water

MDPI

Editorial

Flash Floods: Forecasting, Monitoring and Mitigation Strategies

Xiekang Wang [1,*], Philippe Gourbesville [2] and Changjun Liu [3]

1 State Key Laboratory of Hydraulics and Mountain River Engineering, Sichuan University, Chengdu 610065, China
2 Université Côte d'Azur, Polytech Nice Sophia, 06903 Sophia Antipolis, France; gourbesv@unice.fr
3 China Institute of Water Resources and Hydropower Research, Beijing 100038, China; lcj2005@iwhr.com
* Correspondence: wangxiekang@scu.edu.cn

In recent decades, flash floods have become a major natural disaster and show a continuously increasing trend on a worldwide scale. The magnitude of the damages associated with flash floods requires forecasting and monitoring strategies to understand the vulnerability factors, analyze the mechanisms of flash floods, and mitigate disasters.

Research efforts are needed to improve early warning mechanisms, risk control, and hazard prevention that could obviously aim at a reduction in casualties, social impacts, and economic losses. New technical approaches such as surface monitoring and combined hydrologic–hydrodynamic models are in development and are offering useful information for field managers.

The main causes of flash flood disasters can be investigated by analyzing the hydrological and hydrodynamic process of flash flood disaster events. The simultaneous flooding of tributaries and the main river has been identified as one of the main causes to amplify the discharge peak in the main river. Therefore, the monitoring and forecasting of tributaries' discharge may be an effective solution to issuing a flash flood early warning. Meanwhile, subgrade water damming that serves to mitigate flash flood impact, however, may exaggerate the risk of a flash flood disaster if a subgrade water damming structure collapses due to extreme weather conditions. Thus, artificial efforts to a mitigate flash flood disaster should be discussed and assessed.

Recently, the sediment-transport-related geomorphological evolution of mountain rivers drew considerable attention when assessing flash flood propagation. Due to sediment deposition in local mild reaches, the flash flood stage under a significant change in the riverbed morphology essentially differs from that under relatively stable river morphology, which is likely to result in the incorrect warning of flash flood disasters.

Debris flows might be triggered by storms and flash floods, which have not yet been understood. Well-designed flume experiments may help researchers to deepen the understanding of the triggering mechanisms of debris flows, as well as the dynamic characteristics of debris flows under different impact factors.

Data-driven approaches are considered appropriate to predict flood behavior due to the availability of an increasing number of high-quality data. Models with different complexities from simple regression to complex machine learning can be applied for the hydrological prediction and susceptibility map establishment of flash floods. Specific treatments, such as parameter regionalization, have a good potential to improve the modeling performance.

Flash flood disaster prevention and mitigation have not only been studied with the development of different approaches, but they have also been practiced with these appropriate approaches. However, the relationship between different socio-economic effects and flash flood disaster prevention and control should be discussed, which can offer information for good planning and policies for a further support of flash flood disaster prevention and mitigation.

Citation: Wang, X.; Gourbesville, P.; Liu, C. Flash Floods: Forecasting, Monitoring and Mitigation Strategies. *Water* **2023**, *15*, 1700. https://doi.org/10.3390/w15091700

Received: 14 April 2023
Accepted: 17 April 2023
Published: 27 April 2023

The Special Issue *Flash Floods: Forecasting, Monitoring and Mitigation Strategies* includes major flash flood disaster event analysis; the key factors for flash floods and monitoring strategies; field observations for flash flood processes; the modeling and forecasting of flash flood events; a risk assessment for flash floods; and the prevention and mitigation measures for flash floods. It includes twelve research papers.

Three papers describe flash-flood-caused hazard events which have recently happened in small mountain catchments in China. Different mechanisms triggering flash flood disasters occurred across different regions. One paper is about discharge peak amplification caused by simultaneous flooding for tributaries and main river. The second paper addresses the impact of the collapse of subgrade water damming on the severity of the disasters. The third paper details the coupling effect of flow and sediment transport to exaggerate the flash flood dynamics, which caused a disaster. With the insights of these three papers, common causes for mountain basin flash flood disasters can be checked.

Post-event reanalysis can be effective and necessary for identifying the causes of flash flood disasters which can be implemented using hydrologic and hydrodynamic approaches.

By developing a new distributed hydrological model named China-FFMS that simulates the evolution of natural disasters and make an assessment, Hao et al. [1] simulated the 8.12 flash flood disaster that occurred in the Liulin county of Hubei province on 12 August ("8.12") and the paper includes the data collected from the national flash flood disaster investigation and assessment. They identified that the main factor leading to the disaster was the overlapped peak flow where the Dunne flood peak of three different tributaries from the upper reach met together at the same time, and the peak flow of the Lianhua river at the downstream of Liulin County also arrived at the same time as the upstream peak, which obstructed the flood's progress and increased the damage of the disaster.

When a hydrodynamic model is coupled with a hydrological model, the simulation can provide not only flood discharge routing but also the evolution of flood stage, which, once overbank, a flooding disaster is caused in theory. Hao et al. [2] numerically investigated the "7.20" flash flood in the Wangzongdian river basin by establishing a hydrological–hydrodynamic model using limited measured data. The extreme rainstorm accounting for flooding in mountainous areas and the collapse of subgrade water damming led to the high-level flood quickly flowing into Wangzongdian Village over a short distance, causing a serious disaster.

In mountain basins, the sediment supply and its delivery have a significant impact on the geomorphological change in steep rivers with sediment deposition and erosion processes, thus determining the geometric boundaries where flash floods evolve. Therefore, Yang et al. [3] used a depth-averaged two-dimensional hydrodynamic model to simulate a flash flood that occurred in Sanjiang Town, Sichuan, China, on 20 August 2019. Inflows and sediment deposition were the main factors that contribute to flash flood enlargement in confluence and bifurcation streams. This study deepened the understanding that flow in the supercritical slope runs at a very fast velocity and seldom deposits sediment in the steep channel, while most sediment is transported to the streams with flat hydraulic slopes.

Currently, an increasing sense of awareness has been realized that the triggering of flash floods may cause other kinds of natural water-sediment-related disasters such as debris flows. Two papers, therefore, addressed the importance of mountain gully debris flows in a strong earthquake area and the periglacial debris flow in Southeast Tibet. Zhang et al. [4] designed a lateral erosion flume model experimental device to explore the erosion characteristics of debris flow. In total, 18 groups of incomplete orthogonal experiments were conducted to investigate the effects of the unit weight of debris flow, the content of fine particles, and the longitudinal slope gradient of the gully. The major finding demonstrates that the erosion width, depth, and volume decrease with the increase in the fluid bulk density and increase with the increase in the gully slope and the unit weight of debris flow has the greatest impact on the erosion degree of the side slope. Du et al. [5] analyzed the importance of potential indicators to the development of periglacial debris flows in the Parlung Zangbo Basin of southeast Tibet and introduced three machine learning approaches combined with the borderline resampling technique for predicting debris flow occurrences. They found that temperature, precipitation, and vegetation coverage are closely related to the development of periglacial debris flow in the study area. By testing and comparing several scenarios, the best model of predicting debris flow events was suggested.

Precipitation data as the input driving the hydrological process, as well as the quality and representation and data source, control the performance of hydrological modeling. Guo et al. [6] Evaluated the performance of three precipitation products (rain gauge observations, CMADS, and TRMM) in the hydrological modeling of the Danjiang River Basin (DRB) with the SWAT model at monthly, daily, and spatial scales. Simulation calibration and validation were performed at three hydrological stations using the SWAT Calibration Uncertainties Program (SWAT-CUP). This study finally provides a reference for choosing precipitation datasets in watersheds like the DRB where ground-based rain gauge data are unavailable.

Apart from precipitation, the surface condition of the catchment may largely influence the runoff and sediment generation. Ding et al. [7] numerically assessed the impact of grass coverage degrees and spatial arrangements on the runoff and sediment yield both on the hillslope and gully slope. The relative contribution of hillslope and gully side account for the total erosion on the entire hillslope gully system was analyzed, which helps to understand the validity of the policy on soil and water conservations in Loess Plateau. This study highlighted the importance of vegetation coverage in reducing soil erosion and the need for further research on the impacts of different vegetation coverage and arrangement patterns on the slope gully system.

Data-driven approaches are becoming increasingly popular to predict flood behavior. As the quantity of historical data is becoming larger and the quality is better due to systematical monitoring techniques, different data-driven approaches, such as logistic regression and machine learning, can be applied. El-Rawy et al. [8] provided a method for flood risk assessment by incorporating principal component analysis and logistic regression in the Sinai Peninsula, Egypt, using hydro-morphometric parameters. Cross-validation of the model was conducted to ensure reliability and robustness. A flash flood susceptibility map with four categories of risks (low, moderate, high, and very high) was established for the Sinai Peninsula that can be useful for authorities and decision makers in impact assessment, flash flood management, and the planning and implementation of mitigation measures.

Wang et al. [9] studied the influence of different methods on the parameter regionalization of distributed hydrological model parameters in hilly areas of Hunan Province, China. Shortest distance, attribute similarity, support vector regression, generative adversarial networks, classification and regression tree, and random forest methods were evaluated to create parameter regionalization schemes, with 426 floods of 25 catchments for calibration and 136 floods of 8 catchments for verification. The study showed that the random forest model is the most stable solution and significantly outperforms other methods and can improve the accuracy of flood simulation in ungauged areas with parameter regionalization, which is of great significance for flash flood forecasting and early warning.

The regionalization method can be also applied in the process-based modeling of flash floods. Williams et al. [10] applied a rainfall regionalization method to construct flash flood hyetographs with several return periods using the flash flood shape of the historical event that occurred in the Tlalnepantla River basin, Mexico. A semi-distributed model in HEC-HMS was used to obtain the outflow hydrograph and hydrodynamic model in Iber, and Hec-Ras 2D to simulate free surface flow was used for a hydrological–hydrodynamic two-dimensional analysis. This study successfully estimated the potential consequences of synthetic design storms on the site and provided insights into the study of flash floods at the global level, highlighting the need for a methodology for threat assessment.

With effective modeling approaches, a flash flood early warning system can be designed and established for disaster mitigation, such as for a reduction in causality and economic loss. Arganis et al. [11] developed a pilot impacts-based flood early warning decision support system for the Vaisigano River in Samoa. The flood early warnings decision support system alerted the hazard monitoring and emergency responders of imminent flooding with up to 24–48 h lead time, with information of a specific context and real-time automated river monitoring and forecast. It includes a web-based information portal which enables interaction with the decision support information tools, which was conducted in a practice of operational testing during the 2020/2021 tropical cyclone season in Samoa.

Finally, to mitigate the hazard impact of flash flood on mountain area residents and the environment, China has implemented a two-decadal flash flood prevention and mitigation project, which is still under operation currently. Therefore, whether these projects with recent advanced technology and methods are useful for the prevention and mitigation of flash flood disasters in a mountain area is important for sustainable investment, policy, and research. Zhang et al. [12] applied the Kaya identity and a Logarithmic Mean Divisia Index (LMDI) approach to quantitatively measure the driving effects of interannual changes in economic loss related to flood disasters in China. Five flood-related driving effects, including demographic effect, economic effect, flash flood disaster control effect, capital efficiency effect, and loss-rainfall effect, were evaluated. This paper shows that the flash flood disaster control effect most obviously reduced flood-related economic losses, and non-engineering measures for flash flood prevention and control have been implemented since 2010, achieving remarkable results. The discussion of the relationship between flood-related economic loss and flash flood disaster prevention and control in China adds value for the adjustment and formulation of future flood disaster prevention policies.

This collection of papers highlights the efforts of researchers in mitigating flash flood disasters, involving deepening the understanding of the causes triggering the disasters with existing cases, finding appropriate modeling approaches, and practicing disaster mitigation. This topic is a good example, which not only inspires the future research direction for flash floods but also supports the current practice of flash flood disaster prevention and mitigation.

Author Contributions: Conceptualization, X.W., P.G. and C.L.; writing—original draft preparation, X.W.; writing—review and editing, X.W., P.G. and C.L.; supervision, X.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the National Natural Science Foundation of China (Nos. 52239006, 51579163).

Data Availability Statement: Not Available.

Acknowledgments: As Guest Editors, we sincerely appreciate the authors for their contributions to this Special Issue. Our thanks also go to the editors and referees because their professional contributions obviously improved the quality of the twelve published papers.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Hao, S.; Wang, W.; Ma, Q.; Li, C.; Wen, L.; Tian, J.; Liu, C. Analysis on the Disaster Mechanism of "8.12" Flash Flood in Liulin River Basin. *Water* **2022**, *14*, 2017. [CrossRef]
2. Hao, S.; Wang, W.; Ma, Q.; Li, C.; Wen, L.; Tian, J.; Liu, C. Model-Based Mechanism Analysis of "7.20" Flash Flood Disaster in Wangzongdian River Basin. *Water* **2023**, *15*, 304. [CrossRef]
3. Yang, Q.; Wang, X.; Sun, Y.; Duan, W.; Xie, S. Numerical Investigation on a Flash Flood Disaster in Streams with Confluence and Bifurcation. *Water* **2022**, *14*, 1646. [CrossRef]
4. Zhang, J.; Luo, D.; Li, H.; Pei, L.; Yao, Q. Experimental Study on Gully Erosion Characteristics of Mountain Torrent Debris Flow in a Strong Earthquake Area. *Water* **2023**, *15*, 283. [CrossRef]
5. Du, J.; Zhang, H.-y.; Hu, K.-h.; Wang, L.; Dong, L.-y. Prediction of the Periglacial Debris Flow in Southeast Tibet Based on Imbalanced Small Sample Data. *Water* **2023**, *15*, 310. [CrossRef]
6. Guo, Y.; Ding, W.; Xu, W.; Zhu, X.; Wang, X.; Tang, W. Assessment of an Alternative Climate Product for Hydrological Modeling: A Case Study of the Danjiang River Basin, China. *Water* **2022**, *14*, 1105. [CrossRef]

7. Ding, W.; Wang, X.; Zhang, G.; Meng, X.; Ye, Z. Impacts of Grass Coverage and Arrangement Patterns on Runoff and Sediment Yield in Slope-Gully System of the Loess Plateau, China. *Water* **2023**, *15*, 133. [CrossRef]
8. El-Rawy, M.; Elsadek, W.M.; De Smedt, F. Flash Flood Susceptibility Mapping in Sinai, Egypt Using Hydromorphic Data, Principal Component Analysis and Logistic Regression. *Water* **2022**, *14*, 2434. [CrossRef]
9. Wang, W.; Zhao, Y.; Tu, Y.; Dong, R.; Ma, Q.; Liu, C. Research on Parameter Regionalization of Distributed Hydrological Model Based on Machine Learning. *Water* **2023**, *15*, 518. [CrossRef]
10. Williams, S.; Griffiths, J.; Miville, B.; Romeo, E.; Leiofi, M.; O'Driscoll, M.; Iakopo, M.; Mulitalo, S.; Ting, J.C.; Paulik, R.; et al. An Impacts-Based Flood Decision Support System for a Tropical Pacific Island Catchment with Short Warnings Lead Time. *Water* **2021**, *13*, 3371. [CrossRef]
11. Arganis, M.; Preciado, M.; Luna, F.D.; Cruz, L.; Domínguez, R.; Santana, O. Application of a Regionalization Method for Estimating Flash Floods: Cuautepec Basin, Mexico. *Water* **2023**, *15*, 303. [CrossRef]
12. Zhang, Z.; Li, Q.; Liu, C.; Ding, L.; Ma, Q.; Chen, Y. Driving Effects and Spatial-Temporal Variations in Economic Losses Due to Flood Disasters in China. *Water* **2022**, *14*, 2266. [CrossRef]