-universal coverage by 2019. The country was officially declared open-defecation-free on 2 October 2019, with over 105 million toilets constructed under the programme (Saha & Bhattacharya, 2021). The Jal Jeevan Mission, launched in August 2019, has raised the share of rural households with functional household tap connections from approximately 16.7 per cent at programme launch to 76.80 per cent by June 2024 (Government of India, Ministry of Jal Shakti, 2024). The Atal Mission for Rejuvenation and Urban Transformation extends comparable infrastructure investment

to urban areas. Taken together, by 2020 approximately 90.5 per cent of India's population was using basic drinking-water services and 71.3 per cent was using basic sanitation services, with India broadly on track on Targets 6.1 and 6.2 (Sachs et al., 2022).
Targets 6.3 (water quality and wastewater treatment), 6.5 (integrated water-resources management at all levels), and 6.6 (water-related ecosystems) are where the harder gap lies. Roy and Pramanick (2019), reviewing India's progress against all SDG 6 targets, identify wastewater management and ecosystem-protection indicators as the laggards relative to drinking-water and sanitation. The Najafgarh case illustrates the gap precisely. The city has built sewage-treatment-plant capacity adequate for 84 per cent of generated wastewater. The Yamuna remains in critical condition because the planning system has not anchored its built-environment regulation to receiving-water consequences. Target 6.5 in particular implies a basin-scale planning unit, and basin-scale planning is precisely what India's master-planning regime, organised as it is around municipal and ward boundaries, does not produce.

6.3 Statutory anchoring through the Master Plan and the Unified Building Bye-Laws

The framework's statutory anchoring is designed to operate within existing instruments rather than against them. The Master Plan of Delhi 2041 and its predecessor MPD 2021 contain explicit provisions for special area designations under Section 13 and for sub-area regulatory plans under Section 17. The Unified Building Bye-Laws contain provisions for transferable development rights under Section 3.4 and for permeable-surface requirements under Section 6.5. The Drainage Master Plan for Delhi defines drain priority classes and associated discharge standards under Section 5. Each of the four LWRI action classes (Conserve, Protect, Retrofit, Restructure) maps to a defined combination of these existing levers. The framework therefore does not require new legislation to enter the regulatory environment. What it does require is the use of the index outputs as the trigger for which lever applies in which planning cell. This represents a substantive but implementable change in how Delhi's master-planning workflow operates. The planning cell becomes the unit of regulation rather than the use zone, and the river segment becomes the receiving variable that the regulation is calibrated against.

7. DISCUSSION AND CONCLUSION

7.1 Findings

Three findings emerge from the synthesis presented in this paper. The first concerns the empirical case for treating urban land use as the primary driver of urban-river degradation. That case is now sufficiently robust across geographies and methodologies that the question facing Indian planners is no longer whether the relationship exists. The question is how to operationalise its measurement and consequences. Across hydrological, chemical, thermal, and morphological dimensions, the literature converges on a coherent picture: urban land-use intensification produces predictable, dose-dependent degradation in receiving rivers, with thresholds frequently observed in the 10–15 per cent imperviousness range. The second finding concerns the Yamuna at Delhi as an unusually clear-cut empirical case. The 22-kilometre stretch within Delhi carries 76 to 80 per cent of the river's pollution load. The Najafgarh and Shahdara drains alone account for roughly 84 per cent of that. The Najafgarh sub-basin therefore offers a defensible test ground for any framework that attempts to integrate land-use planning with river-health outcomes. The third finding concerns the procedural challenge. Statutory levers are not the missing element; Delhi has them. What is missing is a measurement architecture that converts evidence of land-use pressure into binding regulatory consequence at the planning-cell scale. The proposed index family addresses that gap by supplying a measurable, statutorily anchored, threshold-driven instrument that fits within the existing Master Plan and Unified Building Bye-Laws regime.

7.2 Limitations

Four limitations should be acknowledged at the close of this argument. The first concerns coverage of the DPSIR components. Two of the five (Vulnerability and Capacity) are designed but not yet fully operational. The empirical demonstration in this paper rests on the Pressure and State indices, with the Composite index running on placeholder Vulnerability and Capacity values. The second concerns the calibration. Land-use

weights, CPCB anchor values, and the 500-metre decay half-distance are calibrated to NCT-Delhi conditions. Application to other Indian basins requires re-anchoring against the relevant master-plan and pollution-control instruments. The third concerns the scope of empirical demonstration. The current paper relies on sample-cell verification across five paired cells and three river segments, not on a full basin-wide application. Complete basin-wide computational application is the natural next step. The fourth concerns enforcement. The statutory anchoring is interpretive in the sense that the framework recommends an action class but does not enforce it. Enforcement remains a function of administrative will and inter-agency coordination, neither of which the framework can substitute for.

7.3 Conclusion

Securing urban futures means securing the rivers urban futures depend on. Cities cannot persist as functional human settlements if the freshwater systems that drain them, supply them, and define their flood risk are progressively destroyed by the same urbanisation that grew them. The Yamuna at Delhi is now widely cited as the cautionary example of what happens when a megacity's land-use plan does not internalise its receiving water as a planning constraint. The Najafgarh sub-basin is the operational unit at which any corrective framework must be tested. The argument I have advanced in this paper is that the existing Indian planning architecture contains sufficient statutory levers to address the problem. What it lacks is a measurement and decision instrument capable of converting evidence of land-use pressure into binding action at the cell scale. The integrated index family proposed here, comprising pressure, state, and composite components, is one such instrument. Its full empirical demonstration on the Najafgarh sub-basin, including basin-wide computational application and the operationalisation of the Vulnerability and Capacity components, constitutes the agenda for the doctoral research from which this paper is drawn. The broader argument, however, is independent of the specific framework. Until urban land-use planning in India internalises river health as a measurable consequence of land-use decisions, the country will not meet its commitments under SDG 6.3, 6.5, and 6.6, and its urban futures will remain structurally insecure.

8.1 Funding Declaration

The authors gratefully acknowledge the financial support provided by Guru Gobind Singh Indraprastha University, New Delhi, through a grant awarded under the Faculty Research Grant Scheme (FRGS)

REFERENCES

1. Annayat, W., Ashwini, K., & Sil, B. S. (2022). Channel migration detection and land use/land cover change for the Barak River, India. Environmental Earth Sciences, 81(11), Article 282.
2. Biswas, A., & Gangwar, D. (2021). Studying the water crisis in Delhi due to rapid urbanisation and land use transformation. International Journal of Urban Sustainable Development, 13(2), 199–213. https://doi.org/10.1080/19463138.2020.1858423
3. Brandes, D., Cavallo, G. J., & Nilson, M. L. (2005). Base flow trends in urbanizing watersheds of the Delaware River basin. Journal of the American Water Resources Association, 41(6), 1377–1391. https://doi.org/10.1111/j.1752-1688.2005.tb03806.x
4. Central Pollution Control Board. (2006). Water quality status of Yamuna River (1999–2005) (Assessment and Development of River Basin Series: ADSORBS/41/2006-07). Ministry of Environment and Forests, Government of India.
5. Central Pollution Control Board. (2022). Status report on water quality of River Yamuna (2022–23). Ministry of Environment, Forest and Climate Change, Government of India.
6. Chen, J., Theller, L., Gitau, M. W., Engel, B. A., & Harbor, J. M. (2017). Urbanization impacts on surface runoff of the contiguous United States. Journal of Environmental Management, 187, 470–481. https://doi.org/10.1016/j.jenvman.2016.11.017
7. Claessens, L., Hopkinson, C. S., Rastetter, E. B., & Vallino, J. J. (2006). Effect of historical changes in land use and climate on the water budget of an urbanizing watershed. Water Resources Research, 42(3), W03426.
8. Delhi Pollution Control Committee. (2020). Report on water quality of major drains discharging into the Yamuna in NCT of Delhi. Government of NCT of Delhi.
9. European Commission and European Environment Agency. (2003). Common implementation strategy for the Water Framework Directive (2000/60/EC): Guidance document on monitoring. Office for Official Publications of the European Communities.
10. Foran, T., Kiik, L., Hatt, S., Fullbrook, D., Dawkins, A., Walker, S., Chen, Y.-W., & Kham, T. N. (2019). Large hydropower and legitimacy: A policy regime analysis, applied to Myanmar. Energy Policy, 133, 110820.
11. Gohain, K. J., Goswami, A., Mohammad, P., & Kumar, S. (2023). Modelling relationship between land use land cover changes, land surface temperature and urban heat island in Indore city of central India. Theoretical and Applied Climatology, 151(3–4), 1981–2000.
12. Government of India, Ministry of Jal Shakti. (2024). Jal Jeevan Mission – Har Ghar Jal: Operational dashboard. Department of Drinking Water and Sanitation, National Jal Jeevan Mission.

13. He, C., Liu, Z., Wu, J., Pan, X., Fang, Z., Li, J., & Bryan, B. A. (2021). Future global urban water scarcity and potential solutions. Nature Communications, 12, 4667. https://doi.org/10.1038/s41467-021-25026-3
14. He, S., Li, P., Wu, J., Elumalai, V., & Adimalla, N. (2020). Groundwater quality under land use/land cover changes: A temporal study from 2005 to 2015 in Xi'an, Northwest China. Human and Ecological Risk Assessment, 26(10), 2771–2797.
15. Lalande, N., Cernesson, F., Decherf, A., & Tournoud, M.-G. (2014). Implementing the DPSIR framework to link water quality of rivers to land use: Methodological issues and preliminary field test. International Journal of River Basin Management, 12(3), 201–217. https://doi.org/10.1080/15715124.2014.906443
16. Liu, Y., Zhang, Z., & Zhang, F. (2019). Challenges for water security and sustainable socio-economic development: A case study of industrial, domestic water use and pollution management in Shandong, China. Water, 11(12), 2480.
17. Lundy, L., & Wade, R. (2011). Integrating sciences to sustain urban ecosystem services. Progress in Physical Geography, 35(5), 653–669. https://doi.org/10.1177/0309133311422464
18. McCallum, A., Kent, D., Rathnayaka, C., & Fairweather, H. (2023). A review of sedimentation rates in freshwater reservoirs: Recent changes and causative factors. Aquatic Sciences, 85(2), 51.
19. McGrane, S. J. (2016). Impacts of urbanisation on hydrological and water quality dynamics, and urban water management: A review. Hydrological Sciences Journal, 61(13), 2295–2311. https://doi.org/10.1080/02626667.2015.1128084
20. Odhiambo, B. K., Rihl, G., & Hood-Recant, S. (2021). Historic land use and sedimentation in two urban reservoirs, Occoquan Reservoir and Lake Manassas, Virginia, USA. Environmental Science and Pollution Research, 28, 41368–41379.
21. Okeke, C. A. U., Uno, J., Academe, S., Emenike, P. C., Abam, T. K. S., & Omole, D. O. (2022). An integrated assessment of land use impact, riparian vegetation and lithologic variation on streambank stability in a peri-urban watershed (Nigeria). Scientific Reports, 12(1), 13. https://doi.org/10.1038/s41598-021-03873-w
22. Organisation for Economic Co-operation and Development. (2003). OECD environmental indicators: Development, measurement and use. OECD Publishing.
23. Pathirana, A., Denekew, H. B., Veerbeek, W., Zevenbergen, C., & Banda, A. T. (2014). Impact of urban growth-driven land use change on microclimate and extreme precipitation: A sensitivity study. Atmospheric Research, 138, 59–72. https://doi.org/10.1016/j.atmosres.2013.10.005
24. Paul, M. J., & Meyer, J. L. (2001). Streams in the urban landscape. Annual Review of Ecology and Systematics, 32(1), 333–365. https://doi.org/10.1146/annurev.ecolsys.32.081501.114040
25. Roy, A., & Pramanick, K. (2019). Analysing progress of sustainable development goal 6 in India: Past, present, and future. Journal of Environmental Management, 232, 1049–1065. https://doi.org/10.1016/j.jenvman.2018.11.060
26. Sachs, J. D., Lafortune, G., Kroll, C., Fuller, G., & Woelm, F. (2022). Sustainable development report 2022: From crisis to sustainable development — The SDGs as roadmap to 2030 and beyond. Cambridge University Press.
27. Saha, D., & Bhattacharya, R. K. (2021). Achieving Sustainable Development Goals in water and sanitation sectors in India. Journal of Water, Sanitation and Hygiene for Development, 11(5), 693–705. https://doi.org/10.2166/washdev.2021.002
28. Sharan, A. (2016). A river and the riverfront: Delhi's Yamuna as an in-between space. City, Culture and Society, 7(4), 267–273.
29. Sharma, A., Bhardwaj, G., & Cherian, R. (2020). Water quality monitoring in urban rivers. Environmental Pollution, 258, 113498.
30. Sharma, D., & Singh, R. K. (2009). DO–BOD modeling of River Yamuna for national capital territory, India using STREAM-II, a 2D water quality model. Environmental Monitoring and Assessment, 159(1), 231–240. https://doi.org/10.1007/s10661-008-0625-7
31. United Nations Educational, Scientific and Cultural Organization. (2024). The United Nations world water development report 2024: Water for prosperity and peace. UNESCO Publishing.
32. United Nations. (2024). The Sustainable Development Goals report 2024. United Nations Department of Economic and Social Affairs.
33. Wang, C., Wang, D., Wang, H., & Dong, R. (2011). Impacts of urbanisation on river systems and their functions in Yanggong River watershed of Lijiang City. International Journal of Sustainable Development and World Ecology, 18(6), 498–502.
34. Wang, Y., Ouyang, W., Zhan, Q., & Zhang, L. (2022). The cooling effect of an urban river and its interaction with the littoral built environment in mitigating heat stress: A mobile measurement study. Sustainability, 14(18), 11700.
35. Xu, K., Wang, Y., Su, H., Yang, J., Li, L., & Liu, C. (2013). Effect of land-use changes on nonpoint source pollution in the Xizhi River watershed, Guangdong, China. Hydrological Processes, 27(18), 2557–2566.
36. Zhu, W., Graney, J. R., & Salvage, K. (2008). Land-use impact on water pollution: Elevated pollutant input and reduced pollutant retention. Journal of Contemporary Water Research & Education, 138(1), 15–21.