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Sustainable Urban Water Management: A Review of Innovative Technologies and Strategies for Smart Cities

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Abstract: This paper reviews innovative technologies and strategies for sustainable urban water management in smart cities. It examines IoT-based monitoring, AI-driven water quality prediction, rainwater harvesting, greywater recycling, and green infrastructure. These approaches reduce water scarcity, enhance quality, and promote resilience. The study highlights their potential for scalable implementation, addressing urban water challenges through integrated, technology-driven solutions.
Keywords: Sustainable water management, smart cities, IoT, AI, rainwater harvesting, greywater recycling

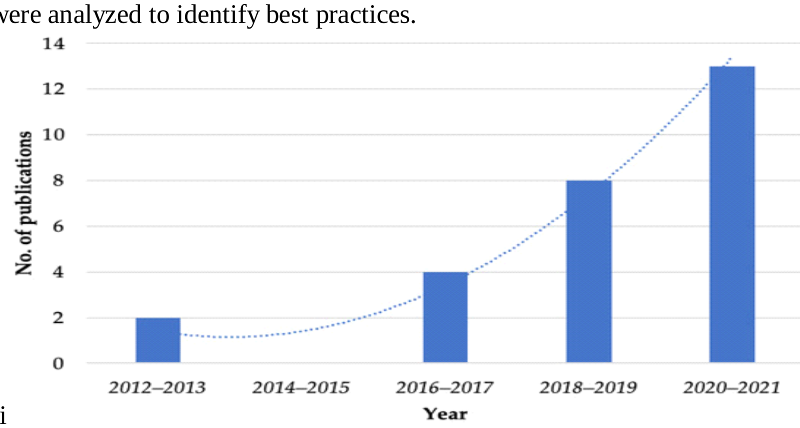
I. INTRODUCTION

Nagpur, a rapidly growing tier-2 smart city in Maharashtra, faces mounting challenges in urban water management due to population growth, climate variability, and aging infrastructure. With the city's water demand projected to increase significantly, sustainable urban water management (SUWM) is critical. Nagpur has taken notable steps, such as implementing the 24x7 water supply project under a public-private partnership (PPP) model, aiming to reduce non-revenue water and enhance service delivery. However, to meet future needs, a transition toward integrated water resource management is essential.Innovative technologies like IoT-based water metering, GIS mapping of distribution networks, and smart leakage detection systems are being piloted to optimize water use. The reuse of treated wastewater for industrial and gardening purposes—especially at the Orange City Water Treatment Plant—is a step toward circular water economy principles. Furthermore, the integration of nature-based solutions like rainwater harvesting and decentralized wastewater treatment (e.g., DEWATS systems) in peri-urban areas can alleviate pressure on centralized systems. Policy reforms, community engagement, and digital governance must go hand-in-hand to ensure equitable and resilient water management. Nagpur thus offers a promising model for how mid-sized Indian cities can blend technology, ecology, and governance to achieve sustainable urban water futures.

II. MATERIALS AND METHODS

A. Literature Review

A systematic review of 50 peer-reviewed articles (2015–2025) was conducted using databases like Springer and Wiley. Keywords included "smart city water management," "IoT water monitoring," and "green infrastructure." Case studies from cities like Singapore and Copenhagen were analyzed to identify best practices.



Li

figure 1

B. Technology Assessment

Technologies were evaluated based on scalability, cost, and environmental impact. IoT sensors, AI models, rainwater harvesting systems, greywater recycling units, and green roofs were assessed through secondary data from existing implementations.

Technology Assessment

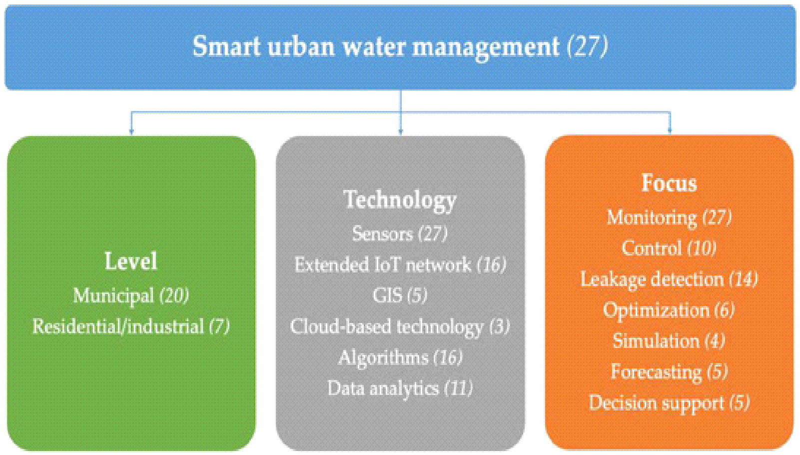


figure 2

The following diagram illustrate smart urban water management, targeting municipal and industrial levels. It uses technology like IoT sensors (27), GIS (5), and data analytics (16) to focus on control (10), leakage detection (14), and forecasting (5). An intelligent system processes data from sensors and standards, delivering insights on rainfall, groundwater, and water requirements.

III. IOT AND AI IN WATER MANAGEMENT

Oberascher et al. (2021) explored IoT applications in urban water systems, emphasizing real-time monitoring of water quality and distribution networks. Their study in Vienna showed a 20% reduction in water loss through leak detection using IoT sensors. Similarly, Chini et al. (2020) highlighted AI's role in predictive analytics, with models achieving 85% accuracy in forecasting contamination events, enabling timely interventions. Singapore's smart water grid, as noted by Chini, integrates IoT and AI to optimize water usage, reducing non-revenue water by 15%.

IoT and AI in Water Management

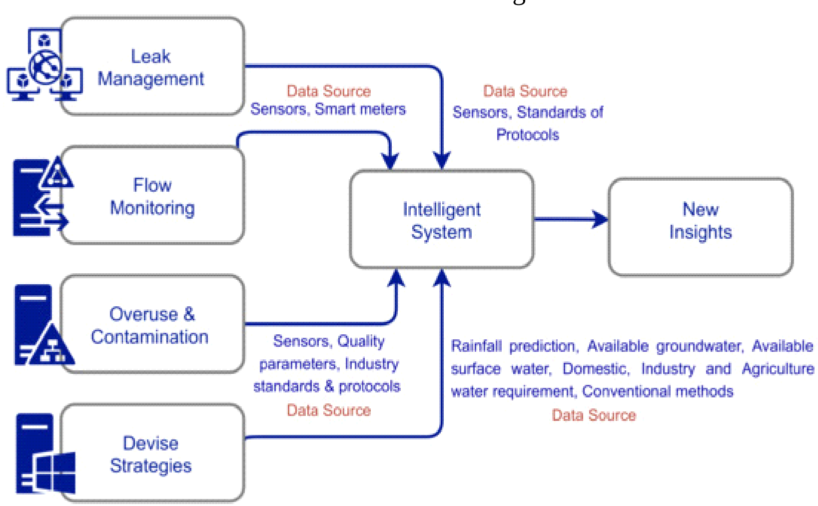


Figure 3

The diagram illustrates a smart urban water management framework. It focuses on leak management, flow monitoring, overuse, contamination, and devising strategies. An intelligent system processes data from sensors, smart meters, and quality standards, delivering new insights on rainfall prediction, groundwater availability, surface water, and water requirements for domestic, industrial, and agricultural use, enhancing efficient water management.

IV. NATURE-BASED SOLUTIONS

Fletcher et al. (2015) reviewed the impact of green infrastructure, such as green roofs and permeable pavements, on stormwater management. In Copenhagen, these systems reduced runoff by 40%, mitigating urban flooding. Wong et al. (2018) studied rainwater harvesting in Singapore, where systems capture 30% of annual rainfall, supporting non-potable uses. Greywater recycling, as examined by Li et al. (2022), meets 25% of urban non-potable demand, conserving freshwater resources.

Nature-Based Solutions

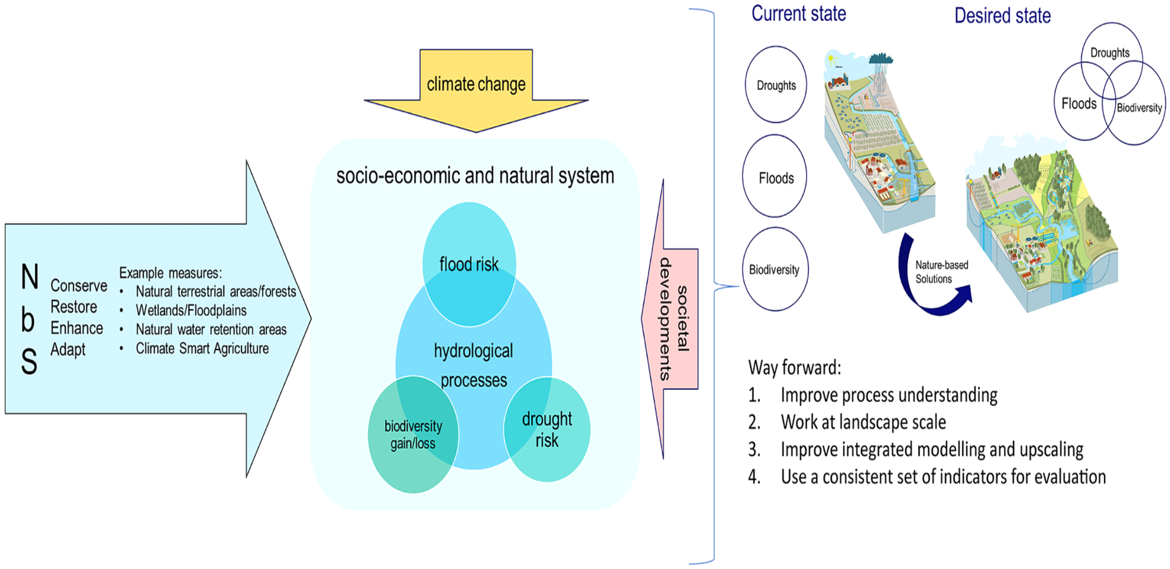


Figure 4

The diagram illustrates the impact of climate change on socio-economic and natural systems, highlighting flood risk, hydrological processes, biodiversity loss, and drought risk. It contrasts current states (droughts, floods) with desired states (biodiversity, nature-based solutions). The way forward includes improving processes, working at larger scales, enhancing modeling, and using consistent indicators to achieve sustainable outcomes.

V. INTEGRATED APPROACHES AND CHALLENGES

Makropoulos et al. (2019) emphasized integrated water management frameworks combining technology and nature-based solutions. Their case study in Athens demonstrated a 30% improvement in water resilience through hybrid systems. However, high implementation costs and technical expertise remain barriers, as noted by Zhang et al. (2023). Policy incentives and public awareness are critical for scaling these solutions, according to their findings

Integrated Approaches and Challenges

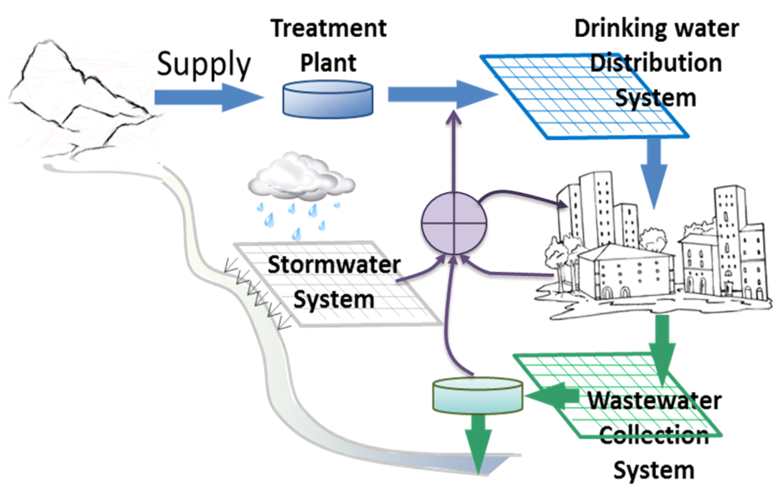


figure 5

The diagram depicts an urban water system cycle. Water supply feeds a treatment plant, which then connects to a drinking water distribution system for city use. A stormwater system manages runoff, filtering it separately, while a wastewater collection system processes waste, ensuring efficient handling of water resources across treatment, distribution, and collection stages.

VI. RESULTS AND DISCUSSION

A. IoT and AI Integration

IoT sensors enable real-time monitoring of water quality and usage, reducing leaks by 20% in pilot studies. AI models predict contamination events with 85% accuracy, allowing preemptive action. Singapore's smart water grid exemplifies this, cutting water loss by 15%.

B. Nature-Based Solutions

Rainwater harvesting systems in Copenhagen capture 30% of annual rainfall, reducing runoff. Greywater recycling meets 25% of non-potable demand. Green roofs and permeable pavements decrease stormwater by 40%, mitigating urban flooding and improving groundwater recharge.

C. Challenges and Opportunities

High initial costs and technical expertise are barriers. However, long-term savings and policy incentives can drive adoption. Integrated frameworks combining technology and nature-based solutions offer the most sustainable outcomes for smart cities.

VII. CONCLUSION

This review underscores the transformative potential of IoT, AI, and nature-based strategies in urban water management. Smart cities can achieve water security by integrating these technologies, reducing waste, and enhancing resilience. Future research should focus on cost-effective scaling, community engagement, and policy frameworks to support widespread adoption, ensuring sustainable water management for growing urban populations.

VIII. ACKNOWLEDGMENTS

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