URBAN RIVER RESILIENCE INDEX: A STRATEGIC FRAMEWORK FOR ENHANCING RIVER HEALTH AND RESILIENCE IN INDIAN COASTAL CITIES

Total word count: 3848

Number of tables- 11

Number of figures-85

Urban River Resilience Index: A Strategic Framework for Enhancing River Health and Resilience in Indian Coastal Cities

Ananya K S[1], Dr. Jayeeta Sen[1] Banibrata Choudhury[2], Varsha Singh[2]

[1] School of Planning & Architecture, New Delhi

[2] National Institute of Urban Uffairs, New Delhi

Abstract

Urban rivers play a pivotal role in sustaining ecological balance, supporting dependent livelihoods, and enhancing city resilience. Coastal cities face compounding threats from climate variability, sea level rise and issues urban river face such as pollution, encroachments, and ecosystem degradation.

The Urban River Management Plan (URMP), jointly developed by the National Institute of Urban Affairs (NIUA) and the National Mission for Clean Ganga (NMCG), provides a framework for assessing the health of urban rivers across 10 indicators under three categories: Environment, Economic, and Social. Building on this approach, this research introduces the Urban River Resilience Index (URRI), an extension tailored for coastal cities. By incorporating CRZ compliance, mangrove and estuarine habitat health, and urban flood resilience, URRI offers a resilience-oriented evaluation complementing the URMP framework. Applied to the Gurupura River in Mangaluru, Karnataka, a coastal city facing rapid urbanization, mangrove loss, flood risk and regulatory lapse, it supports sustainable urban river management in dynamic coastal contexts.

The Gurupura River scores 2.7 under the URMP, subscribing to average level of urban river management, but 2.5 under URRI, indicating **low resilience**. The results highlight gaps in governance, ecological protection, and disaster preparedness. URRI provides a replicable, adaptive framework, recommended for institutionalization in coastal cities and integration into AMRUT 2.0 and SAPCCs.

Keywords

Urban rivers, resilience index, coastal cities, river management, Gurupura River, CRZ compliance, mangrove ecosystem, urban flooding, Mangaluru.

1. Introduction

Urban rivers are the lifelines of India's cities, supporting ecological health, economic productivity, and social well-being. They supply water for domestic, industrial, and agricultural use, act as natural drains, and support rich habitats such as the estuary with mangroves that build urban resilience. Once centrally located in settlement trends in the past, now they are beneath the sustainability and liveability of burgeoning urban agglomerations. But uncontrolled urbanisation, industrialisation, and land use change have pushed their ecological equilibrium to the limit. Decline in water quality, encroachment of floodplains, hydrological modification, and loss of biodiversity increasingly erode the ecosystem services upon which cities depend.

In coastal cities, these pressures are intensified by region-specific threats. Sea-level rise, saline intrusion, cyclones, and coastal erosion overlay chronic river management issues, contributing to threats to communities and ecosystems. Estuarine ecosystems like mangroves provide crucial natural protection and sustain fishery livelihoods but are some of the most exposed. Mangaluru, one of India's west coast’s largest cities, is a classic example of these forces, as its Gurupura River is threatened by flood risks, mangrove loss, and regulatory strain in the face of rapid urbanization.

Having recognized the need for integrated tools to guide urban river management, the National Mission for Clean Ganga (NMCG) and the National Institute of Urban Affairs (NIUA) introduced the Urban River Management Plan (URMP). The URMP offers cities a diagnostic tool to measure river health on environmental, social, and economic metrics. Although much strength has been added to baseline assessment and intervention guidance through its three-pillar framework, a resilience approach becomes essential in ecologically sensitive and climatically exposed coastal zones. This research addresses this by proposing the Urban River Resilience Index (URRI), an adaptation of the URMP for coastal cities. URRI incorporates three more indicators, namely adherence to Coastal Regulation Zones (CRZ), mangrove and estuarine ecosystem health, and urban flood resilience to better comprehend a river's ability to absorb and recover from environmental and climatic pressures. By incorporating resilience into urban river evaluations, the URRI expands the range of sustainable river management.

This paper is organized further by outlining the current frameworks and situates the URRI concept within broader literature followed by discussing the methodology adopted in constructing and applying the index, outlines the results of its application to the Gurupura River, considers policy and planning implications and concludes with institutionalization suggestions for Indian coastal cities.

2. Literature Review

The Urban River Management Plan (URMP), initiated in 2020 by National Mission for Clean Ganga (NMCG) and the National Institute of Urban Affairs (NIUA), is a first in developing a standardized framework for Indian urban river governance. The URMP assesses river systems on ten thematic indicators on the environmental, social, and economic axes, including water quality, riverbank conservation, biodiversity enrichment, public access, and governance. Piloted in Pune, Rishikesh, and Varanasi, the URMP has been an effective baseline for the comprehension of urban river health and has facilitated cities in planning intervention proportional to ecological conservation, socio-economic conditions, and citizens' engagement. Its multi-dimensional approach has enhanced data-driven policy deliberations and has opened doors to the development of future innovations in urban river management.

Designed to be applicable across a wide range of urban environments, the URMP has been found to be comprehensive and adaptive. With growing urban India, there is an increasing appreciation of scope for further evolving the framework by incorporating resilience parameters, especially for coastal rivers. Coastal rivers play important ecological and social functions, protecting cities from flood by mangrove and estuarine systems and supporting livelihoods based on fishing and ports. They are subject, however, to some vulnerability from sea-level rise, saline intrusion, cyclonic storm activity, and coastal erosion—drivers that are compounded by already prevailing pressures of pollution, encroachment, and loss of biodiversity.

Incorporating resilience aspects into river assessment frameworks enables stronger risk anticipation and long-term adaptive planning. Globally, many resilience-focused frameworks reference the need to integrate climate foresight into waterfront and river planning. **New York City's Waterfront Edge Design Guidelines (WEDG)** (Waterfront Alliance, 2023) employ a performance-based scorecard to guide waterfront development with a focus on ecological restoration and climate adaptation, and public access for everyone. London's

Thames Estuary 2100 Plan (Environment Agency, 2012) sets adaptive trajectories that respond dynamically to climate futures, integrating natural and engineered defence to safeguard communities and ecosystems. International practice reveals how diagnostic tools can be translated into forward-looking, resilience-based practices in riverine and estuarine system management.

At the national level, initiatives such as India's AMRUT 2.0 and the Smart Cities Mission promote water-sensitive urban design but are not underpinned by targeted river health indicators. Following the URMP, the Urban River Resilience Index (URRI) is recommended as a secondary framework for underpinning resilience-based indicators to better appreciate the capacity of a river system to withstand and bounce back from ecological and climatic stresses. URRI underpins the URMP vision, enabling smart, foresightful management of India's climatologically sensitive coastal urban rivers.

3. Methodology

Urban River Resilience Index (URRI) was developed through a mixed-method process of secondary data analysis, field observation, and stakeholder consultation. Material utilized was national and state policy documents such as the Urban River Management Plan (URMP) and the Coastal Regulation Zone (CRZ) Notification 2011, government reports, and unpublished research studies. Technical datasets of institutions such as the Central Pollution Control Board (CPCB), Ministry of Environment, Forest, and Climate Change (MoEFCC), Karnataka State Pollution Control Board (KSPCB), and municipal departments were used as a baseline for ecological condition estimation. Primary data was obtained through environmental observations, household surveys, and stakeholder assessment. These documented use of water resources in the city, flood impacts, and governance issues and provided ground-truthed information to consolidate secondary research.

Conceptualisation of URRI

The URRI was envisioned as an extension of the URMP framework as a strategic incorporation of resilience to river assessments in the urban context. While the URMP evaluates river condition based on ten thematic indicators in environmental, social, and economic areas, the URRI extends the framework by adding three key indicators for climate-exposed and ecologically sensitive environments: CRZ compliance, mangrove and estuarine ecosystem integrity, and flood resilience in the urban context. The thirteen indicators, collectively, allow for detailed understanding of ecological condition and adaptive

capacity, and allow decision-makers to prioritize among interventions and monitor progress over time.

Integration of New Indicators

CRZ Compliance: In contrast to the Coastal Regulation Zone Notification 2011, this indicator considers the availability and correctness of CRZ maps, the level of encroachment in No Development Zones (NDZs), and the operation of regulatory norms. The desirable features with their fixed points and the calculation of final score for the indicator is presented in table 1 & table 2.

Table 1 Indicator 11: CRZ Compliance Score

No	Desirable feature	Fixed Points
1	All CRZ-I areas (like mangroves, salt marshes) are strictly protected with no violations	30
2	All permitted activities in CRZ-II (urbanized areas) have obtained necessary CRZ clearances	20
3	No unauthorized construction in CRZ-III	20
4	Presence of updated CRZ maps integrated into local planning documents	15
4	Citizen sensitization efforts on CRZ norms (signage, awareness drives)	15
Total		**100**

Source 1 Author

Table 2 Calculating the final score for CRZ compliance

If CRZ Compliance points = > 80	CRZ Compliance Score = 5
If CRZ Compliance points = 60 - 79	CRZ Compliance Score = 4
If CRZ Compliance points = 40 - 59	CRZ Compliance Score = 3
If CRZ Compliance points = 20 - 39	CRZ Compliance Score = 2
If CRZ Compliance points < 20	CRZ Compliance Score = 1

Source 2 Author

Mangrove and Estuarine Ecosystem Health: Rated according to satellite-derived trends in mangrove cover, biodiversity research, and location-specific ecological observations in terms of ecological connectivity, species diversity, and human impact exposure. The desirable features with their fixed points and the calculation of final score for the indicator is presented in table 3 & table 4.

Table 3 Indicator 12: Mangrove & estuarine ecosystem health score

No	Desirable feature	Fixed Score
1	No net loss in mangrove area (year-on-year)	35
2	Presence of >75% native species among estuarine vegetation	15
3	Visible signs of healthy biodiversity (bird nesting, juvenile fish presence)	15
4	No solid waste or oil contamination in estuary	20
5	Community initiatives for mangrove conservation	15
Total		100

Source 3 Author

Table 4 Calculating the final score for Mangrove & estuarine habitat health

If Mangrove and Estuarine Habitat Health Points > 80	Mangrove and Estuarine Habitat Health = 5
If Mangrove and Estuarine Habitat Health Points 60 - 79	Mangrove and Estuarine Habitat Health = 4
If Mangrove and Estuarine Habitat Health Points 40 - 59	Mangrove and Estuarine Habitat Health = 3
If Mangrove and Estuarine Habitat Health Points 20 - 39	Mangrove and Estuarine Habitat Health = 2
If Mangrove and Estuarine Habitat Health Points < 20	Mangrove and Estuarine Habitat Health = 1

Source 4 Author

Urban Flood Resilience: Measured via municipal flood maps, stormwater infrastructure surveys, and secondary data, as a function of drainage capacity, green–blue infrastructure integration, floodplain zoning, and early warning system availability. The desirable features with their fixed points and the calculation of final score for the indicator is presented in table 5 & table 6.

Table 5 Indicator 13: Urban flood resilience

No	Desirable feature	Fixed Score
1	Flood forecasting system and early warning systems	30
2	Flood protection infrastructure (Levees, flood walls, etc)	20
3	100% coverage of storm water drains and sewerage	20
4	Flood insurance and financial support mechanism for recovery	20
5	Mapping of vulnerable population (Low-income communities, elderly, children, and people with disabilities)	10
Total		**100**

Source 5 Author

Table 6 Calculating the final score for Urban flood resilience

If Urban Flood Resilience points > 80	Urban Flood Resilience score = 5
If Urban Flood Resilience points 60 - 79	Urban Flood Resilience score = 4
If Urban Flood Resilience points 40 - 59	Urban Flood Resilience score = 3
If Urban Flood Resilience points 20 - 39	Urban Flood Resilience score = 2
If Urban Flood Resilience points < 20	Urban Flood Resilience score = 1

Source 6 Author

Scoring Method

All thirteen indicators, ten URMP indicators and three new resilience-based indicators are scored on a 1 to 5 scale, where 1 is poor and 5 is good. The arithmetic mean of all the scores of the indicators is the ultimate URRI score, a composite of ecological health and resilience of a river system.

Scoring sources for the three new resilience-focused indicators included Landsat satellite data, CRZ demarcation plans, flood hazard maps, government reports, and published studies, with ground validation added through field surveys and stakeholder consultations, data Gathering and analysis of environmental surveys on mangrove health & ecosystem services and floodplains, Household surveys recorded water use, flood occurrences, and resident perceptions, and stakeholder consultations with local governments and regulators supplied governance data. The URRI framework, by the systematic integration of these datasets, offers a decision-support tool extending the URMP by incorporating resilience into assessment of urban rivers.

4. Results

The Urban River Resilience Index (URRI) was employed to identify the health and resilience of Mangaluru's Gurupura River, an urban coastal river supporting crucial ecological services and socio-economic activities. The river flows to the west across the Dakshina Kannada district, supporting irrigation of agriculture, fisheries, and drinking water supply and maintaining ecologically sensitive estuarine and mangrove ecosystems. Urbanization, industrialization, and climatic pressure have led to increasing vulnerability, and thus the integrated assessment process employing both the existing Urban River Management Plan (URMP) and the extended URRI framework is justified.

As per the URMP model (NIUA & NMCG, 2020), the Gurupura River reached the "Average" level of river management with a score of 2.7 out of 5. It improved in terms of wastewater treatment facilities and documentation of biodiversity. There are still gaps in significant areas like floodplain zoning, urban water body restoration, reuse of treated wastewater, and public participation mechanisms. Institutional action against river degradation is fragmented and largely reactive, cancelling out the efficacy of management interventions.

The other resilience-oriented indicators under URRI brought in yet more insights. **Compliance with CRZ ranked 3.0**, indicating the difficulty of imposing Coastal Regulation Zone standards on ecologically sensitive zones. Encroachments continue along the estuary and industrial zones like Baikampady and Tannirbhavi. While there are demarcation maps, enforcement is uneven and affected by a lack of interdepartmental coordination, permitting ongoing pressure on safeguarded buffers. The points earned and the final score for this indicator is presented in table 7.

Table 7 Indicator 11: CRZ Compliance score in Mangaluru

No	**Desirable feature**	**Fixed Score**	**Points earned**
1	All CRZ-I areas (like mangroves, salt marshes) are strictly protected with no violations	30	30
2	All permitted activities in CRZ-II (urbanized areas) have obtained necessary CRZ clearances	20	0
3	No unauthorized construction in CRZ-III	20	0
4	Presence of updated CRZ maps integrated into local planning documents	15	15
5	Citizen sensitization efforts on CRZ norms (signage, awareness drives)	15	0
Total		**100**	**45**
CRZ Compliance points = 40 - 59		**CRZ Compliance Score = 3**	

Source 7 Author

Mangrove and estuarine habitat health score came up to 1 based on satellite imagery and ground surveys. Decline in mangrove cover, particularly those affected by industrial effluent dumping and urbanization, was monitored for trends. Mangrove patches and species richness have been affected due to water quality deterioration from sewage dumping and stormwater runoff. Being natural flood defence features and biodiversity hotspots, restoration and conservation efforts are limited, and ecological connectivity is compromised. The points earned and the final score for this indicator is presented in table 8 below.

Table 8 Indicator 12: Mangrove & estuarine habitat health score in Mangaluru

No	Desirable feature	Fixed Score	Points earned
1	No net loss in mangrove area (year-on-year)	35	0
2	Presence of >75% native species among estuarine vegetation	15	15
3	Visible signs of healthy biodiversity (bird nesting, juvenile fish presence)	15	0
4	No solid waste or oil contamination in estuary	20	0
5	Community initiatives for mangrove conservation	15	0
Total		**100**	**15**
Mangrove and Estuarine Habitat Health Points < 20		**Mangrove and Estuarine Habitat Health Score = 1**	

The **urban flood resilience indicator** was **2.0**, indicating high flood-risk settlement vulnerability in Bengre, Kulur and Kenjar. Over-land transformation, poor stormwater drainage infrastructure, and removal of natural buffers such as marshes and paddy fields result in more than just an increase in the frequency and intensity of flooding. There are guidelines for disaster management, but active integration of green–blue infrastructure and community preparedness are not common. The points earned and the final score for this indicator is presented in table 9.

Table 9 Indicator 13: Urban flood resilience score in Mangaluru

No	Desirable feature	Fixed Score	Points earned
1	Flood forecasting system and early warning systems	30	30
2	Flood protection infrastructure (Levees, flood walls, etc)	20	0
3	100% coverage of storm water drains and sewerage	20	0
4	Flood insurance and financial support mechanism for recovery	20	0
5	Mapping of vulnerable population (Low-income communities, elderly, children, and people with disabilities)	10	0
Total		**100**	**30**
Urban Flood Resilience points 20 - 39		**Urban Flood Resilience score = 2**	

Source 8 Author

The final composite score of URMP with the three new resilience indicators is presented in table 10 below. The URMP indicators sum up to a score of 2.7, which subscribes to “Average level of urban river management as per URMP score index interpretation. The 2.5 cumulative URRI score positions the Gurupura River in the "Low Resilience" category as per the URRI score interpretation presented in table 11.

Table 10 UURI calculated for Gurupura river in Mangaluru

URMP Monitoring Indicators		
No	**Indicator**	**Score**
1	Floodplain Management Score	1
2	Net Dissolved Oxygen Score	5
3	Water Body Revival Score	1
4	Riparian Buffer Score	2
5	Wastewater reuse score	1
6	Return flow score	4
7	Eco-friendly riverfront score	3
8	River economy score	5
9	Citizen sensitization score	1
10	Citizen engagement score	4
	URM_{index}	2.7
Proposed indicators for URRI		
No	**Indicator**	**Score**
11	CRZ Compliance Score	3
12	Mangrove and Estuarine Habitat Health Score	1
13	Urban Flood Resilience score	2
	URR_{index}	2.5

Source 9 Author

Table 11 URRI score interpretation

$URRI_{index}$	Interpretation	What it means
<1.5	Poor resilience of the urban river	The river ecosystem is highly vulnerable to environmental and climate-related stressors. There is minimal or no adaptive infrastructure or planning in place. Communities and biodiversity around the river are at risk.
1.6-2.5	Low resilience of the urban river	Some preliminary efforts toward resilience are evident, but systemic gaps remain. Flood risk, pollution, and ecological degradation persist without long-term mitigation strategies.
2.6-3.5	Moderate resilience of the urban river	The river shows signs of resilience with functioning infrastructure in some areas. However, inconsistencies exist in governance, ecosystem health, and climate adaptation.
3.6-4.5	High resilience of the urban river	The river is generally resilient with integrated risk management systems. Ecosystems are protected or restored, and urban systems show readiness for future stressors. However, occasional vulnerabilities remain.
4.6-5.0	Ideal resilience of the urban river	The river and its urban context are fully climate-adaptive and ecologically stable. Nature-based solutions are implemented, stakeholders are engaged, and disaster preparedness and response systems are robust and proactive.

Source 10 Author

5. Discussion (500 Words)

The Urban River Resilience Index (URRI) assessment of the Gurupura River showed a resilience score of 2.5, an indicator of city system vulnerabilities to absorb and accommodate climate and environmental shocks. Although a score of 2.7 in Urban River Management indicates the availability of crucial elements of river management, the URRI offers a lens of resilience that reveals underlying vulnerabilities. This divergence suggests that management strategies on a daily basis, as useful as they are, are ineffective in dealing with unfolding threats in climate-exposed coastal cities.

Analysis of the three resilience-based indicators provides the explanation of the low resilience score. CRZ compliance with 3.0 indicates ongoing difficulties in keeping enforcement of protective regulations for sensitive estuarine and coastal habitats in check. Encroachment in No Development Zones (NDZs), especially in industrial and estuarine zones, goes unchecked due to sporadic enforcement and poor interdepartmental coordination. Mangrove and estuarine ecosystem health with 1 indicates pollution, urbanization, and fragmented conservation as explanations of habitat degradation.

Mangrove destruction reduces the river's natural flood and storm surge protection function, undermining ecosystem services essential for community and biodiversity resilience. Urban flood resilience at 2.0 also reflects the absence of stormwater infrastructure. Ineffective

drainage networks, and floodplain and wetland losses have enhanced pluvial and fluvial flooding in city's low-lying area.

International experience shows the promise of resilience-based practices to enhance river management performance. New York City Waterfront Edge Design Guidelines integrate ecosystem recovery, climate resilience, and public access in waterfront planning using a performance-based scorecard. The Thames Estuary 2100 Plan in London uses adaptive policy trajectories that revise with changing climate projections, integrating nature-based defence and engineered defence. The two practices are examples of action-oriented planning that enhances long-term resilience through multi-stakeholder collaboration that builds the significance of including forward-looking resilience analysis in planning and management systems.

For Mangaluru, the implications of URRI are clear. Enhancing enforcement capabilities for CRZ adherence, mangrove rejuvenation, and stormwater management infrastructure renewal are to be the top priority. Institutional coordination among municipal governments, environmental agencies, and urban citizens must be enhanced to de-mystify conflicting roles and improve ground-level implementation. Green-blue infrastructure investments such as bioswales, wetlands, and retention basins can be used to complement traditional flood control measures, improving adaptive capacity.

6. Conclusion

Urban rivers are ecological and cultural lifelines that foster the liveability, diversity, and resilience of India's cities. Against compounding climate stresses, it is necessary to transition from traditional management to resilience-informed planning that takes into account shifting risks. The Urban River Resilience Index (URRI) demonstrates how resilience can be systematically applied to urban river management, providing a scalable, evidence-based framework for comparing, diagnosing, and constructing adaptive capacity.

The example of the Gurupura River in Mangaluru shows the need and success of having such a program. Despite the lack of many management interventions under the Urban River Management Plan (URMP), the low resilience score of the URRI suggests significant loopholes in CRZ compliance, mangrove ecosystem health, and flood preparedness. These loopholes need to be filled with robust ecological buffers, institutional coordination, and participatory planning with long-term resilience.

URRI builds upon URMP by adding resilience indicators to the framework and is hence a decision-support tool with an impact on investment, monitoring progress, and facilitating

targeted interventions. The National Institute of Urban Affairs (NIUA) as the nodal agency for URMP is best suited to lead this extension by streamlining URRI methodology, facilitating capacity building in cities, and mainstreaming resilience indicators into national programs like AMRUT 2.0 and State Action Plans on Climate Change (SAPCCs).

Integration of URRI into policy with the technical expertise of NIUA can make the process of transition to resilience-based urban river planning smooth. Inter-sector coordination and institutionalization of local data and governance systems can render URRI an easy option to implement in creating a paradigm shift, making India's urban rivers not just survive but thrive in the face of increasing climate and urbanization stressors.

Declaration of conflicting interests

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

References

1. Waterfront Alliance. (2023). *WATERFRONT EDGE DESIGN GUIDELINES.*
2. Environment Agency. (2012). *Thames Estuary 2100.* London: Environment Agency.
3. NIUA & NMCG. (2020). *Urban River Management Plan.* New Delhi.