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Editorial: Urban water network planning and management: perspectives and solutions in the transition towards smart systems from the city to the end-use scale

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Editorial on the Research Topic
Urban water network planning and management: perspectives and solutions in the transition towards smart systems from the city to the end-use scale

Introduction

Climate change effects, population growth, and urbanization are among the main causes of water stress across extensive regions of the world (Cosgrove and Loucks, 2015; Attallah et al., 2023; Xing et al., 2025), a situation that is further complicated by aging infrastructure and the deterioration of water quality due to natural, accidental, or intentional contamination (Renwick et al., 2019). In this global context, characterized by escalating socio-economic, environmental and technical challenges, the effective planning and management of urban water networks have become crucial to address the increasing scarcity of water resources (Avni et al., 2015; Ramos et al., 2020). Understanding where, when, and how water is used is fundamental to ensuring efficient water-resource allocation in space and time (Cardell-Oliver et al., 2016) and in the definition of optimal design criteria. Simultaneously, the preservation of water resources can benefit from strategies aimed at enhancing supply efficiency, reducing leakage, and improving overall network performance and sustainability. Such strategies should be grounded in integrated approaches that account for multiple spatial scales, from the urban level down to individual end uses of water (Mazzoni et al., 2024).

Under these circumstances, the implementation of sound strategies for planning and management of water distribution networks (WDNs) has become essential to safeguard natural resources and ensure a reliable supply for both current and future generations (Marsili et al., 2024). These strategies should be informed by a deep understanding of water-consumption dynamics—the primary driver of network operation (Li and Song, 2023)—and by the identification of feasible technological solutions tailored to the specific temporal, spatial, and contextual characteristics of each system. Achieving these objectives is promoted by the increasing integration of innovative tools such as smart meters and real-time monitoring systems (Cominola et al., 2015), along with the emergence of data-driven, adaptive approaches that can support more adaptive and responsive management of WDN (Cunha et al., 2019; Elshaboury and Marzouk, 2020; Perelman and Ostfeld, 2024).

This Research Topic was conceived to collect original research and reviews providing new insights into approaches that enhance the performance, resilience, and sustainability of WDNs—from the urban scale to the end-use level—across diverse socio-environmental contexts. In line with the objectives of the Call for Papers, the contributions gathered in this Research Topic explore methodologies and technologies that promote equitable water supply, reduce the water–energy footprint, maximize resource savings, and foster informed and responsible water use. Together, they provide a comprehensive overview of current advances, reflecting the diversity of strategies adopted in both developed and developing countries to address the multifaceted challenges of water infrastructure planning and management.

Content overview

The articles included in this Research Topic address critical issues affecting WDNs in various regions of the world, employing methodologies to enhance water resource planning and WDN management across a range of urban environments, often by means of smart technologies. The studies encompass a wide range of topics, from large-scale urban metabolic planning and optimization strategies (Tesfay et al.; Kapata and Ilemobade), to the development of cost-effective and non-intrusive techniques for WDN monitoring based on machine learning (Jamadarkhani et al.), and the modeling of residential and non-residential user behavior in terms of related water consumption (Giudicianni et al.). Collectively, they illustrate how interdisciplinary research can inform the development of sustainable and resilient WDNs.

The research conducted by Tesfay et al. addresses the limited availability of studies exploring urban metabolism in developing countries by focusing on an Ethiopian city assumed as case study. Using the urban water mass balance approach, the authors quantify both anthropogenic (e.g., water supply, wastewater) and natural flows (e.g., precipitation, runoff). The results reveal a negative water balance, symptomatic of a linear "take–make–use–dispose" metabolism that depletes natural resources and undermines long-term sustainability. The study demonstrates significant potential for substituting centralized water supply through alternative sources, such as rainfall and stormwater harvesting, and advocates a shift toward more circular and water-sensitive urban management practices. Importantly, the methodology adopted provides a transferable framework for assessing water metabolism in data-scarce contexts, supporting local authorities in designing integrated water management strategies.

Working from a complementary perspective, Kapata and Ilemobade tackle the challenge of determining the optimal location of storage tanks in WDNs. The study is developed in the face of the existing design guidelines, often neglecting the evaluation of system reliability in the event of pipe failures. To address this gap, the authors develop a methodology based on a reliability index that quantifies the percentage of total demand met during component failure scenarios. The method is tested on a benchmark synthetic network, where tanks are placed at different locations, and evaluated through hydraulic simulations. The results indicate that positioning a supplementary tank downstream of the area requiring the largest amount of water yields the highest tolerance to failure. Furthermore, the analysis identifies investment priorities for improving network robustness, offering a practical decision-support tool for engineers and managers seeking to balance cost, resilience, and performance.

With a focus on intermittently operated WDNs, Jamadarkhani et al. propose an innovative, cost-effective, and non-intrusive Internet of Things (IoT) approach to smart water metering. Their methodology integrates low-cost water level sensors installed in household or community storage tanks with auxiliary data—such as pump operating status—to infer water flow dynamics. Two flow estimation methods are adopted and compared: one based on predefined flow rates, and another employing dynamic estimation to capture temporal variability. Validation against field data reveals that the dynamic method provides more accurate estimates under real-world conditions, including fluctuations in borewell yield and water withdrawals. This contribution illustrates how even low-cost digital technologies can significantly improve monitoring and operational decision-making in WDN contexts where intermittent supply and limited data availability hinder the successful application of traditional approaches.

Finally, Giudicianni et al. investigate residential and non-residential users' behavior in terms of related minimum night consumption (MNC), a key parameter for assessing leakages in WDNs. Conventional models, which link aggregate MNC to the number of users, often suffer from high uncertainty. The authors propose an alternative formulation that expresses MNC as a function of the long-term average aggregate user consumption, derived from billed data. By applying this model to three Italian case studies equipped with smart meters capable of recording hourly consumption, the authors demonstrate that the new modeling approach can reduce uncertainty—especially for non-residential users—and provide reliable leakage estimates, making it a promising tool for water utilities aiming to optimize leakage control strategies.

Key findings and future directions

The collection of studies presented in this Research Topic provides valuable insights into how urban water systems, and especially WDNs, planning and management can evolve to meet the challenges of sustainability, resilience, and efficiency. Many cross-cutting themes emerge.

First, from a strategic and urban planning perspective, it becomes clear that cities must incorporate water-sensitive principles into their design and development frameworks. Transitioning from linear, resource-intensive metabolic models to circular ones is vital for achieving resilience and long-term sustainability. Studies such as that by Tesfay et al. demonstrate the potential of the metabolic perspective to guide such transitions and highlight the opportunities for integrating alternative water sources into urban systems.

Second, from an infrastructure and engineering standpoint, quantifying system reliability and tolerance to failure emerges as a critical approach to enhance network robustness. The work by Kapata and Ilemobade shows that reliability-based design not only improves operational continuity under stress conditions but also supports investment prioritization.

Third, the digitalization and IoT-based monitoring are transforming the way intermittent and data-scarce WDNs are managed. The approach developed by Jamadarkhani et al. demonstrates that low-cost sensor infrastructures can significantly improve data collection, facilitate real-time analysis, and enable adaptive control strategies. Such tools are particularly valuable in rapidly urbanizing regions of developing countries, where continuous-supply WDNs remain difficult to achieve.

Finally, advances in data analytics and consumption modeling, as illustrated by Giudicianni et al. highlight the potential of smart metering data to enhance understanding and characterize of users' behavior and improve leakage detection. Reliable estimation of parameters, such as MNC, can aid water utilities in accurately assessing leakages, thus supporting both operational practices and long-term planning.

Looking ahead, the studies in this Research Topic underscore the importance of integrating predictive modeling, flexible monitoring technologies, and performance assessment tools into WDN planning and management. The systematic incorporation of indicators reflecting circular metabolism, failure tolerance, and real-time monitoring within decision-support and simulation frameworks is essential for advancing resilient and sustainable urban water systems. Collectively, these studies contribute to both the scientific understanding and practical implementation of strategies to ensure reliable, efficient, and sustainable water infrastructure in the face of evolving socio-economic and environmental pressures, while establishing a robust foundation for future research.

Author contributions

FM: Conceptualization, Visualization, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. SR: Conceptualization, Visualization, Formal analysis, Investigation, Methodology, Resources, Writing – review & editing. VM: Conceptualization, Visualization, Formal analysis, Investigation, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. NE: Conceptualization, Visualization, Formal analysis, Investigation, Methodology, Resources, Writing – review & editing. TZ: Conceptualization, Investigation, Methodology, Writing – review & editing.

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Conflict of interest

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