

Water Management Through Artificial Intelligence Capabilities

Authors:

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Abstract

The water industry is facing critical challenges due to the growing demand for fresh water, exacerbated by climate change, population growth, urbanization, and industrialization. Traditional water management practices are becoming increasingly inadequate to address these challenges. Artificial intelligence (AI) offers significant potential for transforming water and wastewater systems, optimizing operations, improving efficiency, and ensuring sustainability. This paper reviews the application of AI in water management and wastewater treatment, focusing on its use in monitoring, data analysis, decision-making, and predictive maintenance. It also highlights the opportunities and challenges of AI integration into the water sector, including data availability, technological limitations, and the need for interdisciplinary expertise. The article concludes by proposing recommendations for enhancing AI implementation in water management.

Keywords: Water Resources, Artificial Intelligence, Smart Management, Water Treatment, Water Services

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1. Introduction

Water resource management involves the assessment, allocation, and use of resources to meet the demands of various sectors, considering factors such as availability, quality, and environmental sustainability. With population growth, urban development, and industrialization, the demand for clean water is increasing (Mishra, 2023). Water resources, being one of the most essential elements for human life and production processes, are now under serious threat from harmful pollutants resulting from both human activities and natural processes. Water treatment is a vital process that encompasses the purification and management of water resources to ensure safe and sustainable access to clean water. Traditional methods face limitations in efficiency, resource optimization, and decision-making due to the complexity of systems, variations in water quality, and the dynamic nature of resources (Fameso et al., 2024). To address these challenges, innovative solutions are required. Artificial intelligence (AI) and big data analytics are at the forefront, holding the potential to revolutionize the management of water resources (Kamyab et al., 2023).

The application of mathematical-experimental models as predictive tools for control systems faces operational limitations (Wang and Xiang, 2019). Most of these models are limited in describing the overall complex dynamics and nonlinear dependencies present in water treatment processes (Ghandehari et al., 2011). Seasonal variations in water quality parameters and extreme events, which can lead to data fluctuations, necessitate rapid, reliable predictions and adjustments of operational parameters. However, since AI techniques rely on historical data to provide solutions to these challenges, the availability of data is crucial (Chowdhury and Karanfil, 2024). Moreover, the unavailability of effective, timely, and highly accurate models means that determining specific operational states often depends on manual approaches and prior experience. For instance, in water treatment plants, achieving turbidity and total organic carbon removal from source waters with variable water quality is often carried out by manually adjusting coagulant doses based on previous experience (Ding et al., 2013). Traditional coagulant dosing adjustments, based on jar test experiments or experience-based choices, may not always lead to reliable results (Li et al., 2021). Additionally, it should be noted that water quality parameters follow nonlinear patterns that vary seasonally (Chowdhury and Husain, 2021).

The emergence of data-driven smart applications has transformed our daily practices. Advancements in sensor technology, data collection, storage capacities, and data processing have significantly accelerated the development and expansion of AI applications. The evolution of AI applications, particularly machine learning models, has been remarkable in fields such as medicine, finance, economics, and engineering. AI techniques have also increasingly been used over the past decade to protect against environmental threats, reduce environmental risks, ensure water quality, mitigate flood risks, and enhance water and wastewater treatment processes and waste management (Zhong et al., 2021). The evolution of AI techniques used in

data-driven decision-making has created opportunities in various environmental engineering fields, such as water and wastewater treatment processes, water quality protection, cost reduction, and process control (Ismail et al., 2021). AI can analyze vast amounts of data from sensors, monitoring systems, and historical records, providing insights into water quality, usage patterns, and resource availability. This data-driven approach enables precise treatment outcome predictions, optimization of treatment processes, and active resource management (Nourani et al., 2018). AI can improve water treatment efficiency and automation by enabling real-time monitoring and control of treatment systems, minimizing energy consumption, and facilitating timely adjustments (Ismail et al., 2021). AI-based decision support systems assist operators in making informed choices regarding treatment strategies, resource allocation, and maintenance planning (Gunasekaran and Boopathi, 2023). AI has been recognized as a powerful tool for enhancing efficiency, optimizing resources, and improving decision-making in water treatment (Alam et al., 2022). By leveraging AI algorithms and big data analytics, water and wastewater companies can make more efficient decisions while improving water quality, customer service, and cost reduction (Jenny et al., 2022).

This review aims to introduce the role and impact of AI in water management and treatment by collecting and examining the latest scientific literature on AI, its various applications in the water and wastewater industry, and its connection to intelligent water resource management. In the local literature, there have been few focused studies on the role and impact of AI in water management. The article is structured into four sections. The second section elaborates on the research methodology. The third section presents the results and discussion of the research findings, and finally, the fourth section provides a summary of the results.

2. Methodology

This study is an applied research that, considering the significant role and impact of artificial intelligence in water management and treatment, aims to identify its transformative dimensions and potentials in the supply chain, treatment, and water services. It explores the potential benefits of AI in water management and hopes to provide valuable information for planners and decision-makers in this field. In terms of methodology, this research is descriptive-analytical, and data collection was conducted using a library-based approach by reviewing the latest available literature and searching for credible scientific research sources. The data used in this study were obtained through searches in reference scientific databases such as Scopus, Science Direct, and Google Scholar. The search keywords included water resources, artificial intelligence, smart management, water treatment, and water services. Subsequently, the various results were analyzed and summarized.

3. Results and Discussion

In the literature reviewed in this study, a broad spectrum of the capacities and roles of artificial intelligence (AI) in water management is presented, which includes: the role of AI in decision support systems and policy-making, reservoir management and flood control, data analysis and predictions regarding water availability and potential shortages, optimization of water treatment processes, leak detection and monitoring of infrastructure, management of water consumption, and its role in efficient irrigation systems. The categorized results, summarizing the capacities and roles of AI in water management, are presented in Table 1.

Table 1. Capacities and Roles of Artificial Intelligence in Water Management

Role	Capacity	References
Decision Support Systems	Provides data-driven insights for water resource management; evaluates various policies through scenario modeling and simulation; ensures informed decision-making for sustainable water management.	(Doorn, 2021) (Ray, 2023) (Sánchez et al., 2020) (Hmoud Al-Adhaileh and Waselallah Alsaade, 2021) (D'Amore et al., 2022)
Reservoir Management & Flood Control	Analyzes historical and real-time data using AI models for effective reservoir level management; predictive analysis plays a crucial role in implementing preventive flood control measures; minimizes the impact of extreme climatic events on communities.	(Niu and Feng, 2021) (Krishnan et al., 2022) (Ibrahim et al., 2022) (Boulouard et al., 2022) (Arabameri et al., 2020) (Pham et al., 2021)
Prediction	Analyzes large datasets including satellite imagery, weather forecasts, and sensor networks through AI algorithms to make accurate predictions regarding water availability and potential shortages; enables the adoption of proactive strategies against variable climatic conditions.	(Gorlapalli et al., 2022) (Hmoud Al-Adhaileh and Waselallah Alsaade, 2021) (Kavya et al., 2022)
Optimization of Treatment Processes	Predicts demand fluctuations and adjusts treatment processes accordingly; improves efficiency through smart control systems; reduces energy consumption; enhances overall water treatment standards.	(Alam et al., 2022) (Zhao et al., 2020) (Jawad et al., 2021) (Li et al., 2021)
Leak Detection & Infrastructure Monitoring	Real-time analysis of water distribution system data by monitoring pressure changes and flow patterns for early detection of leaks;	(Vanijjirattikhan et al., 2022) (Hu et al., 2021) (Fan et al., 2021) (Dawood et al., 2020)

	helps preserve infrastructure, reduce water loss, and ensure the longevity of water supply networks.	(Lowe et al., 2022) (Xiang et al., 2021)
Water Consumption Management	Monitors and manages water consumption for consumers using smart meters equipped with AI algorithms; provides personalized recommendations for water conservation through AI-driven applications; encourages responsible water usage at the individual level.	(Jenny et al., 2020) (Doorn, 2021)
Irrigation Systems	Assists in optimal water use by continuously monitoring soil moisture, weather dynamics, and plant needs.	(Talaviya et al., 2020) (Obaideen et al., 2022) (Ben Ayed and Hanana, 2021)

These various and diverse transformative potentials can provide key drivers for the adoption and integration of AI into water management programs as a revolutionary solution. Examining the roles and potential capacities of AI in the future management of water reveals that AI, through advanced algorithms and data-driven insights, provides unparalleled capabilities to enhance water security, optimize resource allocation, and reduce the impacts of climate change. This enables water management companies and utilities to make more efficient decisions aimed at improving water security, water quality, customer service, reducing costs, and increasing flexibility and resilience in the face of climate change.

One of the most significant transformations that AI can bring to the manner and quality of service delivery in the water and wastewater industry is related to the role and impact of AI in water quality and treatment. Access to clean water and sanitation is a fundamental aspect of human dignity, with the water and wastewater industry playing a crucial and decisive role in this regard. According to research from the United Nations Children's Fund (UNICEF), approximately 400,000 child deaths under five years of age are reported annually due to unsafe drinking water and poor sanitation. Each year, around 829,000 people die due to issues related to unsafe water and inadequate sanitation (Maurya et al., 2024). Figure 1 shows the annual death toll due to unsafe water consumption across various countries.

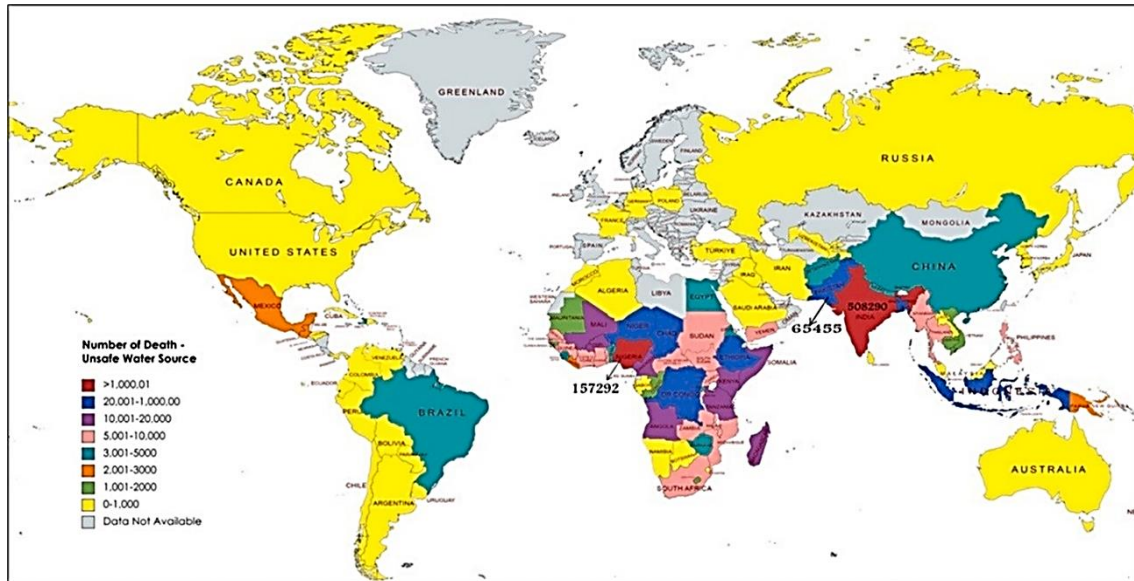


Figure 1. Global Map of Annual Deaths Due to Unsafe Water Consumption

(Source: Maurya et al., 2024)

India accounts for the highest annual mortality due to contaminated water, with more than 500,000 deaths. As shown in Figure 1, Iran ranks among the countries with the lowest mortality rates due to unsafe water consumption. Nonetheless, the use of AI can transform water treatment systems, elevate drinking water quality standards, and thus support the water and wastewater industry in fulfilling its critical role in safeguarding public health. In the reviewed literature, several examples of the impact of AI on the water treatment industry are presented, with categorized results shown in Table 2.

Table 2: Impacts and Capacities of Artificial Intelligence in the Water Treatment Industry

Impact	Capacity	References
Smart Treatment Systems	Adaptable to dynamic water quality conditions; equipped with sensors and AI algorithms to optimize filtration processes based on specific pollutants; ensures complete treatment and minimizes harmful substances in drinking water.	(Wu et al., 2021) (Lowe et al., 2022) (Alshehri et al., 2021)
Real-Time Water Quality Monitoring	Enables real-time monitoring of water quality parameters with AI-enabled sensors; allows rapid response to deviations from water quality standards; ensures a proactive approach to maintaining safe drinking water.	(Ighalo et al., 2021) (Jan et al., 2021) (Ramadhan et al., 2020) (Hmoud Al-Adhaileh and Waselallah Alsaade, 2021) (Li et al., 2021)

Prediction	Predicts changes in pollutant levels based on historical data and environmental factors; with this insight, water treatment plants can preemptively adjust processes, optimize efficiency, and maintain consistent water quality.	(Malviya et al., 2021) (Li et al., 2021)
Energy Efficiency	Enhances energy efficiency, reduces the environmental footprint of treatment processes, and aligns with sustainable methods by optimizing pump, valve, and other equipment operations.	(Kristian et al., 2024) (Chen et al., 2021)
Detection, Maintenance & Repair	Predicts equipment failures and schedules maintenance activities; facilitates automatic detection of issues; minimizes downtime; ensures continuous delivery of safe drinking water.	(Alam et al., 2022) (Doorn, 2021)

AI, through its rapid and accurate identification of various pollutants, clearly outperforms traditional water testing methods. Machine learning algorithms analyze complex datasets and enable early detection of contaminants that may compromise water quality. The adaptive nature of AI enables quick responses to emerging pollutants or water quality challenges. By identifying new threats, AI systems can quickly adjust settings in water treatment processes to deal with evolving risks. AI applications also provide personalized insights into water quality for consumers. By utilizing data from local treatment plants and real-time monitoring, individuals can make informed decisions regarding their consumption and take steps to address specific concerns. Overall, integrating AI technologies into water treatment plant programs can deliver better water quality at lower costs.

However, AI applications in water management face several challenges (Toryila et al., 2024). AI technologies in water treatment plants encounter challenges related to assumptions, data limitations, interpretation of analyses, data preprocessing, initialization, and conceptualization. Designing sensors and monitoring systems that assist in creating a large, systematic dataset and enable successful AI modeling is crucial (Chowdhury and Karanfil, 2024).

4. Conclusion

With climate change and resource constraints, the water industry faces significant challenges. Population growth, urbanization, and industrialization have increased the demand for clean water. Water resources have been polluted by both human activities and natural processes. On the other hand, extreme weather events are increasingly making water scarce, unpredictable,

and contaminated, placing additional pressure on water infrastructure, treatment processes, and system management. Artificial intelligence (AI) technology has the potential to transform the future of water and wastewater systems. The modeling capabilities of AI techniques in water and wastewater treatment processes are highly beneficial, as the automation of such facilities leads to easier, lower-cost operations and a significant reduction in human errors. AI technologies incorporate both linear and nonlinear relationships and process dynamics, which are typically impractical to model using conventional methods. The review findings also highlight the fact that AI provides unique capabilities to enhance water security, optimize resource allocation, and reduce the impacts of climate change. It enables water managers and utilities to make more efficient decisions aimed at increasing water security, improving water quality and customer services, reducing costs, and enhancing flexibility and resilience against the impacts of climate change.

However, the applications of AI technologies in water management face several challenges. One of the main challenges is the need for access to large and systematic datasets. Furthermore, there is a shortage of skilled human resources in the interdisciplinary field of water-AI expertise. The upgrading of infrastructure and the training of human resources are also essential prerequisites in this regard. Therefore, it is recommended that regulations and operational programs be established to promote the development of AI-based solutions in the water industry. These programs should focus on training human resources and equipping infrastructure to ensure the successful application of AI in the water sector. Establishing a national information portal for exchanging AI data related to the water sector will have a significant impact on aggregating and strengthening the necessary datasets. Universities, by establishing interdisciplinary training programs in water informatics and AI, will play a key role in developing specialized human resources in this field.

5. References

- Alam, G., Ihsanullah, I., Naushad, M. and Sillanpää, M., (2022). "Applications of artificial intelligence in water treatment for optimization and automation of adsorption processes: Recent advances and prospects". *Chemical Engineering Journal*, 427, p.130011.
- Alshehri, M., Bhardwaj, A., Kumar, M., Mishra, S. and Gyani, J., (2021). "Cloud and IoT based smart architecture for desalination water treatment". *Environmental research*, 195, p.110812.
- Arabameri, A., Saha, S., Mukherjee, K., Blaschke, T., Chen, W., Ngo, P.T.T. and Band, S.S., (2020). "Modeling spatial flood using novel ensemble artificial intelligence approaches in northern Iran". *Remote Sensing*, 12(20), p.3423.
- Ben Ayed, R. and Hanana, M., (2021). "Artificial intelligence to improve the food and agriculture sector". *Journal of Food Quality*, 2021(1), p.5584754.
- Boulouard, Z., Ouaisa, M., Ouaisa, M., Siddiqui, F., Almutiq, M. and Krichen, M., (2022). "An integrated artificial intelligence of things environment for river flood prevention". *Sensors*, 22(23), p.9485.

Chen, C., Hu, Y., Karuppiah, M. and Kumar, P.M., (2021). "Artificial intelligence on economic evaluation of energy efficiency and renewable energy technologies". *Sustainable Energy Technologies and Assessments*, 47, p.101358.

Chowdhury, S. and Karanfil, T., (2024). "Applications of Artificial Intelligence (AI) in Drinking Water Treatment Processes: Possibilities". *Chemosphere*, p.141958.

Chowdhury, S. and Husain, T., (2020). "Reducing the dimension of water quality parameters in source water: An assessment through multivariate analysis on the data from 441 supply systems". *Journal of Environmental Management*, 274, p.111202.

D'Amore, G., Di Vaio, A., Balsalobre-Lorente, D. and Boccia, F., (2022). "Artificial intelligence in the water–energy–food model: a holistic approach towards sustainable development goals". *Sustainability*, 14(2), p.867.

Dawood, T., Elwakil, E., Novoa, H.M. and Delgado, J.F.G., (2020). "Artificial intelligence for the modeling of water pipes deterioration mechanisms". *Automation in Construction*, 120, p.103398.

Ding, S., Li, H., Su, C., Yu, J. and Jin, F., (2013). "Evolutionary artificial neural networks: a review". *Artificial Intelligence Review*, 39, pp.251-260.

Doorn, N., (2021). "Artificial intelligence in the water domain: Opportunities for responsible use". *Science of the Total Environment*, 755, p.142561.

Fameso, F.O., Ndambuki, J.M., Kupolati, W.K. and Snyman, J., (2024). "On the Development of State-of-the-Art Computational Decision Support Systems for Efficient Water Quality Management: Prospects and Opportunities in a Climate Changing World". *Air, Soil and Water Research*, 17, p.11786221241259949.

Fan, X., Zhang, X. and Yu, X.B., (2021). "Machine learning model and strategy for fast and accurate detection of leaks in water supply network". *Journal of Infrastructure Preservation and Resilience*, 2, pp.1-21.

Ghandehari, S., Montazer-Rahmati, M.M. and Asghari, M., (2011). "A comparison between semi-theoretical and empirical modeling of cross-flow microfiltration using ANN". *Desalination*, 277(1-3), pp.348-355.

Gorlapalli, A., Kallakuri, S., Sreekanth, P.D., Patil, R., Bandumula, N., Ondrasek, G., Admala, M., Gireesh, C., Anantha, M.S., Parmar, B. and Yadav, B.K., (2022). "Characterization and prediction of water stress using time series and artificial intelligence models". *Sustainability*, 14(11), p.6690.

Gunasekaran, K. and Boopathi, S., (2023). "Artificial intelligence in water treatments and water resource assessments". In *Artificial Intelligence Applications in Water Treatment and Water Resource Management* (pp. 71-98). IGI Global.

Hmoud Al-Adhaileh, M. and Waselallah Alsaade, F., (2021). "Modelling and prediction of water quality by using artificial intelligence". *Sustainability*, 13(8), p.4259.

Hu, X., Han, Y., Yu, B., Geng, Z. and Fan, J., (2021). "Novel leakage detection and water loss management of urban water supply network using multiscale neural networks". *Journal of Cleaner Production*, 278, p.123611.

Ibrahim, K.S.M.H., Huang, Y.F., Ahmed, A.N., Koo, C.H. and El-Shafie, A., (2022). "A review of the hybrid artificial intelligence and optimization modelling of hydrological streamflow forecasting". *Alexandria*

Engineering Journal, 61(1), pp.279-303.

Ighalo, J.O., Adeniyi, A.G. and Marques, G., (2021). "Artificial intelligence for surface water quality monitoring and assessment: a systematic literature analysis". *Modeling Earth Systems and Environment*, 7(2), pp.669-681.

Ismail, W., Niknejad, N., Bahari, M., Hendradi, R., Zaizi, N.J.M. and Zulkifli, M.Z., (2021). "Water treatment and artificial intelligence techniques: a systematic literature review research". *Environmental Science and Pollution Research*, pp.1-19.

Jan, F., Min-Allah, N. and Düşteğör, D., (2021). "Iot based smart water quality monitoring: Recent techniques, trends and challenges for domestic applications". *Water*, 13(13), p.1729.

Jawad, J., Hawari, A.H. and Zaidi, S.J., (2021). "Artificial neural network modeling of wastewater treatment and desalination using membrane processes: A review". *Chemical Engineering Journal*, 419, p.129540.

Jenny, H., Alonso, E.G., Wang, Y. and Minguez, R., (2020). "Using artificial intelligence for smart water management systems". <https://doi.org/10.22617/brf200191-2>

Kamyab, H., Khademi, T., Chelliapan, S., SaberiKamarposhti, M., Rezaia, S., Yusuf, M., Farajnezhad, M., Abbas, M., Jeon, B.H. and Ahn, Y., (2023). "The latest innovative avenues for the utilization of artificial Intelligence and big data analytics in water resource management". *Results in Engineering*, p.101566.

Kavya, M., Mathew, A., Shekar, P.R. and Sarwesh, P., (2023). "Short term water demand forecast modelling using artificial intelligence for smart water management". *Sustainable Cities and Society*, 95, p.104610.

Krishnan, S.R., Nallakaruppan, M.K., Chengoden, R., Koppu, S., Iyapparaja, M., Sadhasivam, J. and Sethuraman, S., (2022). "Smart water resource management using Artificial Intelligence—A review". *Sustainability*, 14(20), p.13384.

Kristian, A., Goh, T.S., Ramadan, A., Erica, A. and Sihotang, S.V., (2024). "Application of ai in optimizing energy and resource management: Effectiveness of deep learning models". *International Transactions on Artificial Intelligence*, 2(2), pp.99-105.

Li, L., Rong, S., Wang, R. and Yu, S., (2021). "Recent advances in artificial intelligence and machine learning for nonlinear relationship analysis and process control in drinking water treatment: A review". *Chemical Engineering Journal*, 405, p.126673.

Lowe, M., Qin, R. and Mao, X., (2022). "A review on machine learning, artificial intelligence, and smart technology in water treatment and monitoring". *Water*, 14(9), p.1384.

Malviya, A. and Jaspal, D., (2021). "Artificial intelligence as an upcoming technology in wastewater treatment: a comprehensive review". *Environmental Technology Reviews*, 10(1), pp.177-187.

Maurya, B.M., Yadav, N., Amudha, T., Satheeshkumar, J., Sangeetha, A., Parthasarathy, V., Iyer, M., Yadav, M.K. and Vellingiri, B., (2024). "Artificial intelligence and machine learning algorithms in the detection of heavy metals in water and wastewater: Methodological and ethical challenges". *Chemosphere*, 353, p.141474.

Mishra, R.K., (2023). "Fresh water availability and its global challenge". *British Journal of Multidisciplinary and Advanced Studies*, 4(3), pp.1-78.

Niu, W.J. and Feng, Z.K., (2021). "Evaluating the performances of several artificial intelligence methods in forecasting daily streamflow time series for sustainable water resources management". *Sustainable Cities and Society*, 64, p.102562.

Nourani, V., Elkiran, G. and Abba, S.I., (2018). "Wastewater treatment plant performance analysis using artificial intelligence—an ensemble approach". *Water Science and Technology*, 78(10), pp.2064-2076.

Obaideen, K., Yousef, B.A., AlMallahi, M.N., Tan, Y.C., Mahmoud, M., Jaber, H. and Ramadan, M., (2022). "An overview of smart irrigation systems using IoT". *Energy Nexus*, 7, p.100124.

Pham, B.T., Luu, C., Van Phong, T., Nguyen, H.D., Van Le, H., Tran, T.Q., Ta, H.T. and Prakash, I., (2021). "Flood risk assessment using hybrid artificial intelligence models integrated with multi-criteria decision analysis in Quang Nam Province, Vietnam". *Journal of Hydrology*, 592, p.125815.

Ramadhan, A.J., Ali, A.M. and Kareem, H.K., (2020). "Smart water-quality monitoring system based on enabled real-time internet of things". *J. Eng. Sci. Technol*, 15(6), pp.3514-3527.

Ray, P.P., (2023). "Leveraging deep learning and language models in revolutionizing water resource management, research, and policy making: A case for ChatGPT". *ACS ES&T Water*, 3(8), pp.1984-1986.

Sánchez, J.M., Rodríguez, J.P. and Espitia, H.E., (2020). "Review of artificial intelligence applied in decision-making processes in agricultural public policy". *Processes*, 8(11), p.1374.

Talaviya, T., Shah, D., Patel, N., Yagnik, H. and Shah, M., (2020). "Implementation of artificial intelligence in agriculture for optimisation of irrigation and application of pesticides and herbicides". *Artificial Intelligence in Agriculture*, 4, pp.58-73.

Toryila, T.M., Obiora, O.C., Jiya, V. and Mustapha, M., (2023). "An overview of the application of artificial intelligence in water engineering". *International Journal of Engineering Science and Application*, 7(1), pp.22-31.

Vanijjirattikhan, R., Khomsay, S., Kitbutrawat, N., Khomsay, K., Supakchukul, U., Udomsuk, S., Suwatthikul, J., Oumtrakul, N. and Anusart, K., (2022). "AI-based acoustic leak detection in water distribution systems". *Results in Engineering*, 15, p.100557.

Wang, D. and Xiang, H., (2019). "Composite control of post-chlorine dosage during drinking water treatment". *IEEE Access*, 7, pp.27893-27898.

Wu, J., Cao, M., Tong, D., Finkelstein, Z. and Hoek, E.M., (2021). "A critical review of point-of-use drinking water treatment in the United States". *NPJ Clean Water*, 4(1), p.40.

Xiang, X., Li, Q., Khan, S. and Khalaf, O.I., (2021). "Urban water resource management for sustainable environment planning using artificial intelligence techniques". *Environmental Impact Assessment Review*, 86, p.106515.

Zhao, L., Dai, T., Qiao, Z., Sun, P., Hao, J. and Yang, Y., (2020). "Application of artificial intelligence to wastewater treatment: A bibliometric analysis and systematic review of technology, economy, management, and wastewater reuse". *Process Safety and Environmental Protection*, 133, pp.169-182.

Zhong, S., Zhang, K., Bagheri, M., Burken, J.G., Gu, A., Li, B., Ma, X., Marrone, B.L., Ren, Z.J., Schrier, J. and

Shi, W., (2021). "Machine learning: new ideas and tools in environmental science and engineering". *Environmental science & technology*, 55(19), pp.12741-12754.