RESILIENCE AND LIVABLE CITIES IN A WARMING WORLD

A FESTSCHRIFT IN HONOUR OF

TPL. DR. JOSHUA ADEWUMI ADEBISI FNITP, RTP



EDITED BY

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CHAPTER 09

AI-DRIVEN PORTFOLIO MANAGEMENT FOR IBADAN WASH INFRASTRUCTURE: A STRATEGIC FRAMEWORK FOR SUSTAINABLE PLANNING IN IBADAN METROPOLIS

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Abstract
Accelerated urbanization in Ibadan has significantly intensified pressure on Water, Sanitation, and Hygiene (WASH) infrastructure, resulting in persistent inefficiencies in service delivery, inequitable access, and suboptimal resource allocation across the metropolis. As one of the largest and rapidly expanding urban centers in Nigeria, Ibadan exemplifies the complex challenges faced by cities in developing countries, where conventional WASH portfolio management approaches struggle to effectively prioritize projects and respond to dynamic urban growth. Despite the growing relevance of data driven planning, the potential of Artificial Intelligence (AI) to enhance forecasting, planning, and decision-making within Ibadan's WASH sector remains largely underutilized. This study develops a strategic framework for integrating AI into urban WASH portfolio management, with specific application to Ibadan metropolis. Adopting a conceptual framework approach, the research is supported by secondary data analysis drawn from global and national WASH datasets, alongside comparative insights from cities that have implemented AI enabled infrastructure solutions. The study demonstrates how AI tools including predictive analytics, optimization algorithms, and intelligent decision support systems can improve project prioritization, optimize resource allocation, and enhance overall service delivery efficiency within the Ibadan context. The proposed framework provides context-specific guidance for urban planners, policymakers, and infrastructure stakeholders, with a focus on improving operational performance, promoting equitable service access, and strengthening the long-term sustainability of WASH systems in Ibadan. By situating AI within the realities of a rapidly urbanizing African metropolis, this study contributes to ongoing discourse on smart cities, sustainable development, and resilient urban planning, highlighting the role of intelligent technologies in transforming urban infrastructure management.

Keywords: Artificial Intelligence, Water, Sanitation and Hygiene (WASH), Portfolio Management, Urban Planning, Infrastructure Sustainability, Smart Cities.

1.0 Introduction

Rapid urbanization has become a defining feature of the twenty-first century, reshaping population distribution, infrastructure needs, and the spatial structure of cities worldwide. In Ibadan one of the largest and fastest-growing urban centers in Nigeria this trend is particularly evident, as expanding population pressures continue to stretch existing urban systems. Globally, it is projected that nearly 70 percent of the world's population will reside in urban areas by 2050, with the most rapid growth occurring in low- and middle-income countries (United Nations, 2023). This surge places significant

strain on critical urban services, especially Water, Sanitation, and Hygiene (WASH) infrastructure, which is fundamental to public health, environmental sustainability, and socio-economic development (World Bank, 2022).

In the context of Ibadan metropolis, WASH infrastructure increasingly struggles to keep pace with rising demand. Persistent challenges such as inadequate investment, aging facilities, and limited institutional capacity have led to inconsistent service delivery, unequal access across neighborhoods, and weakened system resilience. Rapid expansion into peri-urban areas often characterized by informal development has further compounded these issues, resulting in gaps in sanitation coverage and increased pressure on water distribution networks. These deficiencies not only undermine the operational efficiency and financial sustainability of service providers but also heighten public health risks and environmental degradation within the metropolis.

The growing complexity of urban systems in Ibadan, driven by fluctuating population densities, climate variability, and interconnected resource demands, underscores the need for more innovative and adaptive planning approaches. Conventional infrastructure planning models, which are often reactive and fragmented, have proven insufficient in addressing these evolving challenges. Against this backdrop, Artificial Intelligence (AI) is emerging as a transformative tool in urban infrastructure management. Through predictive analytics, optimization techniques, and intelligent decision-support systems, AI offers opportunities to forecast demand, enhance resource allocation, and improve the overall performance of WASH infrastructure systems (Batty, 2020; Zhang et al., 2022).

The application of AI in WASH portfolio management within Ibadan despite its valuable important promise, remains largely underexplored. Planning institutions continue to rely on traditional methodologies that do not fully capture the dynamic and interconnected nature of urban growth. This study therefore seeks to develop a strategic framework for integrating Artificial Intelligence into the planning and management of urban WASH infrastructure in Ibadan metropolis. It begins by critically assessing existing institutional frameworks and portfolio management practices that shape service delivery, and further examines how AI-driven tools such as predictive modelling, real-time monitoring, and decision-support systems can improve planning accuracy, investment prioritization, and operational resilience. By proposing a conceptual model that aligns AI capabilities with long-term sustainability goals, this research emphasizes the importance of adaptive planning and equitable service provision within the Ibadan context. Drawing insights from comparable cities that have adopted AI-enabled infrastructure solutions, the study also identifies transferable lessons and best practices applicable to urban and regional planning. Ultimately, it positions AI not merely as a technological intervention, but as a strategic planning intelligence capable of supporting Ibadan in navigating the complexities of sustainable infrastructure development amid rapid urban transformation.

2.0 Literature Review

Rapid urbanization in developing countries has intensified pressure on urban infrastructure systems, particularly Water, Sanitation, and Hygiene (WASH) services, which remain critical to public health and sustainable development. Recent global

assessments by the United Nations (2023) and the World Bank (2024) indicate that cities in Sub-Saharan Africa are experiencing accelerated population growth, resulting in widening service gaps and infrastructure deficits. In Ibadan, these challenges are evident in the form of unreliable water supply, inadequate sanitation systems, and inequitable access across socio-economic groups. Empirical studies (Adams et al., 2023; Adelekan et al., 2023; Ogunbode & Akinwale, 2024) attribute these deficiencies to rapid peri-urban expansion, aging infrastructure, and insufficient investment, while Olajuyigbe and Rotowa (2024) further highlight the public health implications of poor sanitation coverage in densely populated communities.

Infrastructure portfolio management has been widely recognized as a strategic tool for optimizing investment decisions and improving project prioritization in urban systems. Contemporary studies (Martins et al., 2023; Chen & Li, 2024) emphasize its role in balancing competing demands, risks, and long-term sustainability objectives. However, in many developing cities including Ibadan, traditional portfolio management approaches remain fragmented, data-constrained, and institutionally weak. Research by Olawale et al. (2023) and Ezeh and Nwankwo (2024) identifies governance inefficiencies, lack of integrated data systems, and political influences as key barriers to effective infrastructure planning. Within this context, the emergence of Artificial Intelligence (AI) presents new opportunities for enhancing planning processes through predictive analytics, optimization algorithms, and decision-support systems (Kumar et al., 2023; Batty, 2023; Zhang et al., 2024). Applications in the WASH sector, such as those documented by García et al. (2023) and Singh and Jain (2024), demonstrate AI's potential to improve demand forecasting, reduce system losses, and enhance operational efficiency.

Despite these advancements, the integration of AI into WASH portfolio management remains limited, particularly in African urban contexts. Recent studies (Chen et al., 2023; López & Torres, 2024; Rahman et al., 2024) suggest that AI-driven portfolio systems can significantly enhance decision-making by enabling multi-criteria analysis, real-time monitoring, and efficient resource allocation. However, challenges such as data limitations, technical capacity gaps, and weak institutional frameworks continue to hinder adoption (UN-Habitat, 2023; 2024). Scholars such as Almeida et al. (2023), Bibri (2024), and Akinyemi et al. (2024) further link AI integration to broader smart city and sustainability agendas, emphasizing the need for context-specific frameworks that align technological innovation with local realities. Consequently, there remains a critical research gap in developing an integrated, AI-driven portfolio management framework tailored to WASH infrastructure in Ibadan, which this study seeks to address by bridging technological capabilities with sustainable urban planning practice.

2.1 Conceptual Review

The concept of Artificial Intelligence (AI) driven portfolio management in urban infrastructure planning is rooted in the intersection of three key domains: WASH service delivery, infrastructure portfolio management, and intelligent data driven systems. WASH infrastructure encompasses the systems and services that ensure access to safe water, adequate sanitation, and hygiene, which are fundamental to public health

and socio-economic development. In rapidly urbanizing cities such as Ibadan, WASH systems are often characterized by capacity deficits, spatial inequality, and operational inefficiencies due to population growth and unplanned urban expansion (Adelekan et al., 2023; Ogunbode & Akinwale, 2024).

Infrastructure portfolio management refers to the systematic process of selecting, prioritizing, and managing a collection of projects to achieve strategic objectives under resource constraints. It emphasizes optimal allocation of financial, technical, and institutional resources across competing infrastructure needs (Martins et al., 2023). However, conventional approaches are often limited by static data, weak feedback mechanisms, and inadequate integration of socio-spatial dynamics. AI-driven portfolio management introduces advanced computational techniques such as machine learning, predictive analytics, and optimization algorithms to enhance decision making processes. These tools enable planners to analyze large datasets, forecast demand patterns, and dynamically adjust investment priorities (Chen et al., 2023; Kumar et al., 2023).

The concept of smart and sustainable cities further reinforces the integration of AI into infrastructure systems. According to the UN-Habitat (2024), smart cities leverage digital technologies to improve service delivery, resource efficiency, and environmental sustainability. Within this framework, AI driven WASH portfolio management is conceptualized as a strategic planning tool that aligns infrastructure investment with long-term sustainability goals, equity considerations, and resilience to urban shocks such as climate variability.

2.2 Theoretical Review

This study is anchored on three complementary theoretical perspectives: Systems Theory, Resource-Based View (RBV), and Smart City Theory. Systems Theory provides a holistic framework for understanding urban infrastructure as an interconnected network of components that interact dynamically. In the context of WASH systems, this theory highlights the interdependencies between water supply, sanitation services, environmental factors, and socio-economic conditions. Scholars such as Batty (2023) argue that AI enhances systems thinking by enabling real time data integration and predictive modelling, thereby improving the adaptability of urban infrastructure systems.

The Resource-Based View (RBV) emphasizes the strategic importance of organizational resources and capabilities in achieving sustainable performance. Within urban infrastructure planning, AI can be viewed as a critical intangible resource that enhances institutional capacity for data analysis, forecasting, and decision-making (Chen & Li, 2024). By leveraging AI technologies, urban authorities in cities like Ibadan can improve their ability to allocate scarce resources efficiently and respond to changing urban demands.

Smart City Theory further underpins this study by advocating the integration of digital technologies into urban governance and infrastructure systems. The theory posits that cities can achieve improved efficiency, sustainability, and quality of life through the use of intelligent technologies such as AI, Internet of Things (IoT), and big data analytics (Bibri, 2024). In the WASH sector, this translates into the use of AI-driven

tools for monitoring infrastructure performance, optimizing service delivery, and enhancing resilience. Together, these theories provide a robust framework for understanding how AI can transform WASH portfolio management into a more adaptive, data-driven, and sustainable process.

2.3 Empirical Review

Empirical studies on urban WASH systems consistently highlight the challenges of service delivery in rapidly growing cities, particularly in developing countries. Research by Adelekan et al. (2023) and Olajuyigbe and Rotowa (2024) reveals significant disparities in access to water and sanitation services in Ibadan, with low income and peri-urban communities being disproportionately affected. Similarly, global studies by the World Bank (2024) and the United Nations (2023) indicate that infrastructure deficits and weak institutional frameworks are major constraints to achieving universal WASH access.

Recent empirical research also demonstrates the growing role of AI in improving urban infrastructure management. García et al. (2023) show that machine learning models can significantly reduce water losses in distribution systems through predictive leak detection. Singh and Jain (2024) find that AI-enabled sanitation monitoring systems enhance service efficiency and accountability. Furthermore, Rahman et al. (2024) provide evidence that AI-driven decision-support systems improve infrastructure investment outcomes by enabling data-driven prioritization and risk assessment. Despite these advancements, studies by Okeke and Yusuf (2023) and UN-Habitat (2023) reveal that the adoption of AI technologies in African cities remains limited due to data constraints, lack of technical expertise, and institutional barriers.

In the area of portfolio management, empirical evidence suggests that integrating AI into decision-making processes enhances efficiency and transparency. Chen et al. (2023) and López and Torres (2024) demonstrate that AI-based optimization models improve project selection and resource allocation in infrastructure planning. However, there is limited empirical research specifically addressing AI-driven portfolio management in the WASH sector, particularly within the Nigerian context. The Summary of Key Indicators from Global WASH and AI Readiness Datasets (2020–2024).

Table 1: Summary of Key Indicators from Global WASH and AI Readiness Datasets (2020–2024)

City/Country	Access to Safely Managed Water Services (% Urban Population)	Access to Improved Sanitation (% Urban Population)	Public Expenditure on WASH (% of GDP)	AI Readiness Index (0–100)	AI-Enabled Monitoring Systems in Operation	Observed Service Efficiency Outcome	Observed WASH Performance
Singapore	100	100	0.85	89	Yes (WaterSmart System)	98% leak detection efficiency; 15% reduction in water loss	Near-universal coverage, advanced smart metering, predictive maintenance fully operational
Amsterdam (Netherlands)	99	99	0.73	92	Yes (Smart Infrastructure Program)	35% reduction in maintenance downtime	Fully digitized network monitoring; continuous optimization of wastewater management
Kigali (Rwanda)	86	78	1.12	58	Partial (Urban WASH Strategy Pilot)	12% improvement in coverage efficiency	Expanding coverage through pilot AI systems; efficiency improving with limited digital infrastructure
Lagos (Nigeria)	71	65	0.48	41	No	Persistent service gaps; frequent maintenance backlog	Low service reliability, weak monitoring capacity; emerging digital mapping projects
New Delhi (India)	88	82	0.62	64	Limited (Smart City Mission Initiatives)	9% improvement in distribution efficiency	Partial AI integration in sanitation and water networks; moderate progress

São Paulo (Brazil)	93	90	0.77	72	Moderate (SABESP Data Integration Project)	20% reduction in unaccounted-for water	Expanding machine-learning applications in leak detection; stable service coverage

Source: Compiled from World Bank (2024), WHO/UNICEF JMP (2024), ITU Global AI Index (2024), and OECD AI Policy Observatory (2024).

3.0 Materials and Methods

3.1 The Study Area

The study area for this research is Ibadan, a major urban centre in Nigeria and the capital of Oyo State. As one of the largest and fastest-growing cities in the country, Ibadan has experienced significant population expansion and spatial growth, resulting in increasing pressure on its urban infrastructure systems. The city is characterized by a mix of densely populated traditional cores, expanding peri-urban settlements, and emerging planned developments, many of which lack adequate infrastructure provision. This rapid and often uncoordinated urbanization has placed considerable strain on Water, Sanitation, and Hygiene (WASH) services, leading to challenges such as unreliable water supply, inadequate sanitation coverage, and unequal access across different socio-economic groups.

These conditions make Ibadan a suitable case study for examining the application of Artificial Intelligence (AI) in WASH infrastructure portfolio management. The city's complex urban structure, coupled with institutional and resource constraints, highlights the limitations of conventional planning approaches in addressing dynamic service demands. Environmental factors, including seasonal rainfall patterns and drainage challenges associated with river systems such as the Ogunpa River, further complicate infrastructure management and increase vulnerability to flooding and sanitation-related risks. Within this context, Ibadan provides a practical setting to explore how AI-driven tools can enhance project prioritization, optimize resource allocation, and improve the efficiency and sustainability of WASH service delivery in rapidly urbanizing environments.

3.2 Methodology

This study adopts a conceptual analytical research design to develop an Artificial Intelligence (AI)–driven strategic framework for urban Water, Sanitation, and Hygiene (WASH) portfolio management, with specific relevance to Ibadan. The approach emphasizes systematic inquiry, integrative reasoning, and the synthesis of existing knowledge to generate a robust and context-sensitive planning framework. Rather than relying on experimental or purely quantitative techniques, the conceptual analytical design is particularly appropriate for studies focused on theory development, policy innovation, and strategic planning, where the objective is to identify relationships, establish patterns, and propose actionable models based on existing evidence (Creswell,

2018). It also enables the integration of multidisciplinary perspectives across urban planning, infrastructure management, and artificial intelligence, thereby providing a comprehensive understanding of the complexities inherent in WASH systems within rapidly growing urban environments.

The study relies predominantly on secondary data obtained from reputable global and regional institutions, including the World Bank, UN-Habitat, World Health Organization, and the UNICEF Joint Monitoring Programme (JMP). These sources provide comprehensive datasets and reports on urban WASH systems, infrastructure performance, and service delivery trends. In addition, peer-reviewed academic literature is systematically reviewed from established databases such as Scopus, ScienceDirect, and IEEE Xplore to capture recent theoretical developments, empirical evidence, and technological innovations related to infrastructure portfolio management, AI applications, and urban service delivery. The scope of the study focuses on urban WASH systems in low and middle-income countries, with particular emphasis on institutional frameworks, governance structures, investment strategies, and emerging AI-driven technologies, while maintaining a contextual focus on the socio economic and infrastructural realities of Ibadan metropolis to ensure the relevance and applicability of the proposed framework.

The methodological process is structured around four interconnected phases designed to address the study's objectives coherently. The first phase involves a systematic review and content analysis of existing portfolio management practices and institutional structures governing urban WASH infrastructure delivery. This phase identifies management inefficiencies, institutional gaps, and operational challenges influencing project prioritization and sustainability outcomes. The second phase entails a scoping analysis of AI applications across the domains of infrastructure management, urban planning, and environmental systems. This stage examines predictive analytics, optimization algorithms, and decision-support systems evaluating how these tools are applied to enhance planning efficiency, operational monitoring, and data-driven decision-making.

Findings from these two phases provide the empirical and conceptual basis for the third phase, which focuses on constructing the AI-driven strategic framework for WASH portfolio management. Insights are synthesized to outline relationships among institutional variables, AI tools, and decision-making processes. The framework models how predictive analytics, optimization, and real-time data integration enhance project prioritization, transparency, and sustainability within urban WASH management systems. Finally, a comparative case analysis is conducted to validate and contextualize the proposed framework. Case studies of cities that have adopted AI-enabled infrastructure systems such as Singapore, Amsterdam, and Kigali are reviewed to identify transferable lessons, implementation pathways, and adaptive strategies relevant to developing urban regions.

4.0 Results and Discussions

The results of this study are presented in alignment with the research objectives and are derived from the systematic review, comparative case analysis, and conceptual validation process. Collectively, the findings demonstrate that Artificial Intelligence

(AI) has the potential to significantly transform portfolio management within urban Water, Sanitation, and Hygiene (WASH) systems by enhancing decision-support systems, improving predictive capabilities, and optimizing operational efficiency. The synthesis of evidence indicates that integrating AI into WASH infrastructure planning shifts decision-making from reactive and fragmented approaches toward more proactive, data-driven, and adaptive systems capable of responding to the complexities of rapid urbanization in cities such as Ibadan.

Findings from the systematic review reveal that existing portfolio management approaches in urban WASH systems remain largely linear, reactive, and resource-intensive. In many developing cities, project prioritization is still driven by short-term fiscal considerations and political influence rather than evidence-based performance metrics (World Bank, 2022). These conventional systems lack predictive capacity, limiting planners' ability to anticipate infrastructure deterioration, optimize investment sequencing, or respond effectively to dynamic urban demands. Institutional fragmentation between planning, financing, and implementation agencies further exacerbates inefficiencies, as project selection is often based on administrative discretion rather than structured analytical models (UN-Habitat, 2021). This has resulted in duplication of efforts, inefficient asset utilization, and unsustainable maintenance practices. In the context of Ibadan, these challenges are intensified by rapid population growth and uneven spatial development, highlighting the urgent need for more intelligent and integrated portfolio management systems.



(Figure 1: AI-Driven Strategic Framework for Urban WASH Portfolio Management.)

The analysis of Artificial Intelligence applications demonstrates its strong potential as a transformative tool for modernizing WASH infrastructure management. AI technologies such as machine learning, predictive analytics, and optimization algorithms provide advanced computational capabilities for processing large and complex datasets, forecasting system failures, and supporting real-time decision-making (Rahman et al., 2023). Predictive analytics enables estimation of future water demand, infrastructure lifespan, and failure risks using historical and real-time data, while optimization algorithms support multi-criteria decision-making involving cost efficiency, service equity, and environmental sustainability. Decision-support systems further translate these analytical outputs into interactive tools that allow planners to simulate scenarios and evaluate policy alternatives (Zhao & Li, 2022). Despite successful applications in sectors such as energy and transport, AI integration in WASH systems remains limited, particularly in developing contexts, due to institutional inertia, data fragmentation, and capacity constraints. This gap, however, presents a significant opportunity for innovation in urban infrastructure planning.

Building on these insights, the study develops an AI-Driven Strategic Framework for Urban WASH Portfolio Management, which integrates technological, institutional, and operational dimensions into a unified planning model. The framework conceptualizes how AI can enhance governance and decision-making by linking urban data systems with institutional processes through predictive analytics, optimization tools, and adaptive feedback mechanisms. The Data Infrastructure Layer establishes structured systems for collecting and managing water supply, sanitation, and infrastructure performance data, ensuring consistency and interoperability for AI applications. The AI-Analytical Layer applies predictive and optimization models to assess risks, forecast demand, and prioritize interventions based on multi-objective criteria. The Institutional Integration Layer connects AI outputs to governance structures, promoting coordination, transparency, and accountability across agencies. The Strategic Decision Layer translates analytical insights into actionable investment plans and operational strategies, while the Feedback and Learning Mechanism ensures continuous model improvement, adaptive learning, and policy refinement. Collectively, these components establish a dynamic and iterative system for sustainable WASH portfolio management.

Comparative analysis of global case studies further validates the applicability of the proposed framework. In Singapore, the Smart Water Grid demonstrates how predictive analytics can enhance operational efficiency, achieving up to 98% leak detection accuracy and reducing water loss by approximately 15% annually (PUB Singapore, 2023). Similarly, Amsterdam has successfully integrated AI-enabled monitoring systems into its urban infrastructure planning processes, resulting in a 35% reduction in maintenance downtime and improved sustainability outcomes. In emerging urban contexts such as Kigali, pilot AI-driven initiatives in water and sanitation management have led to a 12% improvement in service coverage efficiency, demonstrating the adaptability of AI solutions even in resource-constrained environments. These cases highlight critical success factors including strong institutional coordination, robust data governance systems, and sustained stakeholder engagement, all of which are essential for effective implementation.

5.0 Conclusion and Recommendations

This study developed an Artificial Intelligence (AI)-driven strategic framework for portfolio management of urban Water, Sanitation, and Hygiene (WASH) infrastructure, with a focus on advancing sustainable urban and regional planning. Using a conceptual–analytical research design supported by secondary datasets and comparative case studies, the research demonstrates that conventional WASH portfolio management systems are largely fragmented, reactive, and influenced by short-term institutional and political considerations. These limitations continue to undermine infrastructure efficiency, equity, and long-term resilience, particularly in rapidly urbanizing cities such as Ibadan.

In contrast, the study establishes that AI-driven tools including predictive analytics, optimization algorithms, and decision-support systems offer significant transformative potential for improving infrastructure planning and management. These technologies enhance project prioritization, enable evidence-based resource allocation, and strengthen operational efficiency within WASH systems. The proposed AI-driven strategic framework integrates four interconnected components: data infrastructure, AI analytics, institutional integration, and strategic decision-making, supported by a continuous feedback and learning mechanism. Together, these layers create an adaptive and intelligent planning system that supports more sustainable and responsive WASH infrastructure governance.

Comparative validation using global evidence from institutions such as the World Bank, World Health Organization, and UNICEF Joint Monitoring Programme further confirms that cities with advanced AI integration and digital infrastructure such as Singapore and Amsterdam demonstrate improved service efficiency, reduced maintenance downtime, and higher system reliability compared to less digitally advanced urban systems. These findings highlight that the effectiveness of AI in WASH portfolio management is not solely technological but also institutional, requiring strong governance frameworks, robust data ecosystems, and adequate human capacity development. Meanwhile, the study contributes both theoretically and practically to the field of urban infrastructure planning by presenting a structured model that aligns with global sustainability agendas, particularly Sustainable Development Goal (SDG) 6 on Clean Water and Sanitation and SDG 11 on Sustainable Cities and Communities. It advances the discourse on smart urban governance by positioning AI as both a strategic planning instrument and a catalyst for systemic transformation in WASH infrastructure portfolio management.

Based on the findings of this study and the proposed AI-driven strategic framework for WASH portfolio management, several policy and practice-oriented recommendations are advanced to support sustainable urban infrastructure development, particularly in rapidly growing cities such as Ibadan. First, urban planning and infrastructure management institutions should institutionalize robust AI governance frameworks to regulate the ethical use of data, ensure transparency, and strengthen accountability in decision-making processes. Such frameworks should include standardized data-sharing protocols, privacy safeguards, and formalized inter-agency coordination mechanisms to support integrated WASH planning and implementation. Second, governments at local, state, and national levels, in collaboration with development partners such as the World Bank and UN Habitat, should invest

strategically in digital and data infrastructure. This includes the deployment of Internet of Things (IoT) sensors, geospatial information systems, and real-time monitoring platforms that can generate reliable, high-quality datasets necessary for effective AI model development and application in WASH systems.

Third, targeted capacity development and skills reorientation programs should be implemented for urban planners, engineers, policymakers, and WASH sector professionals. These programs should focus on building competencies in artificial intelligence, data analytics, and digital portfolio management tools to ensure effective utilization and sustainability of AI-driven systems. Fourth, pilot implementation of AI-driven portfolio management systems should be encouraged in selected urban WASH projects within developing cities. These pilot initiatives should incorporate predictive analytics and optimization tools to assess their effectiveness in improving cost efficiency, project prioritization, scalability, and governance adaptability before wider adoption.

Fifth, stronger global, regional, and interdisciplinary collaboration should be fostered among governments, academic institutions, and technology providers. Such partnerships will enhance knowledge exchange, promote joint research initiatives, and support the development of innovative policy frameworks for AI-enabled infrastructure planning and management. Finally, continuous monitoring, evaluation, and adaptive learning mechanisms should be embedded within AI-driven WASH systems. These feedback structures will enable urban authorities to assess system performance, refine predictive models, and adjust planning strategies based on empirical outcomes and evolving community needs, thereby ensuring long-term sustainability and resilience of urban WASH infrastructure.

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