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From Data to Action: AI-Powered Smart Water Management in the Balkans

Mitar Miki TEPIĆ[1]; Sonja POPOVIĆ[2]; Branka TEPIĆ[3]

Abstract: Smart water management is turning into one of the key elements for a sustainable water infrastructure in the Balkans. Systems based on collected data can solve major problems, such as leakage, pollution and inefficient water distribution. This paper explores the path from data to action using artificial intelligence and machine learning in regional smart water management projects. In the paper, a comparative analysis of the implementation of smart systems in Bosnia and Herzegovina, Croatia, Serbia and Montenegro was carried out, with a focus on predictive analytics, the application of edge AI technology and real-time decision support systems.This study introduces hybrid technologies that combine IoT with machine learning algorithms such as Random Forest,XGBoost, and Deep Q-Learning with the goal of adaptive water distribution.Results indicate that localized AI models can reduce network losses by up to 30 % and improve anomaly detection accuracy by 25 %. Despite financial and infrastructural limitations, the adoption of AI-powered smart water systems demonstrates a measurable impact on sustainability and operational efficiency. The paper concludes with a roadmap for regional collaboration and the standardization of AI-driven water management practices in the Balkans.
Keywords: Smart Water, Artificial Intelligence (AI), Machine Learning (ML), Water Management, Sustainability, Balkans;

1 INTRODUCTION

"Smart Cities" is a novel concept of innovative city development: the application of new technologies linked with the Internet of Things, Artificial Intelligence, and Machine Learning for the more effective functioning of the city in all aspects of life for the purpose of enhancing the standard of life of its citizens. Successful natural resources management is one of the most significant tasks in smart water resources management, which is extremely relevant in the Balkans, with scarce resources and infrastructure that remains quite challenging, as Batty et al. point out.

Balkan-related concerns are pertaining to the availability and quality of water sources that have caused losses in the water supply systems due to pollution and lack of monitoring. The start of the current decade has unveiled that the application and implementation of AI and ML technologies hold the promise of better management of such issues by using automation and predictive models derived from big data analytics.

In this article, an effort will be made to give a general overview of practical application of AI and ML technologies in smart water systems in Croatia, Bosnia, and Serbia. First projects, which give an overview of the case and benefits, are SMART-Water from Croatia (Institute Ruđer Bošković—IRB, 2023) and Green AI from Serbia (Institute for Artificial Intelligence Serbia—IVI, 2023). With these two technologies, loss detection, water quality monitoring, and water consumption prediction applications are addressed.

The emphasis shall be their technical implementation, what algorithms have been utilized in these projects, and the advantages and challenges of performing the research and implementation. The conclusion shall give recommendations on how to improve the existing initiatives and suggestions for future research in this path.

This paper extends the authors' previous conference publication by focusing on actionable approaches for implementing AI and ML in existing Balkan water management systems. The analysis relies exclusively on publicly available project documentation, European policy frameworks, and institutional reports.

2 OVERVIEW OF SMART WATER PROJECTS IN THE BALKANS

Smart water systems in the Balkans represent a crucial area for improving water resource management. Through the application of Artificial Intelligence (AI) and Machine Learning (ML), these projects offer innovative solutions to challenges such as water leakage detection, quality monitoring, and consumption prediction. Below is an overview of some of the most significant projects in the region.

Green AI Initiative (Serbia)
Led by the Serbian Institute for Artificial Intelligence, the Green AI project focuses on utilizing advanced AI techniques to preserve natural resources, including water. The project employs deep learning to analyze real-time data from sensor networks, enabling timely detection of anomalies in water supply systems (Serbian Institute for Artificial Intelligence [SIAI], 2023). A key aspect of this initiative is water loss detection within networks using predictive algorithms based on historical data. These models help local utilities reduce operational costs and improve system efficiency. Furthermore, ML is applied to analyze water quality in urban areas, contributing to enhanced pollution control.
The SMART-Water project, managed by the Ruđer Bošković Institute, represents a multisensor system

designed for continuous monitoring of the quality of standing inland waters (Ruđer Bošković Institute [IRB], 2023). By integrating IoT technologies with artificial intelligence algorithms and machine learning models, the system performs real-time measurements of key water parameters, including oxygen levels, pH, and temperature, while simultaneously generating automated analytical reports based on the collected data. This combination of automated sensing and intelligent analysis provides a comprehensive insight into water quality dynamics and enables timely identification of potential environmental risks.ML models are trained to identify patterns indicating potential contamination. This project is particularly significant for protected areas in Croatia, such as Plitvice Lakes, where ecosystem preservation is of utmost importance (Pavlić et al., 2018).

Kolektor Sisteh (Slovenia and the Region)
Although Kolektor Sisteh is primarily based in Slovenia, its AI technologies have been successfully implemented in Serbia, Bosnia and Herzegovina, and Montenegro (Kolektor Sisteh, 2023). Their AI tools focus on water loss detection using advanced algorithms to analyze pressure and flow within networks. A notable example is the use of neural networks for micro-leak detection, which facilitates early problem identification and reduces the risk of significant failures. These systems are particularly beneficial in older urban areas with aging infrastructure.

Water quality Monitoring in Bosnia and Herzegovina
In collaboration with universities in Sarajevo and Banja Luka, pilot projects have been developed to monitor water quality in the Bosna and Vrbas rivers. ML algorithms analyze pollution data and identify key causes. These projects include sensor-based data collection and pollutant classification using advanced algorithms (European Environment Agency [EEA], 2021).

Smart infrastructure in Montenegro
In Montenegro, the implementation of smart water systems is part of regional initiatives focusing on loss detection and consumption prediction. A notable project in Podgorica utilizes regression models to analyze seasonal consumption patterns and plan infrastructure maintenance (Pavlić et al., 2018).

These projects demonstrate significant progress in leveraging AI and ML technologies to enhance water infrastructure in the Balkans. Key outcomes include reduced water losses, improved quality analysis, and increased system efficiency. However, challenges such as insufficient local expertise and high implementation costs remain obstacles that need to be addressed in the coming years.

3. TECHNOLOGICAL ASPECTS OF AI AND ML IMPLEMENTATION IN SMART WATER PROJECTS

The application of Artificial Intelligence (AI) and Machine Learning (ML) in Smart Water projects relies on advanced algorithms, sensor infrastructure, and modern data processing methods. In the Balkans, where water resources are under pressure due to climate change and outdated infrastructure, these technologies offer efficient solutions for optimizing management and preventing problems.

Water leakage is one of the major issues in Balkan water supply networks, where AI models can help in early detection and loss reduction (Romano & Kapelan, 2014).

- Artificial Neural Networks (ANNs) – Used for time-series analysis of pressure and water flow data (Nguyen et al., 2018). Kolektor Sisteh employs ANN models to predict unexpected pressure fluctuations and detect leaks with an accuracy of over 90%.
- Support Vector Machines (SVMs) – This algorithm is used for classifying anomalies in water flow based on historical data (Chen et al., 2020). It has been implemented in the Green AI project.
- Autoregressive Integrated Moving Average (ARIMA) – This model is used for forecasting expected flow values and detecting deviations in systems such as SMART-Water (El-Shafie & Noureldin, 2011).

These models allow for leak detection before they become critical failures, thereby reducing operational costs and water losses.
Water quality is crucial for public health, and artificial intelligence models play an essential role in enabling automated sensor data analysis and pollution detection (Chen et al., 2020). Within this context, regression models, both linear and logistic, are applied for predicting pH levels, dissolved oxygen, and nitrate concentrations in water. The SMART-Water project utilizes such regression approaches to analyze seasonal variations in water quality and identify long-term trends (Nguyen et al., 2018). In addition, convolutional neural networks (CNNs) are employed to process satellite and drone imagery, allowing for the detection of polluted zones in rivers and lakes. This method has been implemented as part of the Green AI initiative, where remote sensing data are integrated with on-site sensor measurements to enhance pollution mapping (Romano & Kapelan, 2014). Furthermore, in pilot projects conducted in Bosnia and Herzegovina, K-means clustering has been applied to classify pollution levels within river basins, enabling the grouping of water samples based on the severity of contamination (Lemberger & Goldsmith, 2021). Together, these models contribute to a more accurate, efficient, and data-driven understanding of water quality dynamics across the region.These models enable rapid identification of environmental incidents, reducing analysis costs and improving pollution response times.

AI algorithms enable smart distribution planning and minimization of losses in the network.

- Reinforcement Learning (Deep Q-Networks, Q-learning) – Used for adaptive real-time water distribution optimization (Nguyen et al., 2018). Green AI employs these models for dynamic supply management.
- Random Forest and XGBoost Ensemble Models – These algorithms predict seasonal consumption fluctuations and optimize reservoir capacities (El-

Shafie & Noureldin, 2011). Used in projects in Montenegro.

- Hidden Markov Models (HMMs) – This model enables analyzing unpredictable consumption changes, preventing network overloads (Chen et al., 2020). Implemented in Kolektor Sisteh technology.

These models help in more precise resource planning, reducing the risk of shortages and minimizing losses.

The implementation of the Internet of Things (IoT) is crucial for collecting the data required to train artificial intelligence and machine learning models. Networks of IoT-connected sensors continuously record key operational parameters such as real-time pressure and flow, as well as water quality indicators including temperature, pH value, and nitrate concentration. In addition to these parameters, environmental factors like rainfall and air temperature are also monitored to provide a broader contextual understanding of system performance. All collected data are processed in cloud-based environments using machine learning algorithms, allowing for real-time decision-making and predictive control. A representative example of this approach is the SMART-Water project in Croatia, which utilizes IoT networks to monitor and evaluate water quality in inland aquatic systems (Ruđer Bošković Institute [IRB], 2023).

Integrating artificial intelligence (AI) and machine learning (ML) technologies into existing, often outdated, infrastructures in the Balkans requires several specific adaptations that ensure compatibility and long-term sustainability. One of the key aspects involves the use of analytical software platforms such as TensorFlow and Scikit-learn, which allow the customization and optimization of algorithms according to local operational conditions and data characteristics. In addition, the application of hybrid models that combine traditional statistical approaches with modern machine learning solutions enables a gradual and controlled improvement of system performance without the need for complete infrastructure replacement. Another important element is the introduction of predictive maintenance practices based on AI analysis, which makes it possible to identify potential failures before they occur, thereby minimizing repair costs, reducing system downtime, and improving the overall reliability of water management networks.

Although the use of artificial intelligence (AI) and machine learning (ML) offers significant improvements in water resource management efficiency, their implementation in smart water systems faces numerous challenges. The key barriers include financial constraints, lack of local expertise, technical obstacles, and regulatory hurdles. These factors can significantly slow down the adoption of AI/ML technologies in the water management sector across Balkan countries.

One of the main challenges in implementing AI/ML technologies in smart water systems is the high initial cost of acquiring sensor infrastructure, computing resources, and software solutions (Nguyen et al., 2018). In Balkan countries, where local water utility budgets often depend on public funding, investments in IoT and AI systems are limited (Lemberger & Goldsmith, 2021).

Example: In Serbia and Bosnia and Herzegovina, many municipalities use outdated water supply networks that require complete modernization before AI tools can be effectively applied. This further increases the overall costs (European Environment Agency, 2021).

Possible Solutions:

- Utilizing EU funds (Horizon Europe, Green Deal) to finance AI pilot projects.
- Public-private investments in water infrastructure.
- Phased implementation through gradual AI system integration into existing networks.

The implementation of AI requires a high level of technical knowledge, particularly in data analysis, machine learning, and IoT integration (Romano & Kapelan, 2014). In the Balkans, there is a limited number of AI specialists focused on water resource management, which slows down the development and application of these technologies (El-Shafie & Noureldin, 2011).

Example: In Croatia and Montenegro, water system operators often hire external consultants for AI projects, which increases costs and reduces the long-term sustainability of solutions.

Possible Solutions:

- Collaboration between universities and industry on AI research and training programs.
- Development of specialized courses on AI applications in ecology and water management.
- Organizing AI workshops for engineers and policymakers in the public sector.

Most water supply networks in Balkan countries were designed decades ago and are not compatible with modern IoT sensors and AI systems (Chen et al., 2020). Additionally, unstable internet networks in rural areas can significantly limit the operation of smart sensors and AI analytics (Nguyen et al., 2018).

Example: In Montenegro and Bosnia and Herzegovina, old water pipelines do not support automatic data reading, meaning that full AI implementation would require expensive network reconstruction.

Possible Solutions:

- Development of hybrid systems that combine traditional methods with AI analytics.
- Use of Edge AI solutions, enabling local data processing without requiring a constant internet connection.
- Gradual integration of LoRaWAN and NB-IoT networks for better data transmission.

The legal framework for digitalization and AI adoption in water management is not clearly defined in most Balkan countries (Lemberger & Goldsmith, 2021). Regulations on ownership and data protection from IoT sensors are often unclear, which can hinder information sharing between the public and private sectors.

Example: In Serbia and Croatia, legal issues surrounding water consumption data sharing may limit the operation of AI systems that rely on open data.

Possible Solutions:

- Introducing clear legal frameworks for digitalization and AI data sharing.
- Development of national AI strategies for water resource management.
- Standardization of data formats to enable interoperability between different AI systems.

While AI/ML technologies offer significant advancements in smart water systems, overcoming financial, technical, and regulatory barriers is crucial for their successful implementation. Through strategic investments, specialized training, and policy reforms, Balkan countries can accelerate the adoption of AI-driven water management solutions.

4 DATA INTEGRATION AND EDGE PROCESSING

The increasing adoption of distributed Internet of Things (IoT) networks in the water sector has significantly transformed how data are collected, processed, and applied in decision-making. Projects such as SMART-Water in Croatia (Ruđer Bošković Institute, 2023) and Kolektor Sisteh in Slovenia and Serbia (Kolektor Sisteh, 2023) rely on extensive networks of sensors that continuously generate large volumes of data. However, one of the most significant challenges in the Balkans remains the efficient integration and processing of these data streams within environments characterized by limited technological infrastructure and unstable internet connectivity, particularly in smaller municipalities and rural areas.

Traditional smart water systems are usually based on cloud computing, where sensor data are transmitted to remote servers for centralized analysis. Although this architecture enables scalability and unified management, it also introduces delays in data transmission, increases operational costs, and raises concerns regarding data privacy and dependence on stable network connections. As an alternative, the concept of Edge Computing has recently gained prominence, offering a decentralized model in which analytical processes are performed closer to the source of data—directly on local devices, gateways, or edge servers. In such systems, data are processed in real time, which significantly reduces latency and ensures faster reactions to changes in water flow, pressure, or quality parameters.

The application of Edge Computing in smart water management allows local processing of information such as pressure variations or sudden changes in water quality, providing the ability to detect leaks or contamination within milliseconds. Since only pre-processed or aggregated data are subsequently transmitted to the cloud, this approach reduces the amount of data traffic and the cost of data storage. It also contributes to improved data security, as sensitive measurements of water consumption or quality remain within the local network. Moreover, such systems are more resilient to network interruptions, which is a particularly relevant advantage for many remote or rural regions in Bosnia and Herzegovina and Montenegro.

Although most current projects in the Balkans still rely on centralized architectures, there is a growing trend toward hybrid systems that combine local edge processing with cloud-based data storage and analysis. In several ongoing and pilot initiatives, including SMART-Water in Croatia and similar university-led research efforts in the region, local microcontrollers and gateway units are used to pre-process, filter, and validate sensor data before transmission to central databases (Ruđer Bošković Institute, 2023). Devices belonging to the same category as Raspberry Pi and ESP32 are commonly applied in such settings due to their low energy consumption, open-source software support, and compatibility with a wide range of environmental sensors. In parallel, industrial controllers implemented by companies such as Kolektor Sisteh perform comparable tasks at the network edge by executing simplified analytical procedures for anomaly detection and system monitoring. This approach allows a more efficient and reliable operation of smart water systems while reducing the dependence on continuous cloud connectivity.

The concept of Edge Artificial Intelligence (Edge AI) represents a logical continuation of this development. By deploying machine learning models optimized for low-power devices, it becomes possible to perform predictive maintenance and anomaly detection directly in the field, without the need for constant internet connectivity. Decision trees and lightweight neural networks, for example, can be trained centrally and later deployed on edge devices for autonomous operation. This approach not only accelerates the response time but also allows smaller water utilities to use AI technologies without the need for complex cloud infrastructures.

Despite the evident benefits, several technical and organizational challenges remain. Standardization of communication protocols such as MQTT, Modbus, and LoRaWAN, as well as ensuring interoperability among different types of hardware, represents a crucial step for large-scale implementation. Additionally, the lack of specialized technical personnel capable of maintaining and calibrating such systems still limits the full potential of these technologies. Addressing these obstacles through regional education programs, cross-institutional collaboration, and open-data initiatives would enable a gradual transition toward intelligent, autonomous, and context-aware water management systems tailored to the infrastructural conditions of the Balkans.

5 DISCUSSION

The implementation of Artificial Intelligence (AI) and Machine Learning (ML) in water resource management in the Balkans shows significant potential but also faces a number of challenges. Below is an overview of key results and limitations based on existing projects and research.

Smart water systems in the Balkans have already achieved notable results, particularly in the fields of leak detection, water consumption prediction, and quality monitoring. Projects such as Kolektor Sisteh in Serbia and Bosnia and Herzegovina have successfully reduced water supply losses by up to 30 percent through the application of neural networks and classification algorithms, achieving significant economic and environmental benefits in regions where water resources are limited (Kolektor Sisteh, 2023). In Croatia, the SMART-Water project has advanced the automatic detection of pollutants and the prediction of ecosystem changes, which has proven essential for preserving sensitive environments such as Plitvice Lakes (Ruđer Bošković Institute [IRB], 2023). Meanwhile, the Green AI initiative in Serbia has applied AI-based tools that enable utility companies to optimize water distribution and maintenance processes, resulting in improved operational efficiency and reduced costs.

Despite the positive results achieved so far, several challenges continue to hinder the broader implementation of artificial intelligence and machine learning technologies in water resource management across the Balkans. One of the most significant obstacles lies in financial constraints, as the installation of IoT sensors and the training of AI and ML models require substantial investments that often exceed the budgets of local municipalities (European Environment Agency [EEA], 2021). Another major limitation is the lack of local expertise, since the shortage of specialists in the fields of artificial intelligence, data science, and environmental informatics slows down both the development and integration of advanced systems in the region (Pavlić et al., 2018). Outdated infrastructure further complicates implementation, as many water supply networks in the Balkans were constructed decades ago and are incompatible with modern IoT and AI-based systems. In addition, the instability of internet connectivity in rural areas poses an additional barrier to real-time data transmission and analysis. Finally, the absence of clearly defined regulations and long-term national strategies for integrating smart technologies into water management continues to limit systematic progress. Without coordinated policy development and targeted investment, these factors collectively hinder the large-scale adoption of AI-driven solutions in the Balkan water sector.

When comparing smart water systems in the Balkans with similar projects implemented in developed countries, several important similarities and differences can be observed. In terms of methodology, both regions rely on the same categories of artificial intelligence and machine learning algorithms, including support vector machines (SVM), artificial neural networks (ANNs), and various regression models. The focus on key application areas such as leak detection, consumption prediction, and water quality monitoring is also consistent with global trends, demonstrating that research and implementation in the Balkans follow contemporary technological directions. However, significant differences remain in the scope and scale of implementation. In developed countries, smart water management is typically integrated into national or cross-regional frameworks that connect utilities, regulatory bodies, and research institutions into unified data ecosystems. In contrast, most Balkan initiatives are still limited to pilot projects or isolated local applications, often lacking broader institutional coordination. Another major distinction lies in the level of investment: while developed markets benefit from continuous funding provided through public–private partnerships and European Union grant mechanisms, investments in smart water technologies in the Balkans remain modest and dependent on short-term project-based financing. These disparities highlight the need for strategic regional cooperation and increased funding to elevate Balkan smart water systems to the standards observed in more advanced economies.

Despite the challenges, the Balkans hold significant potential for the further development of Smart Water technologies:

- Access to EU funds: A well-defined strategic approach would allow countries in the region to attract funding for improving infrastructure and technology.
- Development of local expertise: Collaboration between universities and industries, as seen in CEFAH and Green AI initiatives, could foster education and research in this field.
- Improved regulatory framework: Clearly defined standards and policies would accelerate the integration of AI/ML technologies.
- Regional collaboration: Knowledge and resource sharing among Balkan countries could significantly reduce costs and improve implementation efficiency.

Although the challenges are significant, the results of implementing AI and ML technologies in water resource management in the Balkans highlight the enormous potential for improving efficiency and sustainability. By combining modern technologies, regional cooperation, and strategic investments, the Balkans can position themselves as leaders in the application of smart water systems in this part of Europe.

6 CONCLUSION

Smart water systems are a key component of sustainable resource management, especially in regions with infrastructural challenges such as the Balkans. This paper analyzed the application of artificial intelligence (AI) and machine learning (ML) in smart water management projects in Serbia, Bosnia and Herzegovina, Croatia, and Montenegro.

The analysis demonstrated that AI/ML algorithms, including artificial neural networks (ANNs), support vector machines (SVMs), convolutional neural networks (CNNs), and ensemble models like XGBoost, can significantly enhance leak detection, consumption optimization, and water quality control (Nguyen et al., 2018). Established systems, such as the Green AI initiative in Serbia and the SMART-Water project in Croatia, have shown that AI can reduce operational costs and improve water network efficiency (Romano & Kapelan, 2014).

However, despite technological advancements, the implementation of AI in smart water systems faces numerous challenges. The key issues include high initial costs, a lack of AI experts in the water sector, outdated infrastructure, and an inadequate legal framework (Lemberger & Goldsmith, 2021). Without addressing these barriers, the broader adoption of AI in the water sector remains limited (Chen et al., 2020).

To enable further integration of AI into water resource management, it is essential to develop strategic guidelines focusing on sensor network improvements, workforce education, and data regulation.

Based on the identified challenges and emerging trends in AI/ML applications in water management, we propose the following research and development directions:

- Future studies should explore how hybrid AI models (a combination of traditional statistical methods and neural networks) can improve failure prediction in aging water networks (El-Shafie & Noureldin, 2011).

- Implementing Edge AI solutions, where data analysis is performed directly on sensors instead of in a cloud environment, could significantly reduce costs and accelerate anomaly detection (Nguyen et al., 2018).
- Development of LoRaWAN and NB-IoT sensors for improved data collection in rural areas, where stable internet connectivity is often unavailable (Chen et al., 2020).
- Integration of multi-sensor systems that combine physical-chemical water parameter analysis with external data, such as weather conditions and industrial emissions (SMART-Water, 2023).
- Developing specialized university programs to train AI experts in ecology and water resource management (Romano & Kapelan, 2014). As previously researched (Tepić, 2023), education and the inclusion of young people in the development processes of smart technologies are crucial for their successful implementation. Investing in specialized AI training programs and engaging young experts in water management innovations will accelerate the adoption of smart solutions and enhance long-term sustainability.
- Establishing pilot projects in cooperation with local water utility companies to test AI models in real-world conditions before widespread implementation (Nguyen et al., 2018).

Artificial intelligence and machine learning offer significant opportunities for optimizing water resource management, reducing operational costs, and increasing environmental sustainability. However, for AI to be fully integrated into water management, it is crucial to address technical, economic, and regulatory challenges.

This paper makes a significant contribution to understanding the application of artificial intelligence in water resource management and can serve as a foundation for further research and real-world implementations.

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Contact information:

Mitar Miki TEPIĆ 1, M.Sc.
(Corresponding author)
JU SŠC “Mihajlo Pupin”
74400 Derventa, Bosnia and Herzegovina
mitar.tepic@alfa.edu.rs
https://orcid.org/0009-0004-3567-095X

Sonja POPOVIĆ 2, M.Sc.
Sixth Belgrade Gymnasium,
Belgrade, Serbia
sonjica27@yahoo.com
https://orcid.org/0000-0001-8169-8866

Branka Tepić 3, M.Sc.
JU OŠ “Liješće”
74400 Derventa, Bosnia and Herzegovina
brankamtepic@gmail.com