water

MDPI

Editorial

Towards Integrated Flood Risk and Resilience Management

Guangtao Fu [1], Fanlin Meng [1,*], Mónica Rivas Casado [2] and Roy S. Kalawsky [3]

1 Centre for Water Systems, College of Engineering, Mathematics and Physical Sciences, University of Exeter, North Park Road, Devon, Exeter EX4 4QF, UK; G.Fu@exeter.ac.uk
2 School of Water, Energy and Environment, Cranfield University, College Road, Cranfield, Bedfordshire MK430AL, UK; m.rivas-casado@cranfield.ac.uk
3 Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Advanced VR Research Centre, Loughborough University, Loughborough LE11 3TU, UK; R.S.Kalawsky@lboro.ac.uk
* Correspondence: M.Fanlin@exeter.ac.uk

Received: 4 June 2020; Accepted: 15 June 2020; Published: 23 June 2020

check for updates

Abstract: Flood resilience is an emerging concept for tackling extreme weathers and minimizing the associated adverse impacts. There is a significant knowledge gap in the study of resilience concepts, assessment frameworks and measures, and management strategies. This editorial introduces the latest advances in flood risk and resilience management, which are published in 11 papers in the Special Issue. A synthesis of these papers is provided in the following themes: hazard and risk analysis, flood behaviour analysis, assessment frameworks and metrics, and intervention strategies. The contributions are discussed in the broader context of the field of flood risk and resilience management and future research directions are identified for sustainable flood management.

Keywords: flood risk; flood resilience; machine learning; management strategy; metrics

1. Introduction

Flooding has been widely recognized as a global threat due to the extent and magnitude of damage it poses around the world each year. Globally, flooding affected 2.3 billion people with an estimated economic loss of USD 662 billion from 1995 to 2015 [1]. Flooding can occur from fluvial, pluvial, coastal or groundwater sources, and the economic costs and disruption to communities are expected to increase as a result of urbanization, economic growth and climate change [2,3]. For example, flood risk is the top risk for the UK among 60 risks arising from climate change; 2.6 million people are projected to live in areas of significant risk (i.e., 1 in 75 or more annual change of flooding) by the 2050s under a 2 °C scenario and 3.3 million under a 4 °C scenario with according to the UK Climate Change Risk Assessment. Flood risk management has proven an effective and successful approach to assess risks and support informed decisions on flood measures and thus reduce economic losses and social-environmental damage.

Risk assessment is now a well-established paradigm in flood management in many countries worldwide. In general, flood risk is perceived as the magnitude of loss, calculated as a function of consequence and probability of flood events. The flood risk assessment process can be represented using the Source-Pathway-Receptor-Consequence conceptual model [4], involving the following key components: (1) understanding the frequency, magnitude and location of one or more hazards (such as storms or cyclones) that can lead to flooding, (2) identifying the route that hazards take to reach the receptors, (3) assessing the vulnerability of the receptors, i.e., people, assets and environment, which could be directly or indirectly affected by flooding, and (4) quantifying the damages that occur to those receptors. Scientific advances have been made in all the above components, such as understanding the impacts of climate change on rainfall [5], representation of rainfall variable dependency [6], development of hydrodynamic or data-driven flood models for flood extent and depth estimation [7,8], as well as flood damage data [9]. However, major research challenges remain in many aspects, in particular, in improving accurate representation and modelling of future uncertainties, capture of system interdependency, and understanding the impacts of human behaviours and stakeholder interactions.

Flood resilience has been gradually recognised as a key aspect in flood management. The term of resilience originated from the field of ecology [10] and was then introduced as a property of a water system which has the ability to prepare for and adapt to changing conditions and absorb, respond to, and recover rapidly from disruptions [11,12]. Conceptual frameworks and metrics were proposed for quantitative and qualitative assessment of flood resilience. On one hand, multi-criteria approaches are commonly used for multi-level and -system assessments; for example, considering physical, and economic and social indicators in failure and recovery phases [13]. On the other hand, performance-based metrics are defined to measure the capacity of a water system in response to specific extreme events in terms of failure duration and magnitude [14,15]. Key to these assessments is the concept of rapid recovery which is contrasted to traditional risk concepts and measures.

To tackle the huge challenges in reducing flood consequences and improving flood emergence planning and preparedness, a Special Issue on flood risk and resilience management was proposed to review the latest developments in the field of flood management. The special issue consists of 11 papers and focuses on the following themes: hazard and risk analysis, flood behavior analysis, assessment frameworks and metrics, and intervention strategies, as introduced in Section 2. This Special Issue will help researchers and practical engineers understand the current challenges in flood management and develop an effective intervention strategy based on the current state-of-the-art knowledge and technologies to tackle these challenges.

2. Overview of the Special Issue

This special issue reports some key advances in flood risk and resilience management. The 11 articles compiled in this issue provide the readers an overview of modelling, optimization, and analytical tool studies for building flood resilience as described below.

(1) Hazard and Risk Analysis

A matrix-based multi-risk assessment methodology is proposed in Barria et al. [16] to assess the risk of natural hazards such as floods and tsunami. The proposed method can support urban planning and flood mitigation. Stakeholders are closely engaged in the development of the risk assessment, which is an important aspect for enhancing local flood resilience.

Change in land use and rapid urbanization are widely considered as contributory factors for urban flooding. Areu-Rangel et al. [17] performs a quantitative analysis for Villahermosa, Tabasco (Mexico), which shows that the change in land use can increase flood depth by 7% to 22% and urban growth (until 2050) can raise inundation level by up to 0.7 m. The conclusions from this case study reinforced our current understanding that the current way of urban development is lack of sustainability and resilience from the perspective of flood management.

(2) Flood Behavior Analysis

Our current flood frequency analysis is usually based on stationarity that the probability distributions derived from the historical data is applicable to the future. This can yield misleading results as the temporal and spatial distribution of flood is constantly changing especially under climate change and intensified human activities. Zhang et al. [18] proposes a nonstationary flood frequency analysis for a more accurate representation of flooding. Saravi et al. [19] uses Machine Learning techniques to study the impact of different types of flood based on a big database in the U.S.A. The findings are useful in guiding planning and management to enhance flood resilience.

(3) Analytical Frameworks and Indices

Fenner et al. [20] presents the latest research outputs from the Urban Flood Resilience research project, where methodologies and tools are developed to facilitate transformative change against extreme rainfall events driven by climate change and rapid urbanization. A roadmap is proposed in this project for urban drainage adaptation over the next 40 years. A Natural Capital Planning Tool is also developed to calculate the theoretical minimum and maximum possible scores of a given site with respect to the natural capital and associated multiple benefits, which is useful in guiding the selection, planning and design of various blue-green infrastructures.

Chen and Leandro [21] propose a novel time-varying index to assess flood resilience at household level during and after a flooding event, based on physical factors, and social and economic factors, respectively. The proposed assessment method is tested on a real-life case in Munich, Germany.

Cascading failures caused by flooding are not uncommon, e.g., critical infrastructures such as a water supply network can be knocked down by a flooding event. Joannou et al. [22] proposes a systems-of-systems approach to identify how resilience can be improved to enhance the performance of a water supply system during times of flooding.

(4) Intervention Strategies

The reasonable determination of floodway is key to strike a balance between enhancing resilience towards riverine flooding and maximizing the area of land for human activities. Cho et al. [23] provides a contribution to the literature by the study of optimization of floodway using advanced modeling and optimization tools.

Flood control material and emergency logistics play an important role in enhancing flood resilience by providing resources to prepare for, respond to, and recover from flooding. Wang et al. [24] develops an allocation model to maximize the retrieval efficiency and shelf stability.

Unmanned Aircraft Systems (UAS) are increasingly used by emergency responders to acquire core information pre-, during- and post-events. Salmoral et al. [25] develops a guideline on the use of UAS to maximize its benefits for responding to flood and enhancing system resilience that is transferable to multiple countries.

The public reception of flood risk and resilience is of vital importance to the delivery of flood resilience studies, which is surveyed and analysed in Wang et al. [26] by a case study in Jingdezhen, China. Results show that gender, age, education level, experience and knowledge of flooding, income level, and the attitude/level of trust in the governance have influences on public risk perception of flooding. The findings are useful for developing targeted activities to actively engage public in building flood resilience.

3. Conclusions

The research articles in this Special Issue addressed the challenges in flood management and proposed new methods, models and tools for understanding and improve flood resilience in the following four themes: hazard and risk analysis, flood behavior analysis, assessment frameworks and metrics, intervention strategies. Their contributions are discussed in the broader context of the field of flood management and help move towards integrate risk and resilience management.

Research challenges in achieving sustainable flood management remain in many aspects, including developing fast, accurate, high-resolution flood models, characterizing various uncertainties including deep uncertainty, developing integrated risk and resilience frameworks and effective metrics, understanding the relationships between flood risk and resilience, and developing adaptive management strategies with innovative technologies including machine learning technologies.

Funding: This research received no external funding.

Acknowledgments: We acknowledge the financial support from the EPSRC Building Resilience into Risk Management project (EP/N010329/1).

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

References

1. UNISDR. The human cost of weather-related disasters 1995–2015. 2015. Available online: https://www.unisdr.org/2015/docs/climatechange/COP21_WeatherDisastersReport_2015_FINAL.pdf (accessed on 19 May 2020).
2. Djordevic, S.; Butler, D.; Gourbesville, P.; Mark, O.; Pasche, E. New policies to deal with climate change and other drivers impacting on resilience to flooding in urban areas: The CORFU approach. *Environ. Sci. Policy* **2011**, *14*, 864–873. [CrossRef]
3. Liu, H.; Wang, Y.; Zhang, C.; Chen, A.; Fu, G. Assessing real options in urban surface water flood risk management under climate change. *Nat. Hazard.* **2018**, *94*, 1–18. [CrossRef]
4. Narayan, S.; Nicholls, R.; Clarke, D.; Hanson, S.; Reeve, S.; Horrillo-Caraballo, J.; Cozannet, G.; Hisseld, F.; Kowalska, B.; Parda, R.; et al. The SPR systems model as a conceptual foundation for rapid integrated risk appraisals: Lessons from Europe. *Coast. Eng. J.* **2014**, *87*, 15–31. [CrossRef]
5. Pachauri, R.K.; Allen, M.R.; Barros, V.R.; Broome, J.; Cramer, W.; Christ, R.; Church, J.A.; Dahe, Q.; Dasgupta, P.; Dubash, N.K.; et al. *Synthesis Report. Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Pachauri, R.K., Meyer, L.A., Eds.; IPCC: Geneva, Switzerland, 2014; pp. 1–151.
6. Fu, G.; Butler, D. Copula-based frequency analysis of overflow and flooding in urban drainage systems. *J. Hydrol.* **2014**, *510*, 49–58. [CrossRef]
7. Guidolin, M.; Chen, A.S.; Ghimire, B.; Keedwell, E.C.; Djordjević, S.; Savić, D.A. A weighted cellular automata 2D inundation model for rapid flood analysis. *Environ. Modell. Softw.* **2016**, *84*, 378–394. [CrossRef]
8. Glenis, V.; Kutija, V.; Kilsby, C. A fully hydrodynamic urban flood modelling system representing buildings, green space and interventions. *Environ. Modell. Softw.* **2018**, *109*, 272–292. [CrossRef]
9. Penning-Rowsell, E.; Priest, S.; Parker, D.; Morris, J.; Tunstall, S.; Viavattene, C.; Chatterton, J.; Owen, D. *Flood and Coastal Erosion Risk Management: A Manual for Economic Appraisal*; Routledge, Taylor & Francis: London, UK, 2013.
10. Holling, C. Resilience and the stability of ecological systems. *Annu. Rev. Ecol. Syst.* **1973**, *4*, 1–23. [CrossRef]
11. Butler, D.; Ward, S.; Sweetapple, C.; Astaraie-Imani, M.; Diao, K.; Farmani, R.; Fu, G. Reliable, resilient and sustainable water management: The Safe & SuRe approach. *Glob. Chall.* **2016**, *1*, 63–77.
12. Linkov, I.; Bridges, T.; Creutzig, F.; Decker, J.; Fox-Lent, C.; Kröger, W.; Lambert, J.; Levermann, A.; Montreuil, B.; Nathwani, J.; et al. Changing the resilience paradigm. *Nat. Clim. Chang.* **2014**, *4*, 407–409. [CrossRef]
13. Kotzee, I.; Reyers, B. Piloting a social-ecological index for measuring flood resilience: A composite index approach. *Ecol. Indicat.* **2016**, *60*, 45–53. [CrossRef]
14. Mugume, S.N.; Gomez, D.E.; Fu, G.; Farmani, R.; Butler, D. A global analysis approach for investigating structural resilience in urban drainage systems. *Water Res.* **2015**, *81*, 15–26. [CrossRef] [PubMed]
15. Wang, Y.; Meng, F.; Liu, H.; Zhang, C.; Fu, G. Assessing catchment scale flood resilience of urban areas using a grid cell based metric. *Water Res.* **2019**, *163*, 114852. [CrossRef] [PubMed]
16. Barría, P.; Cruzat, M.; Cienfuegos, R.; Gironás, J.; Escauriaza, C.; Bonilla, C.; Moris, R.; Ledezma, C.; Guerra, M.; Rodríguez, R.; et al. From multi-risk evaluation to resilience planning: The case of central chilean coastal cities. *Water* **2019**, *11*, 572. [CrossRef]
17. Areu-Rangel, O.; Cea, L.; Bonasia, R.; Espinosa-Echavarria, V. Impact of urban growth and changes in land use on river flood hazard in Villahermosa, Tabasco (Mexico). *Water* **2019**, *11*, 304. [CrossRef]
18. Zhang, T.; Wang, Y.; Wang, B.; Tan, S.; Feng, P. Nonstationary flood frequency analysis using univariate and bivariate time-varying models based on GAMLSS. *Water* **2018**, *10*, 819. [CrossRef]
19. Saravi, S.; Kalawsky, R.; Joannou, D.; Rivas-Casado, M.; Fu, G.; Meng, F. Use of artificial intelligence to improve resilience and preparedness against adverse flood events. *Water* **2019**, *11*, 973. [CrossRef]
20. Fenner, R.; O'Donnell, E.; Sangaralingam, A.; Dawson, D.; Kapetas, L.; Krivtsov, V.; Ncube, S.; Vercruysse, K. Achieving urban flood resilience in an uncertain future. *Water* **2019**, *11*, 1082. [CrossRef]
21. Chen, K.; Leandro, J. A conceptual time-varying flood resilience index for urban areas: Munich city. *Water* **2019**, *11*, 830. [CrossRef]

22. Joannou, D.; Kalawsky, R.; Saravi, S.; Rivas-Casado, M.; Fu, G.; Meng, F. A model-based engineering methodology and architecture for resilience in systems-of-systems: A case of water supply resilience to flooding. *Water* **2019**, *11*, 496. [CrossRef]
23. Cho, H.; Yee, T.; Heo, J. Automated floodway determination using particle swarm optimization. *Water* **2018**, *10*, 1420. [CrossRef]
24. Wang, W.; Yang, J.; Huang, L.; Proverbs, D.; Wei, J. Intelligent storage location allocation with multiple objectives for flood control materials. *Water* **2019**, *11*, 1537. [CrossRef]
25. Salmoral, G.; Casado, M.; Muthusamy, M.; Butler, D.; Menon, P.; Leinster, P. Guidelines for the use of unmanned aerial systems in flood emergency response. *Water* **2020**, *12*, 521. [CrossRef]
26. Wang, Z.; Wang, H.; Huang, J.; Kang, J.; Han, D. Analysis of the public flood risk perception in a flood-prone city: The case of Jingdezhen city in China. *Water* **2018**, *10*, 1577. [CrossRef]