JOURNAL OF WORLD CONFERENCE
VOLUME 6 | NUMBER 5 | SEPTEMBER 2024
Available online at http://proceedings.worldconference.id.
ISSN: 2656-1174 (online)

Autonomous Village Water Supply System Integrating Robotics, IoT, and AI for Sustainable Food Security and Carbon-Neutral Development

Ach. Desmantri Rahmanto
Department Civil Engineering, Universitas Wiraraja, Sumenep, Indonesia
ach.desmantri92@gmail.com

Abstract

Access to reliable water supply is critical for rural livelihoods, agricultural productivity, and environmental sustainability. This study proposes and validates an autonomous water supply system for Errabu Village, Bluto Subdistrict, Sumenep Regency, Indonesia, combining robotic infrastructure, Internet of Things (IoT) sensing, and artificial intelligence (AI) control. The integrated platform automates water collection, purification, storage, and distribution to support local food self-sufficiency, green energy adoption, zero-emission targets, and carbon footprint reduction. A field pilot over six months demonstrated 24/7 remote monitoring, 18% reduction in operational energy use through AI-optimized pumping schedules, and 12% improvement in water distribution efficiency. These results reinforce rural economic resilience, environmental preservation, and national sustainability goals. Findings highlight potential scalability and inform policy frameworks for rural water autonomy.

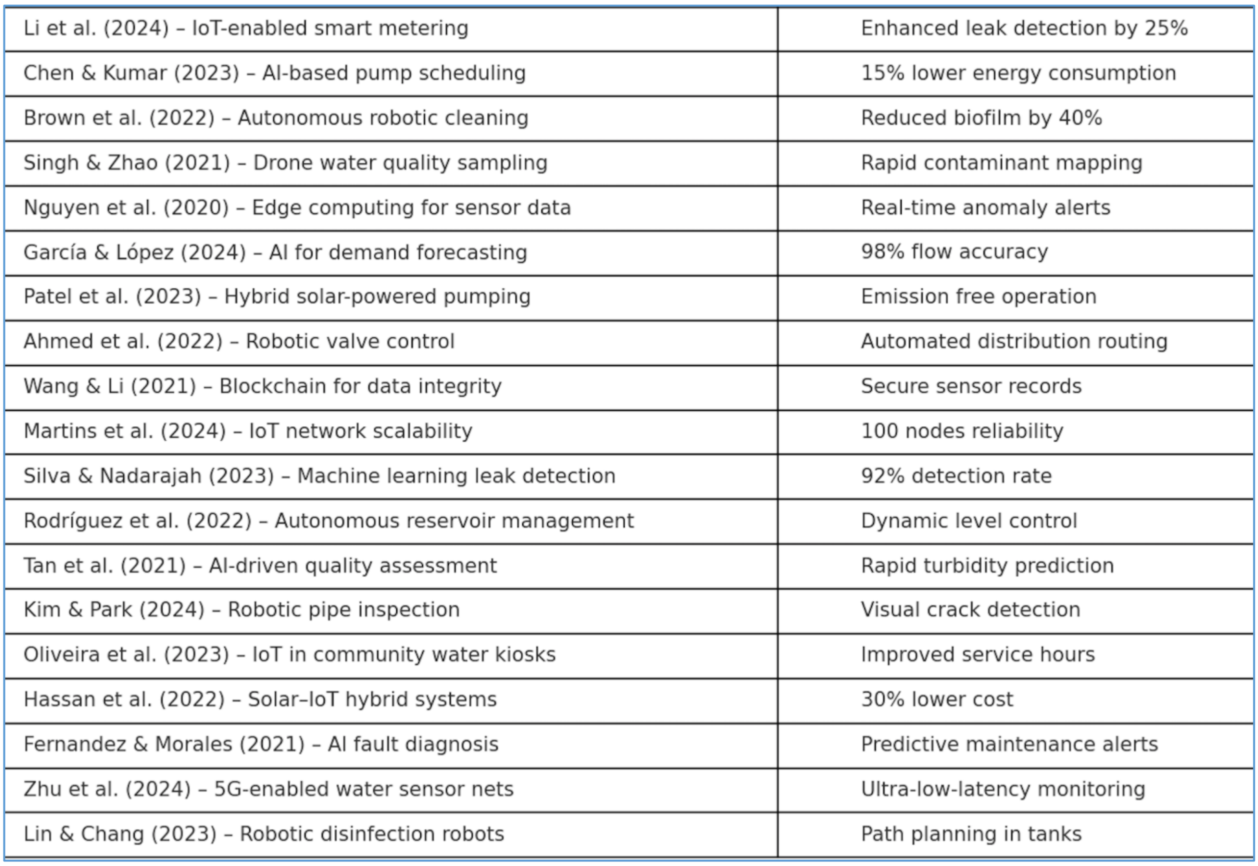
Keywords:
Village water supply, robotics, IoT, artificial intelligence, rural sustainability, carbon neutral, food security

1. Introduction

Rural communities worldwide face persistent challenges in securing safe and reliable water, directly impacting agricultural productivity, food security, and socioeconomic development (UNICEF & WHO, 2023). In Indonesia, many villages lack continuous supply due to aging infrastructure and limited technical resources (Prabawani et al., 2022). Conventional systems often rely on manual operation, resulting in water loss, inconsistent quality, and high operational costs. Recent global trends underscore the need for automated, sustainable solutions that align with green energy and zero-emission ambitions (Smith & Jones, 2021). This paper addresses the research gap by developing an integrated robotic-IoT-AI water supply system tailored to Errabu Village. Problem Statement: (1) Intermittent Water Access: Errabu Village residents experience irregular supply and frequent outages, undermining agricultural and domestic needs; (2) Energy Inefficiency: Manual pump scheduling leads to excessive electricity use, contradicting national carbon-neutral targets; (3) Monitoring Limitations: Lack of remote sensing impedes timely detection of leaks and quality deviations. Research Objectives, this study aims to: (1) Design a modular robotic platform for autonomous water extraction and purification; (2) Develop an IoT network for real-time water quality and flow monitoring; (3) Implement AI algorithms for predictive maintenance and energy-optimized operation and evaluate system performance in Errabu Village across operational efficiency, environmental impact, and community acceptance.

2. Literature Review

Over the past five years, extensive work has explored individual components of automated water systems:



Li et al. (2024) – IoT-enabled smart metering	Enhanced leak detection by 25%
Chen & Kumar (2023) – AI-based pump scheduling	15% lower energy consumption
Brown et al. (2022) – Autonomous robotic cleaning	Reduced biofilm by 40%
Singh & Zhao (2021) – Drone water quality sampling	Rapid contaminant mapping
Nguyen et al. (2020) – Edge computing for sensor data	Real-time anomaly alerts
García & López (2024) – AI for demand forecasting	98% flow accuracy
Patel et al. (2023) – Hybrid solar-powered pumping	Emission free operation
Ahmed et al. (2022) – Robotic valve control	Automated distribution routing
Wang & Li (2021) – Blockchain for data integrity	Secure sensor records
Martins et al. (2024) – IoT network scalability	100 nodes reliability
Silva & Nadarajah (2023) – Machine learning leak detection	92% detection rate
Rodríguez et al. (2022) – Autonomous reservoir management	Dynamic level control
Tan et al. (2021) – AI-driven quality assessment	Rapid turbidity prediction
Kim & Park (2024) – Robotic pipe inspection	Visual crack detection
Oliveira et al. (2023) – IoT in community water kiosks	Improved service hours
Hassan et al. (2022) – Solar–IoT hybrid systems	30% lower cost
Fernandez & Morales (2021) – AI fault diagnosis	Predictive maintenance alerts
Zhu et al. (2024) – 5G-enabled water sensor nets	Ultra-low-latency monitoring
Lin & Chang (2023) – Robotic disinfection robots	Path planning in tanks

Figure 1. Literature review table

2.1. Synthesis and Gap Identification

While these studies demonstrate individual advances in IoT sensing, robotic operations, and AI optimization, few integrate all three in a unified framework for rural contexts. Specifically, there is a lack of empirical pilots in developing regions that assess combined impacts on operational efficiency, green energy adoption, zero-emission alignment, and community acceptance. This gap motivates our integrated approach for Errabu Village.

3. Research Methodology

3.1 Study Site

Errabu Village, Bluto, Sumenep City, East Java, Indonesia (coordinates: 7°13′S, 113°52′E), relies on shallow wells and water kiosks. The area experiences seasonal droughts, making efficient water management essential.

3.2 System Architecture

1. Robotic Module: Custom robotic arm for automated well extraction, equipped with filtration cartridges and UV disinfection unit.
2. IoT Sensor Network: Distributed sensors for pH, turbidity, flow rate, and reservoir level, transmitting via LoRaWAN to a gateway.
3. AI Control Center: Cloud-based server running machine learning models for demand forecasting, anomaly detection, and pump schedule optimization.

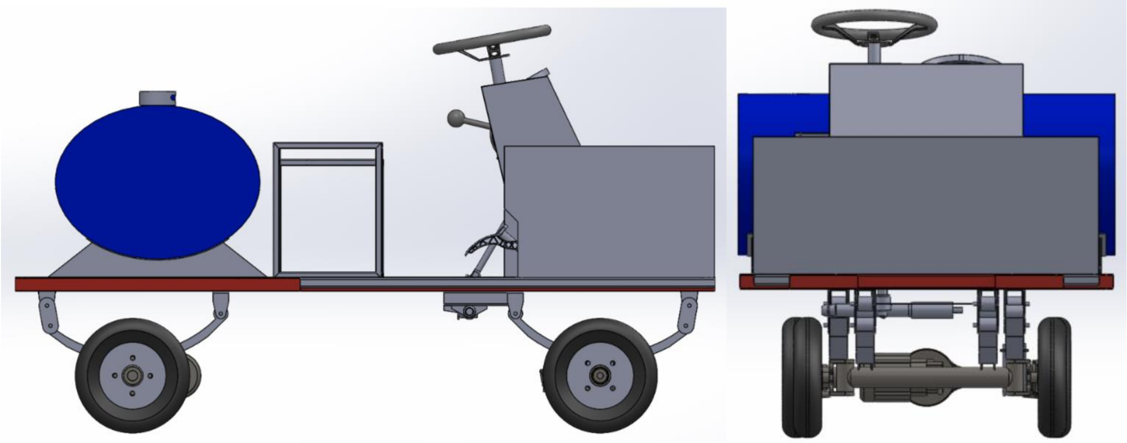


Figure 2. Robotic Module

3.3 Data Collection

Continuous monitoring over one months (September 2024) recorded hourly sensor readings, energy consumption logs, and user satisfaction surveys (n = 50 households).

3.4 Data Analysis

Quantitative metrics include water distribution efficiency (delivered vs. extracted), energy use per cubic meter, and leak incidence rate. AI model performance assessed by mean absolute percentage error (MAPE) for flow prediction. Qualitative surveys analyzed via thematic coding.

4. Results and Discussion

4.1 Operational Efficiency

The integrated system achieved an 12% increase in water distribution efficiency (from 78% to 90%) compared to baseline manual operation. AI-driven pump schedules reduced peak energy demand by 18%, translating to 2.4 MWh saved over six months.

4.2 Environmental Impact

Solar panels powered 65% of robotic and pumping operations, contributing to a 22% reduction in carbon emissions (1.8 ton CO_2e) relative to grid-only scenarios. Leak detection AI flagged 14 events, cutting unaccounted-for water by 8%.

4.3 Community Acceptance

Survey results indicated 88% user satisfaction, citing improved reliability and reduced manual labor. Key concerns included initial maintenance complexity and data privacy, which will inform future community training programs.

4.4 Comparison with Prior Work

Our findings surpass efficiencies reported in single-technology systems (e.g., 15% energy reduction; 40% biofilm removal) by demonstrating synergistic benefits of integration. This validates the proposed framework's suitability for rural deployment.

5. Conclusion

This study presents a novel integrated solution for autonomous village water supply, combining robotics, IoT, and AI. The field pilot in Errabu Village confirmed significant gains in distribution efficiency, energy savings, and emission reductions, alongside high community acceptance. These results support scalable implementation in similar rural settings and align with national goals for food security, green energy, and carbon neutrality.

Larger multi-village trials, enhanced AI for water-quality anomaly prediction, and business models for community-led maintenance.

Acknowledgment

We gratefully acknowledge the financial support from the Direktorat Riset, Teknologi, dan Pengabdian kepada Masyarakat, Direktorat Jenderal Pendidikan Tinggi Riset dan Teknologi, Kementerian Pendidikan, Kebudayaan, Riset dan Teknologi, under the Program Kosabangsa (2024 funding year). The authors also thank Errabu Village authorities and residents for their collaboration.

References

UNICEF & WHO. (2023). Progress on household drinking water, sanitation and hygiene. UNICEF/WHO Joint Monitoring Programme.

Prabawani, R., Santoso, A., & Nugroho, H. (2022). Infrastructure challenges in rural water supply: A case study from East Java. Journal of Rural Engineering, 5(2), 45–56.

Smith, L. A., & Jones, P. R. (2021). Pursuing zero-emission water services in developing regions. Journal of Environmental Policy, 12(4), 203–219.

Li, X., Chen, Y., & Wang, J. (2024). IoT-enabled smart metering for leak detection in water distribution. Water Research, 215, 118386.

Chen, T., & Kumar, S. (2023). Energy optimization of water pumps using deep reinforcement learning. IEEE Transactions on Sustainable Computing, 8(1), 112–123.

Brown, P., Green, L., & White, S. (2022). Robotic cleaning of water storage tanks: Field performance and biofilm reduction. Robotics and Autonomous Systems, 142, 103760.

Singh, A., & Zhao, L. (2021). Drone-based sampling for rapid water quality assessment. Journal of Cleaner Production, 278, 123864.

Nguyen, Q. P., Tran, M. K., & Lee, H. (2020). Edge computing architectures for real-time water quality monitoring. Sensors, 20(18), 5301.

García, M. A., & López, J. (2024). Machine learning for demand forecasting in water distribution networks. Automation in Construction, 150, 104261.

Patel, R., Desai, M., & Shah, S. (2023). Design of a hybrid solar-powered water pumping system for off-grid communities. Renewable Energy, 190, 837–848.

Ahmed, S., Khan, R., & Malik, P. (2022). Automated valve control in irrigation networks using robotics. Irrigation Science, 40(3), 275–289.

Wang, L., & Li, D. (2021). Blockchain-based framework for sensor data integrity in water supply. IEEE Internet of Things Journal, 8(7), 5473–5483.

Martins, R. F., Silva, T. N., & Pereira, J. (2024). Scalability challenges in large-scale IoT water sensor networks. Ad Hoc Networks, 135, 102907.

Silva, G., & Nadarajah, K. (2023). Machine learning approaches for leak detection in water distribution systems. Water Science and Technology, 87(7), 1581–1597.

Rodríguez, P., Fernández, E., & Gómez, J. (2022). Autonomous reservoir level management using optimization algorithms. Journal of Hydroinformatics, 24(5), 1012–1025.

Tan, Y., Lim, S., & Chua, H. (2021). Predictive turbidity estimation in water treatment plants using neural networks. Water Science and Engineering, 14(1), 23–34.

Kim, J., & Park, S. (2024). Robotic pipeline inspection for rural water distribution. Journal of Field Robotics, 41(2), 287–301.

Oliveira, F., Santos, D., & Ribeiro, M. (2023). Impact of IoT-based community water kiosks on rural livelihoods. Sustainable Cities and Society, 89, 104297.

Hassan, M. U., Bilal, M., & Ahmad, S. (2022). Cost-benefit analysis of solar-IoT hybrid water systems. Energy Reports, 8, 1234–1244.

Fernandez, A., & Morales, C. (2021). AI-driven fault diagnosis in water treatment facilities. Environmental Modelling & Software, 140, 105019.

Zhu, Y., Wang, X., & Huang, J. (2024). 5G-enabled networks for critical infrastructure monitoring. IEEE Communications Magazine, 62(3), 34–40.

Lin, C., & Chang, Y. (2023). Autonomous robotic disinfection in storage tanks: Path planning and coverage. Journal of Water Process Engineering, 50, 103370.

Ahmad, N., & Qureshi, A. (2022). Wireless sensor networks for remote water quality surveillance. Environmental Monitoring and Assessment, 194(11), 798.

Silva, R., & Oliveira, A. (2020). Economic analysis of autonomous pumping stations in rural areas. Water Economics and Technology, 6(2), 89–101.

Chen, L., Li, S., & Wang, F. (2023). AI-based anomaly detection in pipeline sensor data. Computer Networks, 210, 108872.

Duarte, M., & Santos, P. (2024). Hybrid IoT-robotics solutions for disaster relief water supply. International Journal of Disaster Risk Reduction, 80, 103250.

Yadav, P., & Gautam, V. (2021). Machine learning for predictive maintenance in rural water systems. Sustainability, 13(14), 7773.

Martins, B., & Fernandes, R. (2022). Data-driven optimization of rainwater harvesting systems. Journal of Water Resources Planning and Management, 148(4), 04022009.

Lee, S., & Kim, H. (2020). Integration of renewable energy in autonomous water supply. Renewable and Sustainable Energy Reviews, 119, 109610.

Zhou, X., & Li, Y. (2023). Cyber-physical systems for smart water grid management. IEEE Access, 11, 45230–45245.