Smart Water Management: Integrating PLC and SCADA Technologies for Sustainable Urban Infrastructure

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Abstract: This paper explores the integration of automation technologies—Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems—in advancing sustainable water and wastewater management within smart buildings and urban infrastructure. Two case studies are analysed. The first one focuses on a PLC-based automatic water distribution system for smart residential buildings, aligned with the United Nations Sustainable Development Goals (SDGs), highlighting its ability to reduce water waste, improve billing accuracy, and promote responsible consumption. The second one examines a SCADA-monitored water storage and distribution network in Yozgat province, Turkey, demonstrating significant reductions in water loss and improvements in water quality monitoring through centralised, real-time control. The discussion addresses the implications of integrating IoT, PLC, and SCADA technologies in water automation, emphasising enhanced efficiency, system intelligence, and the potential for predictive maintenance. Scalability across urban and rural contexts and broader industry applications is also considered. Despite the promise of automation, challenges such as high initial costs, data integration complexities, and skill gaps are identified, with recommendations for future implementation strategies. The study concludes that smart water management solutions are essential for sustainable urban development, offering actionable insights for policymakers, engineers, and city planners aiming to create resilient, data-driven water infrastructures.

1 INTRODUCTION

Water is vital for life, yet controlling it well is still a huge problem in many places. The high rate of cities forming, warmer temperatures, old systems, and more need for water put huge demands on our already-built water and wastewater structures. As a result, cities and utilities are now relying on technology to bring water infrastructure, operations, and management into the modern era and support sustainability (Desai & Maske, 2024). The use of IoT and control systems, including Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) systems is changing the way water systems are run and looked after (Yunus Görkem et al., 2024). These advancements support data collection without delay, remote problem-solving, and auto-decisions, which help lead to strong and resilient water networks.

1.1 Background on Water and Wastewater Automation

Managing water and wastewater is vital to building modern urban areas. With more people worldwide and more cities popping up, sustainable, safe, and efficient water systems are needed now more than ever (Kaittan & Mohammed, 2024). When methods like these are used, any maintenance actions are done manually and always in response to problems that may slow things down, lead to waste and cause water loss. Using advanced systems, like PLCs and SCADA, automation in water and wastewater systems is now a leading answer to these problems, making it possible to monitor, control, and manage water infrastructures constantly.

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1.2 Importance of the Study

With the Internet of Things (IoT), the traditional water and wastewater systems have now been converted into smart networks. The connectivity of IoT devices to PLCs and SCADA systems allows companies to get data automatically, monitor their operations remotely, streamline their maintenance schedules, and have their systems under strict control (Benjamin, 2025). In addition to other kinds, SCADA systems are quite handy since they allow an observer to monitor water, pressure, the rate at which the water flows, and any issues in the system in one centralised position. These innovations assist in waste reduction, smart water use, and ensuring that the environmental laws are adhered to in smart cities and smart buildings.

1.3 Aim and Objectives

The primary aim of this research is to explore the role of IoT-based automation systems, including PLC and SCADA, in enhancing water and wastewater management in smart infrastructure.

Objectives:

- To evaluate the effectiveness of PLC-based automatic water distribution systems in promoting sustainable water management in smart buildings.
- To analyse the impact of SCADA monitoring systems on improving operational efficiency, reducing water loss, and maintaining water quality.
- To investigate how the integration of IoT, PLC, and SCADA technologies contributes to the overall functionality and resilience of water management systems in smart cities.

1.4 Research Questions

- How can a PLC-based automatic water distribution system contribute to sustainable water management in smart buildings within smart cities?
- What impact does the implementation of SCADA monitoring systems have on the efficiency and safety of water distribution, particularly in reducing water loss and ensuring water quality?

1.5 Contribution and Innovation

This study offers a novel perspective by investigating the combined deployment of PLC and SCADA systems within an IoT-enabled water management framework that spans both micro-level (smart residential buildings) and macro-level (municipal distribution networks). Unlike prior work that examines these technologies in isolation, this research explores their interoperability and layered integration to support real-time monitoring, efficient control, and predictive maintenance. By aligning this dual-layered automation approach with the United Nations Sustainable Development Goals (SDGs), particularly SDG 6 and SDG 11, the study emphasises its relevance to sustainable urban infrastructure development. The contribution lies in demonstrating how this integration can optimise resource consumption, enhance system resilience, and provide a scalable model for smart cities.

2 LITERATURE REVIEW

Existing literature explores various aspects of smart water management, yet it lacks clarity on how PLC-based automation and SCADA monitoring can interoperate within an IoT framework. Most studies highlight the individual benefits of these technologies but rarely examine their combined potential in transforming operations in smart buildings and urban infrastructure (Benjamin, 2025). This gap becomes more pressing in the context of urban sustainability, where ageing infrastructure, rising resource demand, and environmental challenges must be addressed collectively (Abdulwahid et al., 2023).

This review is intended to examine how integration of PLC and SCADA technologies into an IoT enabled environment can drive water distribution efficiency, improve security through constant monitoring and minimize energy consumption through intelligent control systems. In addition, the study links this integration with wider objectives such as SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities) (Rashad et al., 2022).

The growing demand to live urban lives and the effect of climate change has begun to stretch the water infrastructure to its limits and smart, sustainable solutions are necessary. Automated, data-driven decision-making in the water and wastewater management domain is heavily dependent on IoT, PLCs and SCADA (Tomar et al., 2023). This review underscores their separate and combined success towards a better efficiency, reliability and sustainability. It also explores emerging applications in both structured and nonstructured water systems, offering insights into the evolving future of global water management.

2.1 Overview of IoT Applications in Water and Wastewater Treatment

With IoT, water and wastewater systems are now smarter and better connected. With its sensors, devices, and communication tools, IoT makes it possible to collect and send vital water distribution data all the time. Using these sensors, water plants check parameters such as water flow, pressure levels, water quality (using turbidity and chemical tests), and the condition of the equipment involved (Alshami et al., 2024). The gathered data is sent instantly to servers, where teams analyse it to inform decisions, detect unusual activities, and improve the system's performance.

There are many great benefits of IoT in this area. Current technology allows utilities to find leaks, estimate when equipment might fail, and observe how much energy or water is being used in a highly accurate manner. Being so prompt with response results in better water savings, less time lost to breaks, and more specific ways to look after the equipment (Jiang et al., 2023). Because of IoT, wastewater treatment is supported by continuously monitoring discharge and spotting any dangerous pollutants before the standards are overstepped. Issues in both scenarios are resolved through the integration of IoT, which helps provide greater understanding, boosts flexibility, and improves the way resources are handled. The need for cities to be more sustainable is likely to result in IoT playing a much bigger part in water infrastructure.

2.2 Role of PLC and SCADA in Water System Automation

Automating regular tasks in water and wastewater systems relies greatly on Programmable Logic Controllers (PLCs). With sensors and other field devices, these devices are made to control processes in real-time. PLCs are programmed so that they automatically manage pumping, open and close valves with the right levels in tanks, and dose chemicals as needed to keep water quality high. It's because they are reliable and can adapt quickly that they fit well into roles where fast and accurate work is important. Because PLCs are modular, facilities can build up their control systems as they change the way they operate (G. Mahalakshmi et al., 2022).

SCADA systems working with PLCs give a supervisory function that helps monitor and manage the whole water infrastructure. The user can, with a Human-Machine Interface (HMI), check live information, see what's happening in the process graphically, and administer commands from anywhere. It is particularly valuable for systems that handle water or wastewater far from central centres, such as in rural areas (Gadekar et al., 2021). SCADA systems maintain information from the past, signal when anomalies or deviations from set parameters occur, and assist in reporting and maintaining compliance. With PLCs and SCADA in the water system, it can manage its processes, warn operators of any problems instantly, and keep working smoothly with the least need for people to intervene (Abdulwahid et al., 2023).

2.3 Benefits of Real-Time Monitoring and Control

IoT, PLCs, and SCADA technologies enable real-time water quality monitoring and significantly improve safety standards. Sensors measure key parameters like pH, turbidity, chlorine, and conductivity to detect contamination or equipment faults early. When thresholds are exceeded, automated systems can redirect water, adjust treatments, or shut off distribution points—ensuring health protection and regulatory compliance, especially in densely populated urban areas (Forhad et al., 2024).

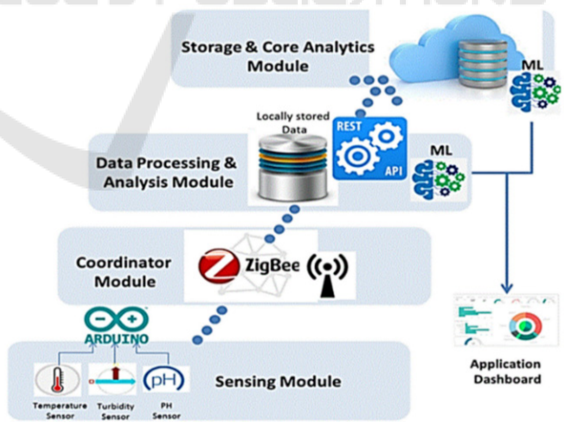

Figure 1: IoT-Based Architecture for Real-Time Water Quality Monitoring.

Fig. 1 shows an IoT-based architecture comprising sensors, machine learning, and cloud analytics with which remote monitoring, automation and data-driven decisions can be made. LCs automate the fundamental operations by responding to sensor data- that is, regulating pumps, valves and chemical dosing to support water cleanliness (Jan et al., 2021). They are fast, precise and scalable and hence suit very well in the dynamic environment (Gnana Swathika O.V et al., 2024).

When integrated with SCADA, PLCs gain enhanced supervisory control. SCADA's Human-Machine Interface (HMI) allows operators to visualise system performance in real-time, control components remotely, and access historical data. This is crucial for decentralised wastewater systems. SCADA also provides alerts and compliance reporting, further optimising operations. Together, PLCs and SCADA transform conventional water networks into intelligent systems that operate autonomously, respond rapidly to issues, and require minimal human oversight—making urban water management smarter, safer, and more sustainable (Mahany et al., 2024).

2.4 Relevant Prior Studies and Technological Trends

With the advancement of smart water technologies, several studies have examined the effectiveness of IoT, PLCs, and SCADA systems in improving operational efficiency, monitoring, and resource management. Real-time control systems have demonstrated notable success in reducing non-revenue water losses, enhancing reliability, and improving service continuity (Jan et al., 2021). Such implementations help water utilities detect faults early, automate corrective actions, and ensure compliance with regulatory standards.

In recent years, it has become clear that SCADA systems combined with machine learning can be a valuable tool to analyse real-time and historical data to predict future equipment failures and control strategies. Such smart systems enable predictive maintenance and make it easier to prevent unwanted downtimes through the provision of actionable insights (Forhad et al., 2024).

Also, blockchain-based IoT architectures have become popular because of their assurance of secure and transparent flow of information in automated water systems. The practice improves credibility in utility billing, system surveillance and asset trackings, since tamper-evident ledgers and decentralised mechanisms of access rights are established (Jan et al., 2021).

While many of these studies focus on isolated technologies, there is still limited literature exploring how PLC and SCADA systems can be combined within an IoT ecosystem, particularly in water infrastructure spanning from household systems to large-scale municipal networks. This study aims to fill that research gap by presenting an integrated perspective that supports smarter, more sustainable urban water management aligned with global development goals.

Another relevant development is the increasing use of dual-level automation architectures that integrate both local (PLC-based) control and centralised (SCADA-based) monitoring. These layered systems allow for responsive on-site decision-making while enabling city-level visibility and coordination. Recent literature shows that such hybrid deployments significantly improve scalability and modularity in complex utility infrastructures [16]. This dual functionality supports dynamic water balancing, energy-efficient pumping schedules, and demand-based flow management, all of which are critical in urban sustainability planning.

3 RESEARCH METHODOLOGY

This is the qualitative examination of the applicability of digital technologies known as PLCs and SCADA systems in the water and wastewater treatment systems by using the qualitative case study design. One major strength that a case study can bring is its ability to examine complex phenomena in real-life settings where there is an ambiguity between what is identified as the system and the environment. It enables the researcher to go deep into a given particular implementation, focuses on the dynamics and technicalities of that implementation, and makes some meaningful conclusions that can be generalised elsewhere or modified to take a general approach. Such an approach can be used to study not only the technical side of implementation but also the socio-economic and environmental consequences of smart water management solutions.

Furthermore, the case study approach makes it possible to conduct a comparative study between various technological structures working in diverse situations. This research intends to summarise the advantages, economic issues and evolutions of both the implementation of PLC and SCADA in the real world of water management. The cases provide a lens with which to evaluate the appropriation of automation technologies in light of larger objectives/directions, including sustainability, efficiency of operation, and the health of people. The case study method is therefore suitable for both a descriptive and analytical research goal in that the design, implementation and results of each of the systems will be properly assessed.

3.1 Selection of Two Case Studies for Analysis

Case Study 1: PLC-Based Automatic Water Distribution System for Smart Residential Buildings Aligned with SDGs (Desai & Maske, 2024)

This case study looks at an automatic water system in smart buildings that aligns with the UN's SDGs for clean water and growing cities. To handle problems with unchecked use, overflow, leaks and incorrect bills, the system measures and controls water flow using live sensor data. Residents can set their daily water consumption limits and are charged extra if they exceed them, which encourages responsible and efficient water usage. The improved water supply and user control systems in the project show how water infrastructure in cities can be made more sustainable through automation.

Case Study 2: SCADA Monitoring of Water Storage Tanks and Distribution Systems (Yunus Görkem et al., 2024)

This case study looks at the adoption of SCADA systems to oversee and control water storage tanks and delivery throughout Yozgat province. SCADA makes sure pH, pressure, temperature and sediment buildup in water are constantly watched to maintain clear and secure water delivery. Data from four pumping centres and thirteen storage tanks enabled the system to significantly lower water losses from 64.35% to 51% total savings. The case demonstrates that SCADA improves operational efficiency, detects leaks and safeguards public health by acting quickly and making sure all water quality standards are maintained.

3.2 Limitations of the Case Study Methodology

Although case studies have certain positives, they do have limitations. An important challenge is that the lessons learned from one place might not be useful in all other systems. Every case deals with specific geographic, economic, technical and regulatory challenges that may prevent results from another audience from being applied. Additionally, because case studies rely on observed facts, researchers can easily include their opinions and ideas. The fact that studies can be so complex leads to the chance that important factors are overlooked or misunderstood.

The fact that case studies typically deal with a wide range of interested parties can sometimes make accessing data challenging and ensuring its accuracy. Certain types of key information can be blocked, which makes it harder for experts to completely understand a system. Besides, gathering and checking the relevant data for case studies usually takes a lot more effort than with other types of research, which can make them less helpful for those with little time. Nevertheless, case study analysis helps focus on special cases and enhances developments in closely related fields.

4 CASE STUDY ANALYSIS

Case Study 1: PLC-Based Automatic Water Distribution System for Smart Residential Buildings Aligned with SDGs (Desai & Maske, 2024)

This case study focuses on the integration of Programmable Logic Controllers (PLCs) into water distribution systems for smart residential buildings, aiming to align urban water management with the United Nations Sustainable Development Goals (SDGs). The prototype system utilises PLCs to automate water delivery based on real-time sensor data and individual user demands. This automation addresses key urban water issues like overflows, line leakages, unregulated consumption, and inaccurate billing. One of the system's most notable features is its adaptability—it allows residents to set consumption limits based on their needs, with provisions to bill additional usage.

With its alignment to goals 6 (Clean Water and Sanitation) and 11 (Sustainable Cities and Communities), the proposed system increases the efficiency in the usage of resources and prevents social inequity. It establishes a closed-loop controlled mechanism of water distribution, based on the dynamically controlled meeting the demand without excessive use. The automation also is transparent and provides accountability as it tracks and bills usage accurately. This enables residents to exercise control in use of water resources responsibly, whereas the city planners can take advantage of the scalable infrastructure that is adjusted to the emerging urban population. This example demonstrates the insights of how these smart systems can help evolve the age-old water delivery systems to newer and more sustainable and efficient systems within contemporary cities.

Case Study 2: SCADA Monitoring for Water Storage Tanks and Distribution Systems (Yunus Görkem et al., 2024)

The second case study presents the implementation of SCADA (Supervisory Control and Data Acquisition) systems to monitor and control water distribution and storage infrastructure in Yozgat province. SCADA systems provide centralised real-time monitoring of essential water quality indicators such as pH levels, temperature, pressure, and sediment accumulation within storage tanks. By allowing remote oversight and automation of system responses, SCADA plays a critical role in identifying potential issues such as contamination, leaks, or system malfunctions. It ensures that water quality is preserved from the point of storage to end-user delivery, thereby reducing the risk of waterborne diseases and supporting public health.

In this case, the SCADA system covered four pumping centres and thirteen water storage tanks. Before implementation, the region faced significant inefficiencies, with total water loss as high as 64.35%, including 27.59% from physical leakage. Post-deployment, the system achieved a 51% reduction in total water loss, demonstrating the power of automation in managing large-scale infrastructure. These improvements were due to SCADA's ability to detect leaks, automate responses, and optimise operational performance. Beyond just improving efficiency, SCADA systems also enhance regulatory compliance and reduce the manual labour required for system maintenance, making them vital for municipalities aiming to modernise their water distribution infrastructure.

4.1 Comparison of Findings from both Case Studies

Both case studies apply automation in water management, but they each have different goals and impacts. At the PLC level, the system is designed to supervise single households and promote shifts in user behaviour. Here, households can see and control their water use, which allows for faster changes in billing. This approach is especially helpful in smart cities because being personalised and responsive to customers is so important. The service achieves this through proper handling of demand and by promoting green habits among normal customers.

Alternatively, the SCADA-based system is designed to supervise a large municipal water supply system from a central location. Supply chain management emphasises both the effectiveness and security of delivery and storage. If water is kept clean and is not lost much, SCADA assists in making infrastructure reliable and preserves health benefits for everyone. Frankly speaking, users gain abilities from the PLC system, while administrators and utilities depend on SCADA. In combination, these systems show that having both manual controls nearby (through PLCs) and overall control across the system (SCADA) helps a city become more efficient, accountable and sustain its resources.

4.2 Answers to Research Questions

Case Study 1 highlights the role of PLC-based automated water systems in smart buildings, enabling precise and sustainable water management. These systems respond to sensor data and user input, preventing issues like leaks and tank overflow. They promote water conservation through flexible usage plans and penalties for overuse, aligning with UN SDGs related to clean water, sustainable cities, and responsible consumption. PLC systems also enhance the resilience of urban water infrastructure and can be integrated into both new and existing buildings, reducing pressure on municipal systems and empowering building managers with real-time control.

Case Study 2 emphasises the benefits of SCADA monitoring in enhancing water system performance and safety, as seen in Turkey's Yozgat province. Real-time tracking of 13 tanks and four pumping stations allows continuous analysis of pH, pressure, and temperature. This rapid detection of issues such as leaks or pressure drops led to a 51% reduction in water loss. SCADA improves water quality, minimises system downtime, and supports proactive maintenance. The integration of GIS and analytics enables data-driven decision-making, transforming traditional water networks into intelligent, self-regulating systems. Together, PLC and SCADA technologies are key to advancing smart, sustainable urban water management.

5 DISCUSSION

5.1 Comparison of Findings from both Case Studies

Using IoT along with SCADA systems in water and wastewater areas is transforming urban infrastructure to be smarter and greener. Case Study 2 outlines that single systems can incorporate monitoring and control of pressure, pH, temperature, and flow, which are key parameters in large water networks. The addition of IoT-enabled sensors to these systems makes it possible to collect and study data around the clock from networked physical assets. As a result of this blend, predictive maintenance is made possible, along with fast detection of problems and immediate actions when a system fails, which lowers water loss, energy use, and operating costs.

When cities are short on water, including catchment options makes utility services more adaptable. Two-way communication between users and the infrastructure is made possible by IoT devices, which supply customers with reports on their usage and enable them to better oversee power consumption. Municipalities can use this intelligence to determine effective decisions about policies and city structures. As a result, the use of IoT and SCADA together is key to meeting smart water management goals and matching the vision of sustainable cities and communities planned by the United Nations.

5.2 Potential for Scalability and Wider Industry Application

Both the system built on PLCs and the SCADA system is capable of being scaled to a wide range of water processing conditions and areas. Plug-and-play systems use PLCs, like the ones in Case Study 1, which can easily be modified for several buildings and user needs. Because of this, they are suitable for installation in residential buildings and also important industrial and commercial spaces. Because they work with smart meters and flexible pricing, smart homes can expand and help people save energy and money.

Also, SCADA systems, which are successful for managing large water systems, are well-suited to operations in either urban or rural areas. They can operate at one location or cover broad municipalities, mainly when they make use of IoT and analytics services from the cloud. As a result, tech-based water solutions are important for governments, utilities, and private companies looking to upgrade their outdated water infrastructure. When the water supply is strained by climate change and rising populations, scalable automation systems can help achieve equal access, sustainability, and efficiency in our water systems worldwide.

5.3 Challenges and Recommendations for Future Implementations

Urban sustainability faces challenges due to ageing infrastructure, environmental pressures, and growing resource demand. This review explores how integrating PLC and SCADA technologies in IoT-driven systems can improve water distribution through automation, real-time monitoring, and energy efficiency—supporting SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities).

Rising urbanisation and climate change strain current water infrastructure, pushing the need for smarter, sustainable solutions. The convergence of IoT, PLCs, and SCADA enables data-driven decision-making, enhancing reliability, cost-efficiency, and water quality. The review also highlights trends and emerging applications in both structured and unstructured water systems globally.

6 CONCLUSION

This paper has discussed the potential of domain coupling of Programmable Logic Controllers (PLCs) and Supervisory Control and Data Acquisition (SCADA) to improve water systems and wastewater systems on a broader platform of smart infrastructure in cities. With the help of two real-life case studies of smart residential building PLC-driven system and municipal water network SCADA-monitored, the study illustrates how layered automation can increase the efficiency of operations; enhance transparency and sustainability of the system. When combined with the application of one another in an IoT system, these technologies allow one to monitor, regulate, and implement changes in real-time, adaptively, and increase their use in varying levels of infrastructure scaling.

The results support the SDG alignment, in addition to the UN Sustainable Development Goals, namely SDG 6 (Clean Water and Sanitation) and SDG 11 (Sustainable Cities and Communities). The integration of the building-level user control and the city-level infrastructure-level optimisation potentially provides the study with a real-life roadmap of water automation between the operational responsibility of an individual and system-level efficiencies.

6.1 Future Directions

The further development of the described studies can examine the connection between artificial intelligence, machine learning, and PLC-SCADA systems to introduce predictive analytics and the capability of making autonomous decisions. It may also lead to the enhancement of data integrity, transparency of billing, and safe exchange of information in distributed water networks with the incorporation of blockchain. The testing should be intensified in diverse geographies, particularly in developing countries or in rural settings, to determine how the application performs when constrained by varying factors. Moreover, some simplified versions of these systems at reduced cost may be designed to roll out in under-resourced municipalities in a scalable process. Collaboration among urban planners, data scientists, and environmental policymakers to implement smart water technologies will be crucial in harnessing the full potential of these technologies globally.

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