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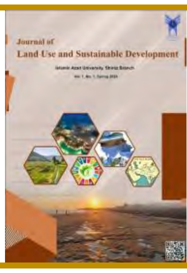

Original Research Paper

Smart City Development: Analyzing the Feasibility of Smart Water Supply Systems in Qazvin

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Abstract

This study investigates the feasibility and implications of implementing smart water supply systems as an integral component of the broader smart city initiative in Qazvin, Iran. As cities worldwide face growing challenges related to urbanization, resource management, and sustainability, smart infrastructure—particularly in water supply—has emerged as a critical area of innovation. The primary aim of this research is to analyze the relationship between smart water systems and overall urban smartness, assessing the extent to which intelligent water management can contribute to more efficient, resilient, and citizen-centered urban development. Employing a mixed-methods research design, this study integrates qualitative insights gathered through in-depth interviews with urban planning experts, and quantitative data obtained from structured surveys distributed among municipal managers and water authority officials. The results indicate that the integration of smart technologies in water systems has the potential to significantly improve the efficiency of water distribution, enhance leak detection, reduce resource wastage, and foster greater public awareness and participation in water conservation efforts. Despite these advantages, several obstacles impede the successful adoption of such systems. Key challenges identified include limited financial resources, inadequate technological infrastructure, a shortage of skilled personnel, and the absence of cohesive regulatory and policy frameworks. The findings emphasize the importance of coordinated planning, capacity building, and multi-stakeholder collaboration to address these barriers effectively.

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INTRODUCTION

In recent decades, Rapid urbanization poses significant challenges for urban water management, particularly in developing countries (El-Bouayady and Radoine, 2023). The unprecedented population growth in cities has led to infrastructure overload, lack of investment, and inadequate service delivery (El-Bouayady and Radoine, 2023; Larsen *et al*, 2016). Key issues include providing safe drinking water, wastewater handling, and flood protection (Larsen *et al*., 2016). To address these challenges, a paradigm shift towards integrated water resources management (IWRM) is necessary (Khatri, Vairavamoorthy, and Porto, 2008; Rees, 2006). This approach involves considering the entire urban water cycle, promoting water reuse, applying natural treatment systems, and increasing stakeholder involvement (Khatri *et al*., 2008). Innovative solutions such as decentralized urban water services and improved stormwater drainage can enhance sustainability (Larsen *et al*., 2016; Rees, 2006). However, successful implementation requires strong strategic frameworks, regulatory oversight, and coordination between different sectors and jurisdictions (Rees, 2006).

Qazvin, a city in northwestern Iran, exemplifies these challenges. The city's water supply system is currently managed in a non-smart manner, which limits its efficiency and effectiveness in meeting the growing demands of its population. Smart water management technologies offer promising solutions for urban water supply challenges, particularly in water-stressed regions like Qazvin, Iran. These systems leverage Internet of Things (IoT), data analytics, and real-time monitoring to optimize water distribution and reduce waste (Adedeji, Nwulu, and Clinton, 2019; Sánchez *et al*, 2020). Smart technologies enable efficient monitoring of water quality, leakage detection, and consumption patterns, enhancing overall system performance (Palermo *et al*., 2022; Sánchez *et al*., 2020). In Qazvin, where water scarcity is a pressing issue, implementing smart water management could address declining groundwater levels and increasing energy consumption for water supply (Naderi, Mirchi, Bavani, Goharian, and Madani, 2021). The integration of smart water devices with building management systems can improve water use efficiency at the urban scale (Palermo *et al*., 2022). However, successful implementation requires overcoming technical challenges and adopting a combination of demand and supply management policies to ensure sustainable water resource management (Adedeji *et al*., 2019; Naderi *et al*., 2021).

This research aims to explore the feasibility of implementing smart water supply systems in Qazvin, focusing on the potential benefits and challenges associated with such an initiative. The study seeks to answer several key questions: How can smart water supply systems contribute to the realization of smart urban systems? What principles and criteria should be considered to analyze the feasibility of smart city models in the context of Qazvin's water supply network? What insights can be drawn from the analysis of existing smart urban systems and their application to Qazvin's water supply?

The significance of this research lies in its potential to inform policymakers, urban planners, and water management authorities about the strategic implementation of smart technologies in urban water supply systems. By addressing the challenges of urbanization and resource management through innovative solutions, Qazvin can enhance its water supply management and contribute to the broader development of a sustainable smart city.

Literature review

Rapid urbanization presents significant challenges for urban water management, especially in developing countries, leading to infrastructure overload and inadequate service delivery. Integrated water resources management (IWRM) is a necessary paradigm shift, considering the entire urban water cycle and promoting water reuse (Khatri *et al*, 2008). Innovative solutions like decentralized urban water services and improved stormwater drainage can enhance sustainability, but require strong strategic frameworks and regulatory oversight (Adigun *et al*, 2025).

Smart water management technologies offer promising solutions, particularly in water-stressed regions like Qazvin, Iran, leveraging the Internet of Things (IoT), data analytics, and real-time monitoring to optimize water distribution and reduce waste (Sánchez, Oliveira-Esquerre, dos Reis Nogueira, de Jong, and Filho, 2020). These technologies enable efficient monitoring of water quality, leakage detection, and consumption patterns, enhancing overall system performance. Implementing smart water management could address declining groundwater levels and increasing energy consumption for water supply in Qazvin.

Smart water technologies (SWT) are crucial tools for efficient water resource management, addressing global water scarcity concerns (Gupta *et al,* 2020). These technologies integrate sensors, IoT, and data analytics to enable real-time monitoring of water quality, distribution, and consumption in urban settings. SWT can significantly improve efficiency, optimize resource use, and enhance water governance by providing timely data for decision-making. The implementation of smart water systems can lead to better detection of abnormalities, reduction of non-revenue water losses, and improved water quality control.

Effective governance structures are crucial for facilitating collaboration among stakeholders in managing resources and addressing complex issues. Key factors for successful collaborative governance include nested structures, conflict resolution mechanisms, and a hybrid of hierarchical and network arrangements (Carr Kelman, Brady, Raschke, and Schoon, 2023). Establishing legal, political, and administrative commonality among stakeholders is essential for building strong collaborations.

Recent research highlights the potential of smart water technologies in enhancing urban resilience and addressing climate challenges (Adelani *et al,* 2024). Smart water grids, incorporating sensors and data analytics, can improve water management and contribute to sustainable urban development. These technologies are applicable in various contexts, from developed to developing infrastructure, with a focus on water efficiency and quality monitoring.

The Area under Study

The research focuses on Qazvin, a city in northwestern Iran, which faces significant challenges in water supply management due to rapid urbanization, population growth, and climate change (Figure 1). The existing water supply infrastructure is characterized by inefficiencies, high levels of water loss, and inadequate service delivery, making it an ideal context for exploring the feasibility of smart water supply systems.

Figure 1. The locatioan of Qazvine city in Iran map.

Methodology

Research Design: This study employs a mixed-methods approach, combining qualitative and quantitative research methodologies to provide a comprehensive analysis of the feasibility of smart water supply systems in Qazvin. Through interviews with experts and surveys of municipal managers, the research aims to gather insights into the current state of water supply management and the potential for smart technologies to improve efficiency and sustainability. The findings will contribute to the ongoing discourse on smart cities and provide practical recommendations for overcoming barriers to the implementation of smart water supply systems in Qazvin and similar urban contexts.

Sampling: The qualitative component of the study involved semi-structured interviews with 150 experts in urban planning, water management, and technology implementation. These experts were selected based on their relevant experience and knowledge of smart city initiatives. For the quantitative component, a survey was distributed to 150 municipal managers and personnel from the water supply authority, achieving a response rate of %80 (Table 1).

Data Collection Methods: Data were collected using two primary methods:

Qualitative Data Collection: Semi-structured interviews were conducted to gather in-depth insights into the perceptions and experiences of experts regarding the implementation of smart water supply systems. The interviews were recorded, transcribed, and analyzed using thematic analysis to identify key themes and insights.

Quantitative Data Collection: A structured questionnaire was developed and distributed to municipal managers and water supply authority personnel. The questionnaire included questions related to the current state of water supply management, perceptions of smart technologies, and barriers to implementation.

Data Analysis: The analysis of qualitative data was conducted using the MAXQDA software, which facilitated the organization and coding of interview transcripts. The grounded theory approach was employed to identify and categorize themes emerging from the data.

For the quantitative data, descriptive statistics were used to summarize the responses, and inferential statistics were applied to assess relationships between variables. The analysis was performed using SPSS software, and structural equation modeling (SEM) was utilized to evaluate the relationships between constructs related to the feasibility of smart water supply systems.

Validity and Reliability: To ensure the validity and reliability of the qualitative findings, several strategies were employed:

Triangulation of data sources through interviews and surveys.

Member checking, where participants were given the opportunity to review and confirm the accuracy of the findings.

Peer debriefing, involving discussions with colleagues to challenge and refine interpretations.

For the quantitative component, the reliability of the survey instrument was assessed using Cronbach's alpha, with a threshold of 0.70 considered acceptable for internal consistency.

Ethical Considerations: The research adhered to ethical guidelines, ensuring informed consent from all participants. Confidentiality was maintained throughout the study, and participants were assured that their responses would be anonymized in any reporting of the findings. The study was approved by the relevant institutional review board.

Table 1. Demographic Characteristics of the Quantitative Section

Demographic Characteristics		Frequency	Percentage
Gender	Male	86	64%
	Female	49	36%
Age			
	Under 30 years	30	22%
	30 to 40 years	32	24%
	40 to 50 years	38	28%
	Over 50 years	35	26%
Education			
	Bachelor's degree	66	49%
	Master's degree	50	37%
	Doctorate	19	14%
Work Experience			
	Under 10 years	28	21%
	10 to 15 years	42	31%
	15 to 20 years	43	32%
	Over 20 years	22	16%
Total		135	100%

Results and discussion

This section presents the findings from the research on the feasibility of smart water supply systems in Qazvin, emphasizing the integration of smart technologies into urban infrastructure. The results are derived from both qualitative interviews with experts and quantitative surveys conducted with municipal managers and personnel from the water supply authority. The analysis aims to provide insights into the current state of water supply management and the potential for smart technologies to enhance efficiency and sustainability.

Qualitative Findings

The qualitative analysis, based on semi-structured interviews with ten experts in urban planning, water management, and technology implementation, revealed several key themes regarding the implementation of smart water supply systems:

Perceived Benefits: Experts highlighted the potential benefits of smart water supply systems, including improved efficiency in water distribution, reduced water loss through real-time monitoring, and enhanced service delivery to residents. The integration of IoT technologies was seen as a crucial factor in achieving these benefits.

Challenges and Barriers: Despite the perceived advantages, experts identified several challenges to implementation. These included financial constraints, lack of technical expertise, and resistance to change among stakeholders. Additionally, the need for robust infrastructure to support smart technologies was emphasized.

Collaboration and Governance: The importance of collaboration between various stakeholders, including municipal authorities, water supply companies, and the community, was underscored. Effective governance frameworks that facilitate communication and cooperation were deemed essential for the successful implementation of smart water supply systems.

Quantitative Findings

The quantitative survey, which achieved an 80% response rate from 150 municipal managers and water supply authority personnel, provided statistical insights into the perceptions of smart water supply systems:

Current State of Water Supply Management: The survey results indicated that 65% of respondents believed the current water supply management system in Qazvin was inefficient, with significant water loss reported. This inefficiency highlighted the urgent need for modernization through smart technologies.

Willingness to Adopt Smart Technologies: Approximately 70% of respondents expressed a willingness to adopt smart water supply technologies, citing improved efficiency and sustainability as primary motivators. However, 55% also indicated concerns about the initial costs and ongoing maintenance of such systems.

Barriers to Implementation: The survey identified key barriers to the adoption of smart technologies, including budget constraints (72%), lack of technical training (68%), and insufficient public awareness (60%). These barriers align with the qualitative findings and underscore the need for targeted strategies to address them.

The findings from both qualitative and quantitative analyses highlight the feasibility of implementing smart water supply systems in Qazvin. The implementation of smart water supply systems in Qazvin faces both opportunities and challenges. Ancient blue-green infrastructure in Qazvin demonstrates effective flood management and climate change adaptation, providing a foundation for smart water management (Ghaleh and Ghaleh, 2020). However, the region faces significant water resource challenges, including groundwater depletion and increased energy consumption for water supply (Naderi et al., 2021). To address these issues, a combination of water demand and supply management policies is crucial. Quality risk analysis using data perception techniques can enhance water quality monitoring and early warning systems (Wu, Wang, Mohammed, & Seidu, 2019). Additionally, the adoption of precision agriculture techniques could improve water use efficiency, although educational and economic challenges must be overcome (Najafabadi, Hosseini, and Bahramnejad, 2011). Overall, while smart water supply systems are feasible in Qazvin, their successful implementation requires addressing multiple interconnected challenges across various sectors.

Integration of Smart Technologies: Smart water technologies (SWT) are emerging as crucial tools for efficient water resource management, addressing growing global water scarcity concerns (Gupta, Pandey, Feijóo, Yaseen, and Bokde, 2020). These technologies integrate sensors, Internet of Things (IoT), and data analytics to enable real-time monitoring of water quality, distribution, and consumption in urban settings (Aivazidou *et al.*, 2021; Palermo *et al.*, 2022). SWT can significantly improve efficiency, optimize resource use, and enhance water governance by providing timely data for decision-making (Yau, Jalani, Sadun, Rejab, and John, 2025). The implementation of smart water systems can lead to better detection of abnormalities, reduction of non-revenue water losses, and improved water quality control (Gupta *et al.*, 2020). However, challenges such as high implementation costs, data security, and system reliability need to be addressed for successful integration (Gupta *et al.*, 2020). Despite these challenges, the potential of SWT to transform water management and contribute to sustainable urban development is evident, particularly in the context of climate change and rapid urbanization (Wang *et al*, 2023). The potential for smart technologies to transform water supply management is evident. The ability to monitor water quality and distribution in real-time can lead to significant improvements in efficiency and resource management. However, the successful integration of these technologies requires substantial investment and a commitment to training personnel.

Strategic Planning and Governance: Effective governance structures are crucial for facilitating collaboration among stakeholders in managing resources and addressing complex issues. Key factors for successful collaborative governance include nested structures, conflict resolution mechanisms, and a hybrid of hierarchical and network arrangements (Carr Kelman, Brady, Raschke, and Schoon, 2023; Ganeshu, Fernando, Therrien, & Keraminiyage, 2024). Establishing legal, political, and administrative commonality among stakeholders is essential for building strong collaborations, as is the appointment of experts and development of regular collaboration systems (Woldesenbet, 2020). In IT-dependent alliances, co-created governance structures such as joint steering committees and inter-organizational performance management systems are necessary (Prasad *et al*, 2012). These structures contribute to sustaining IT-related capabilities and business value. However, challenges persist, including asymmetrical communication, lack of expertise, and unwillingness to engage in dialogues. Overcoming these barriers requires systematic procedures and consideration of cultural, legal, social, and political contexts (Woldesenbet, 2020). Effective governance structures are crucial for facilitating collaboration among stakeholders. Policymakers must prioritize the development of strategic plans that incorporate stakeholder input and address the identified barriers. This includes securing funding, providing training, and raising public awareness about the benefits of smart water supply systems.

Future Research Directions: Recent research highlights the potential of smart water technologies in enhancing urban resilience and addressing climate challenges. Smart water grids, incorporating sensors and data analytics, can improve water management and contribute to sustainable urban development (Adelani, Okafor, Jacks, and Ajala, 2024). These technologies are applicable in various contexts, from developed to developing infrastructure, with a focus on water efficiency and quality monitoring (Lassiter and Leonard, 2022). The integration of non-grid, small-grid, and hybrid solutions offers promising alternatives to conventional systems, emphasizing resource recovery and adaptability (Hoffmann et al., 2020). Smart technologies, such as Internet of Things and machine learning, are catalyzing efficient monitoring, control, and optimization of urban water consumption and pollution (Aivazidou *et al.*, 2021). However, research gaps remain, particularly in uptake and implementation at the institutional level and in explicitly relating smart water technologies to greenhouse gas emission reduction (Lassiter and Leonard, 2022). The study suggests several avenues for future research, including comparative studies of smart water supply implementations in other cities and the exploration of innovative financing models to support the transition to smart systems. Additionally, further investigation into community engagement strategies could enhance public acceptance and participation in smart water initiatives.

Conclusion

In conclusion, the research indicates that while there are significant challenges to the implementation of smart water supply systems in Qazvin, the potential benefits are substantial. By addressing the identified barriers and fostering collaboration among stakeholders, Qazvin can move towards a more sustainable and efficient water supply management system, ultimately contributing to the broader goals of smart city development.

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