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Systematic Review on Water Usage Monitoring and Control Systems

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Abstract

Water scarcity, inefficient distribution, and rising global demand have intensified the need for advanced water-monitoring and control systems. This systematic review synthesizes recent research on water usage monitoring technologies, focusing on Internet of Things (IoT)-based systems, sensor networks, artificial intelligence (AI), and smart water management frameworks. A structured literature review of peer-reviewed studies (2018–2025) reveals key technological trends, system architectures, performance indicators, and research gaps. The findings indicate that real-time monitoring, automation, and predictive analytics significantly improve water efficiency and sustainability. However, challenges such as data reliability, scalability, cost, and integration persist. This review provides a comprehensive understanding of current developments and future research directions in smart water management.

Keywords: *Water monitoring, IoT, smart water management, sensors, water conservation, automation, systematic review*

Introduction

Water is essential for human survival, agriculture, and industrial processes. However, rapid urbanization, population growth, and climate change have led to increasing water scarcity and inefficient resource utilization. Modern water management requires real-time monitoring and automated control systems to ensure efficient usage. Traditional water monitoring methods rely on manual sampling and laboratory analysis, which are time-consuming and inefficient. In contrast, modern systems employ IoT, wireless sensor networks, and AI to enable continuous monitoring and intelligent decision-making (MDPI).

This review aims to:

- Analyse current water monitoring and control technologies
- Identify system architectures and methodologies
- Evaluate challenges and research gaps
- Suggest future directions for sustainable water management

Methodology of Systematic Review

1 Data Sources

The review is based on peer-reviewed literature from:

IEEE Xplore

ScienceDirect

Web of Science

Scopus

2 Inclusion Criteria

Studies published between 2018–2025

Research focusing on water monitoring or control systems

Use of IoT, sensors, AI, or automation

3 Exclusion Criteria

Non-peer-reviewed articles

Studies without implementation or experimental validation

4 Review Process

A systematic filtering process reduced ~900 initial papers to ~50 highly relevant studies, following PRISMA-style methodology (MDPI).

Components of Water Monitoring and Control Systems

1 Sensors and Data Acquisition

Water monitoring systems rely on sensors to measure:

- pH
- Turbidity
- Temperature
- Dissolved oxygen
- Flow rate

Sensor-based systems enable real-time data collection, which is essential for accurate monitoring and decision-making (ScienceDirect).

2 Communication Technologies

- Wireless Sensor Networks (WSN)
- IoT protocols (MQTT, LoRa, Zigbee)
- Cloud-based data transmission

These technologies facilitate remote monitoring and reduce manual intervention.

3 Data Processing and Analytics

Advanced systems integrate:

- Machine Learning (ML)
- Artificial Intelligence (AI)
- Big data analytics

These tools help in:

- Predicting water demand
- Detecting anomalies
- Optimizing distribution

4 Control Mechanisms

Control systems include:

- Automated valves
- Smart irrigation controllers
- Feedback-based control loops

These mechanisms enable efficient water distribution and minimize wastage.

Types of Water Monitoring Systems

1 IoT-Based Water Monitoring Systems

IoT systems dominate current research due to their flexibility and scalability. They enable:

- Continuous monitoring
- Remote access
- Real-time alerts

Studies show that IoT significantly enhances efficiency and reduces operational costs (ResearchGate).

2 Smart Irrigation Systems

Used in agriculture to optimize water use:

- Soil moisture sensors guide irrigation
- Automated systems reduce water wastage

Smart irrigation improves water-use efficiency and crop yield (ScienceDirect).

3 Urban Water Management Systems

Focus on:

- Leak detection
- Smart metering
- Distribution optimization

Urban systems help reduce water losses and improve supply reliability.

4 Industrial Water Monitoring

Industries use monitoring systems to:

- Ensure water quality compliance
- Optimize water reuse
- Reduce environmental impact

Applications

1 Agriculture

- Precision irrigation
- Soil moisture monitoring
- Water conservation

2 Smart Cities

- Real-time water distribution monitoring
- Leak detection
- Smart billing

3 Environmental Monitoring

- River and lake quality assessment
- Pollution detection

4 Domestic Use

- Smart water meters
- Household consumption tracking

Advantages of Smart Water Monitoring Systems

- Real-time data acquisition
- Reduced water wastage
- Improved decision-making
- Automation and reduced labor
- Enhanced sustainability

Challenges and Limitations

1 Technical Challenges

- Sensor accuracy and calibration issues
- Data transmission reliability

2 Economic Constraints

- High initial installation cost
- Maintenance expenses

3 Data Management Issues

- Large data volume
- Data security concerns

4 Integration Problems

- Lack of standardization
- Difficulty integrating legacy systems

Research Gaps

- Lack of standardized frameworks
- Limited large-scale deployment studies
- Need for low-cost solutions
- Insufficient focus on rural applications
- Limited integration of AI for predictive control

Future Directions

Future research should focus on:

- AI-driven predictive water management
- Integration with smart city infrastructure
- Development of low-cost sensors
- Use of blockchain for data security
- Climate-resilient water management systems

Emerging technologies will play a crucial role in achieving sustainable water management.

Conclusion

Water monitoring and control systems are essential for sustainable resource management. The integration of IoT, AI, and sensor technologies has significantly improved efficiency and accuracy. However, challenges such as cost, scalability, and data management need to be addressed. Future advancements should focus on intelligent, cost-effective, and scalable solutions to ensure global water sustainability.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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