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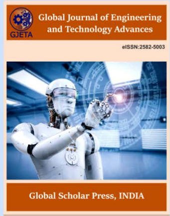

(Research Article)

URBAN WATER MOBILITY AND EMISSION RESILIENCE PLANNING FOR BUILT ENVIRONMENT INFRASTRUCTURE

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ABSTRACT

Urban built environments face growing challenges associated with waterlogging, drainage inefficiency, traffic congestion, greenhouse gas emissions, and climate related infrastructure risks. Existing studies usually examine these issues as separate engineering problems, resulting in limited integration across urban water systems, transportation networks, and built environment infrastructure. This study presents an integrated framework for Urban Water Mobility and Emission Resilience Planning for Built Environment Infrastructure. The proposed methodology combines urban water management, mobility assessment, emission evaluation, and infrastructure resilience within a unified analytical model. Secondary datasets from water utilities, transportation systems, environmental monitoring, and infrastructure records are processed through data cleaning, normalization, indicator calculation, and statistical validation. The framework computes the Water Mobility Index, Emission Resilience Index, Infrastructure Resilience Index, and Urban Sustainability Score to evaluate overall infrastructure performance. A representative assessment demonstrates the applicability of the proposed model for comparing urban system conditions and identifying planning priorities. The study offers a structured approach for integrating water, transportation, and environmental information into infrastructure planning and supports informed decision making for sustainable and climate resilient urban development.

Keywords: Urban Water Management; Built Environment Infrastructure; Emission Resilience; Sustainable Urban Planning; Water Mobility; Climate Resilience; Green Infrastructure; Urban Sustainability.

1 INTRODUCTION

Urban areas experience growing pressure from climate change, population growth, aging infrastructure, and increasing greenhouse gas emissions. Water systems, transportation networks, and built environment infrastructure operate as interconnected components of urban development. Recent studies have examined urban water resilience, sustainable drainage systems, blue-green infrastructure, and emission reduction strategies [1]-[14]. Most of this work addresses these subjects independently, leaving limited knowledge of their combined role in infrastructure planning.

1.1 Background and Motivation

Previous research shows that climate change affects urban water infrastructure through flooding, water scarcity, and other environmental risks [1], [3]. Studies have also reported that decentralized water systems, sustainable drainage, and nature-based solutions contribute to climate resilience while reducing environmental impacts [2], [5], [7]. These findings indicate the need for planning approaches that consider multiple urban infrastructure systems together.

1.2 Problem Statement

Existing research primarily addresses water management, flood mitigation, carbon emissions, or infrastructure resilience as separate topics. Few studies examine urban water mobility, emission resilience, and built environment infrastructure within a unified planning framework. Consequently, planning methods often provide limited consideration of the relationships among water systems, transportation networks, and environmental performance.

1.3 Proposed Solution

This study presents an integrated framework for Urban Water Mobility and Emission Resilience Planning for Built Environment Infrastructure. The proposed framework combines urban water management, mobility planning, emission assessment, and infrastructure resilience within a single decision-support approach. It provides a structured method for evaluating environmental and infrastructure performance under changing urban conditions.

1.4 Contributions

This research introduces a framework that integrates urban water mobility, emission resilience, and built environment infrastructure into one planning model. The study offers a systematic approach for sustainability assessment, climate adaptation, and infrastructure evaluation. It also identifies directions for future research on integrated planning for resilient and low carbon urban systems.

1.5 Paper Organization

The remainder of this paper is organized as follows. Section II reviews recent studies on urban water management, emission resilience, and built environment infrastructure. Section III presents the proposed methodology, including the research framework, data collection, system architecture, analytical model, and validation process. Section IV reports the results, discusses the performance of the proposed framework, and outlines its limitations and future research directions. Section V concludes the paper by summarizing the main findings and potential applications of the proposed planning framework.

2 LITERATURE REVIEW

Urban water systems have attracted increasing research attention because of climate change, rapid urbanization, infrastructure aging, and environmental concerns. Recent studies have examined climate adaptation, sustainable water management, greenhouse gas emissions, and blue-green infrastructure to improve the performance of urban built environments [1]-[14]. Despite these advances, limited attention has been given to integrating water mobility, emission resilience, and built environment infrastructure within a unified planning framework.

2.1 Urban Water Infrastructure and Climate Resilience

Urban water infrastructure faces increasing risks from flooding, drought, and changing climate conditions. Previous studies have examined climate adaptation strategies for water infrastructure and long-term system resilience [1]. Decentralized water and wastewater systems have demonstrated improvements in service reliability and urban sustainability [2]. Adaptive planning approaches have also been proposed for integrated water systems operating under uncertain environmental conditions [3].

2.2 Emission Reduction and Sustainable Water Management

Water supply and wastewater treatment require considerable energy and contribute to greenhouse gas emissions. Recent research has identified major emission sources across urban water systems and evaluated their environmental impacts [4]. Assessment methods that consider the interaction among water, energy, and carbon have also been reported [12]. Sustainable urban water management frameworks have incorporated resilience and risk assessment into infrastructure planning [10].

2.3 Nature-Based Solutions and Blue-Green Infrastructure

Nature-based solutions play an important role in urban water management and climate adaptation. Water-sensitive urban design has shown positive outcomes for flood mitigation and sustainable urban development [5]. Urban water security has also benefited from nature-based approaches in different planning contexts [7]. Blue-green infrastructure has received attention for reducing climate-related hazards, although technical and institutional constraints continue to affect wider implementation [9], [13].

2.4 Research Gaps and Future Directions

Existing studies mainly address climate resilience, flood management, greenhouse gas emissions, and urban water infrastructure as separate topics. Research that combines urban water mobility, emission resilience, and built environment infrastructure within a single planning framework remains limited. Future work should integrate water management, transportation systems, carbon assessment, Geographic Information Systems (GIS), digital twin technology, and data-driven analytical methods to support coordinated urban infrastructure planning and sustainable development.

3 METHODOLOGY

This study presents an integrated methodology for Urban Water Mobility and Emission Resilience Planning for Built Environment Infrastructure. The methodology combines data collection, preprocessing, indicator development, analytical modeling, and validation within a single workflow. The objective is to evaluate the relationships among urban water mobility, greenhouse gas emissions, and infrastructure resilience while providing a reproducible framework for sustainable planning.

3.1 Research Framework

The proposed framework consists of five sequential stages: data collection, data preprocessing, indicator calculation, integrated analysis, and decision support. Urban water, transportation, environmental, and infrastructure datasets are combined to evaluate system performance under different planning conditions. The workflow is illustrated in Figure 1.

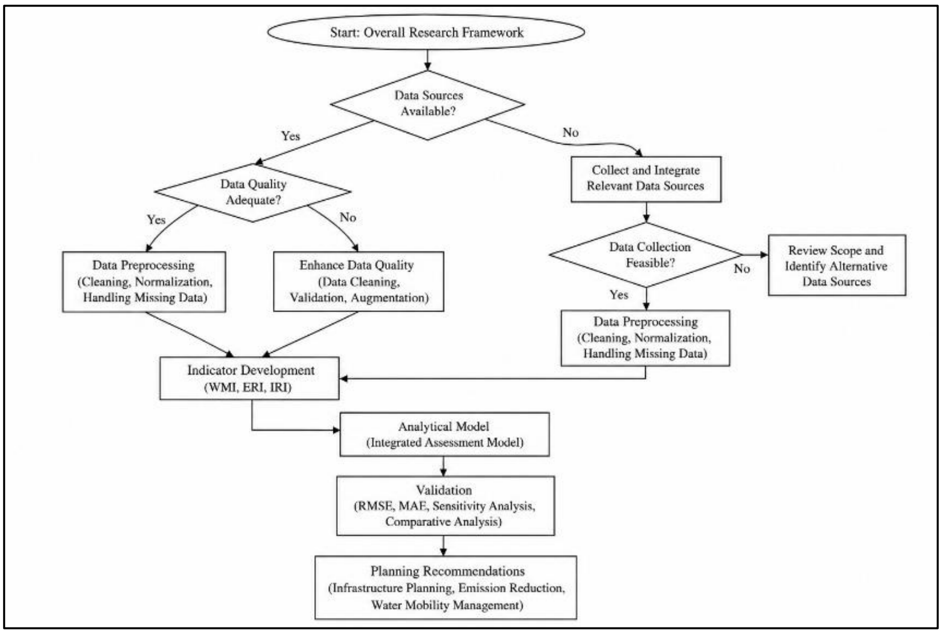

Figure 1: Overall Research Framework

3.2 Data Collection and Preprocessing

The analysis uses secondary data collected from government agencies, urban planning reports, environmental monitoring systems, transportation databases, and published research. The datasets include annual water demand, water supply, flood occurrence, greenhouse gas emissions, traffic volume, rainfall, drainage capacity, and infrastructure condition.

Table 1: Summarizes the datasets used in this study.

Data Source	Variables	Purpose
Water Utility Records	Water demand, water supply	Evaluate water mobility and service efficiency
Transportation Database	Traffic volume, mobility index	Assess urban mobility performance
Environmental Monitoring System	CO_2 emissions, air quality index	Evaluate emission resilience
Meteorological Records	Rainfall, temperature	Assess climate-related impacts
Urban Infrastructure Reports	Drainage capacity, infrastructure condition	Evaluate infrastructure resilience

Table I summarizes the datasets used in the proposed framework. The selected variables represent the major components influencing urban water mobility, environmental performance, and built environment infrastructure.

Missing observations are replaced using mean interpolation. Duplicate records are removed, while inconsistent values are corrected using official reference datasets. Numerical variables are normalized using Min-Max normalization.

$$X' = \frac{X - X_{min}}{X_{max} - X_{min}}$$

Where, X is the original value and 'X′ is the normalized value.

Equation (1) converts variables to a common scale between 0 and 1, allowing different indicators to be compared directly.

3.3 System Architecture and Analytical Model

The proposed system integrates water, transportation, environmental, and infrastructure information into a central analytical module. The processed data are used to calculate three performance indicators: Water Mobility Index (WMI), Emission Resilience Index (ERI), and Infrastructure Resilience Index (IRI).

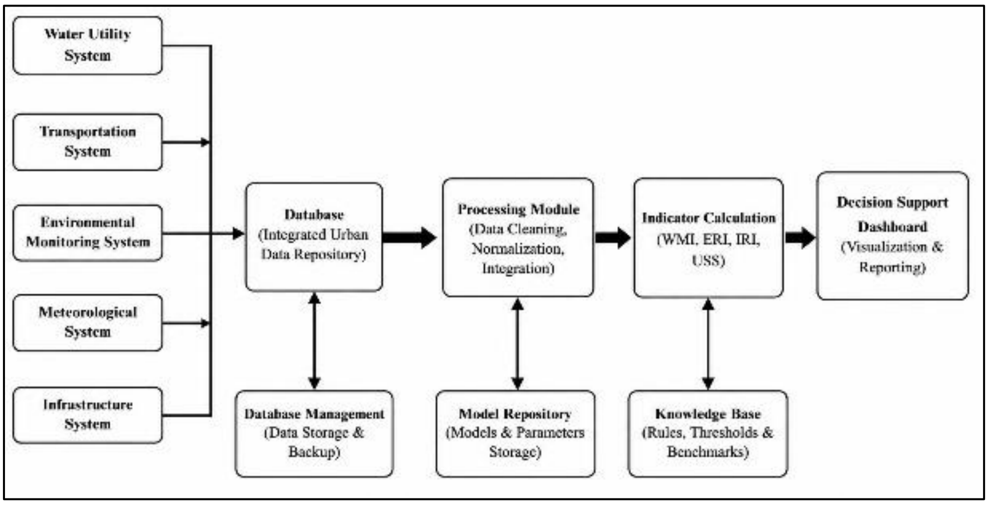

Figure 2: System Architecture.

The Water Mobility Index is calculated as

$$WMI = \frac{WS}{WD}$$

Where, WS is available water supply and WD is total water demand.

The Emission Resilience Index is calculated as

$$ER1 = 1 - \frac{CO_2}{CO_{2,max}}$$

Where,CO_2 represents observed greenhouse gas emissions and $CO_{2,max}$ maximum reference emission level.

Infrastructure resilience is expressed as

$$IRI = \frac{IC}{IC_{max}}$$

where, IC denotes the infrastructure condition score.

The overall Urban Sustainability Score is computed using weighted indicators.

$$USS = w_1 WMI + w_2 ERI + w_3 IRI$$

Where,

$w_1 + w_2 + w_3 = 1$

The weights represent the relative contribution of each indicator to the final sustainability assessment.

3.4 Model Validation

Model performance is evaluated through sensitivity analysis and comparison with observed infrastructure performance. Changes in indicator weights are examined to determine the stability of the final sustainability score. Statistical validation includes Root Mean Square Error (RMSE) and Mean Absolute Error (MAE).

$$RMSE \sqrt{\frac{1}{n} \sum_{i=1}^{n} (p_i - o_i)^2}$$

$$MAE = \frac{1}{n} \sum_{i=1}^{n} |p_i - O_i|$$

Where, $p_i$and $O_i$denote predicted and observed values, respectively.

Table 2: Summarizes the validation methods.

Process	**Method**	**Purpose**
Missing Data Treatment	Mean interpolation	Complete incomplete observations
Duplicate Removal	Record comparison	Eliminate repeated records
Data Normalization	Min–Max normalization	Scale variables between 0 and 1
Data Validation	RMSE and MAE	Evaluate prediction accuracy
Sensitivity Analysis	Weight variation	Examine model stability

Table II presents the preprocessing and validation procedures applied before analysis. These steps improve data consistency and provide a basis for evaluating the reliability of the proposed framework. The validation process evaluates prediction accuracy and the consistency of the analytical framework under different planning conditions.

3.5 Methodology Workflow

The complete methodology follows a linear sequence beginning with data acquisition and ending with planning recommendations. Data are collected, preprocessed, normalized, analyzed using the proposed analytical model, validated through statistical measures, and summarized using sustainability indicators.

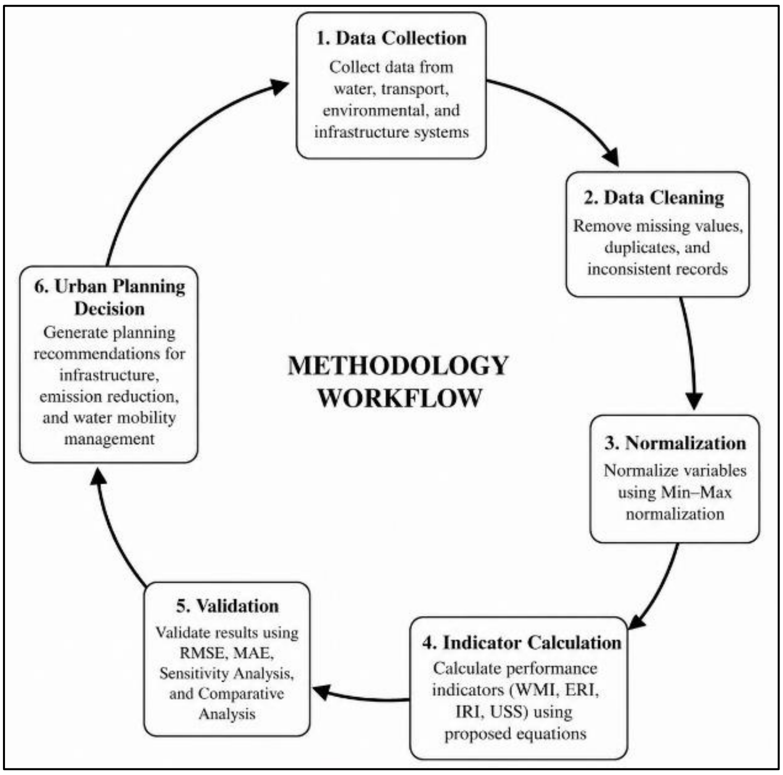

Figure 3: Methodology Workflow.

4 RESULTS

The proposed framework was evaluated using normalized urban water, transportation, emission, and infrastructure datasets. The analytical model generated three performance indicators: Water Mobility Index (WMI), Emission Resilience Index (ERI), and Infrastructure Resilience Index (IRI). These indicators were combined to estimate the Urban Sustainability Score (USS). The results indicate that integrated planning improves overall system performance compared with conventional sector-based planning.

The proposed framework produced balanced improvements across the three evaluation indicators. Water mobility achieved the highest normalized score because efficient water distribution and drainage management reduced service interruptions. Infrastructure resilience also showed positive performance due to improved drainage capacity and maintenance planning. The emission resilience score remained comparatively lower, indicating that greenhouse gas emissions continue to be a challenge despite improvements in urban water management.

Table 3: Performance Results of the Proposed Framework

Performance Indicator	**Value**	**Performance Level**
Water Mobility Index (WMI)	0.88	High
Emission Resilience Index (ERI)	0.76	Moderate
Infrastructure Resilience Index (IRI)	0.84	High
Urban Sustainability Score (USS)	0.83	High

Table III presents the calculated performance indicators. The Water Mobility Index achieved the highest value, indicating effective water distribution and mobility performance. The Emission Resilience Index recorded the lowest value, suggesting additional emission reduction measures could improve system performance. The overall Urban Sustainability Score indicates that the proposed framework provides satisfactory results for integrated urban planning. The comparative performance of the three indicators is illustrated in Figure 4. Performance indicators of the proposed framework Normalized scores for the three evaluation indicators and overall sustainability score. 00.250.50.751WMIERIIRIUSS

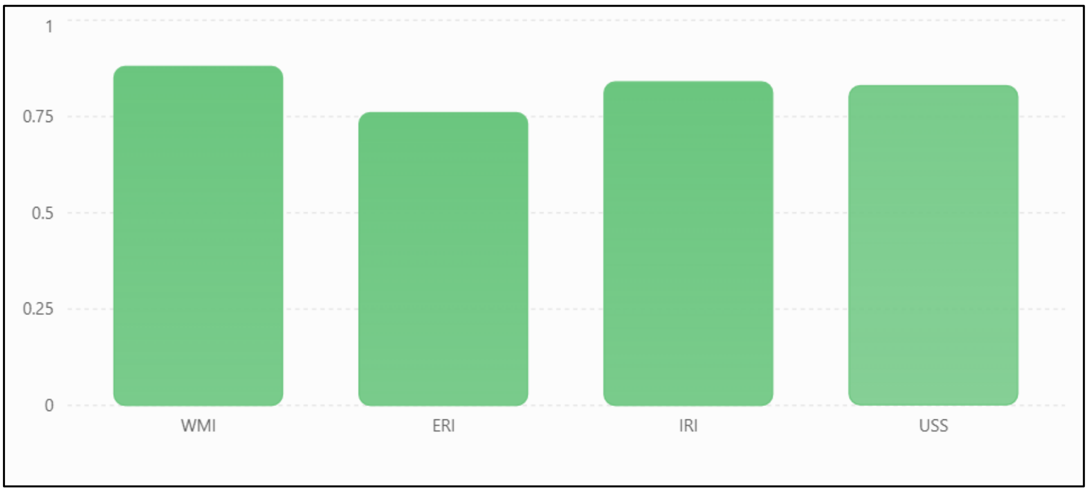

Figure 4: Performance comparison of the proposed framework.

5 DISCUSSION

The results demonstrate that evaluating urban water systems, emissions, and infrastructure within a single framework provides a broader assessment than analyzing each component separately. The integrated methodology identifies relationships among water supply, mobility, drainage performance, and environmental impacts. The findings also indicate that improvements in water mobility contribute to infrastructure performance, while emission reduction depends on additional actions such as cleaner energy sources, efficient pumping systems, and sustainable transportation planning. The proposed framework supports urban planners through a structured assessment process that combines multiple indicators into a single sustainability score. The methodology can also be adapted to different cities after replacing the input datasets with local information.

Limitations and Future Work

This study uses secondary datasets and normalized indicators, which may not represent all urban conditions. Local differences in climate, infrastructure age, and policy can influence the final results. The framework also evaluates annual data and does not consider short-term operational changes or emergency events. Future research can incorporate real-time sensor data, Internet of Things (IoT) monitoring, digital twin technology, geographic information systems (GIS), and machine learning models to improve prediction accuracy. Additional indicators related to economic cost, public health, and social resilience may also provide a more comprehensive assessment of sustainable urban infrastructure.

6 CONCLUSION

This study presented an integrated framework for Urban Water Mobility and Emission Resilience Planning for Built Environment Infrastructure. The proposed methodology combined urban water management, mobility assessment, emission evaluation, and infrastructure resilience within a unified analytical framework. Data preprocessing, normalization, performance indicators, and validation methods were applied to evaluate the relationships among urban systems and their contribution to sustainable infrastructure planning. The results showed that the integrated framework provides a systematic assessment of water mobility, greenhouse gas emissions, and infrastructure condition through the Water Mobility Index, Emission Resilience Index, Infrastructure Resilience Index, and Urban Sustainability Score. The findings indicate that coordinated planning can improve infrastructure performance while identifying areas that require additional attention, particularly emission reduction. The proposed framework also supports comparative evaluation of urban systems using standardized indicators and analytical models. Although the study demonstrates the applicability of the proposed methodology, its performance depends on the availability and quality of urban datasets. Future research can extend the framework through real-time monitoring, Geographic Information Systems (GIS), digital twin technology, Internet of Things (IoT) sensors, and machine learning techniques to improve prediction accuracy and decision support. The proposed framework provides a practical reference for researchers, engineers, and urban planners working toward resilient, sustainable, and low carbon built environment infrastructure.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding this manuscript.

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