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IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING IN SMART WATER PROJECTS IN THE BALKANS

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Abstract: Smart cities represent a key concept in modern urban planning, where smart water resource management plays a central role. This paper analyzes current Smart Water projects in Serbia, Bosnia and Herzegovina, Croatia, and Montenegro, with a special focus on the implementation of artificial intelligence (AI) and machine learning (ML). The emphasis is placed on practical examples such as water consumption prediction, leakage detection, and water quality monitoring.Through an analysis of projects like the Green AI initiative, the SMART-Water system, and innovations by the Kolektor Sisteh company, the paper examines the technologies and algorithms utilized. The main findings demonstrate the significant efficiency of AI/ML models in improving the sustainability of water resources and optimizing costs. However, challenges such as technical implementation and the lack of local expertise remain open issues.In conclusion, the paper provides a comprehensive overview of the current state and proposes future steps toward advancing AI/ML technologies within Smart Water projects 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.

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.

SMART-Water Project (Croatia)
The SMART-Water project, managed by the Ruđer Bošković Institute, is a multisensor system designed for monitoring the quality of standing inland waters (Ruđer Bošković Institute [IRB], 2023). By combining IoT technologies, AI algorithms, and ML models, the system enables:

- Continuous monitoring of oxygen levels, pH, and water temperature.

- Automated generation of reports based on data analysis.

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 AI models enable automated sensor data analysis and pollution detection (Chen et al., 2020).

- Regression Models (Linear and Logistic Regression) – Used for predicting pH levels, dissolved oxygen, and nitrate concentrations in water. SMART-Water utilizes regression models for analyzing seasonal changes in water quality (Nguyen et al., 2018).
- Convolutional Neural Networks (CNNs) – These networks analyze satellite and drone images to identify polluted zones in rivers and lakes (Romano & Kapelan, 2014). Implemented in the Green AI initiative.
- K-means Clustering – Used in pilot projects in Bosnia and Herzegovina to classify pollution levels in river basins. This algorithm enables grouping water samples based on pollution severity (Lemberger & Goldsmith, 2021).

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 data required to train AI and ML models. IoT-connected sensors capture:

- Real-time pressure and flow data.
- Water quality parameters (temperature, pH, nitrate concentration).
- Environmental factors (e.g., rainfall and air temperature).

These data are processed in the cloud using ML algorithms, enabling real-time decision-making. For instance, the SMART-Water project uses IoT networks for monitoring water quality in Croatia (Ruđer Bošković Institute [IRB], 2023).

Integrating AI and ML technologies into existing, often outdated, infrastructures in the Balkans requires specific adaptations:

- Analytical software platforms: Tools such as TensorFlow and Scikit-learn enable customization of algorithms to local conditions.
- Hybrid models: Combine traditional methods and modern ML solutions to gradually improve system performance.
- Predictive maintenance: AI tools help identify potential failures before they occur, reducing repair costs and operational disruptions.

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).
PossibleSolutions:

- 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 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 leak detection, water consumption prediction, and quality monitoring:

- Reduction of water losses: Projects such as Kolektor Sisteh in Serbia and Bosnia and Herzegovina have successfully reduced water supply losses by up to 30% through the use of neural networks and classification algorithms (Kolektor Sisteh, 2023). This reduction has significant economic and environmental benefits, especially in regions with limited water resources.
- Improvement of water quality: The SMART-Water project in Croatia has enabled the automatic detection of pollutants and the prediction of ecosystem changes, ensuring the protection of sensitive areas such as Plitvice Lakes (Ruđer Bošković Institute [IRB], 2023).
- Optimization of operations: AI tools used in the Green AI initiative in Serbia have allowed utility companies to optimize water distribution and maintenance, resulting in reduced operational costs.

Despite positive results, several challenges hinder the broader implementation of AI and ML technologies in water resource management:

- Financial constraints: Installing IoT sensors and training AI/ML models requires significant investment, often exceeding the budgets of local municipalities (EEA, 2021).
- Lack of local expertise: The shortage of AI specialists in the region slows down the development and integration of advanced systems (Pavlić et al., 2018).
- Outdated infrastructure: Many water networks in the Balkans are decades old, making it difficult to install modern IoT systems. Additionally, the lack of stable internet connections in rural areas further complicates implementation.
- Lack of regulations and strategies: Clearly defined policies and strategies for integrating smart technologies into water resource management are still underdeveloped, complicating long-term planning.

Comparison with global standards
When comparing smart water systems in the Balkans with similar projects in developed countries, several similarities and differences can be identified:

- Similarities:
  - The same AI/ML algorithms are used, such as SVM, ANNs, and regression models.
  - The focus on leak detection and water quality monitoring aligns with global trends.
- Differences:
  - Scope of Implementation: In developed countries, integrated national systems are common, while in the Balkans, projects are mainly limited to pilot initiatives and local implementations.
  - Investments: Investments in smart water technologies in the Balkans significantly lag behind developed

markets, where funding is more readily available through public-private partnerships and EU grants.

Opportunities for the future

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.

5 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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