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Research Article

State of the Art in the Use of Wireless Sensor Networks (WSN) and IoT Devices for Water Source Monitoring in Urban Environments

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ABSTRACT
Objective: The study aimed to analyze the use of wireless sensor networks (WSN) and IoT devices in the monitoring of water sources in urban environments, focusing on key applied technologies, advancements, and technological challenges. **Methodology:** A systematic review of 37 scientific articles indexed in Scopus between 2014 and 2023 was conducted, focusing on the analysis of IoT devices, SCADA systems, sensor networks, drones, and unmanned vehicles, as well as the integration of machine learning algorithms for resource use prediction and optimization. **Results:** The findings show that most research concentrates on the use of IoT and sensor networks for water quality monitoring and resource management. The implementation of drones and unmanned vehicles has enhanced monitoring capabilities in remote areas. Predictive models based on machine learning have improved the efficiency of detecting water-related events such as floods, in addition to enhancing decision-making regarding resource use. **Discussion:** Despite advancements in the development of water monitoring technologies, challenges remain in system standardization and real-time data integration, underscoring the need for further development of more robust and scalable technological solutions. **Conclusions:** This study highlights the importance of emerging technologies, such as IoT and sensor networks, in the management and monitoring of water resources, emphasizing their positive impact on the sustainability and efficiency of water systems in urban environments.

KEYWORDS: machine learning, sensor networks, water quality monitoring

INTRODUCTION

In recent decades, the rapid growth of the urban population has placed increasing pressure on the use of water resources in cities around the world (Mu et al., 2021). Urban water sources, such as rivers, lakes, and aquifers, face challenges including pollution, overexploitation, and the impact of climate change, creating a need to improve monitoring and management systems (Ferdowsi et al., 2024; Navas-Gallo et al., 2024). In this context, wireless sensor networks (WSN) have emerged as a key tool for real-time monitoring of water sources, providing accurate and continuous data that allow urban managers to make informed decisions (El Khediri et al., 2024; Palermo et al., 2022).

The main advantage of using WSN for water monitoring is its ability to collect information from multiple points simultaneously and transmit it wirelessly to central stations for analysis (Jabbar et al., 2024). These sensors can measure critical parameters such as water quality, flow, temperature, and contaminant levels, offering a comprehensive real-time view of the status of water sources (Jayaraman et al., 2024). Moreover, integrating these networks with

geographic information systems (GIS) and predictive models allows for problem anticipation and optimization of resource management (Vinueza-Martinez et al., 2024).
However, the implementation of WSN in urban environments presents specific challenges that need to be addressed. Adverse environmental conditions, electromagnetic interference, and the need for sustainable energy sources to power the sensors are some of the most common obstacles (Abdulwahid & Mishra, 2022). Additionally, population density and urban infrastructure can hinder data transmission and compromise the accuracy of measurements (Nurlan et al., 2022). These difficulties highlight the need for continued research into improving sensor design and durability, as well as developing more efficient communication protocols (Nižetić et al., 2020).
Another critical aspect is managing the large volumes of data generated by these sensor networks. Massive data collection requires robust technological infrastructures and advanced analytical algorithms capable of processing and transforming the data into useful knowledge for decision-making (Sivarajah et al., 2017). Artificial intelligence (AI) and machine learning play a key role in this process, enabling predictive analysis and the identification of patterns that facilitate proactive water management (Sanchez-Calle & Castillo Armas, 2022; Soori et al., 2023).
Despite advancements, there is limited standardization in the use of WSN for monitoring water sources in cities, making it difficult to compare studies and replicate results (Demetillo et al., 2019). This remains an evolving area of research, where collaboration between engineers, urban planners, and water scientists is essential to developing more integrated and effective solutions (Puchol-Salort et al., 2021). Experiences in cities of different sizes and geographic contexts show that adapting WSN to each local reality is an ongoing but necessary challenge to ensure their success (Ketshabetswe et al., 2019).
Therefore, the objective of this research is to conduct a systematic review of the scientific literature on the use of wireless sensor networks (WSN) and IoT devices for the monitoring of water sources in urban environments, indexed in Scopus between 2014 and 2023. Through this analysis, the study aims to identify the main technological trends, the challenges in their implementation, and the knowledge gaps in the current literature, in order to provide a solid foundation for future research and the development of more effective technological solutions for urban water management.

METHODOLOGY

Research Characterization

In this study, a literature review was conducted to evaluate and analyze scientific research related to the use of wireless sensor networks (WSN) and IoT devices for monitoring water sources in urban environments. This approach was based on a quantitative and descriptive analysis of the scientific output, including articles and other relevant indicators. The objective was to quantify and characterize the available research using data obtained from specialized databases, providing a comprehensive and detailed assessment of technological trends and the challenges identified in this field.

Search Procedures

The study followed the protocol proposed by Cronin et al. (2008), which includes the following steps: (1) formulation of the research question; (2) definition of inclusion and exclusion criteria; (3) identification of relevant articles; (4) evaluation of the quality and relevance of the selected literature; and (5) analysis and synthesis of the results. To establish inclusion and exclusion criteria, the search was limited to materials published between January 2014 and December 2023, focusing exclusively on articles in English to ensure an international perspective. The search process was conducted in a single phase, ensuring the comprehensiveness of the review through the rigorous application of the aforementioned criteria.

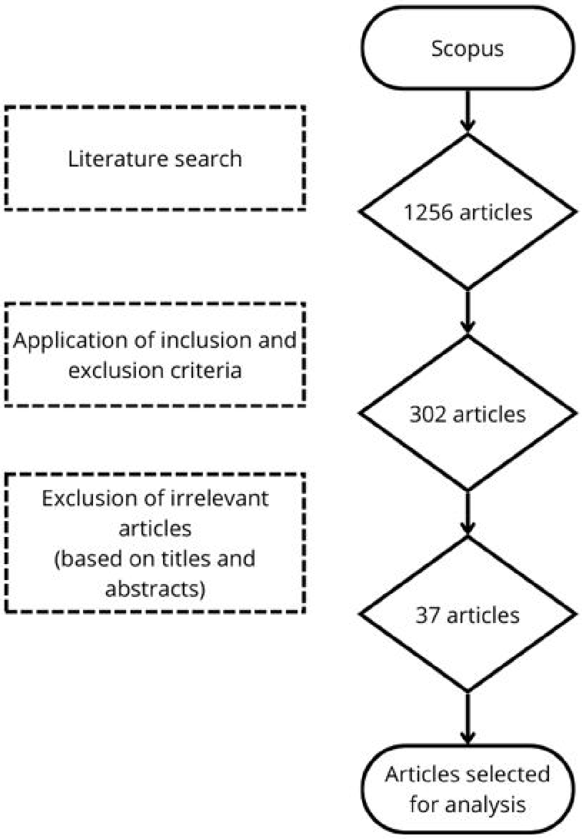
Search Phase in Scopus

During the search phase, the following search terms were used: ("wireless sensor networks" OR "wsn" OR "wireless sensor nodes" OR "wireless sensor systems" OR "IoT") AND ("monitoring" OR "sensing" OR "detection" OR "surveillance") AND ("water sources" OR "water bodies" OR "aquatic resources" OR "water reservoirs" OR "agua" OR "water quality") AND ("urban environments" OR "urban areas" OR "metropolitan regions" OR "city landscapes") to identify articles related to the use of wireless sensor networks (WSN) and IoT technologies in water source monitoring in urban environments. Specific keywords included terms covering both the technical aspects of sensors and their application in water quality monitoring in urban areas. This search resulted in the identification of 1,256 documents, providing a solid basis for further analysis of trends and challenges in the field.

Subsequently, in addition to the keywords, inclusion and exclusion filters were applied to refine the results. Only journal articles were included (LIMIT-TO(SRCTYPE, "j")), and the results were limited to articles written in English (LIMIT-TO(LANGUAGE, "English")). All articles were included regardless of their open access status (LIMIT-TO(OA, "all")). The search was restricted to articles published between 2014 and 2024 (PUBYEAR > 2013 AND PUBYEAR < 2025) and in their final publication stage (LIMIT-TO(PUBSTAGE, "final")). Finally, only research articles were included (LIMIT-TO(DOCTYPE, "ar")), resulting in a total of 302 documents for analysis.

Despite applying specific search terms to narrow the results to the use of wireless sensor networks (WSN) and IoT technologies for monitoring water sources in urban environments, the initial searches yielded a significant number of works unrelated to the topic. After reviewing the titles and abstracts, 37 articles were selected for the final review analysis. Figure 1 summarizes the methodological process for selecting scientific articles related to the use of WSN and IoT devices in urban water monitoring.

Figure 1. Article selection process



From the total number of selected articles, a detailed analysis was carried out in five key stages. First, the most relevant background information was considered, establishing a solid foundation of previous research related to the use of wireless sensor networks (WSN) and IoT devices for water resource monitoring in urban environments. Second, the main objectives or research questions of each study were identified, highlighting the central purpose of the investigations. Third, the theoretical foundations were reviewed, covering the conceptual and theoretical frameworks used to support the research. Fourth, the methods employed were evaluated, including the procedures, technologies, and tools used for data collection and problem-solving in the studies. Finally, key results were examined, emphasizing the main findings that addressed the research objectives or questions posed.

RESULTS AND DISCUSSION

Table 1 presents the selected articles for analysis, detailing the code assigned to each one for easier reference. Additionally, it includes the authors, year of publication, the title of each study, and the journal in which it was published. This structure allows for quick and efficient consultation of the studies used in the research.

Table 1. Selected articles from the Scopus database

Code	Authors	Title	Journal
A1	(Naqash et al., 2023)	A Blockchain Based Framework for Efficient Water Management and Leakage Detection in Urban Areas	Urban Science
A2	(Bonilla et al., 2023)	Digitalization of Water Distribution Systems in Small Cities, a Tool for Verification and Hydraulic Analysis: A Case Study of Pamplona, Colombia	Water (Switzerland)
A3	(Puppala et al., 2023)	New technology adoption in rural areas of emerging economies: The case of rainwater harvesting systems in India	Technological Forecasting and Social Change
A4	(Dwarakanath et al., 2023)	Smart IoT-based water treatment with a Supervisory Control and Data Acquisition (SCADA) system process	Water Reuse
A5	(Sugiharto et al., 2023)	Real-Time Water Quality Assessment via IoT: Monitoring pH, TDS, Temperature, and Turbidity	Ingenierie des Systemes d'Information
A6	(Arsene et al., 2023)	Decision Support Strategies for Household Water Consumption Behaviors Based on Advanced Recommender Systems	Water (Switzerland)
A7	(Langhammer, 2023)	Flood Simulations Using a Sensor Network and Support Vector Machine Model	Water (Switzerland)
A8	(Mamede et al., 2023)	A Prototype for an Intelligent Water Management System for Household Use	Sensors
A9	(Gonçalves et al., 2023)	Hydrometer Design Based on Thin-Film Resistive Sensor for Water Measurement in Residential Buildings	Water (Switzerland)
A10	(Prokop et al., 2023)	End-to-end system for monitoring the state of rivers using a drone	Frontiers in Environmental Science
A11	(Rahu et al., 2023)	Toward Design of Internet of Things and Machine Learning-Enabled Frameworks for Analysis and Prediction of Water Quality	IEEE Access
A12	(Gaagai et al., 2023)	Application of Water Quality Indices, Machine Learning Approaches, and GIS to Identify Groundwater Quality for Irrigation Purposes: A Case Study of Sahara Aquifer, Doucen Plain, Algeria	Water (Switzerland)
A13	(Aliagas et al., 2022)	A Low-Cost and Do-It-Yourself Device for Pumping Monitoring in Deep Aquifers	Electronics (Switzerland)
A14	(Fox et al., 2022)	A case study: The deployment of a novel in situ fluorimeter for monitoring biological contamination within the urban surface waters of Kolkata, India	Science of the Total Environment
A15	(Meyers et al., 2022)	Initial Deployment of a Mobile Sensing System for Water Quality in Urban Canals	Water (Switzerland)
A16	(Arsene et al., 2022)	Advanced Strategies for Monitoring Water Consumption Patterns in Households Based on IoT and Machine Learning	Water (Switzerland)
A17	(Joseph et al., 2022)	Development of an Intelligent Urban Water Network System	Water (Switzerland)
A18	(Ajayi et al., 2022)	WaterNet: A Network for Monitoring and Assessing Water Quality for Drinking and Irrigation Purposes	IEEE Access
A19	(Ufuoma et al., 2021)	Efficiency of camera sensors for flood monitoring and warnings	Scientific African
A20	(Zhao et al.,	Research on design of the safety supervision	Water

	2021)	system for desalinated seawater entering urban water supply network	(Switzerland)
A21	(Mendoza-Cano et al., 2021)	Experiments of an IoT-based wireless sensor network for flood monitoring in Colima, Mexico	Journal of Hydroinformatics
A22	(Zhou et al., 2021)	Urban rain flood ecosystem design planning and feasibility study for the enrichment of smart cities	Sustainability (Switzerland)
A23	(Kang et al., 2021)	Energy-efficient ultrasonic water level detection system with dual-target monitoring	Sensors
A24	(Jurado Zavaleta et al., 2021)	Chemometric modeling for spatiotemporal characterization and self-depuration monitoring of surface water assessing the pollution sources impact of northern Argentina rivers	Microchemical Journal
A25	(W. Chen et al., 2021)	The Mobile Water Quality Monitoring System Based on Low-Power Wide Area Network and Unmanned Surface Vehicle	Wireless Communications and Mobile Computing
A26	(Antzoulatos et al., 2020)	Making urban water smart: The SMART-WATER solution	Water Science and Technology
A27	(Gautam et al., 2020)	Monitoring and forecasting water consumption and detecting leakage using an IoT system	Water Science and Technology: Water Supply
A28	(Hajjaj et al., 2020)	Utilizing the internet of things (IoT) to develop a remotely monitored autonomous floodgate for water management and control	Water (Switzerland)
A29	(Mohapatra & Rath, 2019)	Detection and avoidance of water loss through municipality taps in India by using smart taps and ICT	IET Wireless Sensor Systems
A30	(Olatinwo & Joubert, 2019)	Efficient energy resource utilization in a wireless sensor system for monitoring water quality	Eurasip Journal on Wireless Communications and Networking
A31	(Edmondson et al., 2018)	A smart sewer asset information model to enable an 'Internet of Things' for operational wastewater management	Automation in Construction
A32	(Y. Chen & Han, 2018)	Water quality monitoring in smart city: A pilot project	Automation in Construction
A33	(Spandana & Rao, 2018)	Internet of Things (Iot) Based smart water quality monitoring system	International Journal of Engineering and Technology(UAE)
A34	(Ismail & Mohammed, 2018)	Design and implementation of remotely Tigris river water monitoring system in Baghdad	International Journal of Engineering and Technology(UAE)
A35	(Chacon-Hurtado et al., 2017)	Rainfall and streamflow sensor network design: A review of applications, classification, and a proposed framework	Hydrology and Earth System Sciences
A36	(Jo & Baloch, 2017)	Internet of things-based arduino intelligent monitoring and cluster analysis of seasonal variation in physicochemical parameters of Jungnangcheon, an urban stream	Water (Switzerland)
A37	(Postolache et al., 2014)	Wireless sensor network-based solution for environmental monitoring: Water quality assessment case study	IET Science, Measurement and Technology

Table 2 presents the topics covered in the selected research, classified into five categories: IoT technologies for water management, water quality monitoring, urban water management, predictive models and machine learning, and the design of intelligent monitoring systems. Of the studied articles, 15 (A1, A3, A4, A6, A7, A8, A10, A11, A17, A18, A19, A20, A28, A29, A33) focus on IoT technologies for water management; 12 (A2, A5, A9, A12, A14, A15, A16, A22, A23, A24, A25, A32) analyze water quality monitoring; 10 (A13, A17, A18, A21, A22, A26, A27, A30, A34, A36) address urban water management; 8 (A3, A6, A11, A16, A24, A31, A35, A37) focus on predictive models and machine learning; and 5 (A4, A9, A28, A33, A37) center on the design of intelligent monitoring systems.

Table 2. Topics addressed in the research analyzed

Elements of analysis	Frequency (Percentage)	Articles
IoT technologies for water management	15 (40.5%)	A1, A3, A4, A6, A7, A8, A10, A11, A17, A18, A19, A20, A28, A29, A33
Water quality monitoring	12 (32.4%)	A2, A5, A9, A12, A14, A15, A16, A22, A23, A24, A25, A32
Urban water management	10 (27.0%)	A13, A17, A18, A21, A22, A26, A27, A30, A34, A36
Prediction models and machine learning	8 (21.6%)	A3, A6, A11, A16, A24, A31, A35, A37
Design of intelligent monitoring systems	5 (13.5%)	A4, A9, A28, A33, A37

Analysis of the main background

Table 3 shows that the most frequently addressed topics are IoT technologies applied to water monitoring and management, reflecting the growing interest in leveraging emerging technologies to improve the efficiency of water resource use. It also highlights the importance of water quality monitoring and its impact on sustainability, as well as the relevance of predictive models based on machine learning and the design of intelligent monitoring systems.

Table 3. Analysis of the main background

Elements of analysis	Frequency (Percentage)	Articles
Application of IoT technologies in water management	15 (40.5%)	A1, A3, A4, A6, A7, A8, A10, A11, A17, A18, A19, A20, A28, A29, A33
Importance of water quality monitoring	12 (32.4%)	A2, A5, A9, A12, A14, A15, A16, A22, A23, A24, A25, A32
Prediction models based on machine learning	8 (21.6%)	A3, A6, A11, A16, A24, A31, A35, A37
Design of intelligent monitoring systems	5 (13.5%)	A4, A9, A28, A33, A37
Relevance of sustainability and environmental management	10 (27.0%)	A10, A13, A15, A17, A22, A23, A26, A30, A34, A36

Analysis of the technological component

Table 4 classifies the articles according to the technological components used in the research. Most focus on IoT for water monitoring and system control, employing technologies such as IoT sensors, blockchain, SCADA, and machine learning, enabling precise real-time monitoring and efficient water resource management. These studies highlight the ability of IoT systems to control water consumption, prevent leaks, and monitor both urban infrastructures and rural areas through advanced sensor networks.

On the other hand, several studies focus on the use of sensor networks and predictive modeling for forecasting and monitoring water events, utilizing techniques such as SVM, ANN, and GIS. Other noteworthy studies employ drones and unmanned vehicles for river monitoring, as well as advanced water treatment technologies like in-situ fluorometers and remote monitoring systems. These technological innovations provide effective solutions for improving the quality and sustainability of water management in various contexts.

Table 4. Classification of documents according to the technological component

Elements of analysis	Articles	Technological component
IoT for Water Monitoring and Systems Control	A1, A29	Blockchain and IoT, Smart faucets with ICT
	A5, A33	IoT sensors
	A8	IoT and cloud computing
	A15	IoT mobile sensors
	A16, A11	IoT and machine learning (LSTM, SVR, Random Forest)
	A17, A4	SCADA and sensors, SCADA and deep belief networks (DBNs)
	A18, A21	IoT sensor network
	A22	IoT for flood control
	A26	IoT for urban water management
	A27	IoT with SVM for water consumption forecasting
	A28	Automatic floodgates monitored by IoT
	A30	Efficient wireless sensors
	A31	IoT for wastewater management
	A32	IoT sensors in smart cities
	A36	IoT with Arduino for monitoring physicochemical parameters
Sensor Networks and Predictive Modeling	A7, A35	Sensor network and SVM, Sensor network for flow and precipitation
	A12	Machine learning models (ANN, GBR) and GIS
	A37	Wireless sensor network
	A23	Low-power ultrasonic sensors
Drones and Unmanned Vehicles	A10	Drones and image processing
	A25	Unmanned surface vehicle (USV) and LPWAN
SCADA and Automatic Supervision	A17, A4	SCADA and sensors, SCADA and deep belief networks (DBNs)
Water Monitoring and Treatment Systems	A2, A9	Digitization and hydraulic modeling, Thin film resistive sensors
	A19, A34	Sensor chambers, Remote water monitoring system
	A20	IoT for monitoring desalinated water
	A14	In-situ fluorimeter
Innovations and New Technologies in Water Management	A3	Rainwater harvesting with Fuzzy-Delphi and DEMATEL techniques
	A13	DIY device with edge computing
	A24	Chemometric modeling

Analysis of theoretical elements

Table 5 presents the classification of the articles according to the theoretical elements applied in technological solutions for water management and monitoring. Most studies are based on theories related to the Internet of Things (IoT) and automated systems such as SCADA, highlighting their importance in modernizing infrastructure for monitoring and controlling water resources. The integration of machine learning algorithms and predictive models has been key in several studies, allowing not only for real-time monitoring but also for anticipating future behaviors in water management.

Additionally, the theory of sensor networks plays a central role in studies that use wireless technologies for data collection and transmission. These theoretical studies are complemented by blockchain-based approaches to enhance security and transparency in water resource management. The use of drones and unmanned vehicles is another applied theoretical framework that underscores the shift toward more autonomous and sustainable solutions in the assessment and management of water sources.

Table 5. Classification of articles according to research topics

Elementos de análisis	Artículos	Componente teórico aplicable
IoT and Automation in Systems Control	A1, A29	IoT and Blockchain for water management efficiency
	A5, A33	IoT sensors for real-time monitoring
	A8	IoT and cloud computing for data processing
	A15	IoT mobile sensors for environmental monitoring
	A16, A11	Machine learning algorithms (LSTM, SVR) and IoT
	A17, A4	SCADA theory for process automation
Sensor Networks and Prediction	A7, A35	Predictive modeling with sensor networks and SVM
	A12	Machine learning with GIS and ANN for data analysis
	A37	Wireless sensor networks for environmental monitoring
Innovation in Predictive Modeling	A23	Using low-power ultrasonic sensors
Drones and Vehicle Automation	A10, A25	Drones and unmanned vehicles for remote monitoring
Autonomous Monitoring and Supervision	A2, A9	Hydraulic modeling theories and monitoring with advanced sensors
	A19, A34	Sensor cameras for remote sensing and assessment
Sustainable Management and Innovation	A3, A13	Innovation in water management with DIY harvesting and monitoring techniques
	A14	In-situ fluorimeters for biological analysis of water contamination

Analysis of results

Table 6 presents the results focused on the technological aspects derived from the selected studies. Most of the articles analyzed explore advances in IoT sensors, wireless sensor networks, and unmanned vehicles applied to water quality monitoring and control of water systems. The studies reveal that the use of smart sensors and real-time monitoring systems has allowed for improved accuracy in leak detection, measurement of key parameters such as pH, turbidity, and water temperature, and optimization of efficiency in water resource management.

There are cases where the implementation of drones and unmanned vehicles (USV) has provided effective solutions for continuous monitoring of water bodies, reducing dependence on traditional methods and increasing response capacity to emergency situations, such as floods. The results also highlight the use of machine learning models, such as neural networks and Support Vector Machines (SVM), integrated with monitoring systems to make predictions about water consumption, weather patterns, and flood management. These advances allow for more efficient preventive control, contributing to environmental sustainability.

Table 6. Results obtained from the articles analyzed

Category	Frequency (Percentage)	Articles
IoT monitoring of water quality	13 (28.3%)	A1, A5, A8, A15, A16, A18, A21, A22, A26, A27, A29, A32, A33
Use of unmanned	4 (8.7%)	A10, A19, A25, A34

vehicles (USV and drones)		
Predictive modeling and machine learning	5 (10.9%)	A3, A7, A11, A12, A23
Automated monitoring with SCADA	4 (8.7%)	A4, A17, A28, A31
Digitalization and hydraulic modeling	4 (8.7%)	A2, A9, A20, A34
Sensors for sustainability and monitoring	6 (13.0%)	A14, A19, A23, A29, A42, A44
Innovations in water monitoring	5 (10.9%)	A3, A13, A24, A30, A35
Remote monitoring methods	4 (8.7%)	A14, A19, A25, A34

CONCLUSIONS

The study has revealed that the efficiency in monitoring and managing water resources is strongly influenced by the integration of technologies such as IoT, unmanned vehicles and advanced sensors. The findings indicate that the adoption of real-time monitoring systems with IoT sensors and machine learning-based solutions is essential to optimize water quality and manage water resources more efficiently. These technologies allow for precise and continuous monitoring, improving the ability to respond to environmental variations and promoting sustainability in water resource management.

Furthermore, the implementation of wireless sensor networks and unmanned vehicles (USVs and drones) facilitates remote monitoring in hard-to-reach areas, increasing the capacity for real-time data collection. The combination of predictive models and automated analysis makes it possible to predict events such as floods or droughts, optimizing decision-making and reducing environmental impact. This approach not only improves water management capacity, but also promotes more efficient use of technological and human resources, aligning water management policies with the needs of sustainability and environmental resilience.

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