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Systematic Review of Smart Drainage Systems for Urban Flood Control

Dikshita Kunwar Ranawat[1], Yuvraj Singh Ranawat[2], Aiwant Chandaliya[3]

Student, Department of Civil Engineering, Geetanjali Institute of Technical Studies, Udaipur, India[1]
Student, Department of Civil Engineering, Jodhpur Institute of Engineering & Technology, Jodhpur, India[2]
Assistant Professor, Department of Civil Engineering, Geetanjali Institute of Technical Studies, Udaipur, India[3]

Abstract: Rapid urbanization, climate change, and increasing population density have intensified the frequency and severity of urban floods worldwide. Traditional drainage infrastructures are inadequate to handle dynamic rainfall patterns and extreme weather events. Smart drainage systems (SDS) integrate the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and real-time monitoring technologies to enable adaptive, predictive, and automated flood control. This review synthesizes literature from 2020 to 2025 on SDS applications for urban flood management, focusing on system architecture, sensing and communication networks, AI-driven prediction, and digital twin modeling. Results demonstrate that SDS can reduce flood response times by 35–70%, improve prediction accuracy by up to 92%, and significantly mitigate waterlogging durations. However, scalability challenges persist due to network reliability, maintenance, and institutional integration. The paper concludes with recommendations for improving system interoperability, urban governance, and long-term sustainability in developing economies such as India.

Keywords: Smart Drainage Systems, Urban Flood Control, IoT, Artificial Intelligence, Digital Twin, Real-Time Monitoring

1. INTRODUCTION

Urban flooding has emerged as a pressing environmental and socio-economic challenge in modern cities. According to the World Bank (2023), nearly 56% of India's urban population resides in flood-prone areas due to unplanned urbanization, inadequate drainage, and extreme rainfall. Traditional drainage systems are designed for fixed capacities and lack adaptability to respond to variable rainfall events (Zhang, 2024).

Smart drainage systems (SDS) integrate cyber-physical technologies such as IoT sensors, wireless communication, and AI-based analytics to manage urban stormwater dynamically. These systems enable real-time data collection, predictive modeling, and automated control of flood management infrastructure (Veerappan, 2024). The introduction of digital twins—virtual replicas of drainage networks—further enhances predictive and scenario-based decision-making (Kim, 2025).

This review systematically examines research published between 2020 and 2025, focusing on SDS applications, performance outcomes, and emerging gaps relevant to developing contexts like India.

2. METHODOLOGY

Following the **PRISMA 2020** systematic review protocol, databases such as *Scopus*, *Web of Science*, *Google Scholar*, and *IEEE Xplore* were searched using the keywords: *"smart drainage," "IoT flood control," "urban stormwater," "digital twin,"* and *"AI-based flood management."*

Inclusion criteria:

- Studies published between 2020–2025.
- Research focused on urban drainage or flood management using smart technologies.
- Peer-reviewed articles, conference papers, and institutional reports with experimental or simulation results.

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Exclusion criteria:

- Studies on rural drainage or non-urban applications.
- Papers focusing solely on water quality or pollution.

Data from selected papers were categorized by: (1) region of study, (2) technology used, (3) key performance metrics, and (4) outcomes and limitations.

3. LITERATURE REVIEW

3.1 Evolution of Smart Drainage Systems

Smart drainage systems combine sensing, communication, and automation technologies to transform passive networks into adaptive systems. Zhang (2024) and Veerappan (2024) describe SDS as responsive infrastructures capable of adjusting water flow in real-time through automated valves and pumps, thereby minimizing urban waterlogging.

3.2 IoT and Real-Time Monitoring

IoT-enabled networks collect rainfall, flow, and water-level data in real time. Dabas et al. (2025) and Nageye et al. (2025) reported that LoRaWAN-based drainage sensors in Chennai and Mogadishu reduced detection time by up to 35% and decreased waterlogging duration by 80%. Continuous monitoring enhances early warning systems and predictive flood modeling.

3.3 Artificial Intelligence and Predictive Analytics

AI algorithms such as neural networks and fuzzy logic predict flood events with over 90% accuracy (Hingmire & Bhaladhare, 2023). These systems enable dynamic control—automatically adjusting floodgates and pumps based on forecasted conditions (Veerappan, 2024).

3.4 Digital Twin Technology

Digital twins create synchronized virtual models of physical drainage networks, integrating live sensor data for simulation-based control. Kim (2025) and Liang (2025) found that digital twin-based systems improved flood response times by 40–60% and reduced overflow probability significantly.

3.5 Smart Control and Hybrid Infrastructure

Integrating AI-based control with nature-based solutions (NBS) such as detention ponds, bioswales, and permeable pavements enhances both resilience and sustainability. Cansian (2025) demonstrated a 50% reduction in stormwater runoff when AI-driven control was combined with green infrastructure.

3.6 Indian Context and Case Studies

India's smart drainage pilots in Mumbai, Hyderabad, and Kolkata demonstrated 35–70% faster responses compared to traditional SCADA systems (Veerappan, 2024). However, most are experimental, with limited scalability and poor cross-agency data integration.

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4. COMPARATIVE ANALYSIS

Author (Year)	Region	Technology Used	Key Achievements	Performance Outcome
Hingmire & Bhaladhare (2023)	India	IoT + Fuzzy Logic	Smart gate prototype	73.9% water reduction
Veerappan (2024)	India	Edge-enabled IoT	Automated flood gates	92.4% overflow prediction
Kim (2025)	South Korea	Digital Twin + AI	Predictive control model	40–60% faster response
Nageye et al. (2025)	Somalia	IoT + Cloud Analytics	Real-time flood detection	35% reduced detection time
Cansian (2025)	Global	AI + NBS Integration	Sustainable stormwater design	50% lower runoff volume

5. DISCUSSION

The reviewed studies indicate that SDS technologies significantly enhance flood resilience by improving real-time monitoring, predictive control, and operational automation. Integrating AI with IoT and digital twin frameworks creates data-driven decision systems capable of self-regulation.

However, the widespread implementation faces obstacles including limited interoperability, cybersecurity threats, high initial investment, and inadequate municipal capacity. Moreover, most projects remain at pilot scales, and there is limited empirical data on long-term cost-benefit performance in developing cities.

6. RESEARCH GAPS

1. **Limited large-scale implementation:** Most SDS studies are confined to small pilot projects; large urban systems lack comprehensive evaluation.
2. **Interoperability and standardization:** Absence of uniform communication protocols between IoT devices and legacy systems.
3. **Cybersecurity vulnerabilities:** Lack of encryption and fail-safe measures exposes critical flood control networks to cyber risks.
4. **Data management challenges:** Integration of diverse datasets (sensor, meteorological, and satellite) remains underdeveloped.
5. **Socio-economic assessment:** Few studies analyze cost–benefit ratios or stakeholder involvement in system maintenance.

7. RECOMMENDATIONS

1. **Develop national SDS guidelines:** Establish technical standards for smart stormwater management under Smart City Mission 2.0.
2. **Promote data interoperability:** Mandate open-source IoT frameworks compatible across platforms.
3. **Invest in AI-based training programs:** Build municipal and engineering workforce capacities in AI-driven hydrological management.

4. **Enhance cybersecurity frameworks:** Implement encrypted communication and multi-level authorization for SDS infrastructure.
5. **Integrate with nature-based solutions:** Combine digital monitoring with sustainable design for climate-resilient infrastructure.

8. CONCLUSION

Smart drainage systems signify a technological leap toward sustainable and adaptive flood management. Integrating IoT, AI, and digital twin technologies allows cities to transition from reactive to predictive responses. While India and other developing nations are progressing through pilot implementations, future success relies on policy integration, capacity building, and standardization. Embedding SDS frameworks in national urban development strategies will be crucial to achieving resilient, climate-ready cities.

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