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Global experiences in flood management – perspectives through ICFM Webinar Series

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Abstract. It is a major issue of concern for international organizations and governmental departments in supporting global climate governance. As floods account for 44 % of all natural disasters in recent 20 years, it is of great significance to propose countermeasures by reviewing global extreme flood events in recent years. The International Conferences on Flood Management (ICFM) and Flash Flood Program (FFP), have hosted a series of international academic webinars since 2020. Drawing upon the outcomes of the webinars and reviewing the latest flood mitigation strategies of major countries advanced in water management, this paper focuses on the global experience in response to watershed flood, flash flood, urban flood, extreme flood under climate change, and comprehensive mitigation measures. It can be learned that flood control strategies need combine both structural and non-structural measures, and draw upon nature-based solutions that integrate green, blue and gray spaces within basins or cities through multi-purpose and targeted programs, with a view to achieving flood management goals and promoting social, economic and environmental sustainability in a holistic way.

1 Introduction

Climate change has reshaped the spatial and temporal patterns of water cycle, posing a continuous threat to human survival and development in a way that modifies water availability and endangers water security. It also has multi-directional interactions with water-sediment processes, hydro-chemical processes and hydro-ecological processes. Water cycle variability has affected global change in a very obvious way. As the footprint of climate change and human activities increase, water cycle processes and fluxes have been altered, with significant impact on water resources, droughts and floods, and other extreme hydrological events. Researches revealed that for every degree increase in global average temperature, the water circulation rate will accelerate by 2 %–4 % (Guangming Net, 2022).

Observations found that hot days extend by 2–8 d per decade in most areas of the world, with the average number in recent years tripling compared to 1961–1990, while extreme precipitation adds by 1 % per decade. Since the 1990s, the rate of sea level rise has accelerated, reaching 4 mm per year, which has doubled compared to before (Sohu Business, 2022). Related data shows that between 1998 and 2017, high-income countries suffered an average loss of 0.41 % of GDP due to climate related disasters, while low-income countries accounted for 1.77 % of GDP. And the loss was from 751 million in 1950 to 4.2 billion in 2018. Currently, 55 % of the world's population lives in urban areas. It is expected that this proportion will increase to 68 % by 2050. According to the report of the United Nations Office for Disaster Risk Reduction (UNDRR) (CRED, 2020), there were 3254 floods worldwide reported since ushering into the 21st century (2000–2019), accounting for 44 % of all natural disasters, the highest percentage among all types of natural hazards; and increasing by 1.34 times in comparison to the 1389 floods during 1980–1999.

The frequency and severity of floods increased due to climate change in the past few years, yet the risk of floods has been underestimated. Based on our statistical analysis on the typical flood events occurring during 2020 to 2022 (Fig. 1), floods have the most impact on Asia, accounting for over 35 % among total flood events worldwide (Fig. 2). The most affected country is China. According to a UNDRR report, Asia is currently exposed to the highest flood risks as it experienced 41 % of all the flood events worldwide (CRED,

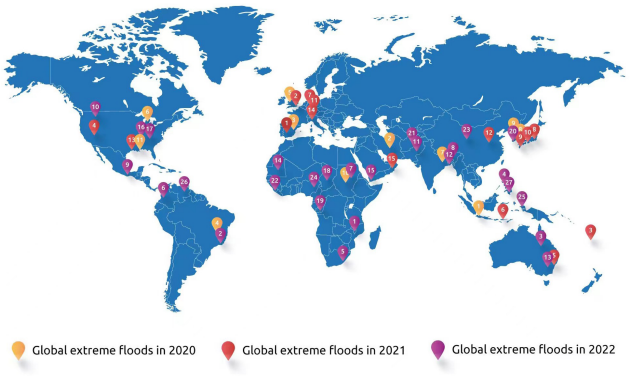

Figure 1. Distribution map of global extreme flood events from 2020 to 2022. (Source: https://www.icfm.world/Statistics/, last access: 10 July 2024).

2020). The conclusion that Asia suffered from the highest percentage of flood events in this report is consistent with the UNDRR report.

Global extreme floods show diversity in time and space in recent years. In 2021, Germany Flood resulted in 180 deaths, and have caused great economic losses of EUR 3 billion. The extreme rainstorm in Zhengzhou China is currently the most severe urban flood, which caused 398 deaths, and the economic losses reached CNY 20 billion. Rare desert floods occurred in Oman, with over 3 years of rainfall accumulated within 24 h. In 2022, rainstorms in Eastern South Africa lasted over months, and had 448 deaths. In Congo, the rainfall amount was over 100 mm in 24 h, and the death reached more than 400 people. The extreme flood in Pakistan caused over 1700 deaths, affecting over two thirds of the country, and over 3.3 million people were affected. The rainstorm in Yemen destroyed dozens of historic buildings in its ancient capital.

Under the circumstances, more attention has been paid to extreme events globally. The 2023 United Nations Water Conference passed a landmark "Water Action Agenda", which calls for strengthening institutional capabilities and integrating risk reduction measures to respond to extreme weather events.

To take joint actions in response to the increasing risk of more extreme floods, the international Conferences on Flood Management (ICFM) secretariat was hosted by China's leading water research institute, China Institute of Water Resources and Hydropower Research (IWHR), in Beijing since 2017. Main work include organizing ICFM conferences and webinar series, writing scientific reports, operating global flood database, public education, etc. Since 2020, ICFM organized international academic webinar series to offer a platform for exchanging experience and practices on flood management. So far, 10 webinars were hosted with more than 20 global experts discussing trending topics. The visitors were from 83 countries, the live streaming had over 10 000 clicks, and our expert database had more than 2900 experts. The official website since then with over 20 thousand visits in the past year.

The following sections will summarize and refine the concept, research projects, methods, insights proposed by the panelists at the webinars.

2 Global perspectives

2.1 Watershed flood

For watershed flood, both structural and non-structural measures should be applied. For structural measures, the joint scheduling of cascade reservoirs was implemented in a refined manner, this manner impounded 24.6 billion m^3 of flood and reduced the outflow by 14.8 % in Yangtze River Flood for 2020 flood (ICFM, 2020). As for non-structural measures, the forecasting system can be applied in collaboration with the decision-supporting system for flood management (ICFM, 2020). Multi-party coordination and collaboration should be strengthened because emergency response is crucial. We should also rationally use flood detention basins based on scientific assessment, and take the initiatives to flood so as to further protect life and property. The dam failures of Michigan flooding in 2020 indicate the significance to normalize safety inspections of flood control projects (ICFM, 2020).

Severe rainfall in several areas of Shanxi Province, China has caused floods. Chinese media pointed out that floods have caused over 1.75 million people to be affected, 120,000 people to be urgently relocated, and 3.58 million acres of crops have been damaged. To manage the watershed flood, we should guarantee that there are no casualties, no dam collapse of reservoirs, no breach of important embankments, and no impact on important infrastructure.

2.2 Flash flood

The Flash Flood Program (FFP) was established, in collaboration with IWHR, which mainly focuses on the floods occurred in mountain areas and emphasizes the speed of the flood. Flash floods disasters account for 70 % of total global water-related mortality. In 2022, 119 people died and disappeared due to disasters in China, which is the lowest year since statistical data is available. In recent years, 70 % of the deaths and missing people in China due to natural disasters have been caused by floods. As there were 171 people died and disappeared due to floods in 2022, coincidentally, it happened to be 70 % of the deaths caused by floods. It can be inferred that flash floods pose a huge threat to the lives and safety of the people (ICFM, 2022).

In order to save money, some bridges built on small and medium-sized rivers had insufficient height and span, which ultimately leads to problems after the formation of flash floods. This situation is a prominent issue in several disas-

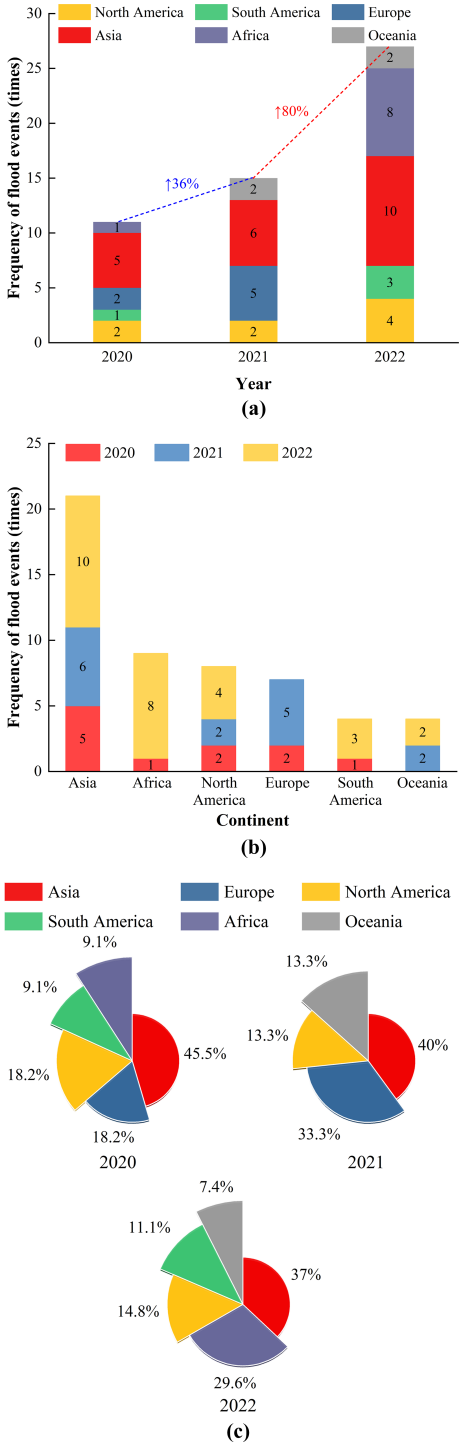

Figure 2. Statistical analysis charts of global typical flood events from 2020 to 2022. **(a)** Flood events in recent 3 years. **(b)** Flood events on each continent. **(c)** Proportion of annual flood events on each continent.

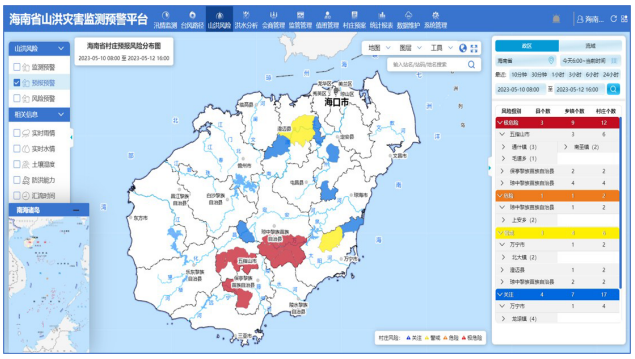

Figure 3. Flash flood forecast and early warning system developed in China. Publisher's remark: please note that the above figure contains disputed territories.

ters occurring in recent years that we have summarized. Of course, there are also bridges in some areas were not directly threatened by flash floods, but due to bridge being blocked, the water flow has been diverted. After the diversion, towns and villages that were not within the defence range would also be threatened.

We should strengthen water-related resilience through "basin-wide flood management" and "rebuilding flood-conscious societies", which coincides with River Basin Disaster Resilience and Sustainability by All proposed by Japan. Country and local government should improve monitoring and early warning technology and strengthen the education of local residents in disaster preparedness, response, and recovery. Such idea is consistent with the International Day motif of Disaster Reduction: Early Warning, Early Action. Notably, the public warning may send messages about how much rain it will rain, for example, 50 and 80 mm, but local people may not understand. Thus, the messages should point out the rainfall amount is large or small, and what measures should be taken. In addition, many transfers are in night, the transfer measures should be refined, and the practical exercises are necessary to help local people memorize the transfer route, especially the places where has a risk of congestion and congestion, such as crossing ditches, bridges and culverts (ICFM, 2022a).

Water conservation measures can be applied in flash flood ditch. Specifically for severe flash flood, it is crucial to build multi-stage progressive flash flood forecast and early warning system. The system developed in China reduced life losses by 71 % from 2013 to 2022 (ICFM, 2022a).

2.3 Urban flood

While the world is rapidly urbanizing, it is worth noting that most of the global risks caused by climate change are concentrated in cities. We are undergoing rapid urbanization, China's urbanization rate varied from 30 % in 2000 to 59.6 % in 2018. About 55 % of the world's population lives

in cities and is expected to grow to 68 % by 2050, there is small space for river regulation and storage. Since there is limited space for river regulation and storage, more attention should be paid to urban flood. We need to adopt a long-term vision and conduct coastal risk assessments facing to extreme events, as about 40 % of the world's population lives within 100 km from the coast. From a technical aspect, cities should establish a data-model-forecast-command integrated intelligent management system. Meanwhile, municipal governments should watch out for the co-occurrence possibility of urban flood, river flood, and coastal risk, improve city resilience by applying urban flood model with AI and big data, and apply engineering allocation in the rivers and plains (ICFM, 2021).

2.4 Extreme flood under climate change

Statistics indicate that 50 %–70 % of the increase in extreme floods are resulted by human activities under climate change. Facing floods like 2022 Pakistan Flood, we should reduce poverty worsened by flooding (10 % increase due to flooding), reduce vulnerabilities, and increase resilience through housing standards and agriculture assistance (ICFM, 2022b), etc. Local governments should also develop overall planning and make good use of funds for flood mitigation and prevention. Forecasting models can be used in operational flood forecasting systems and early warning systems, challenges ahead mainly lie in fundamental datasets, such as, precipitation, DEM, etc. Moreover, we should pay attention to aging water conservancy projects, which triggered the flood disaster in Western Europe in 2021. For the floods in Brazil, we should focus on issues related to floods and diseases, such as arbovirus and dengue fever (ICFM, 2023), etc. The drought-flood abrupt alternation in Italy in 2023 had extreme rainfall lasting 36 h and the rainfall amount reached the precipitation amount in half a year in average years.

2.5 Comprehensive mitigation measures

Comprehensive mitigation measures should be carried out to cope with increase in extreme flood events. Lowering risk by increasing resilience, including preparedness & prevention, reconsider adaptive planning approaches. For inland floods, managed retreat (flood-plain zoning, room for the river) is a sustainable approach. New tools should be used for flood management such as big data and digital twin. The flood rescue team (personnel, equipment) should improve professionalism through equipment upgrade and efficiency of emergency response. Governments can enhance public awareness through education and media publicity, and ensure even distribution and coverage of social flood control facilities. The experience gained from epidemic prevention and control can also provide reference for flood management.

The latest flood mitigation strategies of major countries advanced in water management around the world were reviewed. Due to factors such as unique geographical location and climate change, the Dutch efforts on flood resilience began in 2008 through the multi-layer safety (MLS) approach by constructing a three-layer resilience system (Cao, 2019). The three layers include: (1) Protection, i.e. the primary dike system (10 000-year flood protection standard). Standards for flood control structures are established based on flood risk and disaster loss analysis to foster a system of flood control structures; (2) Sustainable spatial planning. The national space is zoned by secondary dikes and water structures for multiple purposes, with the concept of "Room for the River" being highlighted; and (3) Emergency response and disaster relief, which mainly deal with extreme floods, including better coordination between emergency service providers, managerial decisions, communication models and evacuation plans, building more flood resilient cities such as Dordrecht.

Japan has experienced floods multiple times since 2013. Drawing upon the lessons learned from frequent floods, the country continues to revise its flood management measures accordingly. In 2020, the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan undertook a large-scale flood management reform by introducing a new policy of River Basin Disaster Resilience and Sustainability by All (Ministry of Land, Infrastructure, Transport and Tourism, Japan, 2020). In the past, Japan's flood control relied on structural measures with clear role allocation, implemented mainly in river basins and floodplains by administrators from divisions involving rivers, sewage, erosion and sediment control, and coastal management. The new policy considers river basins as spaces that include watershed and floodplains, and takes comprehensive, multi-layered actions, including flood prevention, exposure reduction and disaster resilience. It calls on all stakeholders in river basins, including the national government, prefectures, municipalities, private enterprises, residents, and water users, to take actions for enhancement in disaster resilience and sustainability.

Over the past two decades, the United Kingdom has experienced a number of floods that have posed a grave threat to individual and commercial properties across the country. To reduce flood-caused losses, the government began to put more emphasis on property resilience to flood. The Property Flood Resilience Roundtable in 2015 suggested that the government is responsible for helping the public protect their own properties from flooding, and therefore proposed an action plan to improve property flood resilience. After one year, the Property Flood Resilience Action Plan was published by the UK Department for Environment, Food and Rural Affairs, which guides the implementation of measures to improve the flood resilience of private and commercial properties.

Also, the United States has developed a set of plans and strategies regarding climate change and water security to mitigate and tackle climate-driven disasters in recent years, such as, Climate Adaptation Plan 2022 Progress Report (DOD,

2022), White House Action Plan on Global Water Security (The White House, 2022).

3 Conclusion

The frequency and severity of floods have increased due to climate change in the past few years, alarming a global challenge that needs to be responded jointly by the world. From 2000 onwards, the proportion of the flood-hit population has risen by 24 %, with the increase by more than 20 % in 40 countries. It is evident that the frequency and coverage of floods and the proportion of the affected population have all expanded since the 21st century as the global water cycle has accelerated over time. The severity of flood increased as well; for example, the 2022 Pakistan floods caused economic loss more than 75 % of the total economic losses by floods over the past 70 years. In the face of more frequent flooding events, countries have adopted a series of strategies and measures accordingly, specifically both in structual and non-structual way. Structural methods include dike safety management measures. Non-structural methods require new policies and actions incorporating flood resilience building and public awareness raising, etc. In a word, flood management should follow the law of nature, applying the nature-based solutions, integrating green, blue and gray spaces within basins. Each river has its own "genes", and there are no standardized flood management solutions, so optimization measures should be proposed as far as possible. We need to improve monitoring and early warning technology and establish intelligent management system. Global cooperations and partnerships, social cooperations on flood management should be strengthened to respond to the climate change.

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Author contributions. CZ planned the campaign; WB analyzed the data; WB wrote the manuscript draft; CZ reviewed and edited the manuscript.

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