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USING ARTIFICIAL INTELLIGENCE FOR HYDROLOGICAL MODELLING

Abstract. Hydrological modelling plays a critical role in managing water resources, especially in arid and semi-arid regions where water scarcity is a major challenge. With the emergence of artificial intelligence (AI), hydrological modelling has experienced a significant transformation in recent years. This paper reviews the recent advances in AI-based hydrological modelling and examines its potential applications in water resource management. The study highlights the role of AI in enhancing the accuracy of hydrological models and facilitating more efficient and sustainable water management practices. The results suggest that AI-based hydrological models have the potential to revolutionize the way water resources are managed, and that future research in this area is warranted.

Keywords: hydrological modelling, artificial intelligence, water resources, water management.

Introduction. Hydrological modelling is a critical tool for managing water resources, particularly in regions where water scarcity is a major concern. Hydrological models use mathematical equations to simulate the behavior of the water cycle, including precipitation, evapotranspiration, surface runoff, and groundwater recharge. These models are used to predict the quantity and quality of water in a watershed, which is essential for effective water resource management [1].

In recent years, the emergence of artificial intelligence (AI) has transformed hydrological modelling. AI is a branch of computer science that uses algorithms and machine learning techniques to enable machines to perform tasks that typically require human intelligence. AI-based hydrological models have shown great promise in improving the accuracy of hydrological predictions and facilitating more sustainable water management practices.

This paper reviews recent advances in AI-based hydrological modelling and discusses their potential applications in water resource management. The study explores the role of AI in enhancing the accuracy of hydrological models and improving water management practices. The paper concludes by identifying key areas for future research in this field.

Hydrological systems, ranging from local river sections to global scales, are undergoing increasing complexity due to the dynamic interplay between natural processes and human activities. Addressing the nonlinearity inherent in the behavior of these systems is a formidable challenge for traditional hydrological approaches. Moreover, the analysis of large-scale hydrological systems demands the handling of voluminous real-time data. In recent years, artificial intelligence (AI), particularly deep learning, has emerged as a potent tool for processing massive data sets and tackling large-scale nonlinear hydrological problems. The potential of AI extends from computer vision and bioinformatics to climate science, where it has demonstrated capabilities comparable to, and sometimes exceeding, human expertise [2].

1. Advances in AI-Based Hydrological Modelling. AI-based hydrological modelling has emerged as a promising approach to improve the accuracy of hydrological predictions. The most commonly used AI techniques in hydrological modelling are artificial neural networks (ANNs) and support vector machines (SVMs). ANNs are a set of interconnected nodes that process information and can learn from experience. SVMs are a type of machine learning algorithm that can be used for classification and regression analysis.

AI-based hydrological models have several advantages over traditional hydrological models. First, they can incorporate a wide range of variables and data sources, including remote sensing data, climate data, and ground-based observations. Second, they can handle large amounts of data and complex relationships between variables. Third, they can learn from experience and improve their accuracy over time [3].

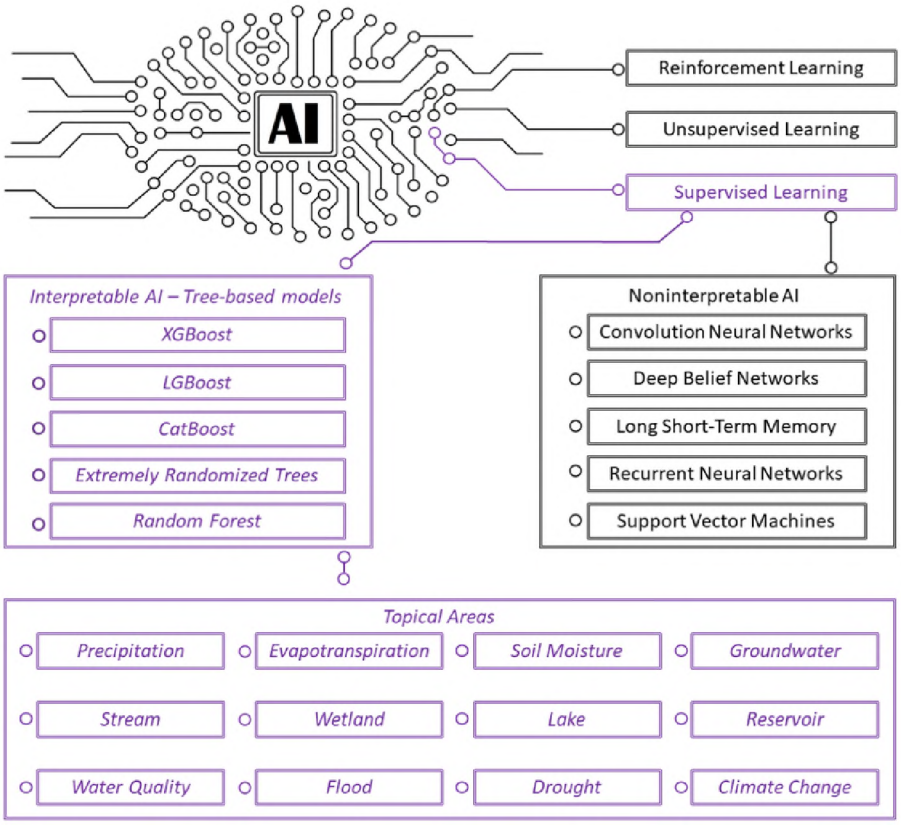

Figure 1 – Taxonomy of AI and actual study fields [4]

AI-based hydrological models have been applied to a wide range of hydrological problems, including flood forecasting, drought monitoring, and water quality modelling. For example, AI-based flood forecasting models have been developed that can provide accurate predictions of flood events in real-time (figure 1). These models use a combination of radar and satellite data to estimate rainfall, and then use ANNs to predict flood levels in rivers and streams.

AI-based drought monitoring models have also been developed that use remote sensing data to estimate vegetation health and soil moisture levels. These models can provide early warning of drought conditions, allowing for more effective water management practices [5].

AI-based water quality models have been developed that use SVMs to predict the levels of pollutants in water bodies. These models can help identify the sources of pollution and guide management practices to improve water quality.

Contributions from Baghanam et al. (2022) addressed the selection of dominant large-scale climate variables in the statistical downscaling of climate models, introducing a wavelet coherence transform and artificial neural networks [6]. de Moura et al. (2022) evaluated the performance of Long Short-Term Memory (LSTM) networks for discharge prediction under changing climate conditions, offering insights into the robustness and limitations of AI-based models [7]. Nourani (2022) emphasized the practicality of self-organizing map clustering in identifying specific soil moisture conditions from satellite images, showcasing the potential for AI in extracting meaningful information from remote sensing data [8].

2. Potential Applications in Water Resource Management. AI-based hydrological models have the potential to revolutionize the way water resources are managed. By providing more accurate and timely predictions of water availability, these models can help water managers make more informed decisions about water allocation and use (figure 2).

For example, AI-based flood forecasting models can help reduce the risk of flooding and minimize damage to infrastructure and property. These models can also help emergency managers to plan for and respond to flood events more effectively. Similarly, AI-based drought monitoring models can help water managers to identify areas that are most vulnerable to drought conditions and allocate water resources more efficiently [9].

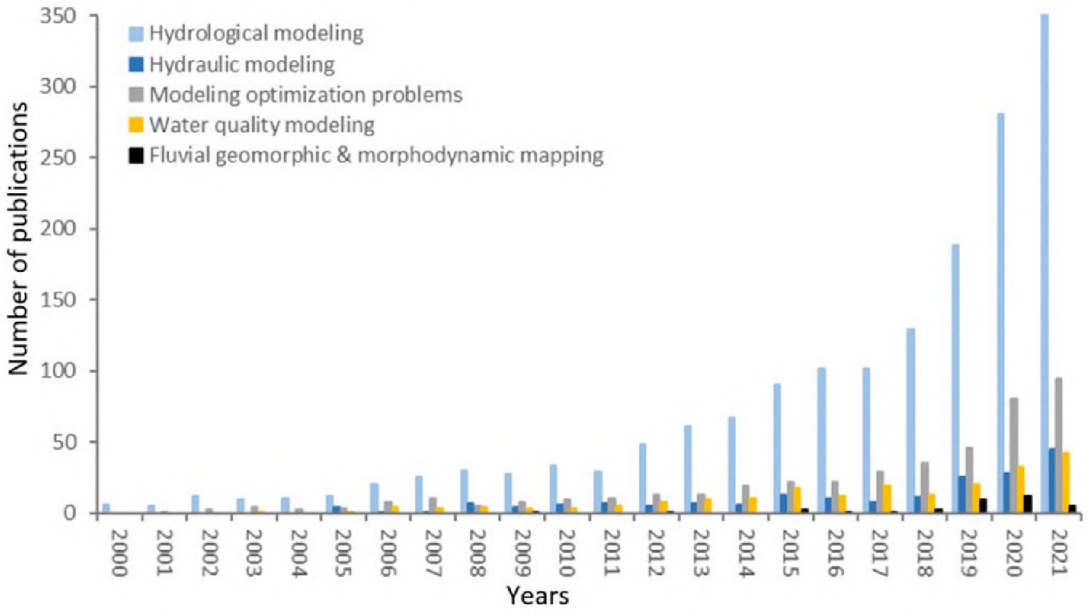

Figure 2 – The yearly number of publications found in Web of Science (2000-2021) on AI and machine learning applications in the different hydrological subfields [10]

AI-based hydrological models can also be used to improve water allocation and irrigation practices. For example, AI-based models can be used to predict crop water requirements and optimize irrigation scheduling, resulting in more efficient water use and increased crop yields. These models can also be used to predict the impacts of climate change on water resources, allowing for more proactive planning and management of water resources [11].

AI-based models can also help to identify and mitigate water quality issues. By predicting the levels of pollutants in water bodies, these models can help identify the sources of pollution and guide management practices to improve water quality. This can help protect the health of aquatic ecosystems and the communities that rely on them.

AI is making significant strides in various domains of hydrology. Roushangar et al. (2021) focused on developing a hybrid model for short-term and long-term drought prediction, showcasing the effectiveness of AI in modeling drought indices [12]. Xu et al. (2021) demonstrated the superior performance of an adapted temporal convolutional network in simulating hourly rainfall–runoff relationships, outperforming traditional models such as artificial neural networks [13]. Lu et al. (2021) employed a decision tree model based on the GF-6 WFV dataset for water body remote sensing extraction, highlighting the advantages of AI in handling high-resolution spatial data [14]. The utilization of stochastic artificial neural networks for accurate and real-time hydrological forecasts was explored by Wu et al. (2021), showcasing the adaptability of AI in addressing hydrological prediction challenges [15].

Incorporating insights from Chang et al. (2023) and the broader landscape of AI applications in hydrology, the transformative potential of AI in water resource management becomes even more evident [16]. The special issue encompasses diverse areas, such as machine learning and deep learning techniques in hydro-meteorological forecasting, smart microclimate control, the role of Geospatial Artificial Intelligence (GeoAI), adaptation strategies for extreme hydrological events, and AI-driven processing of hydro-geo-meteorological data [17].

Conclusion. AI-based hydrological modelling has shown great promise in improving the accuracy of hydrological predictions and facilitating more sustainable water management practices. The use of AI techniques such as ANNs and SVMs has enabled hydrological models to incorporate a wide range of variables and data sources, handle large amounts of data and complex relationships between variables, and learn from experience [18].

AI-based hydrological models have been applied to a wide range of hydrological problems, including flood forecasting, drought monitoring, and water quality modelling. The potential applications of AI-based hydrological models in water resource management are extensive, including improving water allocation

and irrigation practices, predicting the impacts of climate change on water resources, and identifying and mitigating water quality issues.

Future research in this field should focus on improving the accuracy and reliability of AI-based hydrological models, developing new AI techniques to address specific hydrological problems, and integrating AI-based models into decision-making processes for water resource management.

The amalgamation of AI and hydrology presents unprecedented opportunities to revolutionize our understanding and management of hydrological systems. As AI techniques evolve, future research endeavors should focus on refining methodologies, integrating advanced monitoring technologies, and addressing the challenges posed by the dynamic nature of hydro-geo-meteorological processes. The adoption of AI-powered solutions holds the key to achieving sustainable water resources management in the face of climate change and growing hydrological uncertainty.

REFERENCES

[1] Zhang Y., Liu X., Liu Y. Artificial intelligence in hydrology: a review // Water, 11(10), 2019.

[2] Volpi E., KIM J. S., Jain S., Shrestha S. Editorial: artificial intelligence in hydrology // Hydrology Research 1 June 2023; 54 (6): III–IV. doi: https://doi.org/10.2166/nh.2023.102

[3] Wang Z., Zhao Y., Liu Y., Wang Y. Application of artificial intelligence in hydrological modeling: a review // Journal of Hydrology. 2021. 596 p. 126106.

[4] Basa˘gao˘glu H., Chakraborty D., Lago C.D., Gutierrez L., Sahinli M.A., Giacomoni M., Furl C., Mirchi A., Moriasi D., Sengör S.S. A Review on Interpretable and Explainable Artificial Intelligence in Hydroclimatic Applications // Water. 2022, 14, 1230. https://doi.org/ 10.3390/w14081230

[5] Sahoo S., Shrestha B. K., Panda R. K. Artificial intelligence applications in hydrology: A review // International Journal of Hydrology Science and Technology, 2018. 8(1), 1-21.

[6] Baghanam A. H., Norouzi E., Nourani V. Wavelet-based predictor screening for statistical downscaling of precipitation and temperature using the artificial neural network method // Hydrology Research. 2022. 53 (3), 385–406. https://doi.org/10.2166/nh.2022.094

[7] de Moura C. N., Seibert J., Detzel D. H. M. Evaluating the long short-term memory (LSTM) network for discharge prediction under changing climate conditions // Hydrology Research. 2022. 53 (5), 657-667. https://doi.org/10.2166/nh.2022.044

[8] Nourani V. Application of the artificial intelligence approach and remotely sensed imagery for soil moisture evaluation // Hydrology Research. 2022. 53 (5), 684–699. https://doi.org/10.2166/nh.2022.111

[9] Heiko Apel, Zharkinay Abdykerimova, Marina Agalhanova, Azamat Baimaganbetov, Nadejda Gavrilenko, Lars Gerlitz, Olga Kalashnikova, Katy Unger-Shayesteh, Sergiy Vorogushyn, and Abror Gafurov. Statistical forecast of seasonal discharge in Central Asia using observational records: development of a generic linear modelling tool for operational water resource management // Hydrology and Earth System Sciences, 2018. Vol. 22, issue 4, HESS, 22, 2225–2254. https://doi.org/10.5194/hess-22-2225-2018

[10] Gonzales-Inca C., Calle M., Croghan D., Torabi Haghighi A., Marttila H., Silander J., Alho P. Geospatial Artificial Intelligence (GeoAI) in the Integrated Hydrological and Fluvial Systems Modeling: Review of Current Applications and Trends // Water. 2022, 14, 2211. https://doi.org/10.3390/w14142211

[11] Sharma A., Goyal M. K., Nema R. K. Hydrological modelling using artificial intelligence techniques: a review // Environmental Science and Pollution Research. 2021. 28(12), 14235-14253.

[12] Roushangar K., Ghasempour R., Kirca V. S. O., Demirel M. C. Hybrid point and interval prediction approaches for drought modeling using ground-based and remote sensing data // Hydrology Research. 2021. 52 (6), 1469-1489. https://doi.org/10.2166/nh.2021.028

[13] Xu Y., Hu C., Wu Q., Li Z., Jian S., Chen Y. Application of temporal convolutional network for flood forecasting // Hydrology Research. 2021. 52 (6), 1455-1468. https://doi.org/10.2166/nh.2021.021

[14] Lu Z., Wang D., Deng Z., Shi Y., Ding Z., Ning H., Zhao H., Zhao J., Xu H., Zhao X. Application of red edge band in remote sensing extraction of surface water body: a case study based on GF-6 WFV data in arid area // Hydrology Research. 2021. 52 (6), 1526-1541. https://doi.org/10.2166/nh.2021.050

[15] Wu S.-J., Hsu C.-T., Chang C.-H. Stochastic modeling of artificial neural networks for real-time hydrological forecasts based on uncertainties in transfer functions and ANN weights // Hydrology Research. 2021. 52 (6), 1490-1525. https://doi.org/10.2166/nh.2021.030

[16] Chang et al. Artificial Intelligence Techniques in Hydrology and Water Resources Management // Water. 2023. 15(10), 1846. https://doi.org/10.3390/w15101846

[17] Zekrifa D. M. S., Kulkarni M., Bhagyalakshmi A., Devireddy N., Gupta S., Boopathi S. Integrating Machine Learning and AI for Improved Hydrological Modeling and Water Resource Management // In Artificial Intelligence Applications in Water Treatment and Water Resource Management. 2023. P. 46-70.

[18] Liang W., Chen Y., Fang, G., Kaldybayev A. Machine learning method is an alternative for the hydrological model in an alpine catchment in the Tianshan region, Central Asia // Journal of Hydrology: Regional Studies, 2023. 49. 101492.

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ГИДРОЛОГИЯЛЫҚ МОДЕЛЬДЕУ ҮШІН ЖАСАНДЫ ИНТЕЛЛЕКТІ ПАЙДАЛАНУ

Аннотация. Гидрологиялық модельдеу су ресурстарын басқаруда маңызды рөл атқарады, әсіресе су тапшылығы негізгі проблема болып табылатын құрғақ және жартылай құрғақ аймақтарда. Жасанды интеллект (AI) пайда болуымен соңғы жылдары гидрологиялық модельдеу айтарлықтай өзгеріске ұшырады. Бұл мақала жасанды интеллект негізіндегі гидрологиялық модельдеудегі соңғы жетістіктерді қарастырады және оның су ресурстарын басқарудағы әлеуетті қолданбаларын зерттейді. Зерттеу гидрологиялық модельдердің дәлдігін арттырудағы және суды тиімді және тұрақты пайдалану тәжірибесін ілгерілетудегі AI рөлін көрсетеді. Нәтижелер жасанды интеллект негізіндегі гидрологиялық модельдердің су ресурстарын басқару тәсілін түбегейлі өзгертуге әлеуеті бар екенін және осы саладағы болашақ зерттеулердің кепілі екенін көрсетеді.

Түйін сөздер: гидрологиялық модельдеу, жасанды интеллект, су ресурстары, су ресурстарын басқару.

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ИСПОЛЬЗОВАНИЕ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА ДЛЯ ГИДРОЛОГИЧЕСКОГО МОДЕЛИРОВАНИЯ

Аннотация. Гидрологическое моделирование играет решающую роль в управлении водными ресурсами, особенно в засушливых и полузасушливых регионах, где нехватка воды является серьезной проблемой. С появлением искусственного интеллекта (ИИ) в последние годы гидрологическое моделирование претерпело значительную трансформацию. Рассматриваются последние достижения в области гидрологического моделирования на основе искусственного интеллекта и его потенциальные применения в управлении водными ресурсами. Подчеркивается роль ИИ в повышении точности гидрологических моделей и содействии внедрению более эффективных и устойчивых методов управления водными ресурсами. Гидрологические модели на основе искусственного интеллекта могут революционизировать способы управления водными ресурсами и будущие исследования в этой области оправданы.

Ключевые слова: гидрологическое моделирование, искусственный интеллект, водные ресурсы, водное хозяйство.