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Editorial: Theoretical analysis and applications of artificial intelligence in hydrology and water resource management

Artificial intelligence (AI) is being increasingly applied in hydrology and water resource management, as evidenced by the 19 papers included in this special issue. The papers cover a wide range of topics, including ecohydrology measures, groundwater over-exploitation, changes in rainfall and temperature, water resource supply and demand, and stochastic risk assessment.

One of the key themes of these papers is the use of AI to improve the efficiency and sustainability of water resource management. For example, adaptive management strategies based on hydrogeology, precipitation, land use, and other factors are proposed to ensure sustainable water management. Hybrid hydrological forecasting models, such as the sparrow search algorithm (SSA) and Moore–Penrose generalized inverse method, are also being used to effectively forecast hydrological time series for better planning and management of water resources. Stochastic simulation-based risk assessment is introduced as an effective tool to analyze the risks of water resource allocation under uncertain conditions. The papers also highlight the importance of examining specific regions or basins to identify issues with water management and supply, as well as possible solutions and strategies for sustainable water management. For instance, some papers focus on the West Liao River Basin in China and the Sirvan River Basin. Figure 1 presents all the uses of AI studied in the papers of this special issue.

Balist *et al.* (2021) utilized ecosystem services concepts and data on soil, climate, and land use to model water resource supply and demand in the Sirvan River Basin. Their research yielded valuable information for water resource planning at the basin and sub-basin levels and identified sub-basins that face water scarcity and stress. This highlights the importance of ecohydrological management in addressing water resource challenges at the local level and emphasizes the need for sustainable water resource management strategies to ensure long-term ecosystem health and human well-being. Zhou (2022) introduced an improved standard cuckoo search algorithm (ISCSA) for solving multi-objective water resource allocation problems in Xianxiang Region, China. The ISCSA included chaotic initialization and a Gaussian disturbance algorithm to overcome drawbacks of the standard cuckoo search algorithm, such as long search times and falling into local optima. The results showed that the ISCSA was effective in finding multi-objective optimal water supply schemes and predicting water resource allocation for sub-regions. Chen *et al.* (2022) proposed a new methodology called the stochastic simulation-based risk assessment approach for analyzing the risks of water resource allocation under uncertain conditions. The methodology involved fitting hydrological stochastic variables, constructing a two-stage stochastic programming model, using the Monte Carlo method, and proposing a pre-allocated water optimization model. The proposed methodology was applied to the Zhanghe Irrigation District, and the risk of the water allocation plan obtained under the randomness of annual inflow was assessed. The results showed that the proposed methodology provided reliable assistance to water managers in decision-making. One can see from the above statements that ecohydrological management, improved algorithms, and stochastic simulation-based risk assessment can help address water resource challenges and support sustainable water management strategies.

Various management strategies have been proposed to improve water efficiency and groundwater formation. Yan *et al.* (2021) focused on the issue of groundwater over-exploitation in the West Liao River Basin, a key food production area in China. Their adaptive management strategies developed based on hydrogeology, precipitation, land use, and other factors, provided a scientific basis for sustainable water management in the Tongliao Plain. By setting groundwater level thresholds in each of the 21 management zones, their research demonstrated the potential for effective ecohydrological management strategies in addressing critical water resource challenges. Zhang *et al.* (2022) examined the impact of drip irrigation under mulch on groundwater recharge in a semi-arid agricultural region in China using the Hydrus-2D model. The results showed that drip irrigation under mulch increased the infiltration depth and cumulative infiltration amount, which was beneficial to groundwater recharge. The findings suggested that drip irrigation under mulch was an effective method to improve agricultural water efficiency and groundwater formation in semi-arid agricultural regions. Reddy *et al.* (2022) proposed a hybrid artificial intelligence and semi-distributed model for runoff prediction. El Mezouari *et al.* (2022) proposed a hybrid artificial neural network (ANN) and extended genetic algorithm for weight optimization to improve groundwater level prediction. The method was validated using data from a monitoring well in California and showed promising performance. The

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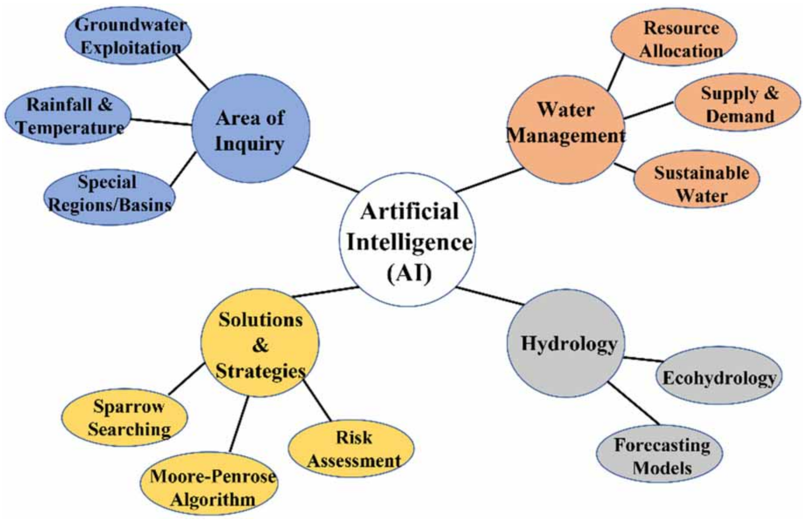

Figure 1 | The uses of AI studied in the papers of this special issue.

study emphasized the importance of using AI engines to enhance water resource management and planning practices in the face of growing water scarcity and demand.

In terms of prediction strategy, Feng *et al.* (2021) developed a hybrid hydrological forecasting model that used the SSA to determine parameter combinations and the Moore–Penrose generalized inverse method to obtain the weight matrix for accurate hydrological time series forecasting. The proposed method outperformed other evolutionary algorithm-optimized ELM variants in both training and testing phases, based on several performance evaluation indexes. The study showed the potential of the proposed method as an effective evolutionary machine-learning tool for water resource system planning and management. Naik *et al.* (2022) proposed a new approach for forecasting the water surface profile of various compound channels with converging floodplains using gene expression programming (GEP). The models were constructed using experimental data, and a new equation was devised to compute the water surface profile using non-dimensional geometric and flow parameters. The findings showed that the GEP-derived water surface profile was highly correlated with experimental data, and it can be considered reliable for the study of compound channel flow. The common theme of these two papers is the development of new models for accurate water forecasting and management, using different algorithms, such as the SSA and GEP, with the potential for application in water resource system planning and management.

Hybrid models have been used to improve water resource management in case studies from India and China. Developed a hybrid model (HEC-HMS-ANN) to simulate daily discharge in the Kallada River basin, Kerala, India. The model integrated the output from HEC-HMS into an ANN and outperformed both the HEC-HMS and ANN models in simulating daily discharge and estimating yearly peak discharge accuracy. The model used precipitation, lagged precipitation, and lagged discharge as input variables for the ANN model, and the optimal number of lags was determined using partial autocorrelation. Li *et al.* (2022a) proposed a hybrid model, VMD-SSA-LSSVM, for monthly runoff forecasting. The model combined variational mode decomposition (VMD) with LSSVM and optimized the LSSVM parameters using a SSA. The model was validated by forecasting monthly runoff for two reservoirs in China, and the results showed that it outperformed other compared models in terms of statistical indexes, indicating that it was effective in enhancing monthly runoff forecast accuracy for water resources management. Li *et al.* (2022c) proposed a hybrid network of CNN and LSTM for river flow prediction in the Hun River Basin, China. The network's structure and parameters, including the shortcut layer, greatly affected its learning efficiency. The hybrid network showed similar performance to the Soil and Water Assessment Tool (SWAT) model but was superior in wet seasons due to its nonlinear learning ability, demonstrating its potential for river flow forecasting.

The importance of data analysis and modeling in ecological environments has been highlighted in several papers. Fattahi & Habibi (2022) compared two methods to estimate probable maximum precipitation (PMP) and found that the modified Hershfield-Desa method provided more reasonable values than the original Hershfield method. Data from 45 synoptic stations throughout the country were used, and the study showed that PMP values were more variable in southern stations,

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making their estimation less reliable. Kanneganti *et al.* (2022) developed a machine-learning model to estimate past wastewater influent flow rates in Louisville, Kentucky, based on various data types, including feces-related indicators, weather data, and area demographics. The algorithm achieved 91.7% accuracy and challenged currently accepted opinions by suggesting that variables such as precipitation and population size were more important for wastewater flow estimation. The study demonstrated the potential of AI in supporting public health applications of wastewater-based epidemiology. Xu *et al.* (2022) analyzed the changes in rainfall in Beijing, China, over the past 50 years and found a close relationship between urban development and the reduction in rainfall and increase in temperature. Their findings emphasized the urgent need for research on rainfall and temperature in rapidly developing urban areas, particularly in light of the potential impact on water resource availability and ecosystem services. Jun *et al.* (2022) examined the impact of climate change and human activities on the ecological environment in the Shiyang River Basin, Gansu Province. The study analyzed changes in temperature, precipitation, glacial and surface water resources, landscape patterns, and natural and anthropogenic factors. The study found that climate warming and unregulated human activities were the main causes of regional environmental deterioration, resulting in downstream water resource reduction and shifting landscape vegetation to high-risk areas. Anthropogenic factors played a dominant role in runoff variation in the basin, and the study provided valuable insights for human adaptation countermeasures to mitigate ecological deterioration and ensure the sustainable development of ecologically fragile areas.

Fan *et al.* (2021) investigated the relationship between ecohydrology measures and their impact on different types of disasters that can have devastating effects on vulnerable communities. Their findings highlighted the importance of water management, hydrology, and ecology in reducing social disasters and protecting against accidents. Li *et al.* (2022b) conducted research on the electrochemical ozone production (EOP) performance of a solid polymer electrolyte (SPE) electrolyzer for disinfection and sterilization. They optimized the electrode configuration and operating conditions and found that BDD-4.9 electrodes with a thickness of 0.54 mm and a water flow rate of 63 L/h were ideal for EOP. The study also found that ozone water had excellent performance in killing *Escherichia coli* with high inoculum concentrations, indicating its potential environmental applications. Wang *et al.* (2022) proposed a method to identify cross sections with large bathymetric errors in rivers. They used forward and reverse flow routing models to obtain two different water stages and compared the spatial variation of differences between them to quantify the influence of bathymetric errors. The method was tested and verified in a hypothetical river case and applied to the Xunjiang River case, showing that it could effectively identify cross sections with large bathymetric errors and improve the accuracy of water flow simulation. Kong *et al.* (2022) used a modified universal soil loss equation RUSLE model with GIS and RS spatial information technology to simulate and explore the distribution of soil erosion in the Sheep Sap Gully sub-basin of the Loess Plateau hilly gully area. The study found that erosion was greater in the southwestern part of the basin and was mostly found in farming areas with sparse vegetation. The results provided a reference for research into ecological security technologies for gully and slope management projects and support for watershed governance and soil and water resource management and conservation. The four studies explored different aspects of environmental management and their potential impact on reducing social disasters, including water management, hydrology, ecology, disinfection, sterilization, river flow simulation, and soil erosion distribution. These findings could inform ecological security technologies for managing projects and support for watershed governance, soil and water resource management, and conservation.

The Editors of this special issue believe that the papers presented in this issue highlight the potential of AI in providing valuable insights for water resource planning and management. Furthermore, these papers emphasize the importance of ongoing research into various factors that impact water resources, such as climate change and urban development, to support sustainable development efforts. We would like to express our sincere appreciation to the reviewers for their valuable contribution to this thematic special issue. Their insightful reviews, comments, and feedback have been instrumental in improving the quality and relevance of the manuscripts submitted for publication.

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