

Editorial

Advances in Hydrologic Forecasts and Water Resources Management

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Abstract: The impacts of climate change on water resources management as well as the increasing severe natural disasters over the last decades have caught global attention. Reliable and accurate hydrological forecasts are essential for efficient water resources management and the mitigation of natural disasters. While the notorious nonlinear hydrological processes make accurate forecasts a very challenging task, it requires advanced techniques to build accurate forecast models and reliable management systems. One of the newest techniques for modelling complex systems is artificial intelligence (AI). AI can replicate the way humans learn and has the great capability to efficiently extract crucial information from large amounts of data to solve complex problems. The fourteen research papers published in this Special Issue contribute significantly to the uncertainty assessment of operational hydrologic forecasting under changing environmental conditions and the promotion of water resources management by using the latest advanced techniques, such as AI techniques. The fourteen contributions across four major research areas: (1) machine learning approaches to hydrologic forecasting; (2) uncertainty analysis and assessment on hydrological modelling under changing environments; (3) AI techniques for optimizing multi-objective reservoir operation; and (4) adaption strategies of extreme hydrological events for hazard mitigation. The papers published in this issue can not only advance water sciences but can also support policy makers toward more sustainable and effective water resources management.

Keywords: artificial intelligence; machine learning; water resources management; multi-objective reservoir operation; hydrologic forecasting; uncertainty; risk

1. Introduction

Natural disasters have been inclined to increase and become more severe over the last decades due to climate change. A preparation measure to cope with future floods is flood forecasting in each river basin for warning persons involved and for mitigating damages and the loss of life. Hydrological forecasting is essential for efficient water resources management and the mitigation of natural disasters such as floods and droughts. Establishing a viable hydrological forecasting model for communities at risk requires the combination of meteorological and hydrological data, forecast tools and trained forecasters. Forecasts must be sufficiently accurate to promote confidence so that communities and users will take effective actions when being warned. Multidisciplinary research and advanced methodologies in hydrological forecasts, especially in extreme floods and droughts, are widely implemented for water planning and management, which ultimately lead to improved optimum water resources management and effective control under a changing environment. Among them, artificial intelligence (AI) techniques are efficient tools for extracting the key information from complex highly dimensional input–output patterns and are widely used to tackle various hydrological problems such as flood forecasts discussed

in this Special Issue [1–14]. Over the last decades, many studies have demonstrated that artificial intelligence (AI) techniques, such as machine learning (ML) methods, can produce flood forecasts in a few hours [15–19] while extending to seasonal forecasts many months in advance for larger river basins [20–24]. AI can also be an ideal tool for managing water resources in an ever-changing environment and for allowing water utility managers to effectively optimize multi-objective water resources revenues [25–30].

Reliable and accurate streamflow forecasts with lead-times from hours to days are critical to managing floods and to improving the efficiency of streamflow forecasts utilized for real-time reservoir operation. All forecasts, however, involve various degrees of uncertainty, which could be associated with meteorological data, hydrological model mechanics and parameters, or the model's errors in forecasts. To implement streamflow forecasts in real-time reservoir operation, we must deal with the uncertainty involved in streamflow forecasts. Although the forecast uncertainty plays an important role in reservoir operation and has been extensively studied in hydrology, there are comparatively less studies discussing the effect of forecast uncertainty on real-time reservoir operations [31–36]. This Special Issue aims at overcoming these challenges, addressing continuing efforts undertaken to gain insights on hydrological processes, dealing with the effect of forecast uncertainty, and engaging in more efficient water management strategies in a changing environment.

2. Summary of the Papers in the Special Issue

The papers in this Special Issue are well-balanced in terms of their focuses, encompassing hydrological forecasts, uncertainty analyses and water resources management. Three papers [1–3] address operational hydrological forecasts by using various machine learning (ML) methods. In [1], the authors propose an Internet of Things (IoT) machine learning-based flood forecast model to predict average regional flood inundation depth in a river basin in Taiwan, and they demonstrate how to on-line adjust the machine learning models so that the models' accuracy and applicability in multi-step-ahead flood inundation forecasts are promoted. They also highlight the combination of IoT and machine learning techniques could be beneficial to flood prediction. In [2], the authors introduce a general framework that fuses an unscented Kalman filter (UKF) post-processing technique with a recurrent neural network for probabilistic flood forecasting conditional on point forecasts. They declare that the proposed approach could overcome the under-prediction phenomena and alleviate the uncertainty encountered in data-driven flood forecasting so that model reliability as well as forecast accuracy for future horizons could be significantly improved. In [3], the authors propose a random forest (RF) model to predict the Normalized Difference Vegetation Index (NDVI) and explore its relationship with climatic factors. The results demonstrate that RF can be integrated into water resources management and can elucidate ecological processes in the Yarlung Zangbo river basin. These studies clearly indicate that machine learning techniques have a great capability to model the nonlinear dynamic features in hydrological processes, such as flood forecasts and NDVI, and IoT sensors are useful instruments for carrying out the monitoring of natural environments and enhancing hydrological forecasts.

Papers [4–6] report research on uncertainty analysis and assessment in hydrological modelling and forecasting. In [4], Hong's method is implemented to execute the point estimate method (PEM) in a case study that simulates water runoff using the ANUGA hydrodynamic model for an area in Glasgow, UK. The authors demonstrate that the Hong's method could more efficiently produce very similar probabilistic flood-inundation maps in the same areas as those of Monte Carlo (MC) simulation, where the Hong's method requires just three 11-minute simulation runs, rather than the 500 required for the MC simulation. In [5], the authors propose a multiple-criteria decision analysis method, namely the Generalized Likelihood Uncertainty Estimation-Technique for Order Preference by Similarity to Ideal Solution (GLUE-TOPSIS). The proposed method was implemented in the Storm Water Management Model (SWMM) and applied to the Dahongmen catchment in Beijing, China. They conclude that the proposed GLUE-TOPSIS is a valid approach to assessing the uncertainty of the urban hydrological model from a multiple objective perspective, which improves the reliability of model results in the

urban catchment. In [6], the authors evaluate the parameter uncertainty for the Snowmelt Runoff Model (SRM) based on different calibration strategies and its impact on a data-scarce deglaciating Yurungkash watershed in China. The results show that the future runoff projection contains a large amount of uncertainty and the onset of snowmelt runoff is likely to shift earlier in the year and the discharge over the snowmelt season is projected to increase.

Hydrological nonstationary has brought great challenges to the reliable applications of hydrological models with time-invariant parameters. Two papers [7,8] investigate the predictive ability and robustness of a hydrological model under changing environments. In [7], the authors propose a new method based on empirical mode decomposition (EMD) to synthesize and generate data which be interfered with the non-stationary problems. The new synthetic and historical flow data were used to simulate the water supply system of the Hushan reservoir in Taiwan, and the compared results show that the synthetic data are like the historical flow distribution. In [8], the authors investigate the predictive ability and robustness of a conceptual hydrological model (GR4J) with time-varying parameter under changing environments. The results show that the performance of streamflow simulation was improved when applying the time-varying parameters. Furthermore, the GR4J model with time-varying parameters outperformed the original GR4J model by improving the model robustness. Overall, these studies emphasize the importance of considering the parameter uncertainty of time-varying hydrological processes in hydrological modelling and climate change impact assessment.

Due to climate change, the importance of reservoirs is likely to increase, not only for water storage purpose but also for maximizing water use benefits and mitigating climate extremes. Four papers [9–12] employ advanced optimization methods to derive reservoir operating rules for multi-reservoir systems and/or optimize multi-objective reservoir operation. In [9], the authors conduct a multi-target single dispatching study on ecology and power generation in the lower Yellow River to solve the single-objective and the multi-objective optimal schema using the genetic algorithm (GA) and an improved non-dominated genetic algorithm (NSGA-II). The results provide a decision-making basis for the multi-objective dispatching of the Xiaolangdi reservoir and have important practical significance for further improvement on the ecological health of the lower Yellow River. In [10], the authors fuse the grey entropy method (GEM) with the Mahalanobis–Taguchi System (MTS) for selecting the optimal water level scheme at the Pankou reservoir in flood season. The results show that the optimal scheme selected by the proposed model can achieve greater benefits within an acceptable risk range and thus better coordinate the balance between risk and benefit, which verifies the feasibility and validity of the model. In [11], the authors show the advancement of the seasonal flow forecasts could provide the opportunity for reservoir operators to identify the early impoundment operation rules (EIOR) in the upper Yangtze river basin. Their results indicate the proposed GloFAS-Seasonal forecasts are skillful for predicting the streamflow condition according to the selected 20th and 30th percentile thresholds and the obtained seasonal forecasts and the early reservoir impoundment could enhance hydropower generation and water utilization. In [12], a novel enhanced gravitational search algorithm (EGSA) is proposed to resolve the multi-objective optimization model by considering the power generation of a hydropower enterprise and the peak operation requirement of a power system located on the Wujiang river of China. The results show that the EGSA method could obtain satisfying scheduling schemes in different cases for the multi-objective operation of hydropower system.

The early warning and post-assessment of extreme hydrological events are crucial for hazard mitigation. In [13], the authors explore the most effective flood control strategy for small and medium-scale rivers in highly urbanized areas. The probable cost-effective flood control scheme is to construct two new tributaries for transferring floodwater in the midstream and downstream of the Shengong river into the downstream of the Tieshan river. Their results indicate that flood control for small- and medium-scale rivers in highly urbanized areas should not simply consider tributary flood regimes but, rather, involve both tributary and mainstream flood characters from a whole region perspective. In [14], the authors report emergency disposal solutions for properly handling the

landslide and dammed lake within a few hours up to days for mitigating flood risk. They present a general strategy to effectively tackle the dangerous situation created by a giant dammed lake with 770 million m³ of water volume and formulate an emergency disposal solution for the 25 million m³ of debris, composed of engineering measures of floodgate excavation and non-engineering measures of reservoirs/hydropower stations operation. The disposal solution not only reduces a large-scale flood (10,000-year return period, 0.01%) into a small-scale flood (10-year return period, 10%) but minimizes the flood risk with no death raised by the giant landslide.

3. Conclusions

Over the last several decades, substantial climate changes have occurred due to global warming. We also notice that artificial intelligence has been satisfactorily used to enhance our knowledge, to learn hydrological processes, and to engage in more efficient water management strategies under changing environmental conditions. The research papers published in this Special Issue contribute significantly to our understanding of the hydrological modelling approaches as well as water resources management. They can be categorized into four main subject areas: (1) machine learning methods for hydrologic forecasting; (2) uncertainty analysis and assessment on hydrological forecasts; (3) AI techniques for optimizing multi-objective reservoir operation; and (4) adaption strategies of extreme hydrological events for hazard mitigation. These papers presented novel methods to learn the complex hydrological processes and model hydrological forecasts, reduce models' uncertainty, and optimize water resources management. The selected manuscripts presented in this Special Issue make original contributions to addressing the state-of-the-art of artificial intelligence techniques, which provide a high level of research and practical information of implementing AI methods and strategies for accurate flood forecasts and reservoir operation, along with case studies from different regions of the world.

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