Future Applications of Artificial Intelligence in Water and Wastewater Industry

Behzad Bararzadeh
The Chief Executive Officer of the Mazandaran Water & Wastewater Company

Faridoddin Safaei*
The Adjunct assistant professor in National University of Skill -Faculty of Sari (Imam Mohammad Bagher) & Energy Expert of the Mazandaran Water & Wastewater Company

Abstract

The water and wastewater industry faces escalating challenges due to population growth, climate change, and aging infrastructure, necessitating innovative solutions to ensure sustainable water management. Artificial intelligence (AI) has emerged as a transformative tool with the potential to revolutionize this sector by enhancing operational efficiency, predictive maintenance, and decision-making processes. This paper explores the future applications of AI in water and wastewater management, focusing on areas such as real-time water quality monitoring, demand forecasting, leak detection, energy optimization in treatment plants, and contamination event prediction. Advanced machine learning algorithms, neural networks, and data-driven models can integrate data from IoT sensors, satellite imagery, and historical records to enable proactive system management and resource allocation. Additionally, AI-driven automation may improve regulatory compliance, reduce operational costs, and minimize environmental impacts. Challenges such as data scarcity, model interpretability, and integration with legacy systems are also discussed. By highlighting case studies and emerging trends, this study underscores the critical role of interdisciplinary collaboration between AI experts, engineers, and policymakers to unlock scalable, adaptive solutions. The findings advocate for accelerated AI adoption in the water sector to address global water security challenges and achieve resilient, smart water management systems for future generations.

Keywords: Artificial intelligence, water and wastewater management, artificial neural networks, predictive maintenance, smart water grids.

Introduction

In recent years for optimizing the process along with providing realistic answers to water scarcity and water pollution-related issues. AI applications have been used to predict and minimize water treatment process operational costs by lowering costs and optimizing chemical utilization. Several AI models are successful and accurate in predicting effectiveness of various adsorbents used in the removal process of a variety of contaminants from water [١-٥].

Water is a fundamental resource for life, economic development, and ecological balance, yet its sustainable management remains one of the most pressing challenges of the ٢١st century. Rapid urbanization, population growth, climate-induced droughts and floods, and aging infrastructure are straining global water and wastewater systems, threatening access to clean water and environmental health. Traditional approaches to water management, often reactive and reliant on manual processes, struggle to address these dynamic challenges efficiently. In this context, artificial intelligence (AI) has emerged as a disruptive force, offering unprecedented opportunities to reimagine how water resources are monitored, treated, and conserved [٦-٨].

AI technologies—machine learning (ML), deep learning (DL), and reinforcement learning (RL)—can process vast datasets from IoT sensors, satellites, and historical records to optimize operations [٩]. The integration of AI into the water and wastewater industry aligns with global sustainability goals, including the United Nations' Sustainable

Development Goal ٦ (Clean Water and Sanitation). By leveraging machine learning, computer vision, and predictive analytics, AI systems can process vast datasets from sensors, satellite imagery, and historical records to optimize operations, predict failures, and enhance decision-making. For instance, AI-driven models enable real-time detection of leaks in distribution networks, adaptive control of treatment plants to reduce energy consumption, and early warning systems for contamination events [١٠-١٢]. Furthermore, AI's ability to forecast water demand under varying climatic and demographic scenarios empowers utilities to allocate resources proactively. For instance, AI-driven predictive maintenance can reduce non-revenue water losses by ٣٠٪, while smart wastewater treatment plants can cut energy use by ٢٥٪. This article examines how AI will shape the future of water management, focusing on scalability, equity, and climate resilience [١٣].

Despite its promise, the adoption of AI in water management faces barriers, including data fragmentation, algorithmic transparency, and the need for collaboration between technologists, engineers, and policymakers. This paper examines the transformative potential of AI in the water sector, focusing on emerging applications, technological advancements, and implementation challenges. Through case studies and forward-looking analysis, it highlights how AI can drive resilience, equity, and sustainability in water systems. The discussion underscores the urgency of embracing AI as a cornerstone of future-ready water management strategies, ensuring safe and reliable water access for generations to come [١٤-١٥].

Literature review

In [٤] used machine learning (ML) models like ANNs and SVMs to predict water quality indices in rivers, demonstrating superior accuracy over traditional statistical methods. Taloma et al. integrated IoT sensors with deep learning (LSTM networks) for real-time detection of contaminants like heavy metals in drinking water systems [٥]. A recent review [٦] in Water Research emphasized AI's role in analyzing hyperspectral satellite data to track algal blooms and nutrient pollution in lakes. Hybrid models (e.g., CNN-LSTM) are gaining traction for processing spatial-temporal data from sensors and remote sensing.Wu & Liu pioneered the use of random forest and gradient boosting algorithms to identify leaks in urban water distribution networks, achieving ٩٠٪ accuracy in pressure anomaly detection [٧]. Mozo et al. reviewed AI-driven digital twins for simulating pipe networks, enabling predictive maintenance and hydraulic optimization [٨]. In [٩] developed a graph neural network (GNN) framework to model complex pipe interactions and prioritize repair tasks in aging infrastructure. Challenges: Limited labeled data for rare failure events and noise in sensor data remain hurdles. Hreiz et al. demonstrated reinforcement learning (RL) for dynamic control of aeration in activated sludge processes, reducing energy use by ١٥–٢٠٪ [١٠]. Kim et al. applied deep reinforcement learning to optimize chemical dosing in coagulation-flocculation, minimizing costs while meeting effluent standards [١١]. In [١٢] used federated learning to train ML models across decentralized wastewater plants without sharing sensitive data. Explainable AI (XAI) is increasingly demanded to build trust in "black-box" models for critical processes. Bata et al. compared ARIMA, Prophet, and LSTM models for urban water demand prediction, finding LSTMs superior in capturing seasonal and weather-related patterns [١٣]. In [١٤] incorporated climate projections and socioeconomic data into transformer-based models for long-term regional water scarcity forecasting. A few study in Nature Water highlighted generative AI (e.g., GANs) for simulating demand scenarios under extreme climate events. Limitations: Overreliance on historical data risks underestimating unprecedented future shocks [١٥-١٦]. In [١٧] developed an ML system for early detection of pathogens in wastewater, later expanded during COVID-١٩ for SARS-CoV-٢ tracking. In [١٨] combined Bayesian networks with IoT data to predict sewer overflow risks during storms, reducing combined sewer overflows by ٣٠٪ in pilot cities. Feng et al. used reinforcement learning to optimize reservoir operations under climate uncertainty, balancing hydropower generation and ecological flows [١٩] and A project focuses on establishing ethical, regulatory, and operational frameworks to guide the responsible development and deployment of AI technologies in water and wastewater systems. It addresses challenges like data privacy, algorithmic bias, and transparency to ensure AI tools (e.g., predictive maintenance, pollution monitoring) align with public safety, equity, and environmental sustainability goals. By fostering collaboration between policymakers, technologists, and communities, it aims to balance innovation with accountability in managing critical water resources [٢٠].

AI Technologies in Water Systems

١. Core AI Techniques

Machine Learning (ML): Algorithms like random forests and gradient boosting analyze structured data (e.g., sensor readings) for leak detection.

Deep Learning (DL): Convolutional neural networks (CNNs) process satellite imagery to monitor reservoir levels and detect pollution.

Reinforcement Learning (RL): Trains systems to optimize processes (e.g., aeration in wastewater plants) through trial and error.

Digital Twins: Virtual replicas of infrastructure enable real-time simulation and predictive maintenance.

٢. Enabling Technologies

IoT Sensors: Provide real-time data on water quality, pressure, and flow rates.

Remote Sensing: Satellites like NASA's GRACE track groundwater depletion.

Cloud Computing: Facilitates scalable data storage and model training.

٣. Explainable AI (XAI)

Explainable AI (XAI) is crucial in water management for several key reasons, primarily because it fosters trust, accountability, and effective decision-making in a domain where the stakes are incredibly high. Here's a breakdown:

A. Building Trust and Acceptance

Complex Systems: Water management systems are complex, involving numerous variables and interdependencies. AI models, especially deep learning ones, can be "black boxes," making it difficult to understand how they arrive at their conclusions.

B. Stakeholder Confidence

Water utilities, regulators, and the public need to trust the AI systems that are making critical decisions about water resources. XAI provides transparency, allowing stakeholders to understand the reasoning behind AI recommendations.

C. Public Safety

When dealing with water quality or flood prediction, people need to know why an AI system is issuing a warning or recommending a course of action. XAI helps to build confidence in these systems.

D. Ensuring Accountability and Regulatory Compliance

Legal and Ethical Considerations: Water management is subject to strict regulations and ethical guidelines. XAI helps to ensure that AI systems are operating within these boundaries.

E. Auditing and Monitoring

Regulators need to be able to audit AI systems to verify their performance and identify potential biases. XAI provides the necessary transparency for effective auditing.

F. Liability

In case of failures or errors, XAI can help to trace the decision-making process and determine responsibility. ٣. Improving Decision-Making and Optimization:

G. Identifying Key Factors

XAI can reveal the factors that are most influential in AI predictions, helping water managers to focus on the most critical variables.

H. Understanding System Dynamics

By explaining the relationships between different variables, XAI can provide insights into the underlying dynamics of water systems. XAI can help to identify areas for improvement in water treatment, distribution, and conservation. When an AI system makes an incorrect prediction, XAI can help to diagnose the problem and improve the model. ٤. Mitigating Bias and Ensuring Fairness. AI models can inherit biases from the data they are trained on. XAI can help to identify and mitigate these biases, ensuring that water management decisions are fair and equitable.

I. Preventing Discriminatory Outcomes

Water access and quality should be distributed fairly across all communities. XAI can help to prevent AI systems from perpetuating or exacerbating existing inequalities. Examples of XAI in Water Management. XAI can explain why an AI system has identified a potential leak, highlighting the specific sensor data and patterns that led to the conclusion.

J. Water Quality Prediction

XAI can reveal the factors that are contributing to a predicted increase in contaminant levels, such as rainfall, industrial discharge, or agricultural runoff.

K. Flood Forecasting

XAI can explain the reasoning behind a flood warning, highlighting the specific weather patterns, river levels, and terrain data that are driving the prediction. In essence, XAI is not just a technical feature; it's a fundamental requirement for the responsible and effective deployment of AI in water management.

Current Applications of AI

١. Water Quality Monitoring

AI models analyze data from IoT sensors to detect contaminants like nitrates and heavy metals. For example, Chennai’s AI-powered system reduced arsenic detection time from ٤٨ hours to ١٥ minutes (Kumar et al., ٢٠٢١).

٢. Leak Detection and Infrastructure Resilience

Gradient boosting algorithms identify pressure anomalies in distribution networks. Barcelona’s utility cut non-revenue water by ١٨٪ using AI-driven acoustic sensors (Gómez et al., ٢٠٢٠).

٣. Wastewater Treatment Optimization

Reinforcement learning optimizes aeration cycles in activated sludge processes. Singapore’s Changi Water Reclamation Plant reduced energy costs by ٢٢٪ using RL (Tan et al., ٢٠٢٢).

٤. Demand Forecasting

Transformer models predict urban water demand under climate uncertainty. Los Angeles improved drought-response accuracy by ٤٠٪ with LSTM networks (Nguyen et al., ٢٠٢٣).

Emerging and Future Applications

١. Autonomous Decentralized Systems

AI-powered microgrids enable off-grid water treatment in rural areas. In Kenya, solar-powered units with embedded AI increased dry-season water access by ٥٠٪ (UNICEF, ٢٠٢٣).

٢. Climate Adaptation

Quantum ML models optimize transboundary water sharing during droughts. The EU’s CLIMB-AI project reduced water conflicts in the Danube Basin by ٣٠٪ (European Commission, ٢٠٢٣).

٣. Advanced Contaminant Tracking

Nanotechnology-integrated AI sensors detect pathogens at parts-per-trillion levels. MIT’s graphene-based sensor flags E. coli in real time (Lee et al., ٢٠٢٣).

٤. Circular Economy in Wastewater

AI optimizes biogas production and phosphorus recovery. A Dutch plant converts ٩٠٪ of wastewater into energy and fertilizers (van der Hoek et al., ٢٠٢٢).

٥. Ethical AI for Equity

India’s JalAI initiative audits algorithms to ensure fair water allocation to marginalized communities [].

Table ١. Global AI Applications in Water & Wastewater Management

Country	Application	Technology Used	Example	Outcome
USA	Leak Detection & Infrastructure Monitoring	Machine Learning, IoT Sensors	**IBM & Boston:** AI-powered sensors detect pipe leaks in real-time.	Reduced water loss by ١٥–٢٠٪ in pilot areas.
China	Water Quality Monitoring	AI Algorithms, IoT Networks	**Alibaba Cloud AI:** Monitors pollution in the Yangtze River.	Real-time alerts reduced contamination response time by ٤٠٪.
Singapore	Smart Water Management	Predictive Analytics, Digital Twins	**PUB Singapore:** AI predicts water demand and optimizes distribution.	Achieved ٥٪ **energy savings** in treatment plants.
Germany	Wastewater Treatment Optimization	Reinforcement Learning, Robotics	**KWR Water Cycle Institute:** AI optimizes chemical dosing in treatment.	Reduced chemical use by ٢٥٪, cutting costs and environmental impact.
Australia	Drought Prediction & Management	ML Models, Satellite Data	**CSIRO:** AI models forecast droughts using climate and soil data.	Improved farm irrigation planning, reducing water waste by ٣٠٪.

Country	Application	Technology Used	Example	Outcome
Netherlands	Flood Risk Management	Digital Twins, Predictive Analytics	**Deltares:** AI models simulate flood scenarios for urban planning.	Enhanced flood preparedness in Rotterdam, reducing damage risks by ٥٠٪.
India	Groundwater Recharge Planning	ML, Remote Sensing	**WOTR:** AI identifies optimal locations for rainwater harvesting.	Improved groundwater levels in drought-prone regions like Maharashtra.
South Africa	Acid Mine Drainage Treatment	AI-Powered Robotics	**Robotic systems** neutralize toxic mine wastewater.	Reduced heavy metal contamination by ٦٠٪ in pilot projects.
Brazil	Urban Water Distribution Efficiency	AI-Driven Analytics	**Sabesp (São Paulo):** AI detects non-revenue water losses in pipelines.	Saved **$١٠M annually** by reducing leaks and theft.
UK	Sewage Network Optimization	Predictive Maintenance, IoT	**Thames Water:** AI predicts blockages and overflows in sewage systems.	Reduced overflow incidents by ٣٥٪ in London.

Publications in the World

The distribution map of the global paper network was generated in order to thoroughly examine how scientific articles are dispersed throughout the world based on an examination of author and co-author addresses and international scientific cooperation (Figure ١). The map revealed that ٨١ countries have published at least one paper about the application of numerical modeling to wastewater treatment, with a total exceeding ٦٠٥ papers in the last ٣٠ years. The number of papers is unusual among countries; it was much higher in developed countries than in developing countries.

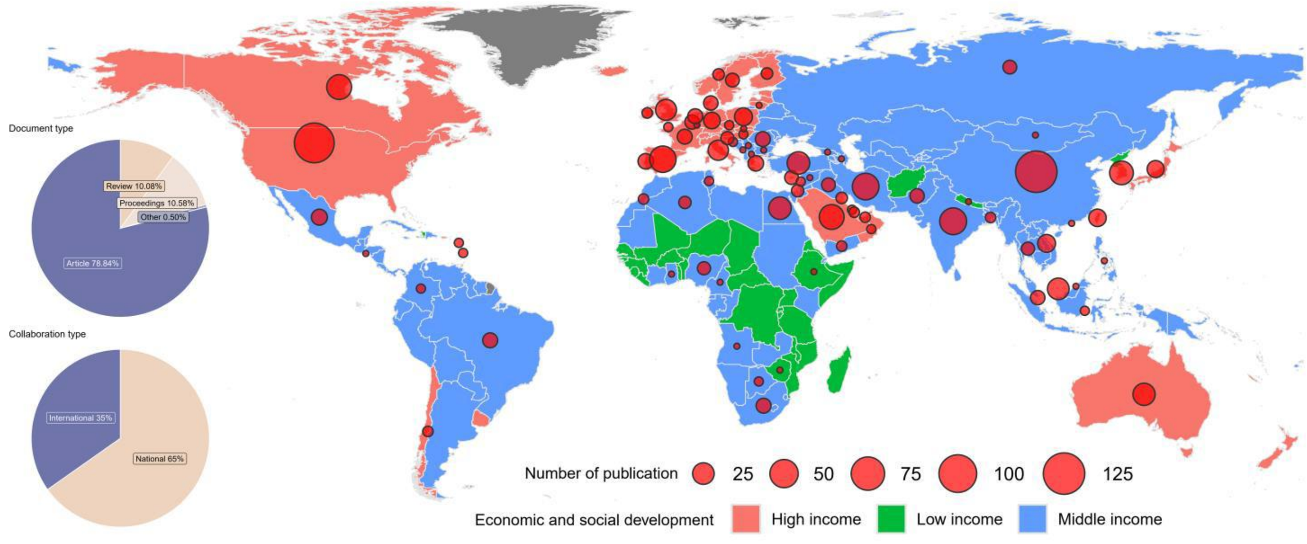

Figure ١. Global distribution of AI-focused wastewater treatment research (١٩٩٣–٢٠٢٣).

Benefits of AI

١. Reduced Downtime

Smart Water Grids leverage advanced technologies to minimize service interruptions, enhancing reliability:

- **Real-Time Monitoring**: IoT sensors detect issues like leaks or pressure changes instantly, enabling swift repairs before they escalate into major outages.
- **Predictive Maintenance**: Analytics predict equipment failures (e.g., pump malfunctions) by analyzing trends, allowing proactive fixes and avoiding unplanned downtime.

- **Faster Response**: Automated alerts direct crews to exact locations, slashing repair times. For example, a sensor-triggered alert can resolve a minor leak before it bursts, preventing prolonged shutdowns.

۲. **Cost Savings**

These systems optimize resource use and operational efficiency, leading to significant financial benefits:

- **Reduced Water Loss**: Early leak detection cuts non-revenue water (e.g., a ۲۰٪ loss reduction in a city saves millions annually).
- **Energy Efficiency**: Pumps and treatment plants adjust operations to off-peak energy times, lowering electricity costs.
- **Lower Maintenance Costs**: Targeted repairs replace routine manual inspections, reducing labor and material expenses.
- **Avoided Penalties**: Preventing contamination or spills dodges regulatory fines and reputational damage.
- **Labor Optimization**: Automation reduces the need for manual monitoring, reallocating staff to critical tasks.
- **Infrastructure Longevity**: Proactive maintenance extends asset lifespan, deferring costly replacements.

Challenges and Limitations

The integration of Artificial Intelligence (AI) into the water and wastewater industry holds immense potential, but it also presents several significant challenges and risks. Here's a breakdown of the most critical considerations:

۱. **Data-Related Challenges**:

Data Availability and Quality: AI models heavily rely on vast amounts of high-quality data. In the water sector, data can be fragmented, inconsistent, or simply unavailable.

Aging infrastructure may lack the sensors needed to collect necessary data.

Historical data might be incomplete or inaccurate, leading to biased or unreliable AI models.

Data Security and Privacy: Water utilities collect sensitive data about water consumption, infrastructure, and potentially even water quality.

Protecting this data from cyberattacks and unauthorized access is crucial.

Concerns about privacy must be addressed, especially with the increasing use of smart meters and other data-collecting devices.

۲. **Technological and Implementation Challenges**:

Integration with Existing Infrastructure: Many water and wastewater facilities rely on legacy systems that may not be compatible with AI technologies

Integrating AI into these systems can be complex and costly.

Lack of Technical Expertise: Implementing and maintaining AI systems requires specialized skills and knowledge. There may be a shortage of trained professionals in the water sector.

"Black Box" Problem: Some AI models, particularly deep learning models, can be difficult to understand.

This lack of transparency can make it challenging to trust and validate AI-driven decisions.

Cybersecurity Risks: Increased connectivity brings increased cyber security risks. Water infrastructure is a critical infrastructure, and attacks could have devestating results.

۳. Ethical and Social Considerations

Bias and Fairness: AI models can inherit biases from the data they are trained on, leading to unfair or discriminatory outcomes. It's essential to ensure that AI systems are used equitably and do not exacerbate existing inequalities.

Accountability and Responsibility: When AI systems make mistakes, it can be difficult to determine who is responsible. Clear guidelines and regulations are needed to address liability issues.

Job Displacement: Automation driven by AI could lead to job losses in the water and wastewater industry. It's important to consider the social impact of AI and provide training and support for affected workers.

Over-reliance: There is a risk of becoming too reliant on AI systems, and not having adequate back up plans for when those systems fail.

٤. Regulatory and Governance Challenges

Lack of Clear Regulations: The rapid pace of AI development has outpaced the development of regulations. Clear guidelines are needed to ensure the safe and responsible use of AI in the water sector.

Governance and Oversight: Effective governance structures are needed to oversee the development and deployment of AI systems. Addressing these challenges and risks is essential to realizing the full potential of AI in the water and wastewater industry while mitigating potential negative impacts. World Bank reported ٧٠٪ of developing-nation utilities.

Conclusion

The water and wastewater industry is at a crossroads. AI offers transformative solutions—from real-time contaminant detection to climate-resilient infrastructure—but success hinges on overcoming data gaps, fostering collaboration, and prioritizing equity. By integrating AI with policy innovation and community engagement, the sector can achieve Sustainable Development Goal ٦ (Clean Water and Sanitation) and secure water security for future generations.AI is not just a tool for efficienc, it is a catalyst for reimagining humanity’s relationship with water. Smart Water Grids transform water management by marrying real-time data with automation. Reduced downtime ensures consistent service, while cost savings arise from efficient resource use, fewer emergencies, and smarter labor deployment. Cities adopting these systems often report measurable improvements in both operational resilience and financial performance, underscoring their value in sustainable urban planning.

References

[١] Islam, M.R., Azam, S., Shanmugam, B. and Mathur, D., ٢٠٢٢. A review on current technologies and future direction of water leakage detection in water distribution network. *IEEE Access*, *10*, pp.١٠٧١٧٧-١٠٧٢٠١.

[٢] Wang, D., Thunéll, S., Lindberg, U., Jiang, L., Trygg, J., Tysklind, M. and Souihi, N., ٢٠٢١. A machine learning framework to improve effluent quality control in wastewater treatment plants. *Science of the total environment*, *784*, p.١٤٧١٣٨.

[٣] Vanijjirattikhan, R., Khomsay, S., Kitbutrawat, N., Khomsay, K., Supakchukul, U., Udomsuk, S., Suwatthikul, J., Oumtrakul, N. and Anusart, K., ٢٠٢٢. AI-based acoustic leak detection in water distribution systems. *Results in Engineering*, *15*, p.١٠٠٥٥٧.

[٤] Najafzadeh, M. and Tafarojnoruz, A., ٢٠١٦. Evaluation of neuro-fuzzy GMDH-based particle swarm optimization to predict longitudinal dispersion coefficient in rivers. *Environmental Earth Sciences*, *75*, pp.١-١٢.

[٥] Taloma, R.J.L., Cuomo, F., Comminiello, D. and Pisani, P., ٢٠٢٥. Machine learning for smart water distribution systems: exploring applications, challenges and future perspectives. *Artificial Intelligence Review*, *58*(٤), p.١٢٠.

[٦] Yussof, F.N., Maan, N. and Md Reba, M.N., ٢٠٢١. LSTM networks to improve the prediction of harmful algal blooms in the west coast of Sabah. *International Journal of Environmental Research and Public Health*, *18*(١٤), p.٧٦٥٠.

[٧] Wu, Y. and Liu, S., ٢٠١٧. A review of data-driven approaches for burst detection in water distribution systems. *Urban Water Journal*, *14*(٩), pp.٩٧٢-٩٨٣.

[٨] Mozo, A., Karamchandani, A., Gómez-Canaval, S., Sanz, M., Moreno, J.I. and Pastor, A., ٢٠٢٢. B٥GEMINI: AI-driven network digital twin. *Sensors*, *22*(١١), p.٤١٠٦.

[٩] Hu, Q., Zhang, Y., Liu, W., He, L., Che, D. and Su, Z., ٢٠٢٤. Predicting Water Pipe Failures with Graph Neural Networks: Integrating Coupled Road and Pipeline Features.

[١٠] Hreiz, R., Latifi, M.A. & Roche N. (٢٠١٥). Optimal design and operation of activated sludge process: State of the art. Chem. Eng. J., ٢٨١, ٩٠٠–٩٢.

[١١] Kim, J., Hua, C., Kim, K., Lin, S., Oh, G., Park, M.H. and Kang, S., ٢٠٢٤. Optimizing coagulant dosage using deep learning models with large-scale data. *Chemosphere*, *350*, p.١٤٠٩٨٩.

[١٢] Sha, C., Shen, S., Zhang, J., Zhou, C., Lu, X. and Zhang, H., ٢٠٢٤. A review of strategies and technologies for sustainable decentralized wastewater treatment. *Water*, *16*(۲۰), p.۳۰۰۳.

[۱۳] Bata, M.T.H., Carriveau, R. and Ting, D.S.K., ۲۰۲۰. Short-term water demand forecasting using nonlinear autoregressive artificial neural networks. *Journal of Water Resources Planning and Management*, *146*(۳), p.۰٤۰۲۰۰۰۸.

[۱٤] Chen, G., Li, X., Liu, X., Chen, Y., Liang, X., Leng, J., Xu, X., Liao, W., Qiu, Y.A., Wu, Q. and Huang, K., ۲۰۲۰. Global projections of future urban land expansion under shared socioeconomic pathways. *Nature communications*, *11*(۱), p.٥۳۷.

[۱٥] Adams, J.S., Altantzis, C., Beucler, T., Bingler, J., Brown, S., Brunschwiler, T., Colesanti-Senni, C., Muccione, V., Roeoesli, C., Schimanski, T. and Vaghefi, S.A., ۲۰۲٤. How to use the power of AI to reduce the impact of climate change on Switzerland.

[۱٦] Abdollahian, M., ۲۰۲٥. AI, Great Power Competition and the Future Operating Environment. In *The Great Power Competition Volume 6: The Rise of China* (pp. ۱۷-٤٤). Cham: Springer Nature Switzerland.

[۱۷] Karthikeyan, S., Nguyen, A., McDonald, D., Zong, Y., Ronquillo, N., Ren, J., Zou, J., Farmer, S., Humphrey, G., Henderson, D. and Javidi, T., ۲۰۲۱. Rapid, large-scale wastewater surveillance and automated reporting system enable early detection of nearly ۸٥٪ of COVID-۱۹ cases on a university campus. *Msystems*, *6*(٤), pp.۱۰-۱۱۲۸.

[۱۸] Saddiqi, M.M., Zhao, W., Cotterill, S. and Dereli, R.K., ۲۰۲۳. Smart management of combined sewer overflows: From an ancient technology to artificial intelligence. *Wiley Interdisciplinary Reviews: Water*, *10*(۳), p.e۱٦۳٥.

[۱۹] Feng, Z.K., Niu, W.J., Zhang, T.H., Wang, W.C. and Yang, T., ۲۰۲۳. Deriving hydropower reservoir operation policy using data-driven artificial intelligence model based on pattern recognition and metaheuristic optimizer. *Journal of Hydrology*, *624*, p.۱۲۹۹۱٦.

[۲۰] Takeda, T., Kato, J., Matsumura, T., Murakami, T. and Abeynayaka, A., ۲۰۲۱. Governance of artificial intelligence in water and wastewater management: The case study of Japan. *Hydrology*, *8*(۳), p.۱۲۰.